TM 5-295

WAR DEPARTMENT

TECHNICAL MANUAL

WATER SUPPLY AND WATER PURIFICATION

1942

FOREWORD

Refer to FM 5-5, FM 5-10, FM 5-35, AR 100-5, Tables of Basic Allowances, TM 5-400, TM 5-405, TM 5-410 and TM 3-215.

TECHNICAL MANUAL

WATER SUPPLY AND WATER PURIFICATION

CHANGES No. 1

WAR DEPARTMENT,
WASHINGTON 25, D. C., 20 November 1943.

TM 5-295, 1942, is changed as follows:

36. General.

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b. Rescinded.

c. Rescinded.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

36.1. (Added.) **Chemical warfare agents in water.**—*a.* Water supplies may be contaminated directly by chemical warfare agents placed in the water or indirectly by the use of toxic gases in the air (see par. 14). It is difficult to contaminate a large quantity of water, particularly a fast-moving stream; small, motionless bodies of water such as wells and ponds are more easily contaminated. When a contaminated source is encountered, reconnaissance is made to find another source because in most areas it is practically impossible to poison all water sources. In a still body of water, the chemical agents may be heavy enough to sink to the bottom, leaving the water near the surface less contaminated. By testing at various intervals and depths in a pond or other still water, it may be possible to locate usable water.

b. Chlorine does not neutralize poisonous chemical agents in water. However, it may reveal the presence of certain chemical warfare agents which react very quickly with chlorine and immediately increase the chlorine demand of the water. When the addition of 6.0 parts per million of chlorine to water fails to leave a residual of at least 2.0 parts per million, *at the end of 2 minutes* chemical warfare agents may be present.

c. Another indication of possible chemical warfare contamination of water is a low pH value. pH tests are routine control tests run by engineer water supply personnel at all water points. When the pH drops below 6.0, chemical warfare agents *may* be present. In some areas the natural pH of the water is below 6.0 In such areas, the pH test alone is not conclusive.

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*The individual items in this change will be cut apart and pasted over the specific paragraphs or subparagraphs affected.

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d. Use of the simple test kit illustrated in figures 9.1 and 9.2 determines whether water contains chemical warfare agents (kit, field, water testing, screening, for chemical warfare agents). This kit contains equipment for making the tests for pH and chlorine demand mentioned in *b* and *c* above as well as for other more comprehensive tests. All these tests are rough qualitative tests only, not sufficiently accurate for any control purpose other than determining the presence of the chemical agents. Each kit is issued with the complete instructions for its use. These instructions are *tentative* as of 1 September 1943, and are subject to changes resulting from continuing experiments. Tests which can be made with it are as follows:

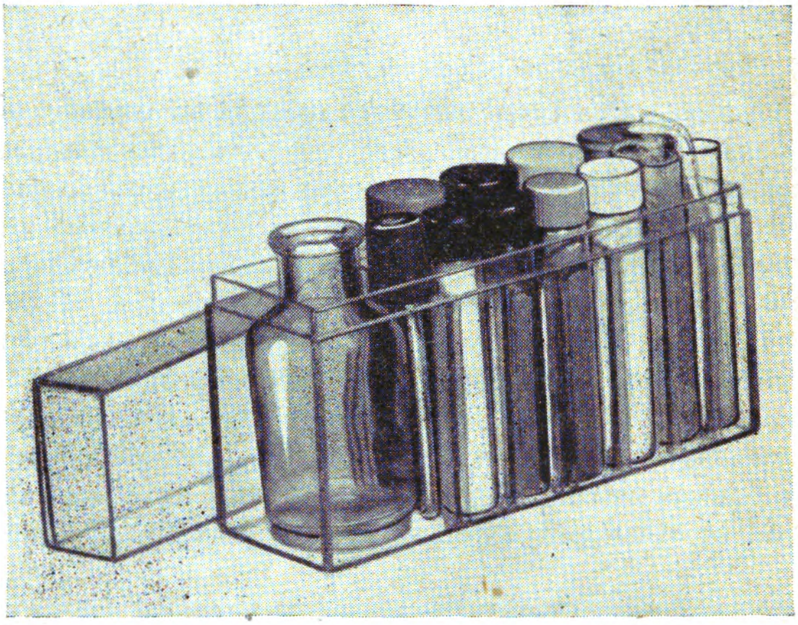

FIGURE 9.1.—Kit for testing presence of chemical warfare agents. All vials are lettered to assist identification.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

(1) *Turbidity and color.*—Place water in a test tube and note the presence or absence of turbidity and color.

(2) *pH test.*—Dip a strip of nitrazine test paper into the water and compare the resulting color of the paper with the color chart. Engineer water supply personnel may determine the pH with a comparator instead of with the nitrazine test paper. A pH below 6.0 indicates possible contamination.

(3) *Arsenic test* (for lewisite and other agents containing arsenic).—(*a*) Fill pot *P* up to mark with water to be tested.

(*b*) Place two pellets from vial *A* into the pot. Shake it to dissolve pellets.

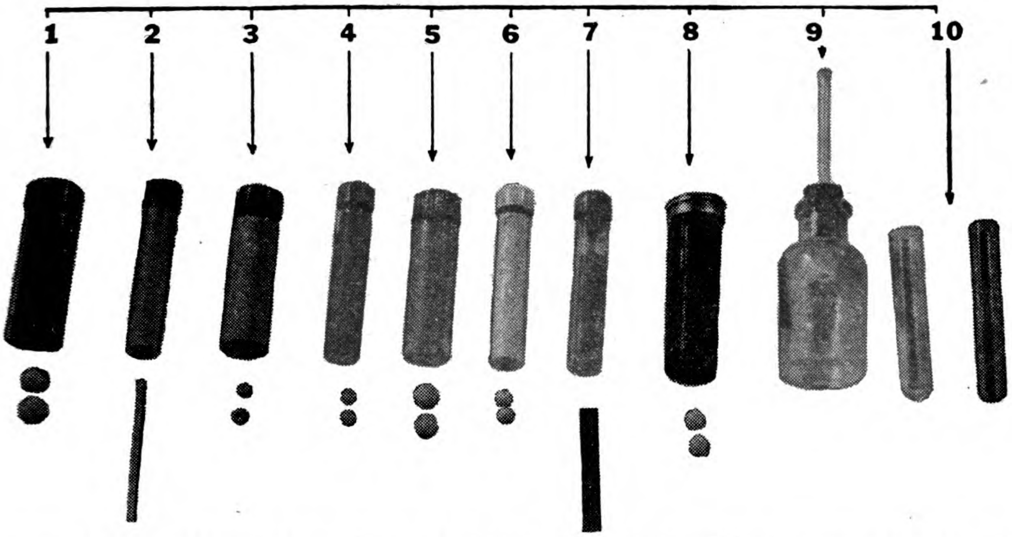

FIGURE 9.2.—Contents of water-testing kit (kit, field, water testing, screening, for chemical warfare agents). Left to right: (1) vial *A*, $KHSO_4$ tablets; (2) vial *B*, arsenic test papers; (3) vial *C*, zinc pellets; (4) vial *D*, RA tablets; (5) vial *E*, RB tablets; (6) vial *F*, water purification tablets; (7) nitrazine strips for pH test; (8) ortholidine testing tablets; (9) pot *P* with tube *H* assembled for arsenic test; (10) test tubes. Wire brush, pipe cleaners, and color chart are not shown.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

(*c*) From vial *B* take a test strip by the top end. Carefully insert the strip into tube *H* as shown in figure 9.3. Bend the strip near the top so it will remain in tube with bent end hanging over the edge of the tube. In handling the strip touch the top end only and keep the strip dry.

(*d*) When pellets from vial *A* have dissolved, add five pellets from vial *C* to the contents of the pot.

(*e*) Promptly fit the test paper assembly (*c* above) into the pot, as indicated in figure 9.3, so that the gases released will rise up past the test paper.

(*f*) If the pot is cold, warm it with the hand. Keep the test paper assembly in the pot for 20 minutes.

(*g*) Remove the test strip and note the length of the resulting yellow or brown stain. A stain of ½ inch or more indicates a positive test; a stain less than ½ inch is negative.

(4) *Mustards test* (*for nitrogen mustards*).—(*a*) Rinse a test tube with the water to be tested and fill it to a depth of ½ inch with suspected water.

(*b*) Add one tablet from vial *D*.

(*c*) Shake for at least 3 minutes.

(*d*) During cold weather warm the tube in the hand or in a pocket for 5 minutes.

(*e*) Break in half one tablet from vial *E* and add both halves to the water being tested. Shake the test tube until the tablet is dissolved. While shaking watch for a blue color to appear.

(*f*) Observe the tube for ½ minute against a white background. Any trace of blue (mainly in curd form) indicates a positive test for mustards. White or gray indicates a negative test. Yellow indicates cyanogen chloride.

(5) *Chlorine-demand test* (see *b* above).—(*a*) Fill a canteen with water to within 1 inch of the top.

(*b*) Add three water purification (halazone) tablets from vial *F*. Place the cap on the canteen and shake it until the tablets dissolve.

(*c*) After 5 minutes, test for chlorine residual. (Five minutes is necessary to allow tablets to dissolve. Reaction of chlorine with chemical warfare agents is practically instantaneous.) This may be done with orthotolidine testing tablets (par. 108*d*(2)); or, water-supply personnel may use the comparator. A positive test is indicated by a residual of less than 1.0 part per million; this means chlorine demand is greater than 4. A negative test is indicated by a residual of 1.0 part per million or greater.

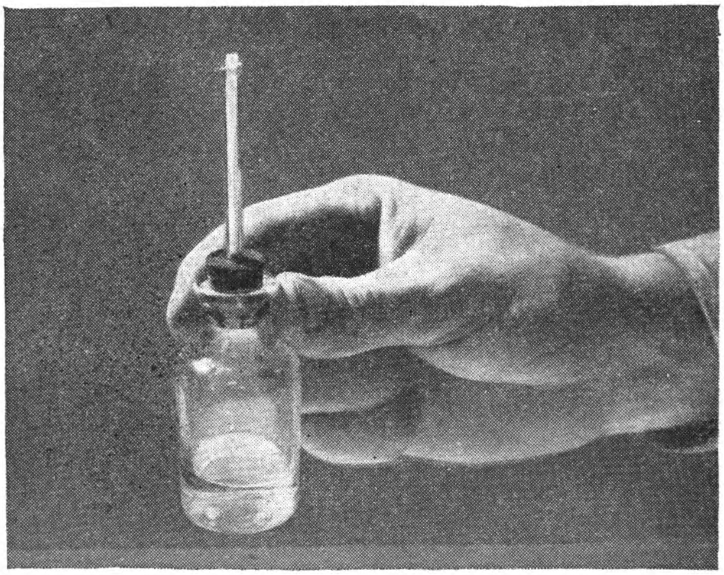

FIGURE 9.3. Arsenic-test assembly.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

(6) *Taste and odor.*—(*a*) If the tests for color and turbidity, arsenic, mustards, and chlorine demand all are negative, carefully smell and taste the suspected water.

(*b*) A positive test is indicated by an odor that makes the eyes smart or stings the nose; a biting, peppery, or strongly objectionable taste; or any taste or odor of a known war gas.

(*c*) Absence of taste or odor indicates a negative test, but does not necessarily mean water is safe. A negative test also is indicated if the only odors and tastes are those normally characteristic of natural water.

e. The test given in *d*(4) above detects nitrogen mustards in concentrations greater than 8.0 parts per million. Since concentrations below 8.0 parts per million may incapacitate consumers, complete reliance cannot be placed on this one test by itself.

f. A more comprehensive kit than the type discussed above is under development. It will permit qualitative analysis of water and will detect nitrogen mustards in concentrations below 8.0 parts per million.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

36.2. (Added.) **Responsibility for detection of chemical warfare agents in water.**—*a.* A water testing kit of the simple type discussed in paragraph 36.1*d* is issued to the medical officer of each battalion or similar unit. One kit also is issued with each engineer water purification set. The more comprehensive kit for both quantitative and qualitative analysis is available to higher echelons.

b. If as a result of an excessive chlorine demand, a low pH value, an intelligence report, or for any other reason water supply personnel suspect that water may be contaminated by chemical warfare agents, tests are made with the simple water test kit. If any single test gives a positive result the water point is shut down and an attempt is made to locate an uncontaminated source. The proper S-2, medical officer, and water control officer are notified at once. The water control officer, or other qualified officer, analyzes the contaminated water with the comprehensive kit to determine the steps necessary for purification.

c. Where a consuming organization obtains water locally instead of from a water distributing point the organization commander, with the assistance of the organization medical officer, is responsible for the purity of the water. When water is suspected of being contaminated with chemical warfare agents, the proper officers are notified as in *b* above.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

36.3. (Added.) **Bone oil and fish oil.**—Enemy troops may attempt to make water sources, particularly wells, unfit for use by contaminating them with fish oil or bone oil. These oils give water such a disagreeable, nauseating taste and odor that personnel cannot use it. For methods of removal, see paragraph 83.1.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

39. Quality variation during distribution.

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b. Where water is * * * to the troops. **Dangerous contamination may be introduced by careless handling or by dipping water from cans with unclean cups or other receptacles. The use of other purpose containers for water is objectionable. If it becomes necessary to use gasoline containers or hose for transporting water, they must be cleaned adequately as described in paragraph 73.1; otherwise the water becomes unsafe and requires special purification.**

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[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

73.1. (Added.) **Removing gasoline from containers and from water.**—Gasoline containers which have been used for leaded gasoline can be cleaned effectively and made safe as containers for water to be consumed by troops. The methods for doing so are described below. Even after careful cleaning, water stored in gasoline containers may be contaminated with objectionable quantities of lead and gasoline retained in the scale, rough surfaces, and cracks and joints in the material of the container. Such contamination usually is delayed, and may be avoided by limiting the time of storage. The odor of gasoline increases during storage of the water and precedes a rise in lead content which sometimes exceeds the allowable limit of 0.1 part per million. The odor, therefore, is an indicator of the potability of the water. A definite odor of gasoline is an indication that cleaning was incomplete, or that safe storage time has been exceeded. Whenever gasoline odor is detected in water drawn from cleaned containers, it must be treated before being used for drinking, cooking, and bathing purposes. Methods of treatment are given in *f* below.

a. Precautions against fire and explosion.—Keep all open flames and portable electric motors away from all openings such as pouring spouts, outlet valves, manholes, and domes in cans, drums, and tanks previously used for gasoline. All such containers retain gasoline vapor even though all liquid gasoline has been removed. This vapor is highly inflammable and explosive. Hence, when starting to clean gasoline containers to convert them to use for water, all fire precautions must be observed and continued in effect until the cleaning process has removed all trace of gasoline vapors. Men must never enter empty tanks until after the vapor is removed. For additional details, see paragraph 16*l*, TM 3–250.

b. Cleaning 5-gallon gasoline cans.—(1) Choose new cans with bright interiors.

(2) Allow the can to drain for 10 to 15 minutes to remove as much gasoline as possible.

(3) Half fill the can with water, add 1 ounce of powdered soap, and shake for 5 minutes. If soap is not available, 3 ounces of activated carbon may be used instead.

(4) Drain, refill with 2 to 3 gallons of water, and shake.

(5) Drain and fill to overflowing with water. Drain.

(6) Fill with drinking water. This water should be used within a few days. Since the can rusts rapidly, it should be cleaned before each filling to remove as much rust as possible.

c. Cleaning 55-gallon gasoline drums.—(1) Choose drums whose interiors show no scale, are bright, or have galvanized coatings clearly discernible. Drain out any remaining gasoline.

(2) If steam is available, steam for ½ to 1 hour and proceed with steps (5) to (8) below.

(3) If no steam is available, blow for 15 minutes with compressed air, or fill to overflowing with water to displace remaining gasoline. Drain.

(4) Add 10 to 20 gallons of water and 1 pound of powdered soap, and shake by rolling the drum back and forth for 15 minutes. Drain.

(5) Put in 10 to 20 gallons of water, ½ pound of powdered activated carbon, and repeat the rolling operations. Drain.

(6) Remove residual carbon by rinsing repeatedly with a little water.

(7) If time permits and sufficient water is available, fill drum to overflowing. Drain.

(8) Fill drum with drinking water.

d. Cleaning gasoline tank trucks.—(1) Drain gasoline from compartments as completely as possible.

(2) Steam each compartment for not less than 90 minutes.

(3) Flush out loose scale with a pressure water hose.

(4) Fill to overflowing with water to displace remaining gasoline.

(5) Drain to gauge level. Storage should not exceed 18 hours.

(6) Soap or activated carbon is not used in cleaning tank trucks. Trucks once cleaned and placed in water service improve with use so far as odor and lead content are concerned, but are flushed with a hose before each filling to remove scale and rust which otherwise will color the water after only a short period of storage.

e. Cleaning gasoline tank cars.—(1) Drain out any remaining gasoline and ventilate the tank by opening the dome.

(2) Steam for not less than 6 hours. This requires locomotive or powerhouse boiler steam.

(3) Have a man enter the tank car to flush away all loose surface scale with a hose and stream of water under pressure. As a precautionary measure, this man must be equipped with mask and safety belt or harness and rope, with two attendants outside the car for rescue or resuscitation purposes.

(4) Fill with water to overflowing, to displace any remaining gasoline.

(5) Drain water to level of dome. Storage should not exceed 25 hours. Soap or activated carbon is not used in cleaning tank cars.

f. Treating stored water.—Two methods of treatment can be employed to remove from water any remaining gasoline odors derived from containers or hose.

(1) *Carbon treatment.*—Enough activated carbon to remove the odors is added to the water. This amount varies according to the concentration of the contamination, but usually is less than 15 grains per gallon, or about 1 cupful per 55-gallon drum. More can be used, if necessary. After the carbon is added to the cans or drums, they are agitated for approximately 5 minutes. Much of the carbon can be removed prior to use by straining the water through a flannel cloth or blanket. Water from tank trucks and tank cars is transferred to 3,000-gallon canvas tanks before adding the carbon. The water and carbon are thoroughly agitated in the canvas tanks. The carbon can then be removed by filtration. As much as 0.40 part per million of lead, together with well-defined gasoline odors, can be removed in this manner.

(2) *Purification with standard mobile or portable unit.*—This treatment reduces the gasoline odor and lead content and also removes color and sediment that the water may have picked up. Activated carbon should be employed in conjunction with purification through the unit.

g. Water transported or stored in the above containers must meet the usual requirements as to chlorination.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

83.1. (Added.) **Removal of bone oil or fish oil from water.**—Both fish oil and bone oil contain water soluble chemicals and have a specific gravity less than that of water. A well contaminated with these oils (see par. 36.3) is not used unless absolutely necessary. If the water *must* be used, the well is pumped to waste for 30 minutes to 1 hour or until its odor is less objectionable. Then water is pumped into storage tanks and allowed to stand for 1 hour. Water which is carefully withdrawn from the bottom of the tank without disturbing the surface film has a much less objectionable odor and taste. It is

safe to drink if it has been treated properly to eliminate bacterial contamination and provided tests show it free from chemical warfare agents. Activated carbon, available in water supply equipment sets and in engineer depots, may be used as an absorbing agent for further removal of objectionable taste and odor.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

108. **Basic.**—*a.* Water supply in its simplest form **is illustrated by an** individual soldier on an isolated mission filling his canteen from a spring or brook and **disinfecting it by adding water-purification tablets or by boiling the water for 1 minute.**

b. Lyster bag chlorination.

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(5) After the calcium * * * onto the ground. Then fill a clean canteen cup **to a depth of ½ inch with** water from the same faucet.

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c. (Added.) *Water purification tablets* (*Halazone*).—Water purification tablets are issued primarily for the purification of small quantities of water. Two 4-milligram tablets are added to one canteen of water if the water is clear, four if it is turbid or colored. The water should not be consumed for 30 minutes after the tablets have dissolved. To speed dissolving of the tablets, the canteen is shaken vigorously. Water may be treated in larger containers by addition of the appropriate number of tablets. Thus a 10-gallon container requires 40 times as many tablets as a 1-quart canteen.

d. (Added.) *Additional tests for chlorine residual.*—In addition to the liquid orthotolidine test covered in *b*(6) above, the following tests may be used to determine chlorine residual.

(1) *Comparator.*—Engineer water purification sets all are equipped with pH and chlorine comparator kits. The comparator is the fastest and most accurate method for determining chlorine residual.

(2) *Orthotolidine tablets.*—These tablets are issued in a small vial which fits inside a larger vial in which the test is made. Remove the inner vial. Fill the outer vial up to the bottom of the colored band with water to be tested. From the inner vial take one orthotolidine testing tablet; drop it into the water, shake, and note the color produced. The result is measured as follows:

(*a*) Equal or darker yellow than the colored band—satisfactory chlorination. The chlorine residual is about 1.0 part per million.

(*b*) Lighter yellow than the colored band—insufficient chlorination. Add more calcium hypochlorite to the water being treated; wait 10 minutes and retest.

(*c*) Orange color—the water is overchlorinated. Add more water to the water being treated; wait 10 minutes and retest.

[A. G. 300.7 (23 Sept 43).] (C 1, 20 Nov 43.)

110. **Iodine sterilization.**—Rescinded.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

111. **Boiling.**—If tubes of calcium hypochlorite **or water purification tablets are not** available, water may be purified by boiling **for 1 minute. Care must be taken to see that the water actually boils for this period of time.** This method **is** not used by the individual soldier, if avoidable. The water should be boiled under supervision in comparatively large quantities, and then distributed to the troops. Water may be boiled in galvanized iron cans.

[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

Appendix I

19. Field test for pH and free chlorine.

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c. Comparator.

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(3) (Added.) Two indicator solutions are issued for use with the comparator in determining pH. One is bromthymol blue which covers pH values ranging from 7.6 to 6.0. The other is bromcresol purple-green which covers values from 6.0 to 4.4.

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[A. G. 300.7 (23 Aug 43).] (C 1, 20 Nov 43.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

U. S. GOVERNMENT PRINTING OFFICE: 1943

US War dept

TM 5–295
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TECHNICAL MANUAL

WATER SUPPLY AND WATER PURIFICATION

CHANGES No. 2 | WAR DEPARTMENT,
WASHINGTON 25, D. C., 18 February 1944.

TM 5–295, 1942, is changed as follows:

37.1. (Added.) **Schistosomiasis.**—*a.* In certain tropical and subtropical countries, a disease caused by worm parasites known as blood flukes may be contracted from contact with water containing the minute larval stages. This disease is called schistosomiasis. The organisms which cause it usually enter the body by penetrating the skin while one is wading or bathing in contaminated water. More rarely the disease may be contracted through drinking water. The principal areas in which schistosomiasis occurs are located in China, Japan, Africa, northern South America, and certain of the West Indies. In areas in which the disease is prevalent, wells and springs which are not subject to contamination by drainage and surface wash should be used in preference to natural bodies of surface water such as ponds and sluggish streams.

b. The Medical Department is responsible for determining whether or not these blood flukes are present in water which is being used for drinking or bathing. Where the presence of these organisms is indicated the following safety measures will be taken by engineer water-supply personnel:

(1) *Sedimentation* (see par. 115).—Settling tanks must be placed between the point at which chemicals are added to the water and the filter. The coagulant dosage should produce a heavy, rapidly settling floc. The sedimentation period should be at least 60 minutes.

(2) *Filtration* (see pars. 128 and 133).—The filter rate must not exceed 6 gallons per minute per square foot of sand area. This means that the maximum filter rate with the portable unit will be 10 gallons per minute; with the mobile unit, 60 gallons per minute.

(3) *Disinfection* (see par. 71).—For proper purification the chlorine content after 30 minutes of contact with the water must be at least one part per million. In making the test for chlorine residual, the reading is taken within 1 minute after the orthotolidine has been added.

(4) *Use of portable bathing unit* (see par. 163).—The best available source of water should be used with the portable bathing unit. Prior

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*The individual items in this change will be cut apart and pasted over the specific paragraphs or subparagraphs affected.

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to use in the unit the water should be treated by one of the following methods:

(*a*) Treat water as given in (1), (2), and (3) above.

(*b*) Place a dosage of 10 parts per million of copper sulphate in water. In a large body of water, this may be done by trailing behind a boat a small cloth sack filled with copper sulphate crystals. The water should not be used for at least 48 hours after the addition of the copper sulphate. This method of treatment is applicable to still bodies of water only; it cannot be used in fast-moving streams.

(5) *Protection of water supply personnel.*—Personnel operating water supply points should wear rubber gloves and rubber boots when they are required to place their hands in or wade in untreated water.

[A. G. 300.7 (2 Dec 43).] (C 2, 18 Feb 44.)

128. To Start the Mobile Unit in Operation.

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q. When the effluent * * * pump discharge pipe. Open the valve in the filter discharge pipe slowly, as long as the effluent remains clear and until the the flow is just sufficient for the requirements over the period available, but not more than 75 gallons per minute, as indicated by the manometer. The plant is now in complete operation, and purified water is being delivered.

[A. G. 300.7 (2 Dec 43).] (C 2, 18 Feb 44.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

U. S. GOVERNMENT PRINTING OFFICE: 1944

WATER SUPPLY AND WATER PURIFICATION

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WATER SUPPLY
AND
WATER PURIFICATION

Chapter 1

GENERAL

1. **The Purpose and Scope.**— The purpose of this manual is to provide technical information concerning water supply and water purification and to assist Engineer troops in fulfilling their water supply functions. It discusses those basic principles of water supply and water treatment which pertain to both civilian and military practice and in addition, the expedients necessary in the field.

2. **The Problem of Water Supply.**— *a.* Water is normally procured from local sources when practicable. Permanent installations, stations, and camps may find it necessary to develop water supplies. It will often be necessary to operate and extend civilian water supply facilities in occupied territory. Treatment of the water may or may not be required.

b. The first consideration in all water supply problems is the quantity of water available. If an adequate amount of water is not procurable locally, it must be transported by truck, tank car, or pipe line.

c. Where there are several sources from which the necessary quantity of water may be obtained, the supply with the most desirable characteristics is selected. To determine which of several sources is to be chosen on the basis of water quality, the characteristics of water should be considered in the following order:

(1) *Safety.*
Freedom from bacteria—especially pathogenic types—pathogenic protozoa, parasitic worms, other objectionable organisms and physiologically active chemical substances.

(2) *Palatability.*
Acceptable taste, odor, and temperature.

(3) *Attractiveness.*
Freedom from noticeable color and turbidity.

(4) *Mineral characteristics affecting convenience of use.*
Iron, manganese, hardness, soluble salts, and acidity or alkalinity.

d. Few water supplies are entirely satisfactory, as found in nature, but any source which can yield enough water should be given consideration. Appropriate treatment can alter almost any natural water, so as to permit its use for military purposes. If, however, the required treatment is complicated or difficult, another source should be sought, even if it is necessary to transport water from a more suitable supply located at a distance.

e. The quality of military water supplies in the field need not meet the standards of municipalities, but when the tactical situation warrants, it should be progressively improved until the quality compares favorably with municipal supplies.

3. **Importance.**— *a.* Water supply is vital to the accomplishment of the tactical mission. Men can go longer without food than without water. More casualties, both permanent and temporary, can be brought about by water than by any other single cause. A mistake in the procurement or treatment of water can immobilize an entire command.

b. Consumption of impure water results in widespread violent diarrhea which promptly reduces troop efficiency. These diarrhea epidemics may be followed in a week or ten days by outbreaks of serious intestinal disease. Whereas diarrhea may incapacitate a command very suddenly, but only temporarily, the more serious intestinal disorders may require the hospitalization of large numbers of men, and result in serious depletion of the effective strength of the organization.

4. **Responsibility.**— *a.* The Corps of Engineers is responsible for the supply of water for all purposes to all major units of the army in the field down to and including the division, and to smaller units if practicable.

b. The responsibility of the Medical Department in connection with water supply is covered in AR 40-205, which reads, in part, as follows:

> "The Medical Department is charged with the duty of investigating the sanitary condition of the Army and making recommendations in relation thereto, of advising with reference to . . . . . the quality of water supply and purification . . . . . and the execution of all measures for conferring immunity from disease on military personnel."

c. In general, responsibility for the quality of water supplied to troops in the theater of operations to include delivery to the point where it is distributed to consuming organizations rests with the engineers, assisted as may be necessary for laboratory examination by Medical Department personnel. The handling of water in organization water containers, in sterilizing bags, and in the canteen of the individual soldier is a responsibility of the organization commander, acting with the advice and assistance of attached medical personnel.

5. **Duties of Engineers.**— Engineers have the following general duties in connection with water supply:

- *a.* Reconnaissance and collection of data.
- *b.* Development of sources.
- *c.* Purification.
- *d.* Construction and operation of establishments.
- *e.* Transportation to distributing points.

For a discussion of engineer water supply operations in higher units see FM 5-5.

6. **Definitions.**— *pH* is a measure of the degree of acidity or alkalinity of a solution.

An *Indicator* is a substance which has different colors in different pH ranges.

Alkalinity in water practice consists of all those substances which impart a straw yellow color to methyl orange indicator, usually bicarbonates, carbonates and hydroxides.

Acidity in water is divided into two kinds; viz., *mineral acidity,* which consists of all substances which impart a red color to methyl orange indicator, and *carbon dioxide acidity,* which does not impart a red color to methyl orange but causes phenolphthalein indicator to change from pink to colorless.

A *Coagulant* is a substance which forms a gelatinous precipitate capable of attracting other particles to itself.

A *Floc* is the gelatinous precipitate formed by the action of a coagulant with the alkalinity in water.

Coagulation is the process of gathering together finely divided particles suspended in water and consists of feeding a coagulant, reaction of the coagulant and alkalinity, the formation of the floc particles, increasing the size of the particles, and attraction of the suspended matter to them.

Turbidity consists of particles suspended in water which give it a "muddy" appearance.

Color consists of finely dispersed particles which impart color to water.

Hardness consists of calcium, magnesium, and iron salts which destroy soap and form incrustations on heated surfaces.

A *Filter* is an apparatus for the removal of solids from liquids or gases.

Head is the depth of a column of water. Pressure head is the pressure equivalent to that exerted by a column of water of a certain depth. 2.3 feet depth of water exerts a pressure of 1 pound per square inch.

Suction lift is the difference in elevation from the surface of a body of water to the centerline of a pump.

Static lift is the difference in elevation from the centerline of a pump to the point to which the water must be raised.

Friction loss is the reduction in pressure to overcome the friction or drag of the pipe material on the water.

Equivalent loss is the loss in pressure in passing through a valve or fitting, expressed in terms of the equivalent length of straight pipe which would be required to produce the same loss in pressure.

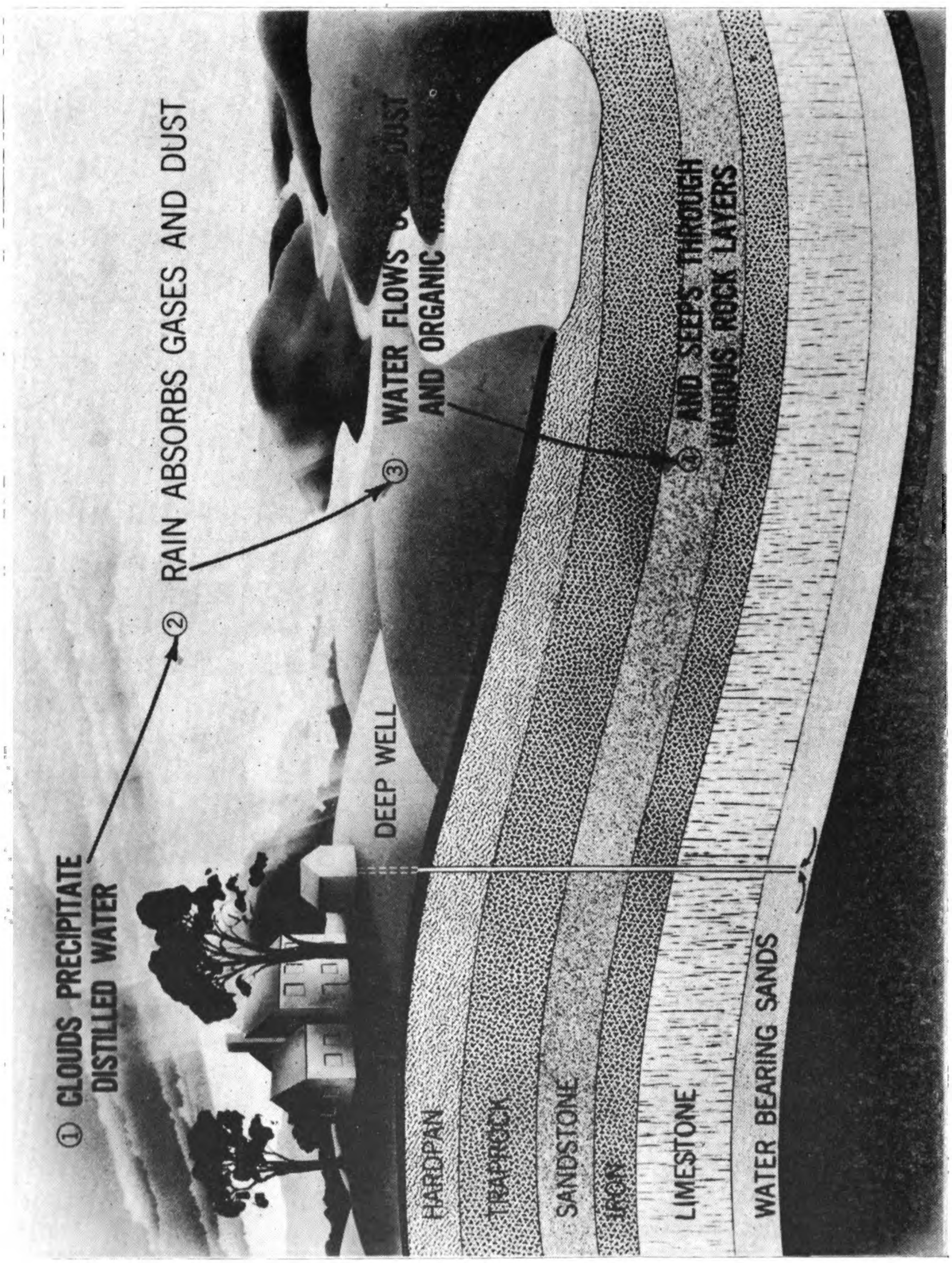


Figure 1. The Water Cycle.
(3) SHOULD READ *"Water flows over dust and organic matter"*.

Chapter 2

SOURCES OF WATER AND ITS IMPURITIES

7. **Classification of Water Sources. (Fig. 1).—** Water is classified as to source as follows:

- *a.* Rainwater
- *b.* Surface water
- *c.* Ground water
- *d.* Sea water (Used only as a last resort)

8. **Rainwater.—** *a.* Rainwater is normally collected on a roof or other surface, such as a bare rock area, and drained to a reservoir. Rainwater is not an important source of military water supply except under special conditions, such as on small islands, on isolated headlands, or in other places where ground waters are brackish or salty and surface waters disappear too quickly to be useful. If the number of persons to be served is very small, and the minimum annual rainfall expected is relatively large, the water collected from the roofs of buildings may be sufficient. Extensions to the roof area may be constructed to augment the volume of water to a limited extent. Larger quantities of rainwater may be collected, as at Gibraltar, by constructing concrete collecting surfaces, or by baring and preparing rock surfaces to drain the water into underground storage cisterns.

b. Rainwater generally contains some dissolved matter. In falling it has washed the air through which it passed. It has dissolved carbon dioxide, salts, and other soluble substances, and picked up dust from the air. Rainwater frequently contains molds, yeasts, and bacteria which multiply in cisterns and reservoirs. It varies somewhat in character according to the locality where it is collected, the amount of smoke in the air, and the recentness of dust storms or strong convection currents. The smaller the amount of dissolved substances in rainwater the stronger the tendency to dissolve materials with which it comes into contact; that is, it will be corrosive to those materials.

c. If the areas on which rainwater is collected are not kept clean, the impurities therefrom will be washed into the collecting cisterns. Dust, leaves, and feces are the usual polluting substances.

d. Subterranean cisterns usually help to keep rainwater cool. In some areas rainwater is collected in barrels and small elevated tanks. Water in these is likely to attract mosquitoes, midges, and other insects which lay their eggs on a water surface. This egg-laying is not usually regarded as pollution of the water, but the worm-like larvae are noticeable and breeding of mosquitoes may be objectionable. They are a nuisance and may be associated with the spread of yellow fever, malaria, dengue and other diseases.

9. **Dew Ponds.**— In some localities water condensed on vegetation, rocks, or purposely laid masses of stone, drains into a pond and accumulates an excess over the losses due to percolation, evaporation and use by plants. Such ponds are known as dew ponds and in some localities contribute to the local available water resources.

10. **Surface Water.**— *a.* When rainwater falls on the ground and runs across the surface to collect in brooks, streams, or lakes, it becomes surface water. Surface water is a very important source of water especially for communities of large size. Small communities frequently find surface waters more satisfactory than ground waters in those areas where the ground waters are hard and heavily mineralized.

b. From the military standpoint, the fact that surface waters can be easily located by maps and aerial or ground reconnaissance, and that the necessary work for development may be estimated quickly, make them the chief source of temporary water supplies.

11. **Physical and Bacterial Impurities in Surface Water.**— *a.* The character of the earth's surface on which rain or snow falls determines the character of the surface water which may be collected in that locality. If the surface is rock or relatively insoluble, the water running from it will probably differ little from the rainwater in the amount of dissolved and suspended matter it contains. If there is a large quantity of the fine products of rock weathering, if the rock surface is covered by soil and wind-blown clay, and especially if the land is tilled, more or less insoluble matter will be picked up by the water, the amount varying with weather conditions, the slope of the earth's surface and the volume of rainfall. When the earth's surface is frozen, the fine earth particles are held in place and the runoff will be low in turbidity, but as soon as the fine surface material begins to thaw, it is easily displaced by running water and the turbidity in the runoff increases. Later, when the earth is completely thawed out, its capacity for absorbing water is increased and minor rains may be absorbed completely without any apparent runoff. Vegetation on the earth's surface has an important effect in retaining earth particles and in reducing the turbidity of the runoff.

b. Surface waters which come in contact with peat, humus or decomposing organic substances tend to take on a yellowish, or brownish appearance due to the substances which the water extracts and holds in solution or colloidal dispersion. The effect produced by the extracted matter is to give the water a color ranging from a light green to the color of strong tea. This color is called the "true color", and should be differentiated from the apparent color of water which is the "true color" modified by the color of materials in suspension. Thus, a water which is turbid from coal dust will be grayish; one which contains iron oxide or red earth will be reddish; one which contains fine silica or undissolved air will have a milky appearance. When the turbidity is removed, the true color, or stain, in the water will be seen.

c. Some forms of turbidity may be irritating if present in sufficient amount and may produce a type of diarrhea. Water having brownish stains is not usually considered objectionable.

d. Greenish colors in water are also produced by the color of the bodies of minute organisms, such as algae and protozoa. These organisms grow best in clear waters exposed to sunlight, but they appear in large numbers only when temperatures, alkalinity, and the concentration of oxygen, carbon dioxide and dissolved mineral substances are such as to give them the necessary stimulus. Heavy growths of these and other aquatic organisms, such as duck-weed, may make surface scums on waters of ponds and streams. When the organisms are removed, the color disappears.

e. Growths of algae and aquatic protozoa are objectionable chiefly because they sometimes give offensive odors and tastes to the water. It has been claimed that blue-green algae belonging to the family nostocaceae may produce poisonous growths under certain conditions.

f. The gravest dangers associated with the use of surface waters are due to pathogenic bacteria, parasitic protozoa and certain types of higher organisms, including parasitic worms.

g. Large numbers of bacteria, mostly non-pathogenic, live in the surface earth where oxygen, moisture and the organic debris on which they live are abundant. These organisms are washed into surface collections of water with the fine particles of material which make up the suspended matter. With these bacteria may go pathogenic organisms derived from the feces of man and other higher animals. Animal parasites such as certain protozoa, and the eggs, larvae, and even the adults of some disease-producing worms, may also be carried into surface waters. Consequently, surface waters need careful purification to remove the turbidity and the living organisms which might cause consumers to suffer from simple diarrhea or more serious diseases such as typhoid fever and amebic dysentery.

12. **Dissolved Impurities.**— The mineral characteristics of surface waters vary with the mineral character of the mantle rock and of the soils over which they pass. Some are hard; others are almost as free from dissolved mineral substances as distilled water. Limestone and dolomite are among the more soluble rocks which contribute to the hardness of surface waters. During the winter, when surface runoff is negligible, due to the retention of the water as ice, streams and ponds are fed mostly by springs and seeps. This spring or seepage water is really

ground water escaping from the formations in which it has been held. Such water is often hard and has the characteristics of the ground water of the region. In the warm months the surface runoff dilutes water from the springs and seeps and the influence of the ground waters upon the composition of the water in streams and ponds is correspondingly reduced.

13. **Pollution of Surface Water.**— *a.* Pollution of streams by sewage and industrial waste is to be expected in inhabited areas. The degree of pollution will vary with the density of population, the development of industry in the vicinity, and the flow of the stream. If treatment of the wastes is completely or partially provided for, reduction in the pollution load upon the stream may be expected.

b. Nuisances such as floating sludge and bad odors are apt to develop in polluted streams. These are greatest during hot weather. In the summer, the violence of bacterial action reduces the oxygen content of the water and gives rise to the evolution of hydrogen sulfide and foul odors. Fish are killed by lack of oxygen in the stream water. In the winter a similar effect is produced because the ice-covered surface of the water prevents reaeration and the action of the bacteria, though slower on account of the lowered temperature, ultimately exhausts the natural oxygen supply. The need for oxygen may result in the removal of oxygen from unstable compounds. Thus, removal of oxygen from the oxides of manganese in the silt of the stream bottom will result in the formation of troublesome manganese salts. Black deposits of the oxides of manganese may form when these manganous salts are acted upon by the chlorine used in the sterilization of the filtered stream water.

14. **Chemical Warfare Agents in Surface Water.**— Surface water supplies may be exposed to contamination by chemical warfare agents distributed over the watersheds on which water is collected. The seriousness of the contamination depends upon the amount of the chemical agent spread, where and how it is distributed, and the character of the chemical agent itself. Each chemical agent has its own solubility, toxicity, and rate of hydrolysis and decomposition. Chemical agents on the watershed at a point distant from that where the water is taken for use may be expected to undergo decomposition more completely, and to be less dangerous to the consumers than the same agent, in equivalent amount, at the water intake. Odors and tastes of non-toxic decomposition products of the chemical agents may also be undesirable.

15. **Ground Water.**— *a.* If the surface water seeps down into the earth it becomes ground water, and is recovered from wells or collecting galleries. The surface water which enters the ground by percolation soon changes its characteristics with the environment. The part which flows into sinkholes, fissures, and other openings leading directly into the underground consolidated rock retains many of the more objectionable charac-

teristics of surface waters, such as the turbidity and high bacterial content, and is slow to alter in character. It remains essentially surface water and without purification is correspondingly undesirable for drinking.

b. As the water starts to penetrate the earth, it carries with it suspended matter, including many bacteria, and it contains oxygen and some carbon dioxide. Bacteria are numerous in the superficial layers of the earth, but as greater depth is reached, the number of bacteria in the soil rapidly decreases—unless the earth has been disturbed by man or burrowing animals. One of the reasons for this decrease is the depletion of oxygen in the soil air and its conversion to carbon dioxide through the life and activities of the bacteria, algae, molds, protozoa and higher organisms. Turbidity and bacteria are also reduced by the filtering out of these suspended matters by their absorption on the surfaces of the grains of the soil. The great increase in carbon dioxide brought about by the utilization of oxygen by the organisms in the earth makes the ground water much more active in the solution of carbonate rocks (limestone and dolomite) and thus brings about the increase in the hardness of the water which is observed where rock formations of this sort are found. If other soluble substances are present in the earth and in the underlying rocks, they too will go into solution. In the absence of oxygen, and the presence of carbon dioxide, iron and manganese oxides are converted into the soluble bicarbonates.

c. Ground water may be hard and contain iron, manganese, and enough carbon dioxide to have a corrosive effect, but it is generally clear when drawn and low in bacterial content. If ground water is not low in bacterial content and hence is to be suspected of contamination and doubtful or dangerous quality for domestic uses, it is practically certain that the condition is due to the entrance of surface waters into the ground water source. Usually, the pollution will enter at the top of the well, though occasionally it will be due to sub-surface drainage within the first eight or ten feet of the surface. In areas where sink-holes, fissures and caverns exist, the pollution may enter a rock formation some distance, even miles, from the source of the supply and be carried through passages in the rock to the spring or well from which the water is taken.

d. Ground waters continue their downward percolation through unconsolidated earth until they reach a saturated zone, the upper surface of which is commonly called the water table. When the water table has been built up to a certain height by the addition of water from above, the water begins to flow laterally toward an outlet, or to approach a static condition. The greater the difference in the elevation of the water table between two points and the greater the porosity of the intervening material, the more rapid is the lateral movement toward the lower point.

e. In the course of this lateral movement, the ground water may pass underneath an impervious layer of clay, shale or rock, or a layer which is so much less porous than the formation in which the water is traveling, that it is essentially impervious. If the ground surface at a point where the water-bearing formation, or aquifer, is to be reached by a well, or where the aquifer comes to the surface, is below the water table, a static pressure will exist. If struck at that depth, the water will flow toward the surface, producing an artesian well. An artesian spring is similarly produced by a fault or other outlet to the surface.

f. The water table rises and falls according to the replenishment of water from the surface by rainfall and the escape of water from the area. When the water table drops below the bottom of a shallow well, the well goes dry. When replenishment of the ground water by rains takes place, the water rises and the well begins to yield water again.

g. If a well is called upon to yield water in large amount, the demand may exceed the rate at which it can be replenished by the water from the surrounding earth and the water surface in the well will be drawn down below the surface of the water table. The distance from this new level to the water table is called the "draw-down" of the well for that particular rate of yield. The draw-down of the well is influenced by the porosity of the earth. (See Fig. 2)

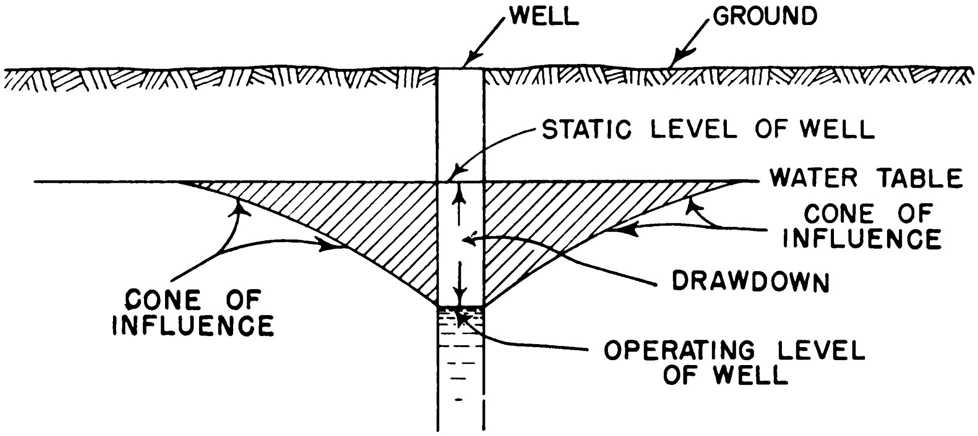


Figure 2. Drawdown and cone of influence.

h. In unconsolidated material a depression will be formed in the water table in the vicinity of the well. This depression will become less as the distance from the well increases. This produces around each well a "cone of influence" (Fig. 2), within which water will not be obtained by other wells. The actual slope of this "cone" of influence is a parabolic curve, but for practical purposes it may be considered to be a straight line. The base of the cone is sometimes called a "circle of influence." Wells within the circle of influence will have their water levels lowered according to their position within the cone of influence. The slope of the cone of influence may be experimentally determined by sinking a series of wells on a radiating line from the yielding well and taking the draw-down values for the other wells. If there is variation in the porosity of the earth within the circle of influence, that area may not be truly circular. Obviously, wells should be located far enough apart so that when they are yielding their maximum quantities of water, the cones of influence will not intersect.

i. When wells secure their water from beneath an impervious layer, there can be no cone of influence reaching the earth's surface. Nevertheless, there may be a reduction in the yield of nearby wells when one well is pumped heavily. If a number of wells are pumped heavily in one locality for a period of time, the draw-down of all of these wells may be progressively increased. Discontinuance of pumping permits the return of the draw-down of the wells to the original value by the normal replenishment.

j. The flow of water in any water-bearing formation is presumably in the direction of the dip of the strata. Therefore, it is not desirable to locate wells along the dip line. It is better to locate the wells along a line at right angles to the dip of the strata. This line is called the strike of the strata. If the direction of the strike is known, the wells should be placed along this line far enough apart so that one will not affect the other's yield. If faults, dykes, or other irregularities occur, they may complicate the situation.

k. Ground waters will escape laterally from formations whenever it is possible. The rate depends upon the porosity of the water bearing material and the slope of the ground water table. In stream valleys, at the foot of cliffs, and in general wherever the surface dips sharply, escape of ground water may occur. If there is a definite current produced by the escaping water, a spring is formed. If the flow is so diffuse or so small that no definite current is observed, seeps are produced.

l. In general, it may be expected that wells will decrease in yield, rather than increase, over a period of years. In addition to the depletion factor, there is often a movement of fine particles of sandy matter toward the well bore, with the result that the interstices between the coarse particles become packed with the smaller grains. The flow from the surrounding earth is correspondingly reduced. Deposits of calcium carbonate, and the oxides of iron or other relatively insoluble matter on well screens and coarse gravelly materials surrounding the well bore may cause a similar loss of water yield. Turbidity from the falling of earth from the roof of a cavern may cause this clogging and in addition, the roof may collapse and produce a sink-hole which will cause pollution by the surface runoff.

16. **Wells.**— *a.* Wells are classified in numerous ways, depending on their depth, artesian or non-artesian character, the method of their construction, and, sometimes, the character of the water delivered.

b. Depth.— Based on their depth, wells are classified roughly as shallow or deep. To the geologist a deep well is one which derives its water from beneath an impervious stratum. Since it is often impossible to learn about the geological conditions encountered when a well is sunk, and hence also impossible to learn whether or not an impervious stratum was passed through, it has become customary to define a deep well, arbitrarily, as any well which is 100 feet or more in depth.

c. Artesian character.— The geologist considers an artesian well to be one in which the water rises toward the surface under a static pressure. The flow does not need to reach the surface according to this definition.

d. Method of construction.— There are a number of variations in the methods of penetrating to a water-bearing formation in well construction and each method has a name. This discussion concerns only four of the construction types: the dug well, the bored well, the driven well, and the drilled well. Each type has its own peculiar advantages and disadvantages, based on diameter, depth, limitations as to formations which can be penetrated, character of the casings used, and the ease with which the well can be safeguarded against pollution. In general, wells of large diameter have the advantage of greater storage capacity and the ability to utilize the water of formations which yield only small amounts of water in a given period of time. However, their larger perimeter makes them more difficult to protect against the entrance of polluting materials and more difficult to case. Bored and driven wells cannot be sunk in consolidated rock or, except in fortunate locations, in boulder-bearing materials. Dug wells may be put down through such hard materials, at the expense of large amounts of labor and explosives. Drilled wells are adapted to great depth and hard rocks, but on account of their small diameter, have limited storage. They are so readily protected against surface pollution however, that water from them is usually safe.

e. Character of water delivered.— Wells are often spoken of as mineral wells. This term commonly means that the water produced is high in mineral salts, but strangely enough is sometimes used to indicate water which is particularly pure, or low in solid content. Mineral waters have been minutely subdivided into types on the basis of the kinds of

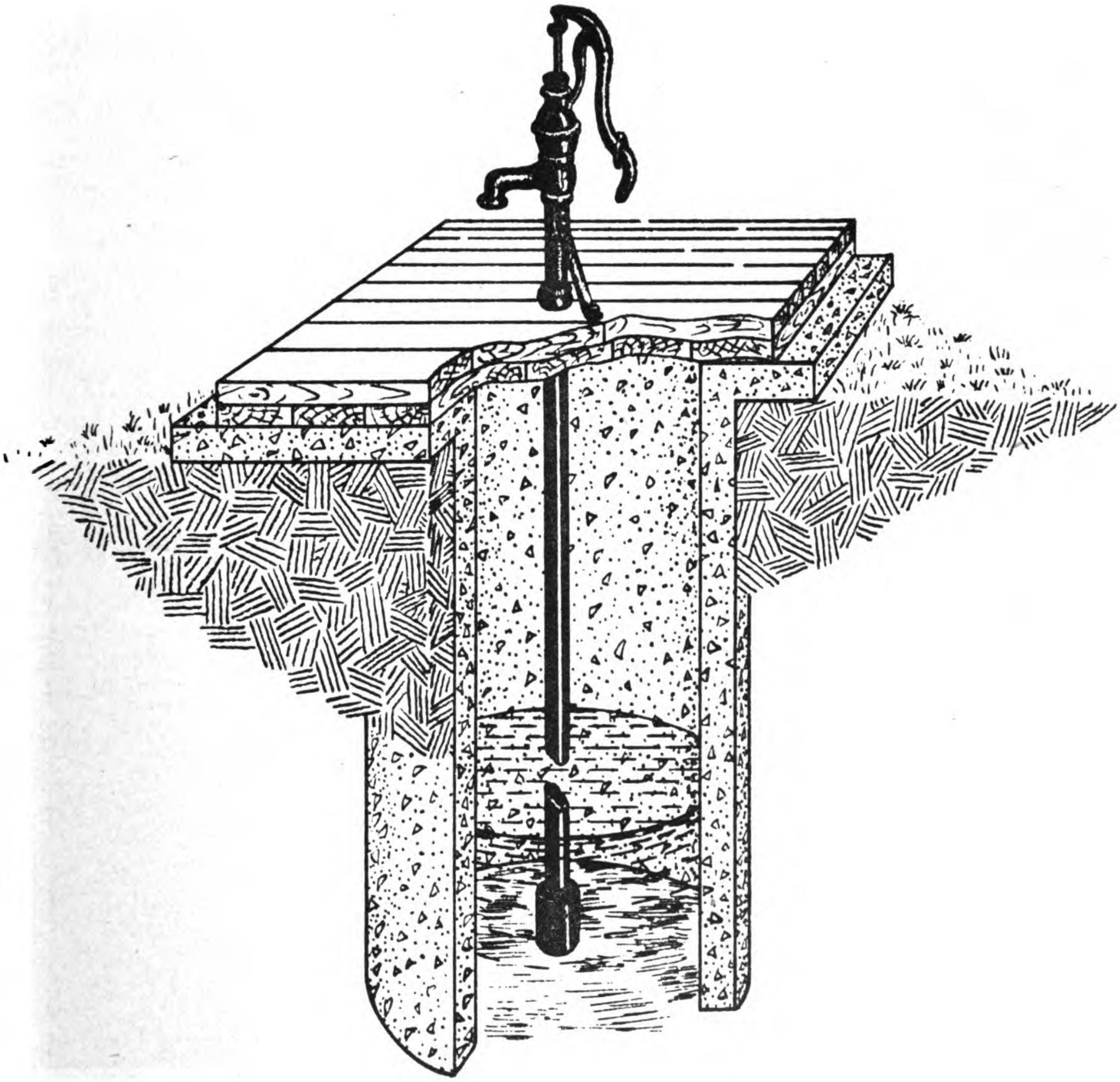


Figure 3. Shallow dug well.

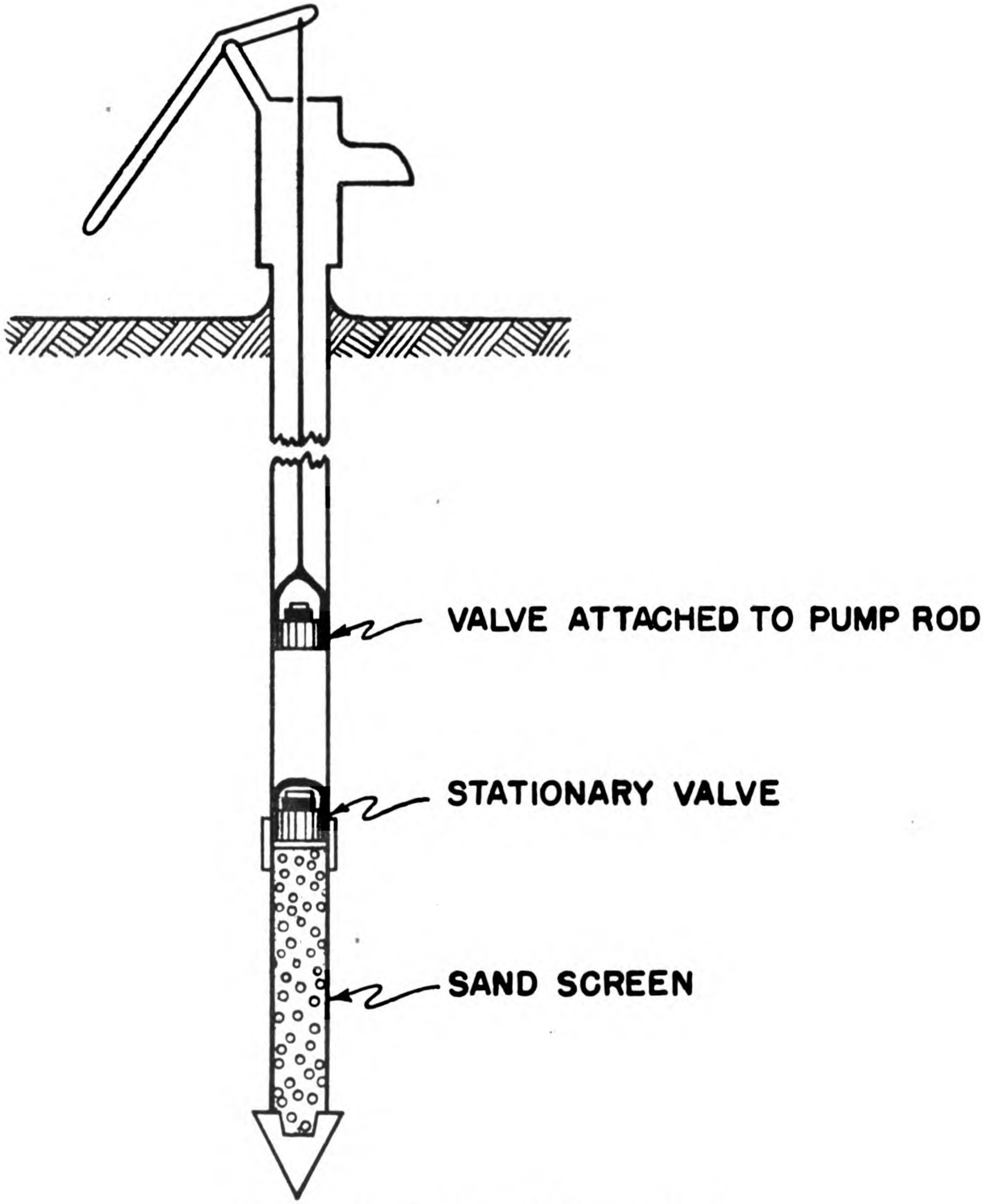


Figure 4. Finished small drive point well.

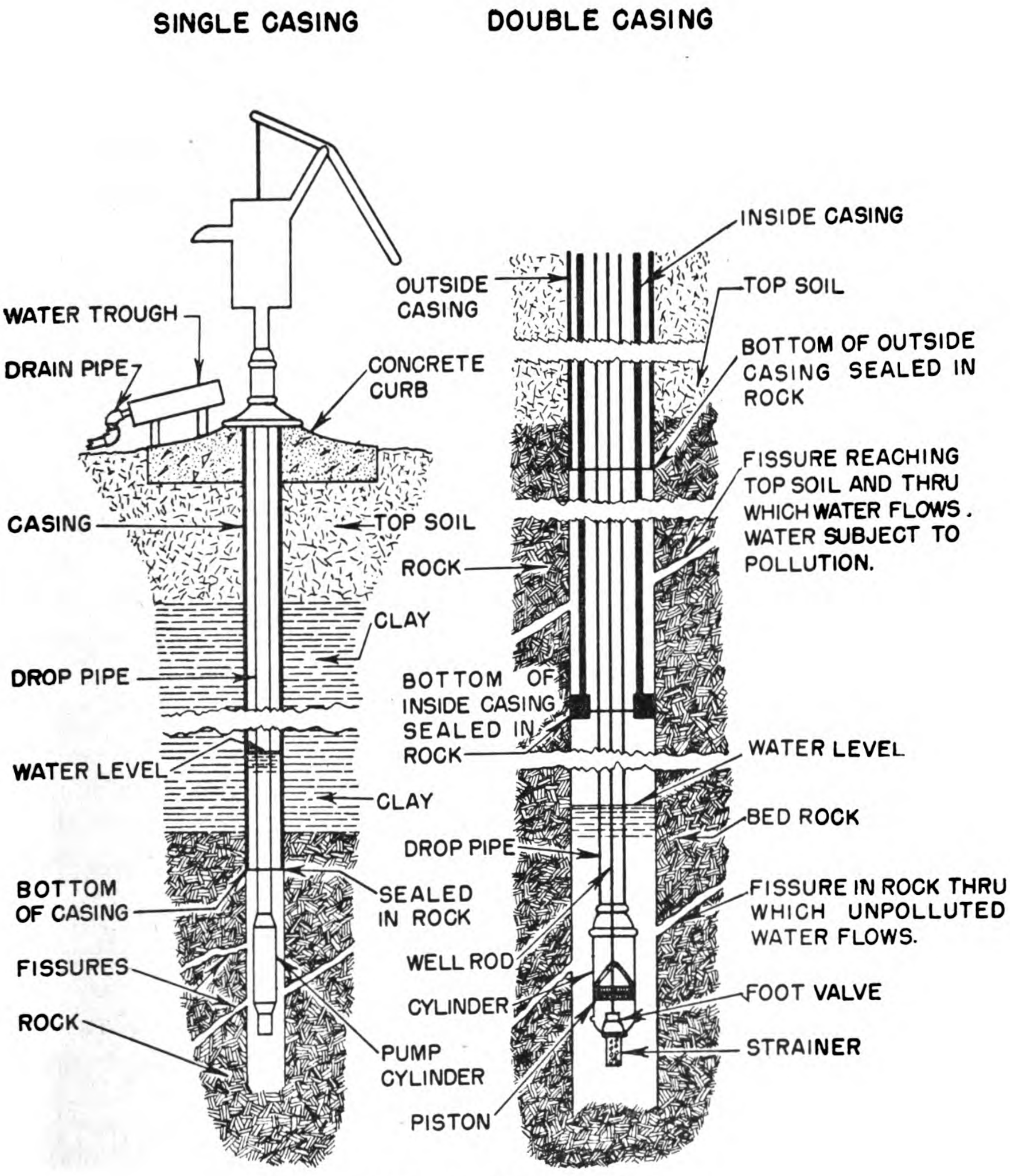


Figure 5. Drilled well.

dissolved substances contained and their supposed physiological action on the human body. Waters which contain hydrogen sulphide are often high in public esteem as mineral waters in spite of their offensive odor. Waters high in sodium chloride are usually objectionable to most persons when they first drink them, but familiarity and continued use frequently cause these waters to be preferred, if the chloride content is just at the concentration where a definite taste is imparted.

f. The characteristics of the four principal types of wells, based on construction procedure, are shown in Table Number I.

TABLE NO. I

GENERAL CHARACTERISTICS OF WELLS

Type of Well	Normal Diameter	Normal Depth	Method of Construction	Remarks
Dug Fig. 3	3-6 feet	20-40 ft	Pick and shovel usually. Drill and explosives. Windlass and bucket to raise materials. Stone, brick, or wood casings.	Most common in old wells. Usually restricted to loose materials.
Bored	2-12 in. (but up to 24″)	20-100 ft	Hand or power-driven augers. Clay, cement, metal, or wooden casing.	Cannot be constructed in consolidated rock, large gravel, or boulders.
Driven Fig. 4	1-6 in.	10-200 ft	Pipes, with driving shoe, sunk by pile-driver, water jet or a combination or with screen and drive point, using sledge, maul, or drive monkey.	Cannot be constructed in consolidated rock or large boulders. Better results obtained if well is equipped with a sand screen. May be gravel-packed.
Drilled Fig. 5	3-20 in.	100 ft or more	Power-driven percussion or rotary drilling machines.	Can be constructed in nearly any kind of rock in which water is found. Capable of reaching great depths. For military use, wells over 1000 ft. deep or in very hard rock are unlikely.

17. Springs.— *a.* Springs are commonly classified as follows:

Class I—The water in its lateral movement comes to the surface at a point where a porous stratum overlies a relatively impervious stratum. This is probably the commonest type of spring. Flow may or may not persist in times of deficient rainfall. The porous stratum may be sand, gravel, till, or porous rock and the underlying stratum may be clay, shale, or any relatively impervious rock.

Class II—This class of spring derives its water from a pervious collecting stratum which passes under an impervious stratum of some sort, so that an artesian type of flow is produced when the impervious cover is broken through in some manner. A fault, or a joint plane in consolidated rocks, may supply the opportunity for the water to escape, or the covering material may be eroded away by the action of water, disturbed by man, or otherwise weakened until the water of the spring breaks through to the surface. This type of spring is sometimes called an artesian spring.

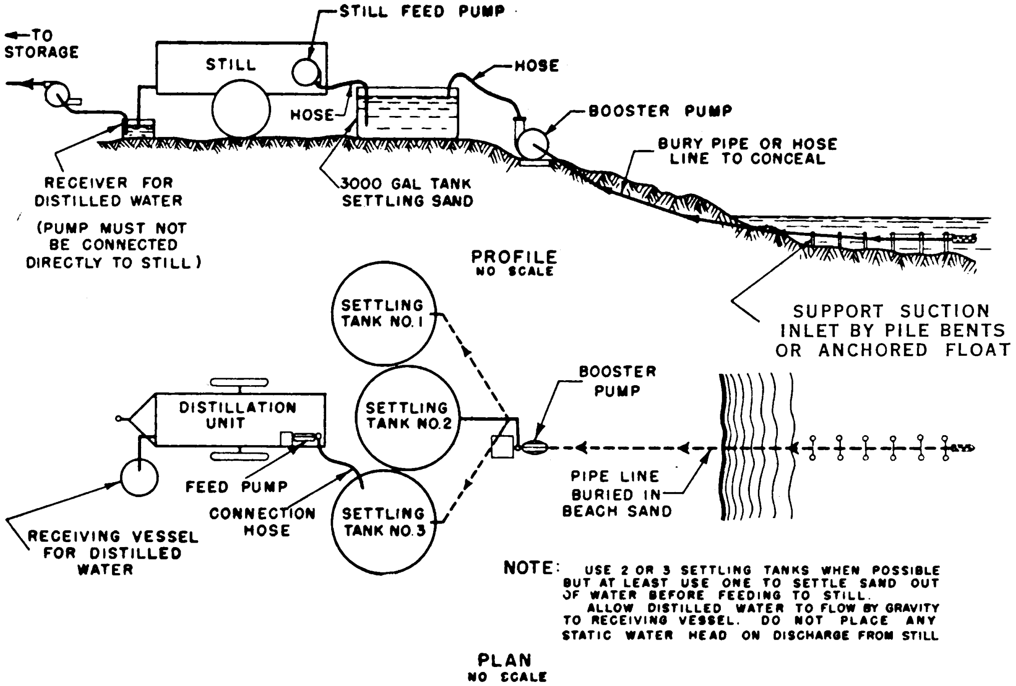
Class III—This type of spring is a mere overflow of ground water and consequently is highly variable in its delivery. It occurs whenever the ground water level, or water table, intersects the earth surface and the formation is sufficiently porous to allow the water to escape with the rapidity necessary to produce a flow having a distinct current. As the volume of water falls off, the flow decreases in velocity and ultimately the spring becomes a seep. There is no impervious cover involved and the impervious substrata may be considerably below the point of emergence of the water.

b. The yield of springs is often variable in volume. Frequently there is a marked increase in flow after heavy rains due to the building up of the slope of the ground water table and the more rapid, lateral movement of water toward the outlet. If turbidity accompanies the increase in yield, it suggests that surface waters are gaining access to passages in the rocks from which the spring derives its water, and if this is so, the bacterial condition of the water will probably be bad.

18. **Sea Water.**— *a.* The surface water streams and the flow of ground waters from springs and seeps along the shore or in the sea bottom, contribute water to the sea, as does the fall of rain water. The salinity of the sea water is due to evaporation and the abandonment of soluble salts.

b. Sea water is used only as a last resort in water supply. It is very high in its dissolved salt content, and frequently contains living organisms and suspended matter. In order for sea water to be usuable, the concentration of the salts must be greatly reduced. Ground waters and surface waters vary greatly in their salt content, ranging from a purity approaching that of rain water to salt concentrations even greater than that of sea water. While the salt content of sea water is approximately 37,000 parts per million, most surface and ground waters which are used for drinking purposes will contain less than 500 parts per million of dissolved solids.

c. It is desirable to filter sea water prior to distillation and to select carefully the intake site so as to reduce the organic content of the water taken for treatment. Sedimentation (Fig. 6) should be provided to permit separation of sand from the sea water and the incidental rise of oil to the surface. Intakes near beaches are likely to pick up both sand and oil. Jetted drive point wells on the beach can often be used to advantage instead of intakes in the sea.



NOTE: USE 2 OR 3 SETTLING TANKS WHEN POSSIBLE BUT AT LEAST USE ONE TO SETTLE SAND OUT OF WATER BEFORE FEEDING TO STILL. ALLOW DISTILLED WATER TO FLOW BY GRAVITY TO RECEIVING VESSEL. DO NOT PLACE ANY STATIC WATER HEAD ON DISCHARGE FROM STILL

Figure 6. Suggested lay out—sea water distillation point for either a 250 gal per hour or 50 gal per hour unit.

d. It is possible to secure water of reduced salt content by digging infiltration gallery trenches near the shore, thereby intercepting ground waters from the land as a part of the supply. Water that filters through the sands from the sea into the infiltration gallery, will also be reduced in its content of organic matter.

19. **Choice of a Water Supply Source.**— *a.* The first consideration in any water problem as already noted, is the securing of an adequate volume of water. It may be necessary to use several sources in order to secure the required amount. But where a selection may be made among several water supplies which offer an adequate volume of water, quality, ease of procurement, distance between source and point of use, and numerous other matters enter into the final selection.

b. There will be occasions when time will be available for thorough study of several possible sources and for the balancing of considerations to determine the most advantageous source. In the majority of cases time is not likely to be available for consultation, study, securing hydrological records, and the investigation of alternate sources. However, even the most temporary water supplies require consideration to avoid undesirable waters when it is possible to secure better sources in the time available, with the equipment at hand and within the designated area. A hasty estimate of quality and adequacy may be all that is possible and the controlling geological and hydrological factors which determine continuity will not be determined. Under these conditions, the needs of the moment, not other seasonal and demand requirements, will determine the actual point at which to begin work.

Chapter 3

DEVELOPMENT OF WATER SOURCES

20. **General.**— *a.* In general, the development of entirely new water supplies will be avoided, but where an entirely new source must be developed for temporary use, the steps in the development would usually be based on the following scheme. (Assuming lack of exact geological knowledge.)

(1) The first step would be to develop a surface water source and treat the water with the usual water purification equipment of engineer troops, unless it is heavily polluted, contains algae in excessive amount, is contaminated by warfare chemicals, or is otherwise dangerous or objectionable.

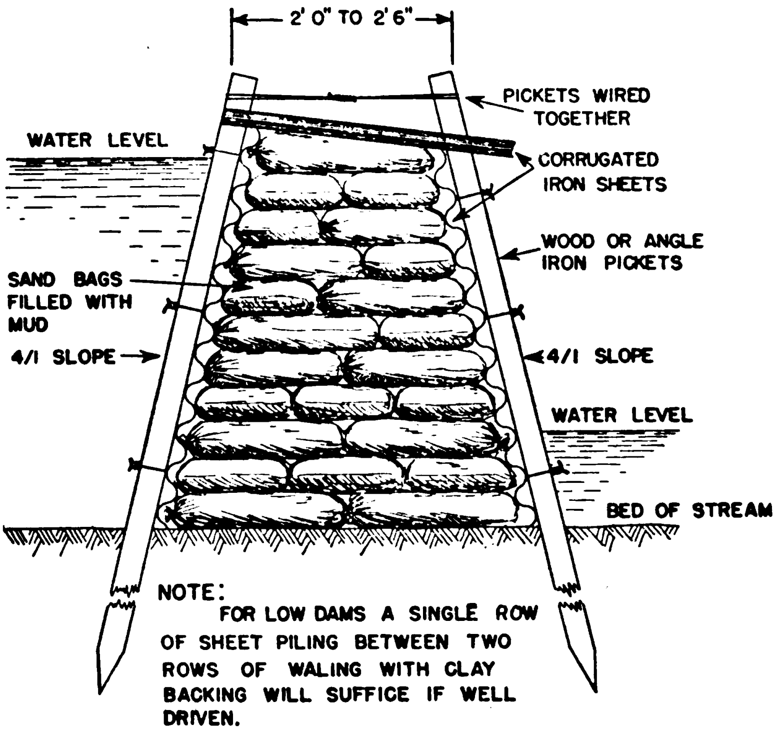
(2) If there is no suitable source of surface water, the next effort would be to try boring, driving, jetting or washing down shallow wells, or even to construct infiltration galleries in a stream bed a few feet back from the water's edge where overflow after a rain is not too likely. (See Chapter 2) If the valley is narrow, sheet piling may be used if necessary as a subsurface dam to hold back the shallow ground water. Water of recently constructed wells is often turbid and contaminated and will require passage through the usual purification apparatus. However, reduction of particularly objectionable foreign substances in the water as compared with the objectionable surface source should make treatment of the ground water easier. Wells in the terraces along the stream may be used, if overflow of wells at lower elevation seems likely to occur at times of freshets. Multiple-well systems may be required.

(3) *(a)* If the shallow wells do not yield freely enough, it will be necessary to go deeper for ground water. In the interest of economy, it is desirable to go no deeper than necessary to get enough water, unless the lower waters are known to be sufficiently better to make the use of time, man-power and equipment worth while. The wells may be pumped with ordinary suction pumps unless the lift is too great (22 feet is a safe maximum). If the lift is greater than 22 feet, a suitable plan is to install a central-type, air-lift pump (see Chapter 6) or to improvise such device, and deliver the water by means of a sweep elbow into a tank from which it may be pumped with the pump units of the portable or mobile water purification apparatus. A maximum depth to reach is about 1000 feet, but at this depth unless the water level rises more than half way, it is unlikely that air-lift pumping will be possible with adequate efficiency. Standard motorized air compressors are contemplated as sources of the air for air-lift operation.

(b) In the field, the wells put down will be of small diameter and the casing used as the eduction pipe. If time permits, wells of greater diameter may be sunk by means of cable-tool (percussion) rigs, or wells sunk by rotary methods may be reamed to greater diameter. Exploratory drilling with core barrels of rotary well rigs will permit the taking of cores in solid rocks. Limestones, sandstones, and shales may usually be penetrated readily. When hard rocks, such as trap rock and granite, are struck by any method of well drilling, continuance of the drilling is usually unprofitable.

b. Concrete basins or tarpaulins draining to storage cisterns, may be used to collect rainfall. The rainfall in inches, the area of collecting surfaces, and the storage provided determine the quantity of water which will be available. Storage cisterns are usually constructed below ground level for protection, for cooling, and for ease in providing the necessary downward gradient from the collecting surfaces, but occasionally the cisterns will be elevated or enclosed within the buildings to be served. In any event, provision should be made to prevent pollution of the water by wasting the first flushings of the collecting surfaces, by preventing the entrance of surface water, and by covering the top of the cistern. It is well to screen vents to prevent the entrance of adult mosquitoes and other insects that lay their eggs on a water surface. This precaution is especially important in localities where malaria or yellow fever may be expected. Down-turned elbow vents can be covered with fine metallic gauze.

21. **Surface Water Intakes.**—*a.* In selecting the point from which surface water is to be drawn, it is necessary that the water be as little influenced by agitation of bottom deposits, organic pollution, and floating debris as possible. It is necessary, however, that an adequate amount of water be available and continue to be available throughout the period of time the water will be withdrawn from the selected source. In temporary installations the protection against violent weather conditions, movements of the stream bed and other occasional difficulties, will not usually receive the attention which they would merit in permanent installations. The intake screen should not rest on the bottom, nor should it be suspended so near the surface of the water that air and floating matter may be drawn into the suction pipe. If the water is too shallow for these conditions to be fulfilled, it will be necessary to increase the depth. This may be done by digging a pit in the stream bed or by building a temporary dam of sand bags, sheet piling, earth, stone, or logs and brush. (Fig. 7)



NOTE:
FOR LOW DAMS A SINGLE ROW OF SHEET PILING BETWEEN TWO ROWS OF WALING WITH CLAY BACKING WILL SUFFICE IF WELL DRIVEN.

Figure 7. Improvised dam.

b. More permanent reservoirs justify efforts to secure information regarding expected rainfall, stream flow, evaporation, water losses, and the rapidity of the collection of silt. Dams, spillways, delivery lines, intake works will also require more careful design. In general, although great variation may be expected, it will be unwise to expect to impound for use more than 10 to 25 percent of the annual flow of the average small stream.

c. The screen selected for the intake hose or pipe should have apertures totaling in area about three times the cross-sectional area of the pipe because there is a definite hydraulic entrance loss for each of the apertures and because there will be an accumulation of obstructions on the screen surface. It is not desirable to have to clean the screen frequently during the pumping period. It is possible to locate the intake so that debris will be carried away from it and so that the screens will clog less frequently. The vertical position of the screen can be controlled by attaching it to a float so that it will hang suspended in the water or by surrounding it with a larger cage made of iron bars or strap-iron. Flexible joints in the pipe line or the use of hose will permit the rise and fall of the float-supported intake screen.

d. In most streams, particularly streams of considerable flow, it will be found that the quality of the water across the section of the stream will be variable. Below sources of pollution, such as sewer outfalls, it may be found that the polluting matter has a definite thread of flow which follows a pattern dependent upon the character of the stream bed, the course of the stream, and the fall. In general, in long, straight sections of a stream, the thread will follow the margin of the stream on the side of entrance and the sewage, if warm, will float upon the cooler surface. Where there is a curve in the bed, and the sewage flow enters on the inner side of the curve, the thread of flow will tend to pass across the stream toward the outer side of the bend. Then there will be a tendency to submerge and cross back to the side on which it entered. In the course of these crossings the thread of flow will broaden and the pollution will be more thoroughly distributed throughout the whole stream. Where there are riffles, dams, or falls, or where the stream velocity is great, the agitation and turbulence will accelerate the attainment of a uniform composition.

e. If time permits, tests with floats are useful in determining the character and direction of surface currents. Submerged vanes with surface floats will help to indicate conditions at lower levels.

f. Tidal back-waters should be avoided when possible because of the possibility of the back-flow bringing in pollution from lower portions of the stream. During high tides there may be more salt in the water at the intake.

g. Low velocity of streams frequently means stagnation and the opportunity for dense growths of algae to accumulate and produce clogging masses of odorous vegetation. High velocity prevents the settling of suspended matter and increases the turbidity. The mud loads carried, particularly near the bottom, are usually greater when the velocity is high, and relatively coarse sedimentary matter may be carried.

h. Winter and ice conditions impose certain considerations upon locating intakes for surface water. If the water surface is covered with ice, a hole may be cut through which the intake line is dropped to the desired depth, if the depth of the water below the ice permits. Unless the water in the intake line is kept moving fast enough, the whole intake line, being exposed, is likely to freeze.

i. Ice exists in several forms the most common of which is a surface sheet. Two forms which cause trouble are anchor ice and frazil ice. Anchor ice forms on the beds of streams, coating the rocks beneath the water surface, and may clog bottom intakes. Frazil ice, or spicular ice, consists of needle-like ice crystals which form throughout the mass of the water and may also clog submerged intake screens.

j. Water plant operators must be particularly attentive to their intakes in winter time. If the intake structures are permitted to freeze into the ice, they may be lifted, torn loose, or carried away by the ice of a rising stream. Winds may pile ice along the shore, buffeting, battering, and crushing exposed intake structures. At the time of spring thaw, ice jams are likely to cause the flooding of low lands and to drive masses of ice far up onto the shore.

k. Certain physical conditions of the intake site merit consideration. It is advantageous to select a site which has an adjacent area for the erection of the pumping equipment. Military conditions may impose the necessity for concealment of the intake, the suction lines, the pumping and purification equipment, and storage facilities. Submerged intakes, buried suction lines, overhead cover for the pumps, filters, and tanks, and the avoidance of tracks of men and vehicles, may also be necessary.

22. **Pump Location.**— It is advantageous to keep the pump which lifts the untreated water as close to the intake point as possible. The friction of the screen, intake, pipes, elbows and hose should be kept to a minimum. The pump should be as near to the surface of the water as possible in order to reduce the suction lift; if it can be put in a pump well below the water surface, with a positive head on the pump suction, so much the better. Friction in hose lines is reduced by keeping the lines as nearly straight as possible and with a minimum of humps which introduce friction and permit air pockets to form at the high points. It may be necessary to install booster pumps, or to provide one or more stages of lift from one tank to another if the distance from the intake to the purification equipment and final storage is too great.

23. **Substream-Bed Sources.**— If the character of the stream water is bad, if the quantity is insufficient, if off-shore conditions make location of the intake difficult, if concealment is not readily provided or if a suitable location for the water point equipment cannot be found, it may be desirable to exploit the ground water resources of the stream-bed sands and gravels or those of the bank of the stream. Infiltration galleries, dug wells, wash-down wells or driven wells may be used as sources of supply. Several shallow wells may be manifolded together, if necessary, in order to secure a sufficient amount of water to keep the pumps operating continuously.

24. **Intakes in Lakes and Ponds.**— *a.* Lakes and ponds sometimes offer convenient sources of water in the field. Most of the considerations which apply to the selection of intake sites on streams (Par. 21) also apply to the intake sites on the shore of lakes and ponds. Of course the water of lakes and ponds ordinarily is not continuously flowing by the selected intake pipe, carrying debris and materials from the upper portion of a watershed as in the case of streams. Except in the dry season, there is always drainage from the shores into a lake or pond and the entrance of tributary streams which bring materials which may modify the condition and composition of the water available in the collecting basin.

b. Lakes and ponds do have currents. Sometimes a lake has a definite inflow and outflow to produce the currents; sometimes the currents are caused by winds or by temperature changes which modify the density of the water. Onshore winds have a tendency to produce on-shore currents, building up the level of the water with resultant off-shore or undertow movements of bottom water and outward beach scour. If the currents are driven by heavy winds, the violence of the effect is greatly increased and a surf, or wave impact action is produced. Large waves may stir up a lake to depths of thirty or forty feet. Off-shore winds push the water away toward the distant side of the lake, tend to lower the level of the water at the near shore line and bring up cooler, bottom waters, sometimes in a state of partial oxidation.

c. Lakes and ponds frequently support considerable quantities of algae and other aquatic vegetation. Dead vegetation falls to the bottom and there it continues its decomposition under the action of bacteria and other living organisms which require oxygen for their metabolic processes. The oxygen is taken first from the water and thereafter from the next easier sources, the more easily reducible compounds such as nitrates, sulphates, and the hydrated oxides of manganese. Ammonia, sulphides, and soluble manganese compounds result from such reducing effects. Some organic compounds having musty tastes and earthy odors may be produced. Under certain circumstances compounds which react with chlorine to form chlorine-addition products of objectionable odor and taste, may be developed. Intakes near the surface may avoid these compounds, unless the whole lake or pond is stirred up.

d. Vertical circulation of many lakes and ponds may be expected in the spring and fall due to seasonal temperature changes. Pure water has a point of maximum density at 3.98° Centigrade (39.2° Fahrenheit). Above the point of maximum density, the weight of a unit volume of water decreases with temperature rise. Below the point of maximum density the weight per unit volume also decreases with the temperature fall until the temperature of 0° Centigrade, or 32° Fahrenheit, is reached. Then, with the formation of ice, a further decrease in density and an expansion of the order of 9 or 10% takes place. This has an important bearing on lakes in the temperate zones. In the fall, as the air temperature cools the surface water toward the temperature of maximum density, there is a progressive sinking of the heavier water toward the bottom, mixing with and bringing toward the surface, the warmer water. This is the fall overturn. Just before freezing takes place, the point of maximum density is passed and colder, but now lighter, water remains at the surface and freezes. In the spring, the surface ice melts and leaves a cold surface water slightly above the temperature of maximum density. The water at the bottom, in shallow lakes or ponds, has been warmed slightly by the heat from the earth and the slow oxidation taking place. The surface water exposed to the air is warmed to the point of maximum density and sinks, bringing up the warmer water from the depths of the pond to take its place. This mixing continues until all of the water has reached the temperature of maximum density. This is the spring overturn. Between the periods of spring and fall overturn, or circulation, there are two quiescent periods which are sometimes called the summer and winter stagnation periods.

e. Intakes on large lakes should be located with some consideration to protection from the direct action wind-driven waves. Otherwise they may be subjected to a severe buffeting by waves and ice. If possible, the intakes should be to windward, that is, on the side of the lake from which the prevailing winds come.

25. **Sea Water Intakes (Fig. 6).**— *a.* Sea water intakes will usually be located beyond the surf, off the beach, or in the deeper water of a protected inlet. The quality of the water will differ according to location. The water of estuaries may be influenced by the amount of fresh water being poured into them from tributary streams. The estuary water will usually be lower in its saline content than sea water, but it may contain a considerable quantity of polluting materials and city drainage. Water taken from the surf will usually contain fine sand and, at times, oil which has been discharged from passing ships. Water from protected inlets may contain more of the marine algae and other living marine organisms than the water from the open sea, and these organisms may contain volatile compounds of a pronounced fishy odor and taste.

b. Shallow beach wells may be practical as a means of securing water of lower salt content and freer from sand, oil and marine life. They may also be sunk nearer the line of vegetation and thus assist in the concealment of beach installations which must depend upon the use of salt water and distillation.

c. Sea water intakes located on beaches must be carried out considerable distances in order to take care of fluctuations in rise and fall of the tide and at the same time have sufficient submergence for the intake screens at all times. The action of the surf on such intake lines may be violent. Strong means must be devised to hold the intake and its pipe line firmly in position. Piles, jetties, rock, and rip-rap are used for this purpose and for protection. On-shore winds, storms, tidal waves, and wave tossed debris or ice may also endanger the beach intake.

d. The exposed position of a beach water supply intake is a military disadvantage. Dispersion of water production facilities becomes necessary and the concealment of equipment, pipe lines, storage tanks and personnel must also receive attention. Protection of personnel and equipment against cold winds from the sea may be secured by placing them behind dunes, if they are available, or behind artificial barricades. It will often be better to construct beach wells than to depend upon pipe lines from the sea. Sea water will not enter into the normal military water supply problem; it will be provided only for emergency use, or when it is not feasible to secure natural fresh waters in sufficient amount.

26. **Permanent Intakes.**— *a.* Engineer personnel will occasionally be called upon to operate, modify, or plan and construct permanent surface water intakes on streams, lakes, or artificial impounding reservoirs. These intakes may be submerged or exposed. They may be simple or elaborate structures and their exact locations may require extensive study and a knowledge of river control procedures to insure the permanence of an adequate depth and volume of water at the ports of the intake.

b. Submerged intakes (single or multiple) may be simple screened pipes carried out to deep water where they will offer little obstruction to the flow of the stream, avoid ice scour during the spring break-up of surface ice, and offer a minimum of obstruction to navigation. They may be secured in position with cribbing, and sometimes given additional protecton by piles, rip-rap, rock, or concrete. Intake screens of submerged intakes are usually relatively coarse, made up of bars of strap iron. The area of the screen openings is about three times the cross sectional area of the bore of the pipe and it is designed to have an intake velocity of less than 0.5 foot per second in order to prevent clogging of the screen by fish. At times in the past the screen area was required to provide at least one square inch of opening for each gallon per minute of rated pump capacity. This is about ten times the suction capacity of the average steam pump that would be connected to the screen. If the water was of low turbidity, a smaller screen, even half this size, might be satisfactory. Finer screens to remove material not rejected by the coarse outer screen, may be provided and placed where they can be cleaned more easily and frequently than the submerged intake screens.

c. Exposed intakes are generally preferred for larger water plants although they have the disadvantages of increased cost, increased interference with navigation, and increased difficulties with floating ice and debris. Usually, however, they are less likely to become clogged, permit choice of one or more levels from which to select the water, and are easier to operate, inspect, and maintain. Exposed intakes usually take the form of intake towers or intake boxes with inclined screens going down into the water source. Calculations for the latter type of screen, since it is only partially submerged, should include only the area beneath the water surface. Box-type intakes are sometimes designed in such a way as to permit the operator to divert a portion of the raw water through the intake box to flush the normal intake screen, cleaning it of accumulated debris. At other times a different scheme is used to produce a back flow to clean the screen. Intake towers may be of either the wet-well or dry-well type. The former is essentially a tower having various intake ports at which water may be admitted, with a delivery conduit leading to the plant. The dry-well type of tower has the conduit pipes connected directly to the intake ports, and these ports are controlled by valves in the pipes. The entire tower of the dry-well type is accessible for operation and repair. Both towers must be structurally stable, heavy enough to prevent floating when unwatered, strong enough to withstand water, ice, and wind pressures, and the forces due to earthquake shock. The intake ports are usually placed on the down-stream side of the tower or at right angles to the current to avoid clogging by debris. Various levels of ports provide for stream or lake height fluctuation and permit selection of the best available water from time to time, based on depth.

d. When intake towers are installed in an impounding reservoir they are usually placed at the deepest point, commonly near the dam which forms the reservoir. This renders the maximum capacity of the reservoir available.

e. The intakes should discharge by gravity into an adequate suction well so constructed that the suction pipes of the pumps will always be submerged. Since the suction lift of pumps is limited to about twenty feet, pumps should be placed in a pit deep enough to permit them always to draw water from the suction well, no matter how great the fluctuation of the water supply source. If water level variation at the source is expected, the pumps should be mounted on a platform which can be raised or lowered to insure their proper functioning. If a positive head of water can be maintained on the suction port of the pump, priming difficulties will be eliminated.

27. **By-Passes.**— Public health authorities will object if the construction of the plant permits untreated water from the surface source to be pumped around treatment equipment and into the mains of the community. The mere possibility of such passage of untreated water into the distribution system will prevent the approval of the supply by the public health authorities.

28. **Development of Ground Waters.**— *a.* Except in those places where ground waters issue from the earth under artesian pressure, or where they can be tapped at an elevation conveniently located so they can be withdrawn by gravity, it will be necessary to make arrangements to lift the water by means of a pump. When the water is near enough to the surface, an ordinary pump located at ground level with a suction lift of about twenty feet will be ample, but in many cases the depth of water will require a lift greater than the capacity of a simple suction pump. It will then be necessary either to use a deep well pump or to lower a pump into the earth and to use a portion of the positive lift capacity to raise the water to the desired elevation.

b. Where there are existing ground water supplies they should be exploited to the utmost. Hand pumps may be removed from wells and power-driven apparatus installed to elevate the water. Larger pumps may be substituted for existing power units of small capacity. Surging, acid washing, and other means (Chapter 7) may be used to increase delivery of the existing ground water sources. Deepening to reach more productive strata or replacement of screens to reduce resistance and increase yields may also be feasible.

c. (1) If the military situation demands the development of additional ground water supplies, speed will be important. The first water that can be obtained may be required for the troops. The construction work involved will almost invariably cause the water to be turbid or muddy. It is very likely that there will be sandy material included with the muddy or earthy suspended matter. It will probably be bacterially contaminated and will require filtration and chlorination to render it acceptable as drinking water.

(2) Suspended matter in the water from the new source may endanger the pumping equipment unless it is specially adapted to the handling of the earthy and sandy materials. Turbine pumps, rotary pumps, reciprocating pumps, and others with closely fitting moving parts are quickly abraded and damaged by gritty matter. Certain other kinds of water-lifting machinery are adapted to delivering the sandy water of new sources. Such equipment includes the diaphragm pump, air-lift, canvas-belt elevator, and open impeller centrifugal pumps. After the well has been developed pumps which are affected by grit may be installed with reasonable safety. By making this change-over the greater efficiency of these pumping machines may be utilized.

d. Shallow wells may be dug, driven, or otherwise sunk in places where the surface contours suggest the presence of ground-water. Deep wells may be drilled to relatively great depths if there is reason to think that water bearing strata carry a sufficient amount of water to justify the work involved. It will frequently be best to drill a relatively small-diameter well as an exploratory measure and then enlarge it if it is successful. Small diameter wells can be sunk and placed in production more quickly than can larger wells. A number of small wells can be sunk if required. Later, when there is less urgency, the small wells can be reamed to larger diameter or larger-diameter wells can be sunk to the level of aquifers already located. The screens and equipment of these larger wells can be more accurately specified than can the apparatus for the small, hastily-sunk sources. Since the time available for larger wells will permit it, the development of the large wells may be carried to a degree sufficient to eliminate the dangerous load of grit before the more efficient pumping equipment replaces the air-lift used initially.

e. All ground waters from new sources should be chlorinated until their safety has been assured by repeated bacteriological examinations, and continued until there is no possibility of contamination under any circumstances. It usually takes several weeks to eliminate all of the contamination incident to the new construction. The removal of the contamination may often be hastened by chlorination of the source with heavy doses of chlorine-yielding compounds if enough of the chemical can be made to reach all those places within the well where objectionable bacteria have lodged. The required treatment should be applied to all waters until they have been proved safe and free from the possibility of casual or intermittent contamination.

29. **Development of Springs.**— *a.* To pump spring water easily it must be collected in a basin after it emerges from the earth unless the flow from the spring is so tremendous that it forms a reasonably deep, water-filled channel. A temporary basin may be prepared by boxing in the area about the point of emergence by means of crude walls of sandbags or wooden planking, or by digging into the ground to a sufficient depth to form a pool of the desired capacity. Such crude basins are almost certain to permit pollution of the water by surface wash and will require careful treatment before use.

b. Covered concrete spring boxes, if properly designed and made to extend back into the earth a sufficient distance, may exclude the polluting surface waters. Hillside surface flows may be diverted from the box by digging a V-shaped trench with the point of the V uphill and the sides of the V straddling the spring box. The overflow from the spring box should pass through a pipe far enough above the ground level that it is unlikely that surface waters or small animals may enter through the pipe and pollute the spring water within. It may be desirable to screen this outlet pipe to exclude insects. The flow of some springs may emerge from channels in the limestone or other cavernous rocks of the region which have sink-hole openings and permit the admixture of polluted surface wash with the normal ground water collected by percolation. Attempts to develop springs to increase their yield may sometimes be unsuccessful.

30. **Dug Wells** (Fig. 3).— *a.* Next to springs, dug wells represent man's most prolific source of ground water. Licks discovered by animals and natural water holes indicate potential well sites; these may be exploited by digging. By deepening the excavation, increasing the diameter, and adding a casing, wells of this type can be provided. Where the water table is close to the surface, where the porosity of the earth permits relatively free drainage of water into the excavation, and where it is possible to sink and case the well without the walls caving in, dug

wells may be a very satisfactory means of securing ground water in the field, particularly if only elementary construction equipment is available.

b. Dug wells have the advantage of utilizing water from practically all of the formations which they penetrate. They permit the storing of considerable quantities of water because of their relatively large diameters and the reservoir effect thus produced. However, on account of the large opening and the large perimeter to be protected against the entrance of surface drainage, dug wells are subject to pollution by surface wash, by windblown material and even by objects falling into the opening. This pollution is readily overcome by treatment with the mobile and portable water purification units or by chlorination in a Lyster bag.

c. Dug wells are seldom less than three feet in diameter and they may be much larger. Usually they are 20 to 40 feet deep, although close to a stream, water may be secured at lesser depths. Dug wells over 60 feet in depth are unusual. Since they are usually dug by hand, great care must be taken to shore up the walls as a safety measure. They may also be sunk by the use of a grab-bucket. Dug wells are ordinarily limited to unconsolidated earth.

d. Particularly favorable locations for dug wells are in the flood plains and alluvial terraces of streams, beside lakes and ponds, and, generally, in those places where high ground water levels may be expected.

31. **Infiltration Galleries.**— *a.* Infiltration galleries are essentially long, horizontal, shallow, dug wells. Frequently they are sunk along the banks of streams where they intercept water flowing toward the stream. When the water in the stream is temporarily higher than the water table in the flood plain, the direction of flow may be reversed.

b. In the field, infiltration galleries may take the form of trenches beside streams, lined with plank sheathing on the inshore side, or unlined and ditch-like. In municipal practice, infiltration galleries may take the form of timbered tunnels or buried tile lines laid with open joints and draining to a pump sump. By the nature of its source, the water resembles that of a dug well or spring. In places where iron is likely to be deposited by ground waters, or where fine sands may pack around coarser materials, the interstices of the earth may clog and reduce the yield of infiltration galleries. Such a reduction in capacity may require a period of years. Infiltration galleries are most suitable for localities where the flood plains of streams contain coarse sediments of sand and gravel. Under these conditions large quantities of water may be recovered. Large communities have been supplied by infiltration galleries. The largest city known to be dependent entirely on infiltration galleries in 1941 was the city of Des Moines, Iowa, with a population of about 150,000.

32. **Bored Wells.**— *a.* Bored wells are wells which are sunk by hand or power augers and cased with wooden planking, tile, or sheet metal. They vary in diameter from 2 to 24 inches. They can be sunk only in unconsolidated earth in which boulders are not large or numerous. Depths of 100 feet may be reached, but depths over 40 feet are unusual.

b. The advantages and limitations of bored wells are essentially those of the dug well. They have a smaller diameter than dug wells, and consequently have less storage capacity. But the smaller diameter and perimeter make it easier to protect the bored wells at the top. Fabricated casing materials are usually available or may be readily improvised.

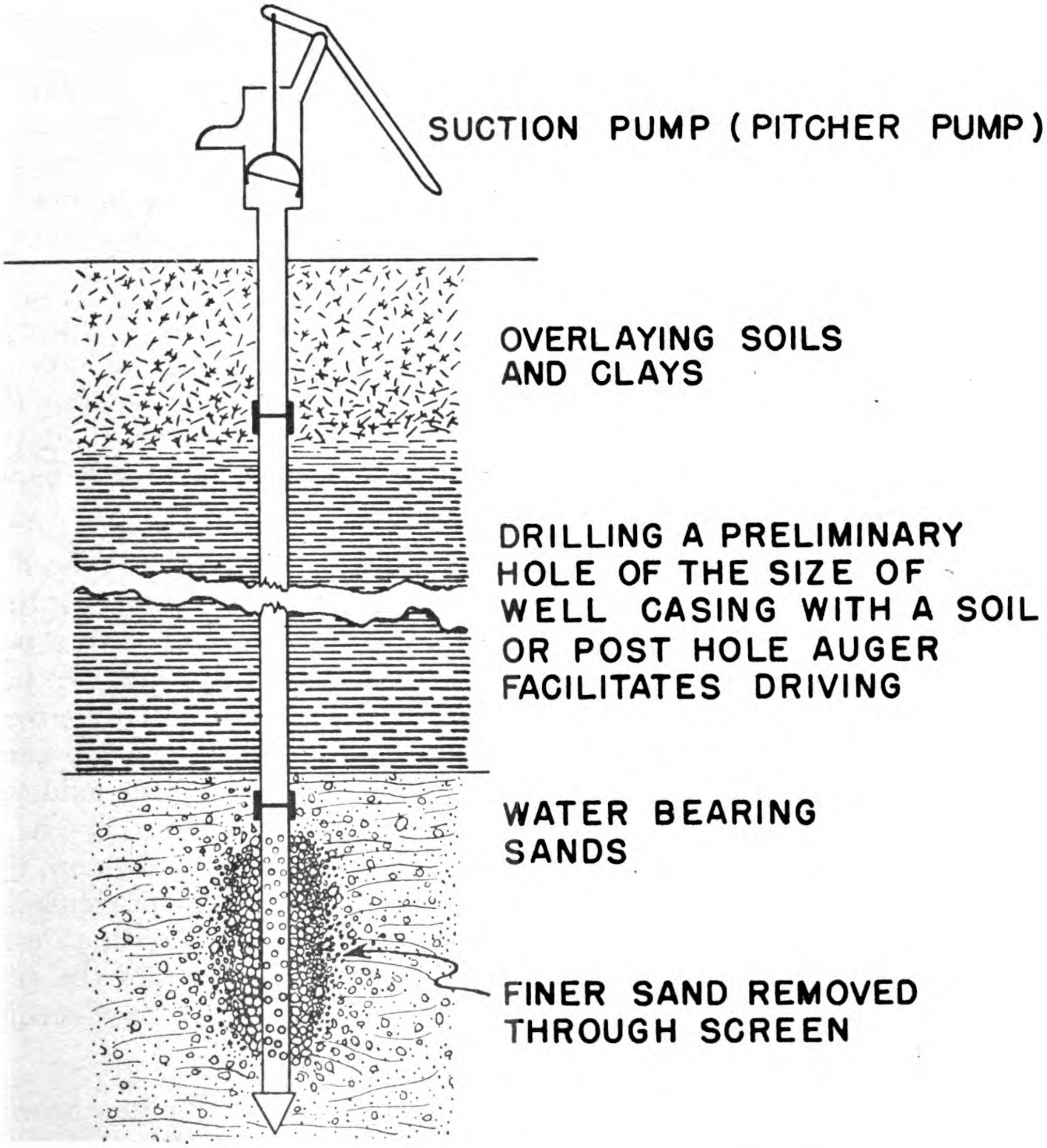


Figure 8. Finished drive point well.

33. **Driven Wells.**— *a.* The term "driven well" is used to describe a tubular well sunk by any one of several processes, but not to be confused with the methods employed for hard-rock drilling. These procedures are, in general, limited to unconsolidated sedimentary deposits relatively free from boulders, but in which the coarseness of the deposit permits such a swift flow into the well that the rapid and continuous removal of water by pumping is possible. Driven wells are of very small diameter for the most part and consequently it is impossible for a large volume of water to be stored within the casing.

b. The procedures which are most commonly used in sinking driven wells are the following:

(1) *The jetting, or wash-down process.*— In this process a string of pipe is sunk into the ground by means of a jet of water which removes the earth at the bottom and carries it out of the well. Sometimes a special well screen with a valve designed to allow jetting is used at the end of the pipe. Occasionally the well casing is open; gravel may be dropped in to form a screen or a commercial well screen may be inserted into the pipe and the pipe jacked up a short distance to permit the contact of the sand of the formation with the well screen.

(2) *Use of a casing with drive shoe and bailer.*— In this process a heavy iron drive shoe with a cutting edge is screwed to the end of a drive pipe and the earth within the pipe is removed by suspending it in water and lifting it out with a bailer. The bottom of the well may be gravel-packed, or a well-screen may be lowered into the well and packed in place after the drive pipe has been jacked up a few feet.

(3) *The drive point process. (a)* This type of well (see Figs. 4 and 8) comprises a series of lengths of pipe, joined by pipe couplings, and fitted at the upper end with a pump and at the lower end with a point and a sand screen through which water is admitted. The first, or point section consists of a 4 to 5 foot length of perforated pipe, usually covered with a screen, at the lower end of which is a mild steel point which serves to break through thin layers of hard material and to push aside the pebbles or rocks it encounters. After this section has been driven, the next section is screwed into place and driven like the first, and so on, until the water-bearing stratum is reached, or further progress prevented by the resistance of the ground. Frequently the well is started with an auger of small diameter and the drive point and screen inserted into the opening before actual driving begins. These wells are commonly referred to in British practice as Norton tube, or Abyssinian wells.

(*b*) The well is pumped until the muddy water has been removed and clear water is delivered. If water is needed badly, the muddy water can be collected in a tank and subjected to the usual purification procedures. It may be found to be bacterially contaminated and even the clear water from the well will require chlorination. Usually the quality of water from a drive point well becomes bacterially satisfactory within a week or two, but chlorination must be continued until the water is passed upon as satisfactory.

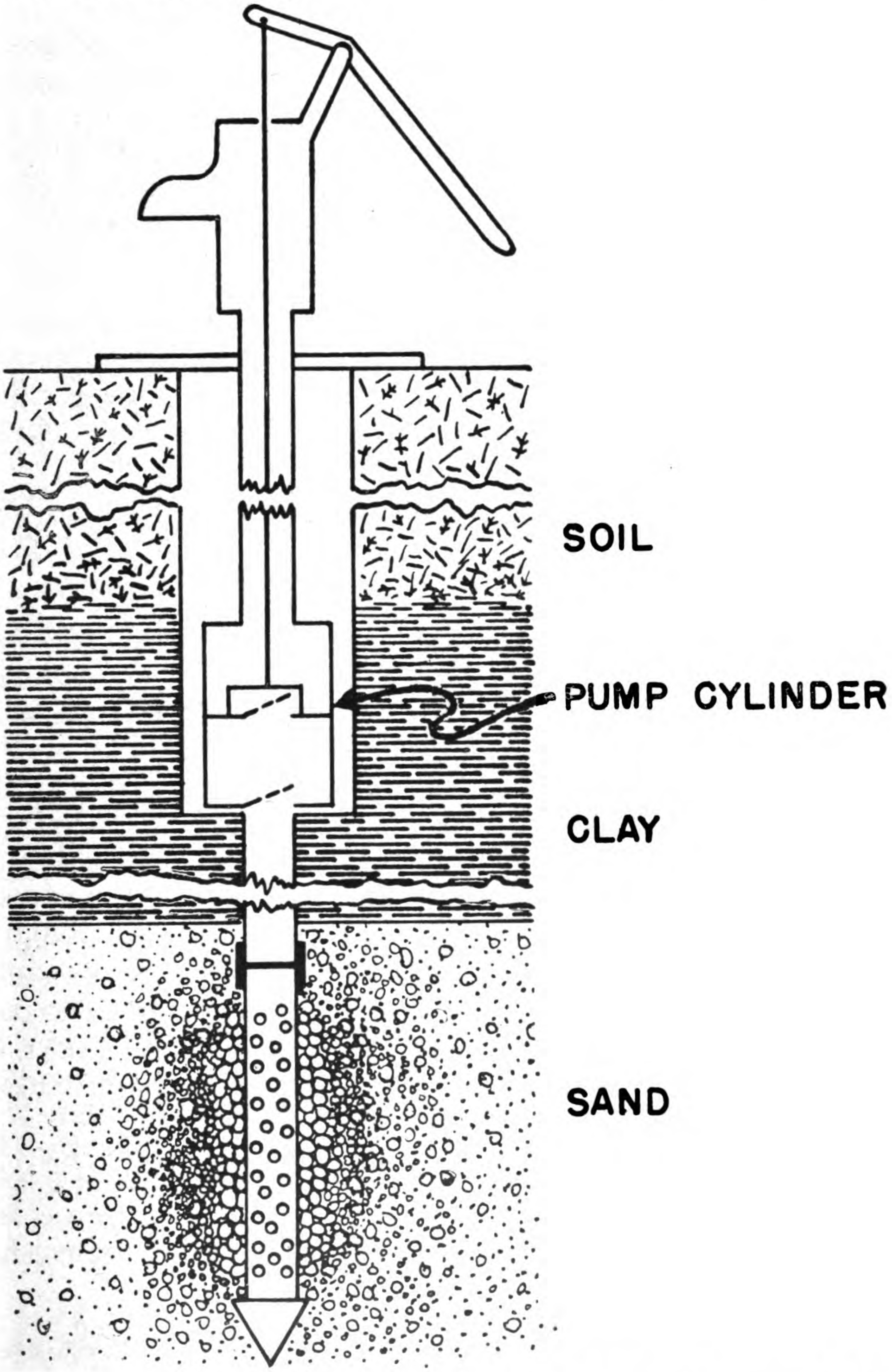


Figure 9. Drive Point well fitted with deep well lift pump with pump cylinder.

(*c*) These wells usually range in diameter from 1¼ to 2″ but they are also driven in sizes up to 4″. The larger sizes, although the casing is of greater weight and more difficult to drive, have the advantage that deep-well pumps can be fitted to them when necessary. Consequently, they are generally employed when the water level is known to lie at depths of more than 25 feet—beyond the reach of ordinary pumps. The smaller well sizes, on account of the reduced weight and greater portability of the screens and pipe, are valuable for proving the depth at which the ground water lies, as well as for testing the yields of water at shallow depths. In many cases it will be possible to supply a sufficient amount of water from one or more wells of small diameter. In other cases it will be easier to sink several of the small-diameter, shallow wells and connect them to a single pump by means of a manifold.

(*d*) Where the water lies below the suction limit of the pump, it may be possible to sink a shaft which will permit the placing of the pump cylinder within reach of the water, and the plunger can then be worked by means of a rod connected to the surface pump handle. (See Fig. 9) The pump cylinder, which is larger in diameter than the well pipe, is attached by removing the upper lengths of drive pipe and screwing the new connection to the remaining lengths, or valves may be fitted into the drive casing itself.

c. Driven wells have many advantages over dug wells, including cheapness, simplicity, speedy sinking and withdrawal, ease of dealing with unstable ground, and exclusion of undesirable surface and shallow waters. The formations tapped must yield water readily. In suitable circumstances a yield of 500 gallons per hour can be obtained from a driven well 1¼ inches in diameter, or 1000 gallons per hour from a well 2 inches in diameter. Pitcher pumps may be screwed directly to the top of the drive-point well pipe.

d. Driven wells can be sunk by 3 to 5 men in unconsolidated sediments at a rate varying from 3 inches to a foot or more per minute. The average time of driving wells 20 feet deep is usually less than an hour and the job requires about 3 to 5 man-hours of work. Under favorable conditions drive-point wells can be put down to depths of 50 to 70 feet, and exceptionally to depths of 100 feet.

e. The driving of successful wells requires care and experience. Failures may result from inexperienced operators. Success has frequently attended persistent and well-directed efforts where only failure had previously been recorded.

f. Physical conditions.— The following conditions are essential to success with driven wells:

(1) The upper strata must not be so hard or dense as to resist the penetration of a pointed pipe.

(2) There must be beds of sand and gravel with pores large enough to admit water to the pipe as fast as it is removed by pumping.

(3) The water must be within 20 to 25 feet of the surface to use a suction pump. If the water is found at a greater depth, some form of deep well pump must be used.

34. **Drilled Wells.**— *a.* While wells of this type are being drilled a log should be kept, recording the depth, thickness, and characteristics of each formation encountered. This log should be filed for reference in drilling other wells in the vicinity. There are two general methods of drilling wells, the cable tool (percussion) rig and the rotary rig. (Chapter 7, Sec. 3)

b. The cable tool rig is especially advantageous in hard formations. It consists of a prime mover, derrick, wheels and spools for cable, and a walking beam which raises the bit and allows it to drop into the hole. The well is deepened by the drill bit striking and breaking the formation, the broken material being removed by means of a bailer. The drill bit should be large enough to permit casing to be introduced when the well has been completed. (See Chapter 7)

c. The rotary method is gaining increasing recognition at the present time because of its speed. The rig consits of a prime mover, derrick, draw works, rotary table, and mud circulation pump. The draw works consist of wheels, equipped with brakes and clutches, which allow transmission and control of the power from the prime mover to the rotary table. A drive chain or shaft from the draw works turns the rotary table. The rotary table, located over the well and the drill stem, with the bit on the bottom, is turned to give an auger effect. (See Chapter 7) The cutting bit, either the rock type or fishtail shape, wears away the rock or other material by downward pressure and grinding action. The drill stem is hollow and drilling mud composed of water and either upper layers of clay or commercial mud material is pumped into the drill stem at the top and allowed to discharge near the cutting surface of the bit. This mud serves to keep the bit cool and return the cuttings to the surface by floatation and overflow, and to plaster the sides of the hole to prevent caving. As the drilling mud may impede or cut off the flow of water into the well, great care is necessary in using rotary drills, especially where the depth to the water-bearing formations is unknown.

d. Casing.— Well casing to prevent caving may be placed while drilling with either rig. The usual procedure is to drill the well to the water-bearing strata and then, if the water is satisfactory, place the casing. Wells should be cased at least down to the top of the water-bearing formation and preferably to the bottom of the well. When the latter practice is used the screens permit taking water only from the strata desired.

e. Cementing.— The casing is cemented in place to prevent the entrance of water from strata that is not satisfactory. Cementing also protects the casing from corrosion.

NOTE: For detailed methods of casing and cementing, and for a discussion of "Increasing Yield of Wells," "Protection and Sterilization of Wells," "Testing and Developing," etc., see Chapter 7, "Operation", Sec. 3.

35. **Capacity.**— The capacity of a well, expressed as the amount of water which can be withdrawn in a stated period of time, depends upon (1) the water available in the water-bearing strata, (2) the head or pressure available to cause the water to flow into the well casing, and (3) the friction loss which occurs when the water moves through the water-bearing formation and into the well casing. Although the amount of water actually present in the formation depends upon a number of factors, such as the rainfall and the rate of percolation through the earth, the quantity of water available to the well may be thought of as nearly constant. It will be assumed that the well has been driven deep enough to furnish sufficient pressure, or head, to cause the water to flow into the well in the desired quantity. Other things being equal, the capacity of the well then depends upon the friction loss which occurs when the water moves through the formation and into the well. The friction loss, in turn, depends upon the velocity with which the water moves. The velocity is governed by the size of the openings through which the movement of water takes place. Therefore, with larger openings, the velocity of flow is less; the slower the velocities, the less the friction; and the less the friction, the greater is the capacity. In other words, given a sufficient depth of penetration into a saturated layer, the coarser the water-bearing material, the greater will be the output of the well.

Chapter 4

WATER QUALITY AND EFFECT OF SUBSTANCES DISSOLVED AND SUSPENDED IN WATER

36. **General.**— *a.* The essential qualities to be sought in water supplies for military purposes in the field are: primarily, safety for drinking, cooking, and washing; secondarily, palatability in water which is to be used for drinking. It is not to be expected, nor is it essential, that the quality of water furnished for field use shall always be of the high standards which would be demanded by civilian communities. The military situation, the needs of the moment, and the difficulties of transportation of equipment, supplies, and the water itself limit the selection of water sources and the extent of the treatment procedures applied. The portable and mobile purification units, which are intended for use only when other and better facilities are not available, are a compromise between mobility and good practice. The quality of the water supplied must be as nearly satisfactory as circumstances permit, and the water must, above all things, be rendered safe for use. When established municipal and industrial facilities become available to the field forces, permitting adherence to standard practice, they will be used to the fullest extent.

b. Water that is contaminated with warfare gases should be avoided if other supplies can be obtained. If not, contaminated water will be considered as potable provided it meets all of the following requirements:

(1) There is no odor of any chemical agent present in the water before chlorination.

(2) There is no excessive cloudiness or discoloration present.

(3) The addition of five parts per million of chlorine (2 ampules of calcium hypochlorite per Lister bag) produces a chlorine residual of one part per million or more.

(4) The pH (acidity), see Appendix 1, of the water before chlorination is above 5.0.

c. These tests apply to all known warfare gases that may contaminate water supplies.

37. Impurities Found in Water Supplies.— The common impurities may be divided as follows:

- Dissolved—
  - Solids—
    - Inorganic—

lead	
copper	
zinc	oxide
aluminum	bicarbonate
calcium	chloride
magnesium	sulphate
sodium	nitrate
iron	fluoride
manganese	sulphide
arsenic	
phosphorous	

    - Organic—
      - vegetable matter
      - animal matter
  - Gases—
    - chlorine
    - ammonia
    - hydrogen sulphide
    - carbon dioxide
    - oxygen
    - nitrogen
- Suspended Solids—
  - Inorganic—
    - iron
    - silica
    - clay
    - silt
    - mud
  - Organic—
    - animal matter
    - vegetable matter
    - sewage
    - oil

38. Selection of Sources and Equipment to be Used.— Where permanent camps and establishments are to be supplied with water, more time can be spent in the selection of sources and greater elaboration of equipment and processes is justified. Existing equipment can be improved after installation as time and availability of equipment permit, and demand requires. Thus, the installations may approach in completeness and efficiency those water treatment plants which have been designed and erected in peace time. If the need arises, the water may be softened, or treated in other ways for particular uses.

39. **Quality Variation During Distribution.**— *a.* Changes may take place in the temperature and the amount of gases and iron in a water between the plant and the consumer. More important is the accidental introduction of foreign matter such as salt, coloring matter, organic pollution, and living parasitic or pathogenic organisms.

b. Where water is distributed in vessels such as the organization water cans, the relative cleanliness of the containers has an important bearing upon the quality of the water delivered to the troops. The use of the tanks and cans for any other materials except water must be prohibited. The introduction of dirt in handling or through the dipping of water from cans with unclean cups or other containers also introduces danger of organic contamination capable of causing diarrhea or other intestinal disorders.

c. Chlorine, which is the chief barrier against bacterial contamination in field water treatment, is continuously lost from the treated water by escape from the surface, or through aeration when the water is poured from one vessel to another, or by combination with chlorine-consuming substances in the water. When the free chlorine and its germicidal addition products have disappeared from a water, contamination introduced thereafter is not destroyed, and living organisms will multiply if temperture and food conditions permit. Time, therefore, is an important factor affecting the quality of chlorine-treated waters. Consequently, in any study of a water supply it is not only necessary to know the quality of the water at the source and after treatment, but it is also essential to have information concerning the quality of the water at the point of use. In addition, it is often desirable to have information about the quality of the water at one or more intermediate points.

d. Important changes in the quality of water, from a sanitary standpoint, may take place in the consumer's own quarters through cross-connections to less satisfactory water supplies or sewer lines, through unintended piping hook-ups, or through back-siphonage.

40. **Effect of Impurities on Animals.**— Animals are susceptible to some diseases which seldom or never attack man, and they are frequently more sensitive than man to certain poisons in waters. At times animals will drink freely of surface water which contains large amounts of blue-green algae. A toxic substance, apparently arising from the growth of these aquatic plants, has injured or even killed livestock. So far as is known, man has not been affected by this particular toxic substance derived from water. Since the droppings of animals frequently foul surface streams, the organisms of bovine tuberculosis, anthrax, and probably undulant fever, as well as the eggs, larvae, and adults of parasitic worms may be swallowed by stock while consuming the water of these surface streams or eating the algae vegetation growing therein.

41. **Non-bacterial Impurities.**— *a.* In addition to pathogenic bacteria and animal organisms, there are dissolved and suspended substances which are irritants or poisons.

b. There are also many substances which, in small amounts, are essential to bodily welfare; greater concentrations may act as undesirable stimulants to some bodily function; and still larger concentrations have an irritant effect upon some tissues, and may even act as poisons. The substances which we think of as the poisons are merely substances which, in small quantities, are able to produce a definite physiological effect. These substances may be either inorganic or organic.

c. The inorganic poisons found in waters are the most easily detected and estimated. Toxic organic substances are more numerous and more difficult to detect. They are also among the most potent toxic agents. Very little is known of many of these organic poisons except that they usually seem to be degradation products of other organic substances produced by the digestive action of bacteria or certain living organisms. Some poisonous organic substances appear to be synthesized in the life activities of plants and animals. The more numerous these organisms, the greater the concentration of the poisonous agent, called toxin, they may be expected to produce.

d. It requires such an extremely minute amount of some of the toxins to produce a physiological effect, that it is seldom possible for the average water laboratory to separate it and detect it by a specific test. Since mineral poisons are more easily detected, and their quantity more easily determined in the laboratory, it is possible to establish safe limits, usually containing a factor of safety, within which there need be no fear of toxic action on consumers of water. However, some of the poisonous substances, notably lead, accumulate to a certain extent in the body and act as cumulative poisons, but even lead is slowly eliminated.

e. While the permissible quantity of lead has remained fairly constant at 0.1 part per million parts of water, the permissible quantity of copper may be 2.0 parts per million because some copper is required in nutrition and that amount in water would not raise the amount of copper ingested to dangerous values. Much of the copper and lead found in water supplies comes from pipes. The copper sulfate which is used in combatting algae growths in reservoirs is completely converted into insoluble compounds which precipitate and are removed by sedimentation, especially in waters containing carbonate hardness.

f. Zinc, which may be dissolved from the galvanizing (zinc coating) on iron pipes and from brass pipes, is also present in the natural waters of areas where the ores of the metal are to be found. The permissible limit is 15 parts per million. However, natural waters containing up to fifty parts per million zinc are reported to have been in continuous use without ill effect.

g. Arsenic may be harmful in quantities even less than ten parts per million if the water is habitually used, but more is necessary to produce poisoning by one drink. However, the maximum which can be safely taken has not been determined for either condition. Arsenic and phosphorous are belived to be cumulative and to cause a progressive disintegration of the boney structure of the jaw, resulting in "phossy jaw."

h. Since a number of chemical warfare agents contain arsenic, this matter becomes of military importance. The matter is further complicated by the fact that the chemical warfare agents containing arsenic are complex organic compounds and the arsenic does not react as it would in inorganic compounds. However, the hydrolysis of the organic arsenicals may proceed through a series of reactions to the point where the arsenic returns, more or less completely, to the inorganic state.

i. Other substances whose exact critical concentrations in drinking water are unknown are selenium, vanadium, boron, and flourine. Apparently the flourine which is present as flourides begins to produce a physiological effect at a concentration somewhere in the vicinity of 1.0 ppm. Habitual consumption by children between the ages of 5 and 10 of water containing in excess of 1 ppm of flourides produces mottled enamel of the teeth, but smaller amounts are said to be beneficial to both children and adults in the prevention of dental caries. The critical concentration of selenium is believed to be somewhere above 0.1 parts per million.

42. **Body Irritants.**— *a*. Although some of the living organisms, such as the immature worms living in water, may attack the skin and invade the body while wading, swimming, or washing, most of the danger is from swallowing the water. Much of the damage which may follow is due to action upon the digestive tract.

b. Certain inorganic salts, normally present in water, cause an irritant effect on the body when taken internally. Continued use of a water containing an irritant substance may habituate consumers to the irritant so that in time they may be able to use the water without annoyance or apparent ill effect. This is observed with waters high in magnesium sulfate. It acts as a laxative on newcomers, but does not bother the permanent population of an area where such waters are used.

c. A case of water failing to supply the desirable traces of a substance which in larger amounts may be toxic, is found in the so-called "iodine deficiency." Lack of iodine is considered to be the chief cause of simple goiter which is found to be most prevalent in the population of areas where the water generally consumed contains practically no iodine.

It is possible to supply the iodine deficiency by adding salt water fish or iodine-containing substances to the diet. Iodized table salt is commonly used for this purpose. In a few instances, the water supply of cities has been treated at intervals with sodium iodide to rectify the iodine deficiency. This practice is not considered desirable, however, because most of the expensive iodine compound added to the supply is wasted by being lost with flushing waters and because there are cases where iodine may actually be harmful to an individual.

43. **Saline Water.**— Some natural waters contain so much dissolved mineral substance that they cannot be used for drinking purposes. The taste of the dissolved substance is offensive and sometimes produces a physiological action of a laxative or diuretic nature. Sea water is an extreme example of high mineralization since it contains approximately 37,000 parts per million of dissolved solids, but even sea water is lower in total solids than are the waters of some lakes in which evaporation has brought about great concentration of total solids. Highly mineralized waters are not always hard waters.

44. **Hardness, Iron and Manganese.**— *a.* Waters which contain calcium and magnesium salts are called hard and destroy soap by converting the sodium or potassium soap of commerce into an insoluble nondetergent form. (No lather is formed.) Calcium soap is a white curdy precipitate. Magnesium soap is also a white curdy precipitate, but is decidedly sticky as compared with the calcium soap. Iron and manganese also produce insoluble soaps, colored in shades of light brown, red, or darker tints. These calcium, magnesium, iron, and manganese soaps produce the "ring in the bathtub," cause the cloudiness of washing waters, and, by destroying the soluble soap, force the use of larger quantities of commercial soap in order to get a suds and cleansing action.

b. Brines cause the precipitation of soap, but this soap curd is still a usable soap in ordinary soft water.

c. Hard water should not be used in a laundry without first softening it. The curd formed represents an operating loss of 1½ lbs. of soap, per grain per gallon of hardness, per 1000 gallons of water. This curd sticks to the fibers of the fabric causing a grayish tinge, and picks up dirt which decomposes, putrifies the fabric, and causes it to "rot." Many laundries use excessive quantities of bleach to overcome this grayness: this increases the cost of operation and weakens the fabric.

d. Hardness also causes deposits in the radiators, passages, and water jackets of water cooled engines. This causes the engines to overheat, which in turn causes the lubricant to break down and burn, and the pistons and bearings to seize. The greater the evaporation and replacement of water the more aggravated will be the difficulties encountered.

e. Heating water containing appreciable amounts of calcium and magnesium either in open vessels or in boilers, causes it to deposit solid matter at the bottom of the vessel or on the heated metal surfaces. Iron, manganese, silica and some other substances may also play a part in the deposition. The character of the deposit is influenced not only by the kind and concentration of the ions present but also by the temperatures to which the liquid rises. Hard, dense scales, such as those of calcium sulfate, are usually associated with considerable concentrations of calcium ions, or high pressures and high temperatures.

f. Any of the waters which contain iron in the form of ferrous bicarbonate may deposit hydrated ferric oxide in the pipes, on bathroom fixtures, and on textiles which have been wet with the iron-containing water. Hydrated oxides of manganese are deposited from manganiferous waters after chlorination, but they are not so readily deposited after aeration or loss of free carbon dioxide as are similar compounds of iron. Iron deposits also result from the corrosion of iron pipes and the production of ferric hydrate. The critical value, beyond which deposition may be expected, is 0.1 parts per million for iron and manganese. The iron content of natural waters may reach as high as 100 parts per million in extreme cases, while 10.0 parts per million of manganese is unusual.

45. **Other Dissolved Mineral Substances.**— Some dissolved mineral substances are capable of influencing the safety of water, not because they themselves are harmful, but because they tend to facilitate the solution of other substances which are dangerous. Substances, such as nitrates and possibly some of the phosphates, may increase the solubility of lead and therefore the quantity of lead dissolved from piping.

46. **Corrosion of Lead, Copper and Brass.**— High concentrations of dissolved salts favor passage of electric currents, and the electrolysis which results may introduce, into the water, metals derived from pipes and fittings. On the other hand, waters which are relatively free of dissolved material are eager to dissolve substances with which they come into contact, and for that reason distilled water is corrosive to metals. Waters containing suspended solids are apt to erode the materials with which they come into contact. In the first instance the longer the water stands in the pipe the greater is the dissolving action, while in the latter case, high velocities are most objectionable as they increase erosion. Corrosive waters which have stood over night in lead or copper house piping are more likely to be dangerous than water that has flowed direct from a main through the house piping without a pause. It is therefore advantageous where long lines of pipe carry waters of low mineralization, to waste the first water drawn in the morning.

47. **Constituents Affecting Boiler and Heater Operation.**— *a.* Waters which are corrosive, or which erode metals, obviously cause diffi-

culty in boilers, heaters, valves, and fittings. Hard waters which produce scale in boilers and heaters are also harmful to the units in another way. The deposition of scale not only reduces the thermal efficiency of the equipment by its insulating effect, but also causes its destruction by overheating.

b. Alkalinity has been claimed to accelerate the cracking of the metal around rivet holes in boiler plate, while the presence of certain other salts in given amounts inhibits the cracking.

c. As the water evaporates in a boiler or water still it leaves behind its dissolved and suspended solids and is replaced with water containing additional solids. Thus the solids concentrate, and when the concentration reaches a certain value, which varies with each type of boiler, moisture begins to be carried over with the steam (foaming). As the concentration continues to build up, the carryover increases until slugs of water are carried over (priming). The concentration, therefore, must be maintained below the "maximum allowable concentration," predetermined by trial, by bleeding a sufficient amount of the concentrated boiler water from the boiler intermittently, or preferably, continuously. This procedure is called boiler blowdown, or blowoff. Blowing off continuously, in addition to permitting closer control of boiler concentrations, makes possible recovery of the heat in the blowoff by transfer to the feedwater. Continuous blowoff therefore effects a large economy of fuel.

48. **Attractiveness.**— The attractiveness of a water is primarily determined by the lack of color and turbidity, although sometimes the odor, which is also a consideration of palatability, is sufficiently pronounced to affect the attractiveness of a water supply.

49. **Color.**— *a.* Color, as a descriptive term applied to water, is more properly described as "stain," since pure water is colorless. Usually the yellow or brownish stains are derived from organic substances, extracted from plants or from organic residues undergoing decomposition. Sometimes iron enters into the composition of the coloring materials. Color is usually due to colloidal material, although the state of aggregation and the particle size is variable. The addition of lime or other alkalies to colored water will often "fix" the color and make removal difficult. The probable effect of the alkali is to cause dispersion of the colloidal coloring substances, producing smaller particles of the colored matter, and making their subsequent absorption by flocculating chemicals more difficult. Colors are usually most easily removed at pH values below 6.0.

50. **Suspended Matter.**— *a.* The effect of the suspended material in water on its appearance depends upon the color of the suspended particles, their opacity and light-scattering power, the size of the particles,

and the number of these particles. The finer the particles, the greater is the turbidity produced by a given weight of the substance and the greater is their resistance to the forces which would tend to cause them to settle.

b. The number of parts per million of suspended matter is determined by separating the suspended particles from a definite volume of water and then weighing the suspended matter removed. The measure of turbidity is obtained by comparing the obscuring ability of the water with that of a standard suspension, made by taking a definite weight of a particular suspendable material and shaking it with a given volume of water. The standard suspension may be diluted with water to bring it to the same range of turbidity as the specimen being examined. The result will be the concentration of the standard suspension which would cause the same optical effect as the suspended matter in the sample. It does not reflect the condition of the suspended matter in the specimen examined.

c. The size of the suspended particles in water is important in the estimate of the rate of settling of suspended matter, and also in predicting the ease of clarification of the water by plain subsidence or by coagulation with chemicals. The finer the material to be removed, the more difficult and time-consuming is the clarification, and usually the more expensive is the process when chemicals are to be purchased.

d. Turbidity can be determined in the field with portable turbidimeters, but the determination of the amount of suspended solids requires laboratory facilities. Consequently, the determination of suspended solids is often omitted in the study of water quality. This practice is apt to lead to confusion, not only when different supplies are being compared, but also when a single water supply from an extensive watershed is being studied over a period of time. This is because waters of identical turbidity may fluctuate widely in their behavior as a result of the state of dispersion of the suspended matter. Colloidal matter, which includes some of the coloring matter in surface waters, may also act as a "protective colloid" and interfere with the sedimentation process. Protective colloids tend to prevent aggregation and hence influence the flocculation on which chemical clarification depends.

e. In considering the effect of suspended matter as modifying the quality of a water supply, we must consider the probable fluctuation in the quantity and character of the earthy suspended matter, the effect of the colloidal substances present, and the ease with which it will be possible to remove objectionable constituents.

f. Water will deposit suspended materials if there is sufficient time and the flow is sufficiently slow. The deposits at the bottom of pipes eddy into quiet points in a pipe system and are dislodged when any marked change in velocity of flow occurs. This is often observed when a fire hydrant is first opened. If the suspended material lodges in an aperture of small size, it may clog it. Suspended material may block the meters and orifices through which small flows pass.

51. **Temperature.**— *a.* Cold water is refreshing. Its coldness prevents the taste buds from detecting many odor and taste-producing substances, if their concentration is not too great. A temperature of 50 degrees F. is desirable for drinking water. At that temperature it does not have some of the objectionable characteristics of ice water and can be consumed without excessive temperature-shock, unless one is greatly over-heated. Water which is much warmer than 50 degrees F. is less satisfactory for drinking.

b. Water from wells with a depth of 50 to 75 feet is usually close to the mean annual temperature of the air at the location of the well. Water from shallower wells is affected by the temperature of the air, and the water temperature tends to follow the air temperature, but with a certain lag and over a narrower temperature range. The shallower the well, the smaller is the lag and the nearer is the water temperature range to that of the air. The water of surface streams reflects the temperature variations of the air more closely than do ground waters, unless there is an addition of water from thermal springs, large volumes of condenser water, or other sources of heat or cold, such as water from snow or ice fields. The temperature of waters from deep wells is higher than those of the wells of 50 to 70 feet depth. The temperature rise with increased depth is not uniform, even in the same well, but it amounts to 1 degree F. for each additional 50 to 75 feet of depth, within the usual ranges.

c. Low temperature reduces the biological activities of bacteria, protozoa and other living organisms in water, but most of the organisms which disappear die off in spite of the low temperature, rather than because of it. Decomposition of organic wastes entering streams in the winter time is retarded, and consequently the contamination is perceptible for longer distances below the point of pollution. Pathogenic organisms in cool water will persist for longer periods.

d. The greater activity of warm water causes it to wet and swell gelatinous films more readily than does cold water. This may introduce difficulties in photographic processes which require the films to be washed free of unchanged salts of silver and developing and fixing chemicals. Films may soften unduly, change shape, or even slip from their supports in warm water. Warm water, however, improves the action of detergents such as soaps and the recently developed wetting agents.

52. **Odor.**— *a.* Musty odors and tastes accompany incomplete decomposition of polluting matter. Sometimes the tastes and odors are

grassy, fishy, or definitely foul. Odors are observed by the action of minute particles of certain substances on the olfactory nerves. Most odors are due to volatile matter carried to the sense organs by diffusion through the air.

b. In general, both volatility and ease of perception increase with rise in temperature. Increasing the concentration of the odorous particles, by increased volatility, usually amplifies the effect and makes the odor easier to detect and identify. This is not always so, and prolonged exposure to the odor-producing particles may dull the sense of odor-perception so that a person may no longer be aware of their presence. There is great variation among individuals in their sensitivity to odor stimuli and to the rapidity with which odor-fatigue becomes apparent. Some highly odorous substances (such as hydrogen sulfide, which has the familiar rotten-egg smell, and which is poisonous in large concentrations) quickly produce odor-fatigue and become especially dangerous when they are forgotten. An individual may also have a greater sensitivity to one kind of odor than another or may find one type of odor more pleasant or more offensive than some other type.

c. Palatability is affected by the character of the odor and its concentration or strength. Since the sense of smell is a protective sense, one of its major functions has been to warn of dangers in the environment. We are naturally inclined to fear most those odors which are unfamiliar, and to disregard those which, in our experience, have not been accompanied by injury.

d. Many of the odors which affect the palatability of a water come from the growth of algae, protozoa and other living organisms which produce odorous substances, in the same manner that flowers produce their characteristic perfumes. The objectionable odor may also come from decomposing organic matter or from industrial waste products. Gases, particularly hydrogen sulfide, may contribute to the effect. Industrial wastes vary widely in the odors they produce. Chlorinous odors (frequently due to chloro-phenols), iodoform odors (due to the chlorination of certain salicyl compounds), and, in general, "drug store" odors are among those to be expected in chlorinated supplies. Water treatment sometimes accentuates these odors unless special means are taken to remove, eliminate, or chemically change the odorous matter.

e. It is difficult to evaluate the importance of specific odors in drinking waters because of the variance of opinion among observers. Likewise, it is difficult to ascribe to any particular method of odor removal an accurate estimate of its efficiency. Much difficulty has been caused by doubt as to whether the change in the odor observed after treatment was due to the action of the process or to a change in water character at the source. Odors observed in the immediate vicinity of an aerator may or may not indicate the degree of removal of odor from the water passed through it.

53. **Taste.**— *a.* The taste of water is due to the presence of gases, mineral substances in solution, or organic substances, many of which are volatile. Waters low in dissolved gases such as oxygen (air) or carbon dioxide are often described as "flat tasting." Waters which contain hydrogen sulfide have a taste in addition to the odor of rotten eggs.

b. Taste and odor are closely associated sensations. Volatile substances may affect both taste and odor senses and their removal is desired to improve the palatability of the water. Near the point of complete removal sometimes the taste and sometimes the odor is the more perceptible. Like odor, the taste of water is affected by the concentration of the substance detected. The impression created is variable through the range from trace to measurable concentration, not only as to strength but also as to the characterization, or association with remembered tastes. Grassy and woody tastes, like grassy and woody odors, are often annoying and difficult to remove from surface waters.

c. Mineral substances in solution give a taste to water which is not associated with an odor impression. Sodium chloride (common salt) and many other salts give a taste to water which is commonly described as salty, though taste differences often permit identification of the substances. Calcium chloride and magnesium sulfate have a more bitter taste than common salt. Waters high in sodium carbonate and similar alkaline substances are frequently described as having a "slick" taste. Waters which contain the salts of iron have an inky, sweetish taste, and sewage contamination is associated with a sweetish taste. Some waters are acid and betray that fact by a sour taste. Acidity in natural water is due usually to sulfuric acid. If the acidity is high, the water may also have an astringent, "puckery" taste.

d. Taste-producing mineral substances frequently have a physiological action when present in water, and the effect, like the taste, is rendered more noticeable when the concentration is increased. Sometimes the concentration, as in sea water and some highly mineralized natural waters from wells and springs, is so great as to render the water unfit for drinking.

54. **Habituation to Tastes and Odors.**— Persons who have been accustomed to consume a particular kind of water become so accustomed to its odor and taste characteristics that they may not notice either the odor or the taste. They may become adjusted to the physiological effects

of relatively large concentrations of such materials so that they no longer experience any noticeable action. Thus, if given water from another source, they may actually miss the familiar taste or odor, and find that odorless or tasteless waters are unsatisfactory and do not satisfy the thirst. However, they may quickly readjust themselves to the new water.

55. **Corrosion by Gases.**— *a.* Oxygen in water causes corrosion of certain metals such as iron, steel, copper, and aluminum, while carbon dioxide (carbonic acid) accelerates corrosion. This is true especially in hot water systems or steam boilers. While these gases are not the sole cause of corrosion, their importance makes it desirable to eliminate them before allowing the water to act on piping systems or boilers. Special linings of zinc, cement, tars, and bitumens are used to prevent the action of corrosive gases when it is not feasible to inhibit corrosion by chemical or other means.

b. Iron has a natural tendency to dissolve in water to a certain extent in the presence of oxygen, setting hydrogen free and ultimately covering the surface of the iron with a passivating layer of hydrogen which effectively stops further solution until it is removed or broken. The dissolved iron forms ferric hydrate, or rust (also called hydrated ferric oxide), represented either as $2Fe(OH)_3$ or as $Fe_2O_3.3H_2O$. This rust forms tubercles, or nodules, on the metal surfaces, or drops to the bottom to be carried along and deposited elsewhere by currents. The process is self-limited unless the hydrogen layer is disturbed. The introduction of free acids or carbon dioxide, which combines with water to form carbonic acid and lowers the pH, permits hydrogen of the protective layer to escape as a gas. This removes the restraint on solution of the iron, and speeds corrosion. The addition of alkalies to the water will neutralize the acid, stop the evolution of hydrogen, and even render the water less corrosive than it was. Another way of explaining this type of corrosion is to say that the free carbon dioxide reacts with water to form carbonic acid which attacks the iron, forming ferrous carbonate. This is acted upon by the oxygen in the water to produce the ferric hydrate and release carbon dioxide to repeat the process of corrosion. Alkalies combine with with the free carbon dioxide and stop the action.

c. Gases other than oxygen and free carbon dioxide have an action on pipes and structures. Hydrogen sulphide is decidedly destructive. It forms a brittle ferrous sulphide on the surface of iron exposed to it. It can also attack concrete by destroying its coherence and strength so it can be scratched away with a knife blade or finger nail. However, hydrogen sulphide requires considerable oxygen for this action, and it is most effective where pipes run partially full, as in sewer lines or flumes. The action may be explained by saying that the hydrogen sulphide combines with the calcium of the cement in the concrete to form calcium sulphide which, with the help of water and oxygen, forms gypsum (calcium sulphate). This acts as a wedge because the molecule of calcium sulphate occupies more space than the calcium sulphide. The pressure produced causes the concrete surface to break down and soften.

56. **Effect of Ammonia on Copper and of Alkalies on Brass.**— If considerable ammonia is present in an alkaline water, it will be volatilized by heat and corrode copper and the copper in brass and bronze. This corrosion is particularly undesirable on valve seats, discs, plugs, or steam radiator valves. Highly alkaline waters dissolve the zinc in brass. This process is known as dezincification.

57. **Effect of Chlorine on Metals.**— Chlorine is used in water treatment, and is a corrosive gas. However, the amount of free chlorine present in the treated water is so small and it is usually so rapidly consumed by organic matter in the water, that the corrosion of water supply equipment by chlorine is much less than is frequently presumed.

58. **Difficulties in Photo Processing.**— *a.* Technical difficulties with water which may be encountered in photographic processes may be summarized as follows:

(1) Temperature, and temperature-dissolved gas relationship.
(2) PH (see Appendix I) variations in the water.
(3) Opaque suspended materials or turbidity.
(4) Presence of iron and manganese.
(5) Presence of the calcium and magnesium salts responsible for the hardness of water.
(6) Separation of particles when softeners are added to the water.

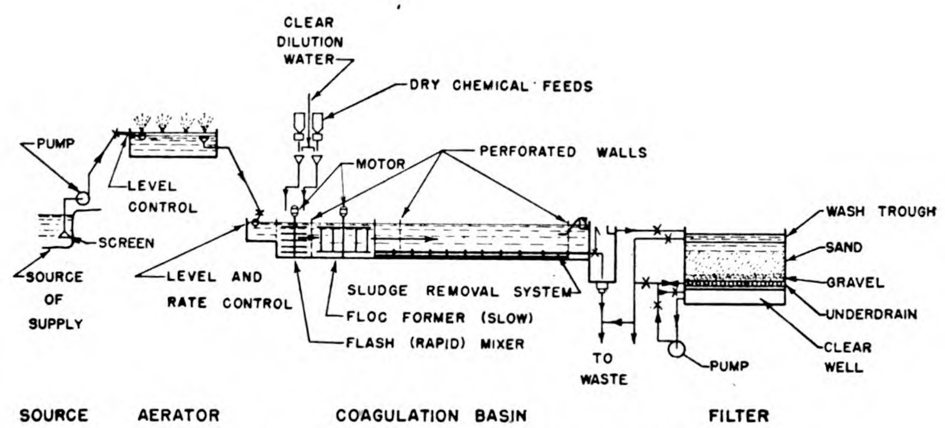
b. Solution of atmospheric gases in water is facilitated by low temperature and by pressures above atmospheric pressure. Raising the temperature or lowering the pressure causes the release of dissolved gases. When cold water is introduced into a pressure distribution system and allowed to warm before drawing, the sudden release of pressure when the tap is opened is followed by the immediate separation of gas in the form of minute bubbles. These bubbles give the water a milky appearance which clears upward from the bottom. In photographic development, these bubbles may adhere to the surface of the film as a scum. When minute film bubbles are broken they produce a beaded appearance resembling that due to a half-tone screen. Much of the details of the photograph may be lost in this way. Storage tanks with open water surfaces at atmospheric pressure permit the escape of gases and stabilization of the water before use.

c. In many of the chemical processes used in photographic and lithographic work the reaction of the solutions, as measured in pH (see Appendix I) units, has an important bearing upon the character of results obtained. For example, the dampening water used in lithographic processes should be kept within the narrow range of pH from 4.2 to 4.4, for best results. This requires the addition of acid, since natural waters of this range are unusual, the correct amount of acid to be used varying with the water supply.

d. Waters which contain much free calcium bicarbonate, associated with free carbon dioxide as is common in the states of the Middle West, resist pH changes more than waters which contain less of these substances and related compounds. Such waters will require more acid to reduce the pH to the desired point than will softer waters with the same original pH value. Similarly, more alkali will be required to raise the pH an equivalent amount above the original value if an alkaline medium is desired. Adjustment of water to a specified pH value, therefore, requires testing of the treated water to see if the desired pH value has been obtained and that the so-called "buffer action" of the dissolved salts has not affected the result too much. This pH adjustment should be made after the regular treatment of the water has been completed if a range outside 5.6 to 8.6 is desired. Above a pH of 8.6 or below a pH of 5.6 there will be interference with the clarifying action of the ammonium aluminum sulfate (or ammounia alum) regularly employed in water treatment (Chapters 5 and 7). Consequently, the final pH value of the treated water must be adjusted to the needs of the photographic or lithographic process. Simple colorimetric testing sets should be used to check the final pH value (Appendix I).

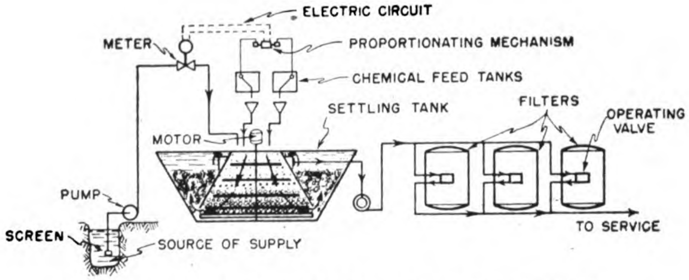
e. If the presence of free chlorine in the water, as required for drinking waters, is objectionable in photographic or lithographic work, it can be destroyed by the use of a small amount of sodium thiosulfate (photographer's hypo). If the hardness of the water is objectionable, one of the approved water softening processes may be used.

f. Iron and manganese, which are sometimes encountered in natural waters, especially those of ground water type, stain negatives and prints with rusty and brown stains. Iron must therefore be removed (Par. 73).



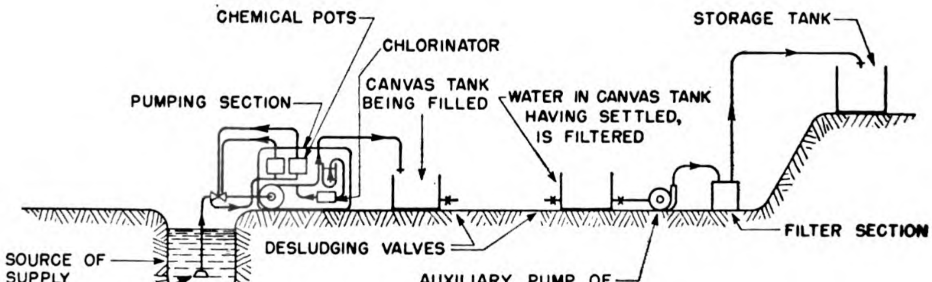
a. TYPICAL CONVENTIONAL CONCRETE GRAVITY FILTER PLANT WITH CONSTANT RATE DRY CHEMICALS FEEDS

10a



b. TYPICAL MODERATE SIZE COAGULATION OR LIME SODA SOFTENING PLANT WITH SOLUTION FEEDS, SLUDGE BLANKET TYPE SETTLING TANK AND PRESSURE FILTERS.

10b



c. TYPICAL FIELD SETUP FOR PORTABLE OR MOBILE WATER PURIFICATION EQUIPMENT

10c

Figure 10.

Chapter 5

WATER PURIFICATION

59. **General.**— *a.* To establish a background for a thorough understanding of the principles upon which water purification is based, paragraphs 2, 3, 4, 5, 7, 11, 13, 14, 15, 20, 21, 22, 23, 27, 29, 34, 35, and 42-91 of TM 3-215, "Military Chemistry and Chemical Agents" should be reviewed.

b. Figure 10 illustrates the various steps in water purification and shows typical water purification plants. The shapes of the various pieces of apparatus shown are only symbolic and represent but one type of the apparatus.

60. **Self-purification.**— While organic contamination of stream water is naturally reduced by so-called self-purification while it is flowing, the reduction is less rapid and less dependable than many people suppose. It is a common saying that "all streams purify themselves in seven miles of flow." Unfortunately, experience shows that this is untrue. Bacterial and protozoic action, sedimentation, oxidation, and other agencies assist in the destruction of contamination, but at the same time, runoff from the shore, additions of farm, city, and industrial drainage, and other circumstances continue to prevent the water from reaching a state of purity. Stream and surface waters in inhabited areas must always be considered unsafe for drinking purposes, and even those encountered in uninhabited areas must be regarded as of doubtful safety, unless they have been treated by approved methods of water purification.

61. **Pre-sedimentation.**— *a.* Where the turbidity of a water supply consists mainly of heavy suspended matter which settles readily without a coagulant, it is advisable to remove most of this material by presettling as this lightens the load on the coagulation, settling, and filtration processes and saves coagulant chemicals. It will be shown in the discussion of coagulation that it is not advisable to remove all of this heavy material by pre-sedimentation as it has a value as an aid to the coagulation of the finer suspended and colloidal particles.

b. Pre-sedimentation can be effected in continuous settling basins or tanks, or by the batch method. Continuous settling basins or tanks are designed so the water will flow from the inlet to the outlet without short circuiting and without dead spaces. The design should be such that the entire body of the water moves as uniformly as possible from inlet to outlet. The velocity of flow should be not less than three quarters of a foot per second nor more than one and one-half feet per second.

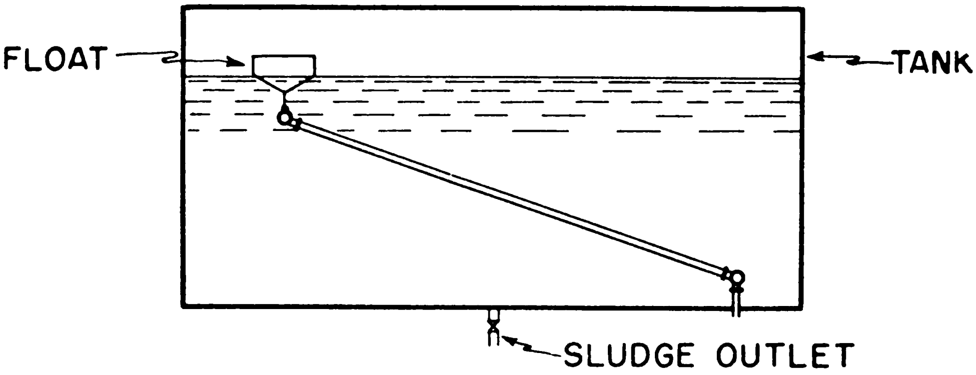


Figure 11. Floating outlet and sludge valve in batch sedimentation tank.

c. In the batch method a tank is filled with the dirty water and allowed to stand while a second tank is being filled. When the second tank is filled, the flow of raw water is directed to a third tank while the water in the first tank is being drawn off for further treatment. In drawing off, the water at the top of the tank should be drawn first. This can be effected by means of a floating outlet pipe as shown in Figure *11.*

d. The time of retention in either the batch tanks or the continuous settling tank or basin will vary for different water supplies from one to six hours. An excellent estimate can be made by noting how fast the material will settle out in a milk bottle or other similar container. If, for example, it settles at a rate of about one-half foot per minute and the tank available for sedimentation is 30 feet deep, one hour would be the minimum retention period, but since water supplies vary, a conservative estimate as to the retention period would be 2 hours. Of course, if time for the required retention period is not avaliable but a shorter time is, pre-sedimentation should be permitted for as long a time as possible.

e. Some means for desludging, that is, removal of the mud which settles to the bottom of the tank, should be provided. This can take the form of a perforated pipe grid in the bottom (Fig. 10a), connected with the outside and discharging through one or more quick-opening valves, or, if the tank is elevated, a quick opening valve can be located in the bottom. (Fig. 16) If the tank is not elevated the valve can be located in the side at the bottom. If none of these methods are feasible the tank can be emptied periodically and the mud removed manually.

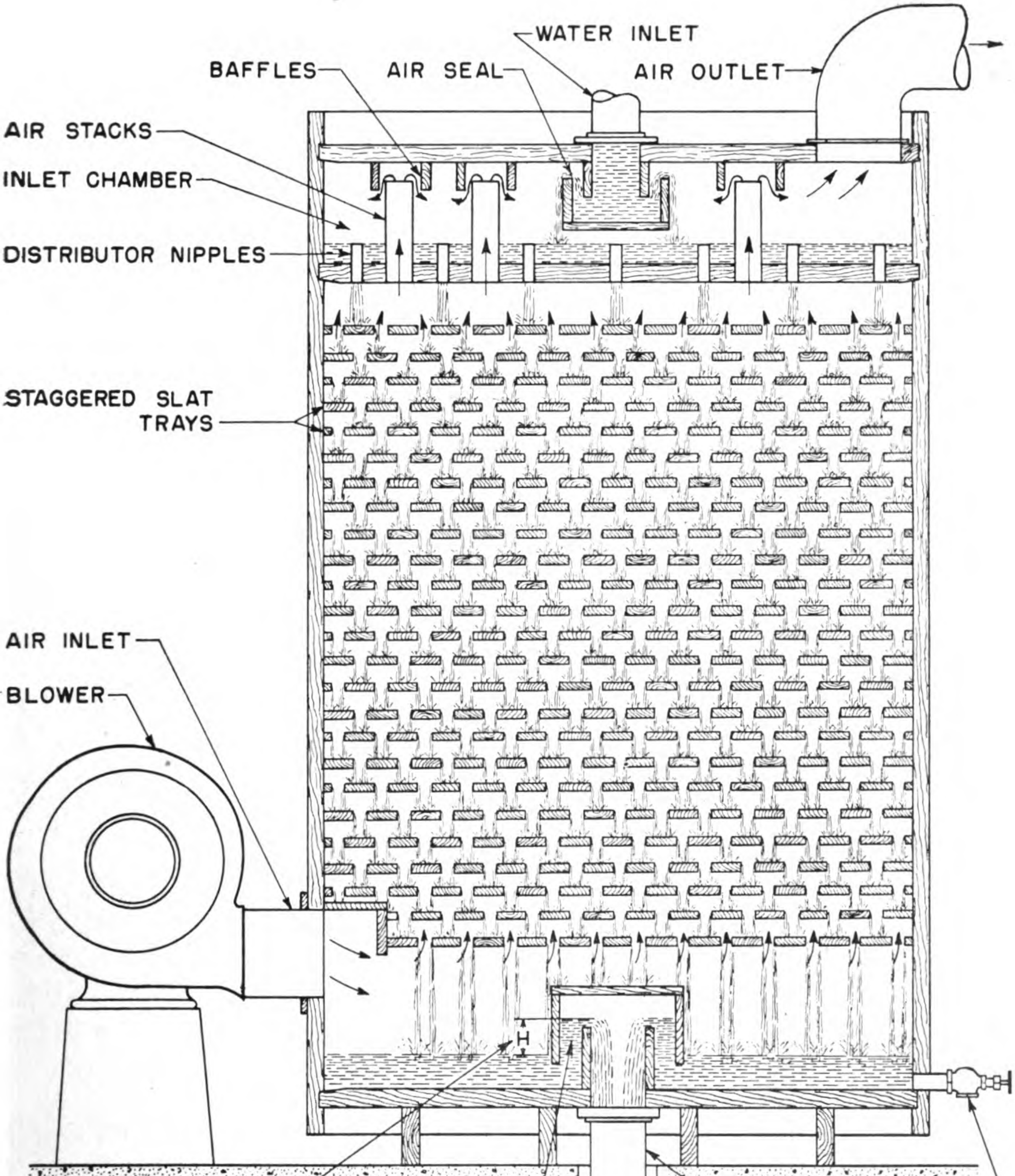


Figure 12. Closed forced draft aerator.

62. **Aeration.— (Figs. 12 to 14)** *a.* Aeration is a process in which water is brought in intimate contact with air. This can be accomplished in a number of ways such as blowing large volumes of air through a container filled with water or by spraying the water from a grid system fitted with ferrules, sprays or other atomizing devices into the air, over a catch basin. The object is to break up the water as finely as possible and to insure that a sufficient amount of continuously changing air comes in contact with the water. Other devices employ beds of broken stone or

coke, nests of wood slats, and the most modern practice is to allow water to trickle over wood slats in a closed rectangular or cylindrical container as air is blown up from the bottom.

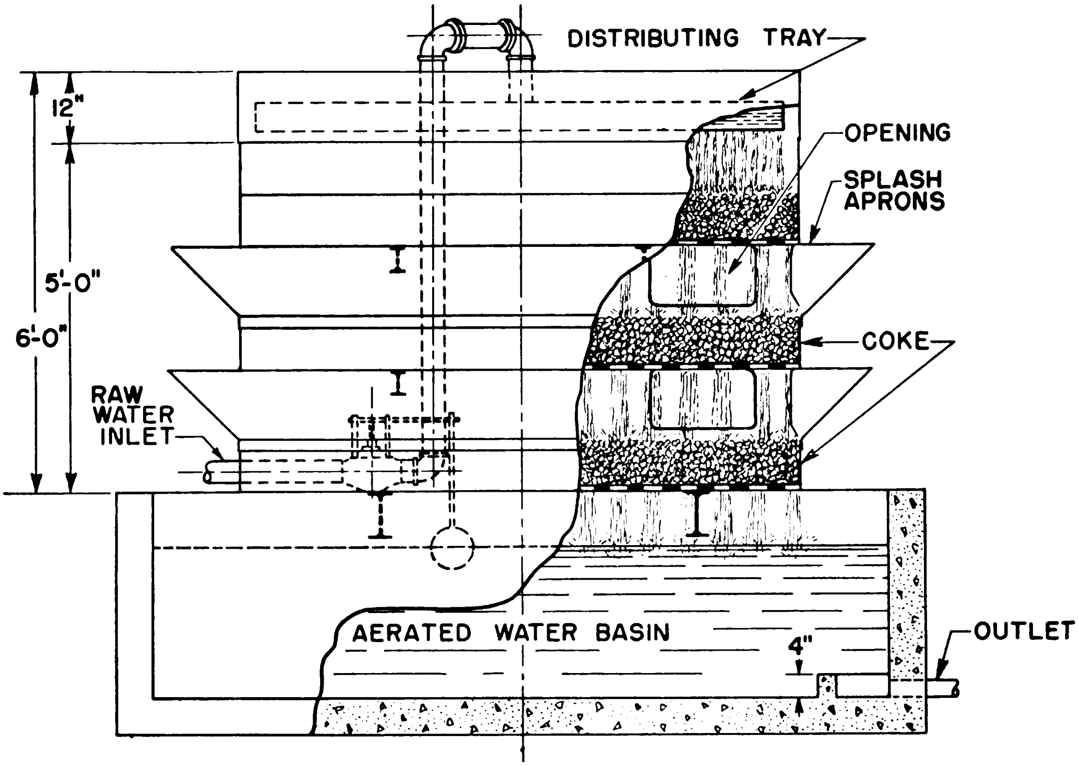


Figure 13 Coke aerator.

b. Aeration is used to free the water of objectionable gases and to oxidize ferrous iron in the water and convert it to the insoluble ferric form. Aeration is also used at times to eliminate part of the flat taste in distilled water, and in many municipal plants to improve the taste of water which has not been distilled.

c. Figures 12 to 14 illustrate a number of typical aerator designs including an expedient for the field.

d. One of the most objectionable dissolved gases is hydrogen sulphide, which can usually be removed by aeration. This constituent causes the "rotten egg" odor and taste in water, but this taste is also caused by salts of hydrogen sulphide such as sodium sulphide and calcium sulphide. When these salts cause the odor it is often necessary to carbonate the water by spraying it in an atmosphere of flue gas (which contains carbon dioxide), and then aerating in the usual way. It is believed that carbonating with carbon dioxide converts the salts of hydrogen sulphide to hydrogen sulphide gas which can be removed by aeration. A two-compartment adaption of the aerator shown in figure 12 is best suited to this purpose.

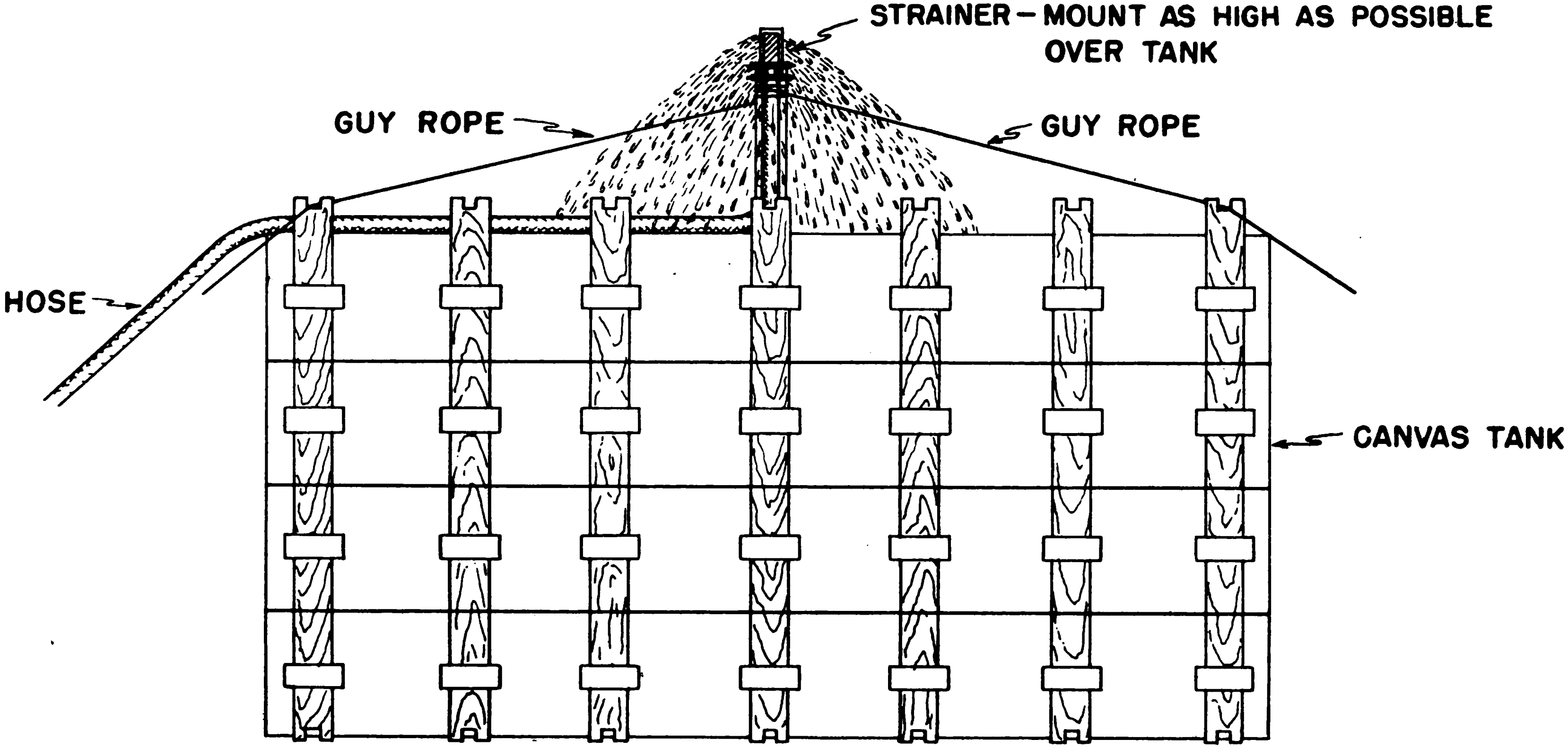


Figure 14. Field aerator made entirely of parts of engineer water supply set.

63. **Coagulation.**— *a.* The purpose of coagulation is to gather together small suspended particles so that they can be disposed of by sedimentation and/or filtration. This process is made possible by the peculiar properties of a group of chemicals known as coagulants, of which aluminum sulphate is the most common. When aluminum sulphate dissolves in water, it reacts to form a gelatinous precipitate, which entraps small particles of suspended matter. This combination of precipitate and suspended matter, called "floc", can then be settled out or removed by a sand filter.

b. The condition for greatest precipitation, or "optimum pH", generally occurs somewhere between pH values of 4.0 and 7.6, depending upon the type of water being purified. Colored waters containing only a small amount of dissolved solids generally coagulate best between pH values of 4.0 and 6.6, while turbid waters coagulate best between 6.0 and 7.6. These pH values are given only as indications, because there is only one optimum pH for any given water. During coagulation, therefore, it is essential to maintain the water at the optimum value. Floc will precipitate at pH values near the optimum but it takes a longer time for the floc to form and a smaller amount will be formed. If, after the addition of the coagulant, the water is not at the optimum pH, the pH value can be adjusted by adding either acid or alkali. (The most common method for obtaining the optimum pH for coagulation is known as the jar test, which is described in Sec. 2 Chapter VII.)

c. In order to obtain the maximum amount of precipitation in the minimum time, it is necessary to accelerate the rate of floc formation by mechanical agitation of the water. This is best accomplished by a gentle stirring motion. In order to remove a substantial amount of floc by sedimentation, it is necessary to agitate the water for about 30 minutes; if, on the other hand, the water is to be filtered only, floc particles will be large enough to be retained in the filter after about 5 minutes of agitation.

d. In the mobile and portable units, no provision is made for floc formation. The coagulating chemicals are added to the water about 1 minute before it starts to pass through the sand. Some waters will not coagulate in this short time, particularly if the water is not at the optimum pH. It is essential, therefore, to provide additional time for floc formation. This is best done in the field by utilizing a canvas tank for coagulation and sedimentation (Fig. 10c) as described in Chapter 7, "Operation".

e. Water of low turbidity and alkalinity, especially colored water, is often difficult to coagulate; the pH range for good coagulation is narrow and the floc forms with difficulty. Upon addition of clay and similar materials which provide neuclei for the floc formation, the precipitation of the coagulant is improved and the particles of floc formed are larger.

The optimum pH range undergoes a small, apparent broadening. The range can also be broadened by the addition of bivalent or trivalent negative irons such as sulphates or phosphates.

64. **Chemicals Used in Coagulation.**— *a.* The chemicals commonly used in the coagulation are described below. The coagulants are given first and are followed by the chemicals used for pH adjustment.

(1) Alum. *(a)* Filter alum or aluminum sulphate $Al_2(SO_4)_3.18\ H_2O$ weighs about thirty-nine pounds per cubic foot. It is available either in the lump, granular, or powdered form. The material is an acid salt and hence is corrosive to most metals. It is readily soluble in water and is easily applied as a solution or as dry material.

(b) Reactions between alum and the natural consituents of various waters are influenced by many factors, so that it is impossible to determine accurately the amount of alum which will be required. The amount of various forms of alkalinity which react with one grain per gallon of aluminum sulphate are as follows:

One grain per gallon of alum react with:
0.45 grains per gallon natural alkalinity, expressed as $CaCO_3$;
0.30 grains per gallon of 85 per cent quick lime as CaO;
0.35 grains per gallon of 95 per cent hydrated lime as $Ca(OH)_2$;
0.48 grains per gallon of soda ash.

The above approximate amounts of added alkali are those required with alum for the formation of aluminum hydroxide floc where the alkalinity of the treated water *is not changed.* That is, water treated with 1.0 gr. p.g. of alum and either 0.35 gr.p.g. hydrated lime or 0.48 gr.p.g. soda ash would have approximately the same alkalinity as the raw water. If no alkali be added, then 1.0 gr.p.g. of filter alum will lower the natural alkalinity of the raw water by about 0.45 gr.p.g., or 7.7 p.p.m.

(2) *Black alum.* This phrase is applied to filter alum which contains powdered activated carbon in quantities of 2 to 5 per cent by weight. Black alum, therefore, is used to secure coagulation with taste and odor reduction with a single compound, which can be fed by a single chemical feeder. Independent adjustment of alum and carbon doses is not possible. However, activated carbon may have to be added separately to remove all the tastes and odors from some waters.

(3) *Ammonium Alum.* Ammonium alum ($Al_2(SO_4)_3.(NH_4)_2SO_4.24\ H_2O$) should not be confused with filter alum (aluminum sulphate) discussed above. It is the alum used in mobile and portable purification units. It is used because it is much less soluble than filter alum, and, therefore, will dissolve more slowly when placed in alum pots, and its controlled application over an appreciable period of time is facilitated. Alum pots are not accurate feeding devices, even with ammonium alum, but are more compact than other feeds and, therefore, more suitable for mobile and portable equipment.

(4) *Sodium Aluminate.* *(a)* Sodium aluminate ($Na_2Al_2O_4$) is a compound prepared by the action of sodium hydroxide on alumina. This coagulant is not used alone but with alum to secure special results. Thus the failure of some very cold waters to coagulate with alum alone may be corrected by adding about 0.2 gr.p.g. of sodium aluminate with the alum. Another use of this coagulant is in connection with "double coagulation" of highly colored water, whereby alum alone or alum and sulphuric acid are added to the influent of the primary basin to coagulate the highly colored water at the required low pH range (pH 4.4-5.0). This results, however, in the presence of undesirable concentrations of soluable alumina ("free alum") in the presettled water, so the alkaline sodium aluminate, and also lime if needed, is added to increase the pH value, to say 6.5. This secondary treatment results in the formation of aluminum hydroxide floc, which settles in the secondary basin. A third use of sodium aluminate is in conjunction with lime-soda softening of water, whereby insoluble calcium aluminate floc is formed and coagulates the calcium carbonate and magnesium hydroxide resulting from the softening reactions.

(b) Sodium aluminate may be procured either as a solution or as a solid and may be applied by conventional chemical feeders. The cost of the material is high but the required doses are small so that the treatment may be applied to advantage and at reasonable cost when special local conditions justify.

(5) *Copperas.* *(a)* Ferrous sulphate (Fe SO_4) ordinarily known as copperas, is a granular, acid, compound which is shipped in bags, barrels, or in bulk. The alkalinity and pH value of natural water are generally too low to react with copperas to form the desired ferric hydroxide floc, because the reaction involves oxidation by the dissolved oxygen in the water, which does not occur when pH value is less than about 8.5. It is necessary, therefore, to add lime with copperas to secure coagulation. Copperas and lime are very effective as a coagulant in lime-soda water softening and in the coagulation of iron and manganese. The exact doses of lime required to react with copperas can not be stated, but it is approximately 0.27 gr.p.g. per each 1.0 gr.p.g. of copperas. Generally speaking, the floc formed by the reaction of copperas and lime is feathery and fragile, but it has a high specific gravity.

(b) While copperas is an acid salt, it is readily applied by either solution or dry feed equipment, although there is a distinct tendency for hygroscopic action to render the material moist and cause "arching" in the hoppers of the dry chemical feeders.

(6) *Chlorinated Copperas.* The oxidation of copperas by the dissolved oxygen of water under the conditions noted above, occurs only at pH values exceeding about 8.5 and preferably over 9.0. Chlorine, how-

ever, may be used to react with copperas irrespective of the pH value, whereby ferric sulphate and ferric chloride are formed and in turn act as coagulants Theoretically, one pound of chlorine reacts with 7.8 pounds of copperas. Additional chlorine is added ordinarily to insure complete reaction and also to disinfect the water being treated. Coagulation with chlorinated copperas, therefore, is especially adaptable to conditions when prechlorination is required and where coagulation by ferric chloride and ferric sulphate over a wide range of pH values is an advantage because of flexibility. As copperas is more readily applied to water than the ferric coagulants, chlorinated copperas treatment may be used with conventional chemical feeding equipment without modification.

(7) *Ferric Sulphate.* ($Fe_2(SO_4)_3$). *(a)* Ferric sulphate was recently introduced as a commercial coagulant in the form of an anhydrous material which may be shipped and stored in wooden barrels. The material will dissolve most readily in a *limited* quantity of warm water so a special "solution pot" must be used with chemical feeders, whereby two parts of water are used to dissolve each part of ferric sulphate, so as to produce a solution of about 40 per cent strength. This is equivalent to about three and one-third pounds of ferric sulphate per gallon of water.

(b) Ferric sulphate reacts with the natural alkalinity of the water or with the lime added for the purpose and forms ferric hydroxide floc. No intermediate oxidation reaction is involved as with copperas. The required natural alkalinity, or the dose of lime, varies with different waters Theoretically, however, the requirements are as follows:

1 gr.p.g. of ferric sulphate reacts with:
  0.75 gr.p.g. natural alkalinity;
  0.58 gr.p.g. 95 per cent hydrated lime.

(8) *Ferric Chloride.* ($Fe\ Cl_3$). *(a)* Three commercial forms of ferric chloride are avaliable, namely, the liquid, the crystaline and the anhydrous material. Liquid ferric chloride is very corrosive and is shipped in rubber lined tank cars or twelve gallon glass carboys. The strength varies from 31 to 45 per cent ferric chloride by weight, depending on the temperature. The crystaline form of ferric chloride contains 60 per cent ferric chloride by weight and is shipped in barrels holding about 435 pounds. Anhydrous ferric chloride is free from water of crystalization and is shipped in steel drums holding about 100 pounds. The material remains non-corrosive to the drums *as long as moisture is excluded.* The drums must be left sealed therefore or their entire contents dissolved in water at one time.

(b) Ferric chloride reacts with the natural alkalinity of the water or with lime added for the purpose to form ferric hydroxide floc.

Here again the concentration of the natural alkalinity or lime required can not be definitely stated, but approximately is as follows:

Each gr.p.g. of ferric chloride requires:
0.92 gr. p.g. natural alkali;
0.72 gr.p.g. 95 per cent hydrated lime.

(9) *Ferric Coagulants.* *(a)* To summarize, chlorinated copperas, ferric chloride or ferric sulphate may give similar results when their doses are compared in terms of iron content, although ferric sulphate generally is a better coagulant than ferric chloride at low pH values required in the coagulation of highly colored water, because of the beneficial influence of the sulphate ion or radical, as contrasted with the chloride ion.

(b) As in the case of coagulation with alum, the positively charged floc, in this case ferric hydroxide, absorbs negatively charged bacteria and the particles causing color and turbidity. There are a number of practical differences between alum and ferric coagulants, however, which should be noted. Briefly, these are as follows:

1. Ferric hydroxide is formed at low pH values, so that coagulation with ferric sulphate at pH values as low as 4.0 and with ferric chloride pH values as low as 5.0 is possible.

2. Ferric hydroxide is insoluble over a wider range of pH values than aluminum hydroxide *except for the zone of 7.0 to* 8.5. Chlorinated copperas, however, has been used with success in this zone.

3. The floc formed with ferric coagulants, is heavier than alum floc.

4. The ferric hydroxide does not re-dissolve at high pH values.

5. Ferric coagulants may be used in color removal at the high pH values required for the removal of iron and manganese and in the softening of water.

(10) *Clay.* *(a)* Bentonite, Fullers earth, and other absorptive clays have been utilized to some extent in recent years to assist in coagulation. Clays assist in coagulation of relatively clear and colored waters by supplying suspended matter as neuclei around which the floc forms. Some of them "swell' when added to water and produce a floc of themselves or with a limited dose of coagulant. In any case their use may improve coagulation and reduce the coagulant cost. It is well, therefore, to try them when difficulty is being experienced in coagulation.

(b) Some of the clays absorb taste and odor-producing substances, especially oily materials, so they may assist in the treatment of waters polluted with trade wastes.

(11) *Sulphuric Acid.* (H_2SO_4) *(a)* Sulphuric acid is of interest only as an aid in the coagulation of soft colored water with alum, where the use of acid is a more econimical means of producing the required low pH value than an equivalent dose of alum.

(b) The usual commercial strength of sulphuric acid is 66° Beaume, which is equivalent to 93 per cent. The material is shipped in ten gallon glass carboys or drums holding 50 to 500 pounds. The concentrated acid may be stored in iron tanks and conducted through wrought-iron pipe, but the dilute acid is very corrosive to iron and must be stored in glazed earthenware vessels, rubber lined steel tanks, or the like.

(12) Alkalies *(a)* *Soda Ash.* (Na_2CO_3) Soda ash, or sodium carbonate, is a white powder very soluble in water so that little difficulty is experienced in introducing this chemical into water to be treated. It is used when waters do not contain natural alkalinity in sufficient quantities to react with the coagulant. The reaction between alum and soda ash produces about one-half the amount of carbon dioxide which is formed when the natural alkalinity of water reacts with alum. No carbon dioxide is formed, however, when an excess of soda ash is used, because the excess combines with the carbon dioxide to produce sodium bicarbonate.

(b) Soda ash is practically pure sodium carbonate, but nevertheless it should be procured by specification to contain at least 98 per cent sodium carbonate. The use of this quality of soda ash has been assumed in the calculation of chemical doses discussed in this manual. It is readily apparent, for instance, that it is necessary to use about 102 pounds of 98 per cent commercial soda ash to provide 100 pounds of sodium carbonate.

(c) *Quick Lime.* (CaO) Quick lime or calcium oxide may be used with alum or copperas to provide artificial alkalinity when necessary. It is used also in water softening. Quick lime varies in quality from about 75 per cent to 99 per cent calcium oxide, so that the operators of water treatment plants must know the quality of the lime they are using before the doses can be calculated. The computations in this manual are based on the use of 85 per cent quick lime. A high calcium lime should be utilized, because of the ease with which it may be slaked.

(d) *Hydrated Lime.* ($Ca(OH)_2$) Slaked or hydrated lime, also known as calcium hydroxide, is a white powder formed when quick lime is slaked in water or in moist air. This material may be obtained in paper or cloth bags in relatively small quantities. It does not deteriorate when stored, does not have to be slaked, and contains fewer impurities than most quick limes. This material may be mixed directly in solution tanks and fed through orifice boxes into the water to be treated, or the chemical can be fed in a dry form by the use of dry feed equipment. Lime is usually fed as a suspension rather than as a solution because of its limited solubility. Suspensions cannot be fed with the pots of either the mobile or portable units.

(b) Properties of Chemicals Used to Coagulate or Adjust Alkalinity (pH) of Water

CHEMICAL	HOW USED	HOW SHIPPED	WEIGHT (POUNDS PER CUBIC FOOT)	DOSE G. P. G.	EFFECTIVE pH RANGE	NATURAL ALKALINITY REQUIRED IN *G. P. G. TO REACT WITH ONE *G. P. G. OF COAGULANT	ARTIFICIAL ALKALINITY REQUIRED IN *G. P. G. TO REACT WITH ONE *G. P. G. OF COAGULANT			REMARKS
							HYDRATED LIME	QUICK LIME	SODA ASH	
Alum.......... $Al_2(SO_4)_3$. $18 H_2O$	Coagulant.....	200 lb. bags.................. 400 lb. bbls. Bulk.	39	0.3 to 3.0	4.4 to 6.0 5.7 to 8.0 9.0 to 10.5	0.45	0.35	0.28	0.48	4.4 to 6.0 pH range used for highly colored water. 5.7 to 8.0 pH range used for turbid and moderately colored water. 9.0 to 10.5 pH range used in alum coagulation of carbonates in lime-soda softening.
Ammonia alum.. $Al_2(SO_4)_3$. $(NH_4)_2 SO_4$. $24 H_2O$	Coagulant.....	400 lb. bbls.................. 100 lb. kegs	39±	0.3 to 6.0	5.7 to 8.0	0.29±	0.23±	0.18±	0.31±	Less soluble than filter alum and costs three times as much in terms of aluminum oxide content. Therefore use generally restricted to swimming pools and pressure filters where "alum pot" is used. Ammonium content available.
Sulphuric acid... $H_2 SO_4$	To adjust pH in connection with alum coagulation	10 gallon carboys.. 500 lb. steel drums.. 1500 lb. steel drums.. } 93% H_2SO_4	(Liquid) 18 lbs. per gallon	0.1 to 1.0		....	....	....	....	Always dilute by adding acid to water, otherwise serious burns may result. Can be fed by use of hypochlorite solution eqiupment.
Sodium aluminate.... $Na_2 Al_2 O_4$	Coagulant	Solid—108 lb. thin steel drums.. 405 lb. thin steel drums 100 lb. bags Liquid—32% $Na_2Al_2O_4$—steel drums 10% NaOH	58±	0.2 to 2.0	6.0 to 7.5 (with alum) 9.5 to 10.5 (softening)	....	....	....	....	Used with alum to assist in the coagulation of cold water. Also used with alum to coagulate alkaline waters, such as with water softening. Supplies alkali as well as aluminum. Commercial grade contains 55% aluminum oxide and 35% combined soda plus 6% excess caustic soda.
Copperas (Ferrous Sulphate) $FeSO_4$	Coagulant.....	200 lb. bags.................. 400 lb. bbls. Bulk.	46±	0.3 to 3.0	8.5 to 11.0		0.27	0.22	Not normally used	

(b) Properties of Chemicals Used to Coagulate or Adjust Alkalinity (pH) of Water (cont.)

Chlorinated copperas	Coagulant....	See copperas..................	See copperas	0.5 to 3.0	3.5 to 9.5	0.85	0.65 (See ferric coagulants)	0.52 (See ferric coagulants)	Not normally used	Chlorine added to copperas. 1 lb. of chlorine required for each 7.8 lbs. of copperas used. A slight excess of chlorine is added in plant practice plus the chlorine needed for disinfection.
Ferric sulphate (ferrisul) $Fe_2(SO_4)_3$	Coagulant.....	200 lb. bags................... 400 lb. wooden bbls.	70	0.5 to 3.0	3.5 to 9.5	0.78	0.58	0.46	Not normally used	If dry feed machine is used, must have solution pot feeding 2 parts water to each part of ferric sulphate. Used with lime for iron and manganese removal.
Ferric chloride.. Fe Cl_3	Coagulant.....	Liquid—12 gallon carboys, 8000 gallon rubber lined tank cars } 42% Crystals—55 gallon hardwood bbls. each containing 435 lbs.... } 60% Anhydrous—100 lb. steel drums		0.5 to 3.0	3.5 to 9.5	0.92	0.72	0.58	Not normally used	Very corrosive. Rubber-lined equipment must be used. Used with lime for iron and manganese removal.
Soda ash....... Na_2CO_3	To adjust pH or remove permanent hardness.	200 lb. bags................... 400 lb. bbls. Bulk.	63±	0.1 to 2.0 For pH adjustment For permanent hardness removal, dose varies with hardness.	....	....	....	....	....	Readily soluble, and non-corrosive to wrought iron or lead piping. May be used to prevent corrosion when hardness of water exceeds about 40 p.p.m.
Hydrated lime.. $Ca(OH)_2$	To adjust pH or remove carbonate hardness.	50 lb. paper bags..............	50±	0.1 to 3.5 For pH adjustment. For carbonate hardness removal, dose varies with hardness.	....	....	....	....	....	Only slightly soluble and thus is fed as a suspension. Cheaper and more effective than soda ash. Used to prevent corrosion irrespective of hardness of water.
Quick lime...... CaO	To adjust pH or remove carbonate hardness.	Wooden bbls., metal drums, waterproof bags, bulk.	65±	0.1 to 3.0 For pH adjustment For carbonate hardness removal, dose varies with hardness.	....	....	....	....	....	Must be slaked before used. Somewhat cheaper and more effective than hydrated lime, but difficulty of handling limits its use to large plants.

*G.P.G.=grain per gallon. One grain per gallon=17.1 parts per million. One grain per gallon=143 pounds per million gallons.

65. **Mixing Basins.—** *a.* A mixing basin serves both to mix the chemical throughly with the water and to form a large floc in a minimum length of time. A very rapid or violent mix is most suitable for the first type of mixing, and is sometimes accomplished before water enters the mixing tank. This type of mixing could be accomplished in a centrifugal pump for example. When this initial mixing is done in the mixing tank, it is often accomplished by a high variable speed propeller type agitator. Flocculation is generally done with slow variable speed paddle type agitators designed to give a gentle rolling motion to the water. Some tanks have stationary blades, designed to accentuate the rolling motion, through which the agitator blades pass.

b. Good floc formation is seldom accomplished in less than thirty minutes. It is essential, therefore, to reduce "Short circuiting" through the tank to an absolute minimum. The speed of the flocculating agitators should be 0.5 to 2 feet per second and will vary with different waters. If the speed is faster than this it will break up the large floc particles which are essential to good settling. There is one type of a flocculating tank which is really a combination of mixing and settling tank (Fig. 10b). Floc is formed in one section of the tank by agitating the incoming water and chemicals in the presence of pre-formed floc. The water then passes into another section where it moves upward through a bed of floc at a velocity such that the bed is kept in suspension. As the water rises, the velocity decreases, so that it is quite easy to prevent the suspended floc bed from washing out of the tank. This floc bed is in effect a filter which removes most of the particles formed in the flocculating chamber; the "floc filter" also removes any particles from the water which escaped being caught by floc in the agitating chamber. This sludge bed type of tank will accomplish in one hour what the usual mixing tank and settling basin will in two to three hours. Several deviations from this method are possible, varying from simple recirculation of sludge to the inlet of the basin, to the arrangement in which the bulk of the water with its precipitates in the tank is recirculated. (Figs. 17 & 18)

66. **Sedimentation.—** *a.* Sedimentation utilizes the force of gravity to remove suspended particles. Because the ability of water to carry suspended particles varies directly with the sixth power of the velocity, the minimum practical velocity is used during sedimentation. If, however, the velocity through the settling tank is too low, currents caused by wind, temperature differences, dissolved gas, etc. will materially interfere with sedimentation. This instability can be prevented by increasing the velocity. The most efficient velocity in a settling tank is, therefore, the minimum velocity which will maintain uniform flow conditions throughout the tank.

b. The depth of the settling tank has little effect upon the removal of floc because as a floc particle settles it picks up smaller particles, and, therefore, settles faster. The degree of removal depends upon the initial particle sizes and the amount of flocculation which takes place during settling. If the material to be removed is non-flocculating, then individual particles will retain their identity. In this type of a suspension, the smallest particle that will be removed is one which will just settle to the bottom of the tank in the detention period of the tank. For this type of sedimentation, a shallow tank is most efficient. The detention period in minutes for a tank is the volume of the tank in gallons divided by the quantity of water in gallons per minute flowing into the tank. When a volume of water passes through the tank in a time less than the detention period, the tank is not operating efficiently. The most common cause for this type of inefficiency is improper design of the inlet and outlet distribution.

67. **Settling Basins.**— *a.* Settling basins are used to remove a substantial amount of the suspended matter in the water by utilizing the force of gravity. The detention period for most tanks is from two to four hours, some periods, however, are as long as twelve hours. Tanks may have almost any shape, although circular and rectangular are the most common. The best flow stability is obtained in long narrow rectangular tanks. (Sewage has settling characteristics very similar to the settling characteristics of floc particles in water.) In this type of tank it is easiest to obtain good influent and effluent distribution. It is essential in any type of tank, particularly circular and short tanks, to design the inlet so that the water is distributed uniformly over the cross section of the tank and so that the entrance velocities are completely dissipated before the water has passed through 10% or less of the tank's length. The collecting outlet should be designed so that these same results are obtained in reverse. It can be readily understood that if the entrance velocities extend for an appreciable distance into the tank, part of the water will pass through the tank in a time much less than the detention period.

b. After the sediment carried by the water is deposited in the tank, the next problem is removing it from the tank. One method is to allow the sludge to accumulate in the bottom of the tank for a month or two, and then to drain the tank and wash the sludge out by hose, but this is wasteful of water and the sludge may putrify. Another method is to remove the sludge continuously by a sludge removal mechanism which moves the sludge to a sump at either end of a rectangular tank or at the center of a circular tank. From this sump the sludge is removed by gravity or by pumping. In the "floc filter" type of tank the sludge is removed continuously by "bleeding" or draining off some of the bed.

68. **Filtration.**— *a.* Filtration is a process by which solids are removed from liquids. Although there are many types of filters employed for the filtration of water, among which are porous plates, paper, cloth, and

other special types, the only types which are used on a large scale are those known as sand filters. This term includes not only those employing sand as the filter medium but also those employing anthracite coal, magnetite, and certain other granular materials. In addition, calcite, zeolite, and granular activated carbon are used in vessels which are essentially filters. These special granular materials will be discussed further under their specific application.

b. Slow Sand Filters. The original granular filters were known as slow sand filters. No coagulant was used, but very often sedimentation basins or reservoirs preceded them to remove the bulk of the material which could settle out by its own weight during the long retention period provided.

c. Slow sand filters employ a very slow filter rate. The sand which acts as a filter medium is very much finer than the sand used in rapid sand filters with which we are more familiar today. Slow sand filters, since no coagulation or preliminary treatment is provided, depend on the slow passage of the water over fine sand grains at a rate normally not in excess of 3 to 4 million gallons per acre per day (0.016 gal. per sq. ft. per minute.) In addition to the sand, a layer of the material removed from the water is gradually built up on the sand grains, improving the filtration in a manner somewhat similar to that of the floc in the rapid sand filter.

d. A slow sand filter will remove about 98% of the bacteria from the water, almost all the other suspended solids, and when properly seasoned will absorb 30 to 40% of the coloring matter in the water. If the raw water is very turbid the bed becomes clogged quickly. After a time, the length of which depends on the amount of material removed by the slow sand filter, the upper layer of the sand bed becomes sufficiently clogged to reduce the flow appreciably. It is then necessary to scrape off the upper few inches of sand and accumulated muck. After the bed is reduced by repeated scrapings of this type to about one-half of its original depth, new, clean sand is added to restore the bed to its original depth (usually 27 to 48 inches.) In slow sand filters the water always passes through the bed by virtue of its own weight (gravity).

e. Rapid Sand Filters. By adding a coagulant, the size of the grains and the rate of filtration can be increased. In municipal practice today it is normal to use a filter rate one and one-half to two gallons per square foot of filter area per minute. Depending largely upon its character, raw water for industrial, swimming pool, and other such uses is filtered at rates as high as 3 gallons per square foot per minute, and in emergencies rates go as high as 4 gallons per square foot per minute for short periods. In our mobile and portable water purification filters (Chapter 7) the *maximum* rate is set at 10 gallons per square foot per minute but this can scarcely ever be attained, even if settling precedes filtration.

f. The criterion in filtration, especially in mobile and portable units, is to use only as high a rate as is absolutely necessary in order to produce the quantity of water that will be required, utilizing the full time alloted, and never exceeding a rate which fails to deliver clear water. When settling is not practiced ahead of filtration in portable and mobile units, the time available for the reaction of the coagulant with the natural or artificial alkalinity is very short. Settling should *always* be used in the tropics, in other climates on every possible occasion, and *always* when the water contains color or contains a turbidity over 50.

g. With rapid sand filters it is not necessary to remove the sand on order to clean the filter. Cleansing is effected by reversing the flow so that the water enters the filter at the bottom, and rises, suspending the sand and gravel, and causing the individual grains of sand to rub against and scour each other. The wash water effluent leaves the filter at the top. This process is called backwashing.

h. It is common to supplement the backwash with a water wash in the surface. This is called surface wash, and is accomplished with rotating jets of water from a revolving distributor which impringe horizontally on the surface. Surface wash is particularly useful where the formation of mud balls on the surface of the filter bed occurs.

i. At times an air wash is employed instead of surface wash. The filter is partially drained, and air is blown upward from the bottom of the filter through a pipe grid to agitate the bed before the water wash has begun, and continued for several minutes after the water wash begins. Air wash is beneficial where the material filtered from the water is of a sticky nature such as oil. Where oil is being removed, it is also beneficial to give the bed of the filter a scour with a solution of caustic soda (sodium hydroxide, NaOH). This caustic scour is not given every time the unit is backwashed, but at periodic intervals, say every 6 months or year.

69. **Types of Rapid Sand Filters.**— *a.* *Gravity.* (1) When water is passed through rapid sand filters contained in vessels open to the atmosphere, that is when no external pressure is applied, they are known as gravity filters. The head necessary to overcome the friction in passing through the filter is furnished by maintaining a sufficient depth of water over the sand bed. Gravity filters are built in open containers of wood, steel, concrete, or similar material.

(2) The advantages of gravity filters are: the appearance of the water being filtered, the sand bed, the effectiveness of washing, and the degree of agitation during the washing process can be observed; it is somewhat less difficult to replace the sand in gravity filters than in pressure filters; and the rate of filtration is limited by the low heads available and thus a careless operator is unable to exceed the rated capacity, as with a pressure filter where the rate is limited only by the head available at the inlet and the loss of head in the filter.

b. Pressure Filters.— When water enters, passes through, and leaves a filter under the influence of an external pressure without reducing that pressure any more than is necessary to overcome the friction in the filter and its bed, it is called a pressure filter. They are constructed in closed vessels, usually of steel. The chief advantage of pressure filters is that it is unnecessary to repump the filtered water as is the case with gravity filters.

70. **Washing.**— *a.* After a layer of floc and dirt builds up on the sand, it is necessary to remove it. In gravity filters this point is determined when the flow is diminished appreciably by the increase in pressure loss across the filter as compared with the head available above the sand. In pressure filters the head loss is generally restricted to between 8 and 10 pounds per square inch, although in emergencies it is permissible to wait until the pressure loss builds up to 15 pounds per inch before washing.

b. Washing is accomplished by reversing the flow in the filter. The upward flow of water floats the sand with the collected dirt on it, expanding it 40 to 50 per cent. The grains of sand rub against and scrub each other, and the dirt and floc scrubbed off, being lighter than the sand, is washed out of the filter, but the sand remains behind. Washing should continue until the wash water effluent starts to clear. It should not be continued beyond this point in order that the sand grains may remain partially seasoned (coated with floc) and the subsequent operation of rewashing (filtering to waste) will not take too long.

c. In the average rapid gravity filter plant the wash rate ranges from 15 to 25 gallons per square foot per minute. In the more modern plants where surface wash is employed, the wash rate may be somewhat lower. Wash rates, especially in gravity filter practice, are sometimes expressed in terms of the rise in water level per minute. Fifteen gallons per square foot per minute is equivalent to two cubic feet of water per square foot per minute and the rise or upward velocity is 24 inches per minute. The wash rates stated are for sand; in other filter media the wash rate must be adjusted to obtain a bed expansion of about 50 per cent. When magnetite is the medium, a higher wash rate must be used because it is heavier than sand, while for anthracite or anthrafilt, as it is called, which is lighter than sand, a rate about 80% of that for sand, is employed. Furthermore, when such devices as air wash are used to supplement the water wash, a rate of approximately 80% of the normal wash without air wash can be used.

d. In pressure filters the wash rate is normally 10 to 12 gallons per square foot per minute. However, if the freeboard (the distance from the top of the sand bed to the wash water collector) is less than normal (40 to 50% of sand depth) it is necessary to restrict the wash rate so that sand will not be washed from the filter.

e. When a filter of any type has been drained, it should be refilled from the bottom otherwise air will be trapped in the bed which will interfere with filtration. Therefore, the control valves should be set as for washing. Before washing, all valves should be closed, and then the wash outlet valve and the air relief valve, if there is one on the filter, should be opened. The wash water inlet valve is then opened slightly until water starts to come from the wash water outlet, after which the opening of the wash water inlet valve is increased slowly until the maximum rate desired is reached.

71. **Disinfection.**— *a.* No one or any combination of several water purification processes: storage, sedimentation, coagulation, filtration, etc. can be relied upon to remove all the bacteria from the water. It is therefore necessary to disinfect the water. Disinfection is the process whereby all dangerous organisms are killed.

b. There are several means of disinfection among which are the use of ozone (O_3), iodine, ultra-violet light, and chlorine. The only disinfectant universally accepted is chlorine since it is the only form of disinfectant, other than iodine, which leaves behind a residual to protect the water from subsequent contamination.

c. Recently it has become common to feed ammonia (NH_3) just before chlorination to form chloramines.

d. The destruction of bacteria by the use of chlorine or chlorine compounds requires that the organisms be exposed to adequate concentrations for a sufficient period of time. It is also essential that the chlorine be distributed uniformly to all parts of the water, and it is for this reason that super-chlorination of a portion of the water and subsequent mixing of this over-chlorinated water with untreated water does not give satisfactory results.

e. Chlorination is most effective in clear water, for if the bacteria or the other organisms to be destroyed are embedded in organic matter it is often impossible for the chlorine to reach them.

f. At times it is advisable to chlorinate both before and after filtration. Prechlorination helps to prevent the sludge in the sedimentation basin and on the filters from putrifying, and is therefore said to keep that basin and filters "sweet".

g. The amount of chlorine to be fed to the water depends on the character of the water and upon the amount of free chlorine necessary in the effluent to maintain it safe for drinking purposes. The safety of the effluent in regard to freedom from pathogenic bacteria requires that sufficient residual free chlorine be present for a sufficiently long period of contact to be effective. Within limits, the higher the chlorine concentration the shorter may be the period of contact, but high concentrations are undesirable on account of the taste and odor imparted to the water. In normal practice, where the effluent of the waterworks is piped to the user, less than 0.5 part per million of free chlorine is maintained in the effluent. In the field, however, where subsequent rehandling presents a definite hazard, at least one ppm residual free chlorine must be maintained, as determined in a sample taken after 10 minutes of storage in an open vessel.

h. As stated above, the use of chlorine and ammonia to form chloramines is gaining wider usage. Chloramine treatment is valuable, especially when water contains industrial waste such as phenol compounds, in which case, if chlorine were added alone, a rather disagreeable taste would be produced. The same situation would present itself if algae were present in considerable quantities. The use of ammonia with chlorine also permits much larger chlorine dosages without producing a chlorine taste. Another advantage of chloramines is that they do not react as readily with organic matter as chlorine alone, and therefore, more chlorine is available for the initial bactericidal process. For the same reason, it is advisable not to use water treated with chloramine until approximately two hours have elapsed after treatment.

i. Another procedure is the use of super-chlorination followed by dechlorination. With this process a large excess of chlorine is fed, and then that part of the residual which is not needed is removed by the addition of powdered activated carbon, or by passing the water through a bed of granular activated carbon, or by the addition of a reducing agent such as sodium thiosulphate, sulphur dioxide, sodium bisulphite. It is claimed that super-chlorination is more effective than ordinary chlorination because there are certain organisms which do not react readily with small amounts of chlorine but are successfully handled with larger concentrations.

j. Chlorine may be fed as such in a gaseous form, or it may be fed in the form of one of its compounds, such as sodium or calcium hypochlorite. In the mobile unit the gas is used; in the portable unit the hypochlorite is used. In most large plants it will be found that chlorine gas is used, and in the smaller plants, hypochlorite.

k. Chlorine gas may be obtained in one ton containers or in 20, 100, and 150 pounds cylinders.

l. When chlorine is compressed it changes from a gas to a liquid at comparatively low pressure. This pressure varies with the temperature, so that in a full tank of chlorine the pressure may be as high as 150 pounds in the summer time and as low as 40 pounds in cold weather. Temperature pressure curves are available, so that knowing the pressure and the temperature one can get an approximate idea of how full the cylinder is.

m. As chlorine is removed from the container it changes from a liquid to a gas due to the reduction of pressure (evaporation).

n. The evaporation of liquid chlorine into a gas involves the absorption of heat which is obtained from the surrounding atmosphere through the walls of the container. Therefore, if the gas is drawn off too rapidly, frost will appear on the outside of the container, and freezing will retard the further passage of heat. The rate of withdrawal of chlorine from one ton cylinders in a heated room should not exceed 450 pounds per 24 hours; and proportionately less for smaller cylinders. When the chlorine is withdrawn intermittently the rates stated above, which are for continuous withdrawal, may be increased by one hundred per cent. Under no condition should chlorine containers be heated in any way to accelerate the withdrawal.

o. Care should be exercised in the handling of chlorine containers; they should not be allowed to strike the ground or bump each other violently. An empty container should have the valve closed and the protective cap replaced. Chlorine containers or containers for any gas should not be used as rollers or supports. They are designed to contain gas and not for any other purpose. Care should be taken in handling the chlorine valve. Chlorine containers should be stored in a dry, protected place where they are not subject to high temperatures. They should not be stored near inflammable substances. Cylinders of smaller than 150 lb. capacity should be stored in an upright position.

p. Sodium hypochlorite may be purchased as a solution and is known under a variety of trade names, such as javelle water. The solutions usually contain from 3 to 15 per cent of available chlorine by weight and are quite stable, due to their high alkalinity. Sodium hypochlorite solution may be prepared by the application of gaseous chlorine to a solution of sodium hydroxide or by adding chloride of lime to soda ash. The solution should be stored in a cool, dark place and should be diluted to a strength of from one-half to one per cent before feeding.

q. Calcium hypochlorite (not chloride of lime or bleach) may be purchased in containers of various sizes. It is somewhat unstable and should be obtained in small containers and not opened until it is to be used. Commercial calcium hypochlorite varies in strength from 25 to 37 per cent of available chlorine by weight. It contains excess lime, which is insoluble, and thus solutions of this material contain suspended solids which should be removed before using. If calcium hypochlorite is used it should be dissolved in a separate solution tank where thorough mixing can be provided and where the soluble solids may be allowed to settle out. Supernatant clear liquid can then be siphoned into the storage tank and diluted with water to the desired strength. Ordinarily a solution containing one per cent available chlorine is correct for use in hypochlorite feed.

r. Recently, special soluble and stable forms of calcium hypochlorite containing 65 to 70 per cent chlorine by weight have been made available. It is these materials that are ordinarily issued for use in the portable purification unit.

72. **Activated Carbon.**— *a.* Certain tastes, notably those of chlorine and chlorophenols, can be removed from water by the application of powdered activated carbon distributed uniformly through the water and subsequently filtered, or the water can be passed over a bed of granular activated carbon in a filter tank.

b. The dose of powdered carbon required may vary from as little as one pound per million gallons to over 500 pounds per million gallons, the average dosage being 16 pounds per million gallons.

c. Activated carbon is furnished in the engineer water supply set and may be used by distributing it uniformly through the contents of a canvas tank full of water, and subsequently filtering the water. Normally the carbon would be fed to the canvas tank being employed for settling between the pumping and treating section, and the filter. One or more of the quick opening gate valves furnished with the water supply set should be fitted to the bottom openings of the tank and the tank desludged before the carbon is added. The carbon should be thoroughly stirred into the water with a tank stave or similar means, and the water should then be allowed to further settle. The filter would then remove the carbon as the water passed through it in the normal filtering process.

d. The removal of taste and the rendering of a water supply palatable is as important as the removal of turbidity and color which makes the water more pleasing to the sight. People will generally avoid a turbid, colored or malodorous water in favor of a clear, taste-odor-color free water even though the latter may be badly contaminated with bacteria and the former, relatively safe.

e. The easiest way to control taste and odor, is to prevent the entrance of industrial waste into the source of supply and to eliminate or avoid swampy, stagnant pools of water containing decaying vegetation and leaves.

73. **Iron and Manganese Removal.**— *a.* Iron is generally present in water in one of three forms: namely, ferrous bicarbonate, iron sulfate, or in combination with organic compounds. The iron which occurs in well water is usually ferrous bicarbonate. That which is found in streams usually originates from the waste from steel mills or other industries or from mine drainage, and occurs as iron sulphate. Organic iron compounds are usually leached from vegetation. Iron very often resists removal, and it is often necessary to make field tests on a small scale in bottles or otherwise determine the best, easiest, and most economical form of treatment.

b. Ferrous bicarbonate can usually be removed by aeration followed by filtration with the possible addition of lime, soda ash, caustic soda or other alkali. The iron when changed to the ferric form usually precipitates most easily at a high pH. If the raw water is clear before treatment, as is usual with well waters, indicating that it has been maintained out of contact with oxygen, the water can be passed through ion exchange materials which will be described in more detail under water softening. (Par. 74). The iron is taken up by the ion exchange material in exchange for sodium.

c. Iron seems to precipitate by aeration better when it is in contact with previously precipitated iron. An aerator in which the water trickles over a bed of gravel or metallurgical coke produces better results than other forms of aerators for iron removal.

d. Manganese can often be removed by aeration and pH correction, but under some conditions manganese will not oxidize as readily as iron; in fact when present with iron it may interfere with iron removal by aeration. In these cases it is preferable to use a contact filter containing specially prepared manganese zeolite which has been treated with potassium permanganate. This serves as an oxidizer and a filter combined. A contact filter is backwashed in the same way as a sand filter, but in addition, after each backwashing the bed is treated with potassium permanganate.

e. Iron in surface water, which as stated above is usually in the form of iron sulfate, can often be removed by pH correction alone. However, in some cases it will be necessary to aerate as well as to correct the pH. After the iron has precipitated, the water must be filtered.

f. For the removal of organic iron compounds coagulation and filtration is employed the same as for the removal of color, and the usual coagulation aids such as clay, floc formers, and the like are generally necessary.

74. **Water Softening.**— Softening is usually effected by either of two processes. In one, the bicarbonates of calcium and magnesium are changed to the insoluble calcium carbonate and magnesium hydroxide by the lime; and their sulphates, to calcium carbonate, magnesium hydroxide and sodium sulphate by soda ash and lime. The precipitates are removed by sedimentation and filtration. The chemical reactions involved are as follows:

$$\mathrm{Ca\ (HCO_3)_2 + Ca\ (OH)_2 \longrightarrow 2\ Ca\ CO_3 + 2\ H_2O}$$
$$\mathrm{Ca\ SO_4 + Na_2CO_3 \longrightarrow Ca\ CO_3 + Na_2SO_4}$$
$$\mathrm{Mg\ (HCO_3)_2 + 2\ Ca\ (OH)_2 \longrightarrow Mg\ (OH)_2 + 2\ Ca\ CO_3 + 2\ H_2O}$$
$$\mathrm{Mg\ SO_4 + Ca\ (OH)_2 + Na_2CO_3 \longrightarrow Mg\ (OH)_2 + Ca\ CO_3 + Na_2SO_4}$$

Hardness can also be removed by passing the water through a bed of ion exchange material which gives up its sodium or hydrogen ions in exchange for the calcium and magnesium ions in the water.

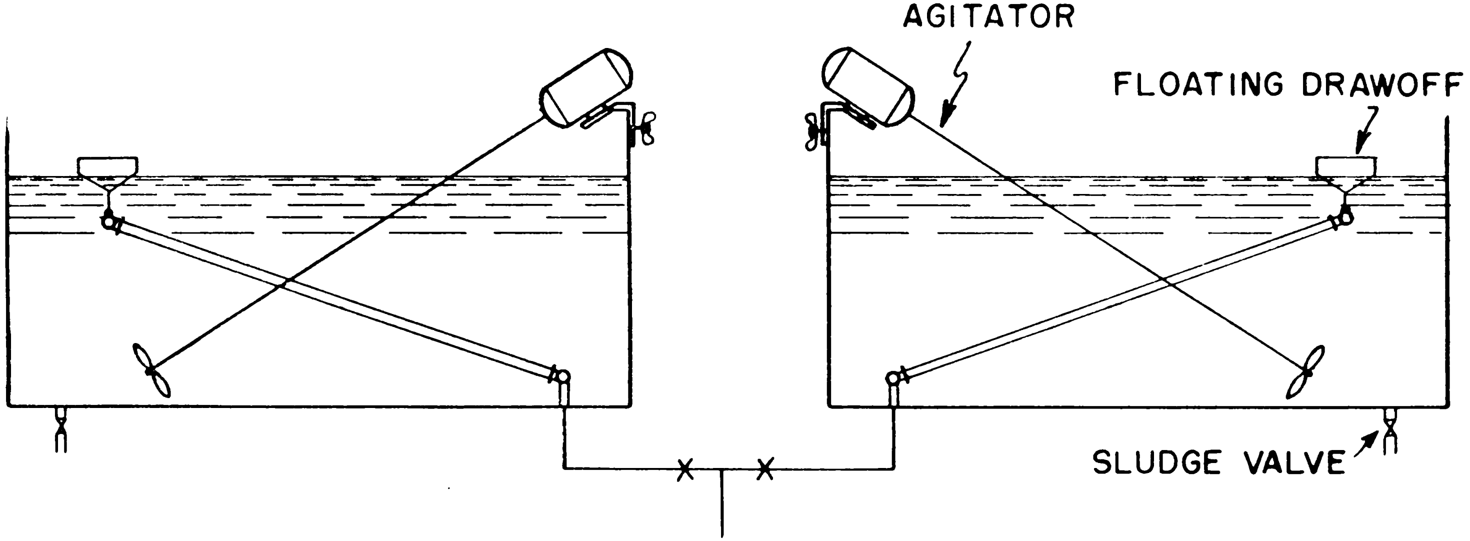


Figure 15. Batch treatment tanks.

Softening with ion exchange material:

$$\left.\begin{array}{l} \mathrm{Ca\ (HCO_3)_2} \\ \mathrm{Ca\ SO_4} \\ \mathrm{Mg\ (HCO_3)_2} \\ \mathrm{Mg\ SO_4} \end{array}\right\} + \underset{\text{(Zeolite)}}{\mathrm{4\ Na_2Z}} \longrightarrow \left\{\begin{array}{l} \mathrm{2\ Ca\ Z} \\ \mathrm{2\ Mg\ Z} \end{array}\right. + \begin{array}{r} \mathrm{2\ Na_2SO_4} \\ \mathrm{4\ Na\ HCO_3} \end{array}$$

Regeneration of the ion exchange material:

$$\left.\begin{array}{l} \mathrm{Ca\ Z} \\ \\ \mathrm{Mg\ Z} \end{array}\right\} + \underset{\text{(common salt)}}{\mathrm{4\ Na\ CL}} \longrightarrow \mathrm{2\ Na_2Z} + \left\{\begin{array}{l} \mathrm{Ca\ CL_2} \\ \\ \mathrm{Mg\ CL_2} \end{array}\right.$$

75. **Softening With Lime or Lime and Soda Ash.**— *a.* When the water contains only calcium and magnesium bicarbonate, lime alone is fed, but when the water contains calcium and magnesium sulfate in addition, it is necessary to feed lime and soda ash, as shown by the reactions above.

b. Early designs of lime and soda softeners employed batch methods (Fig. 15) in which a tank was filled with water, the measured amount of lime and soda ash added, and the entire contents of the tank stirred and subsequently allowed to settle for between 6 and 12 hours before the water was drawn off. Generally, two or more tanks were employed so that a continuous supply of water was available. Then the water was drawn off from the tank, through a floating outlet pipe, and filtered or not as determined from the turbidity of the effluent.

c. Later, continuous processes were developed in which the water enters the top of a tank, or the end of a basin, at which point the chemicals are added. During the passage through the basin, the chemicals react and the precipitates settle similar to the process involved in coagulation and settling.

d. Still later, it was found that better results could be obtained and smaller settling tanks used when the reaction was accelerated by the application of heat. This hot process is usually carried on in a steel or if necessary in a wooden tank. The water enters the top of the tank where the chemicals are fed, passes down through the tank, and is collected by a conical uptake. This apparatus is shown in Figure 16.

e. Most recently it has been found that if the lime treated water is agitated, (Fig. 17 & 18) the precipitation takes place much more rapidly, and if, after deposition of the precipitates, this water is allowed to pass through a blanket of sludge of previously formed precipitates, the hardness is reduced considerably below the point previously possible in the cold process. Other adaptations, as described in par. 65, "Mixing Basins", are also possible.

f. In the batch method with relatively long settling periods and good mixing, it is possible to reduce the hardness to as low as 30 to 40 ppm. In the continuous process with a shorter retention period, the hardness

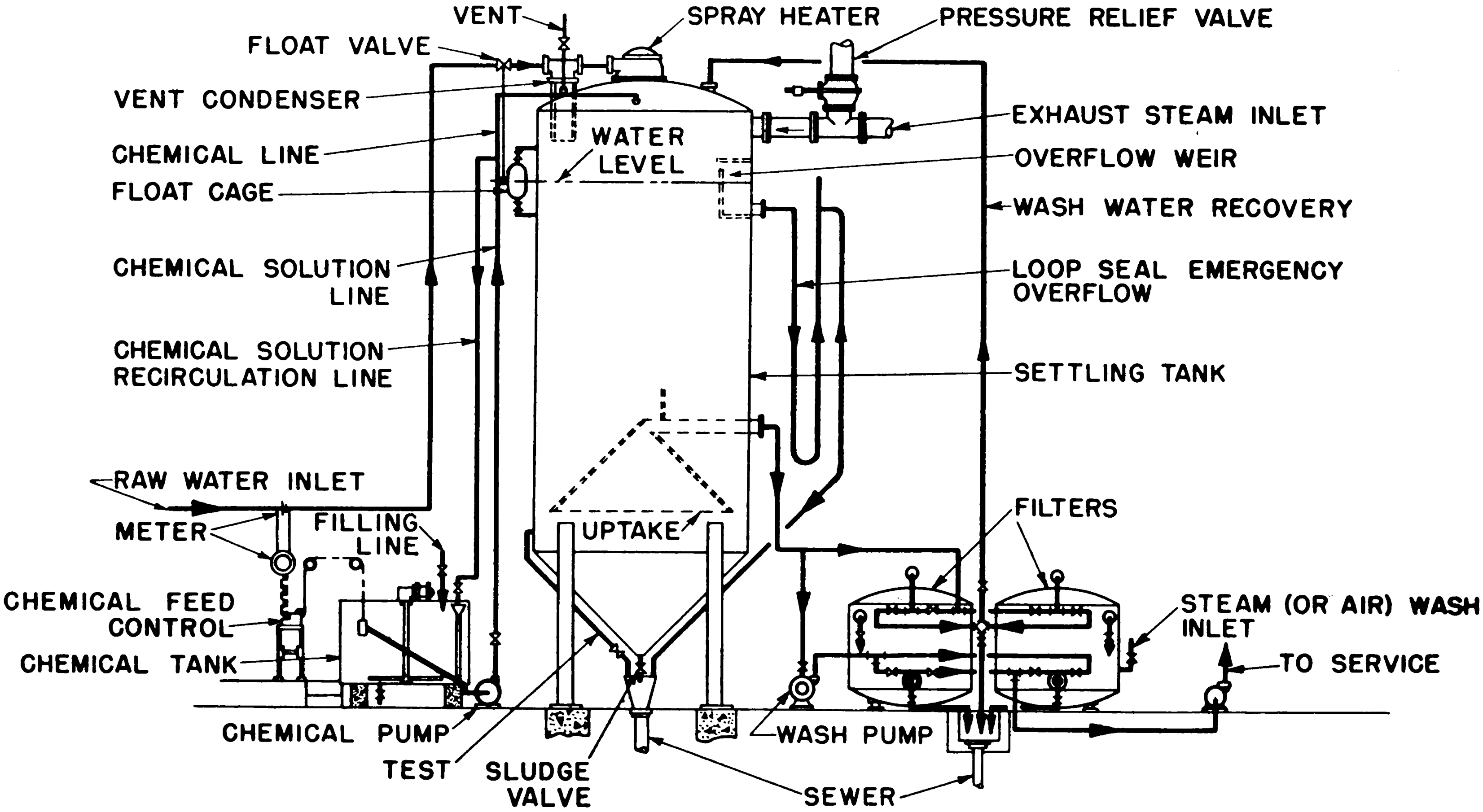


Figure 16. Flow diagram of hot process lime-soda softener of non-deaerating type.

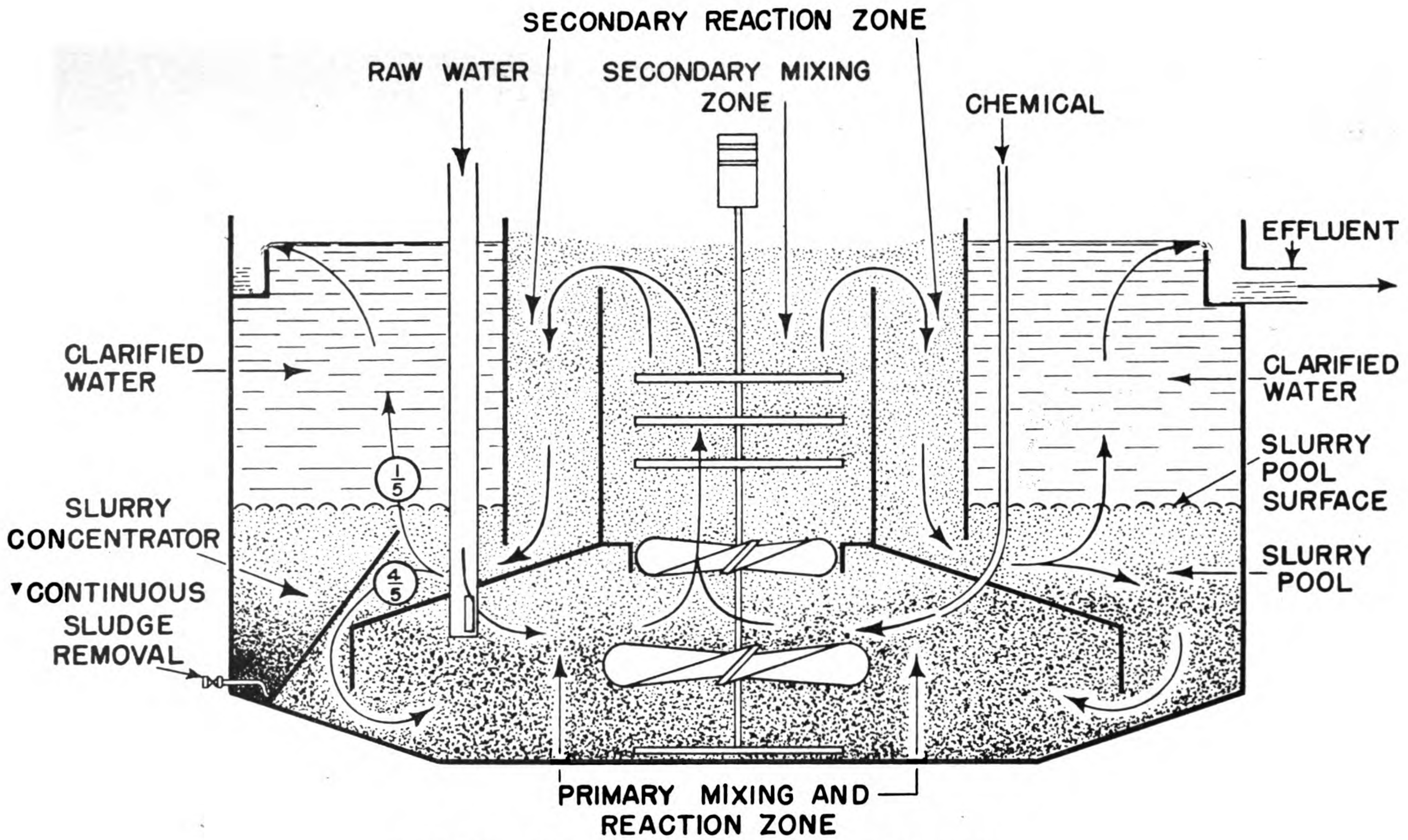


Figure 17. Sludge blanket treater (recirculating type).

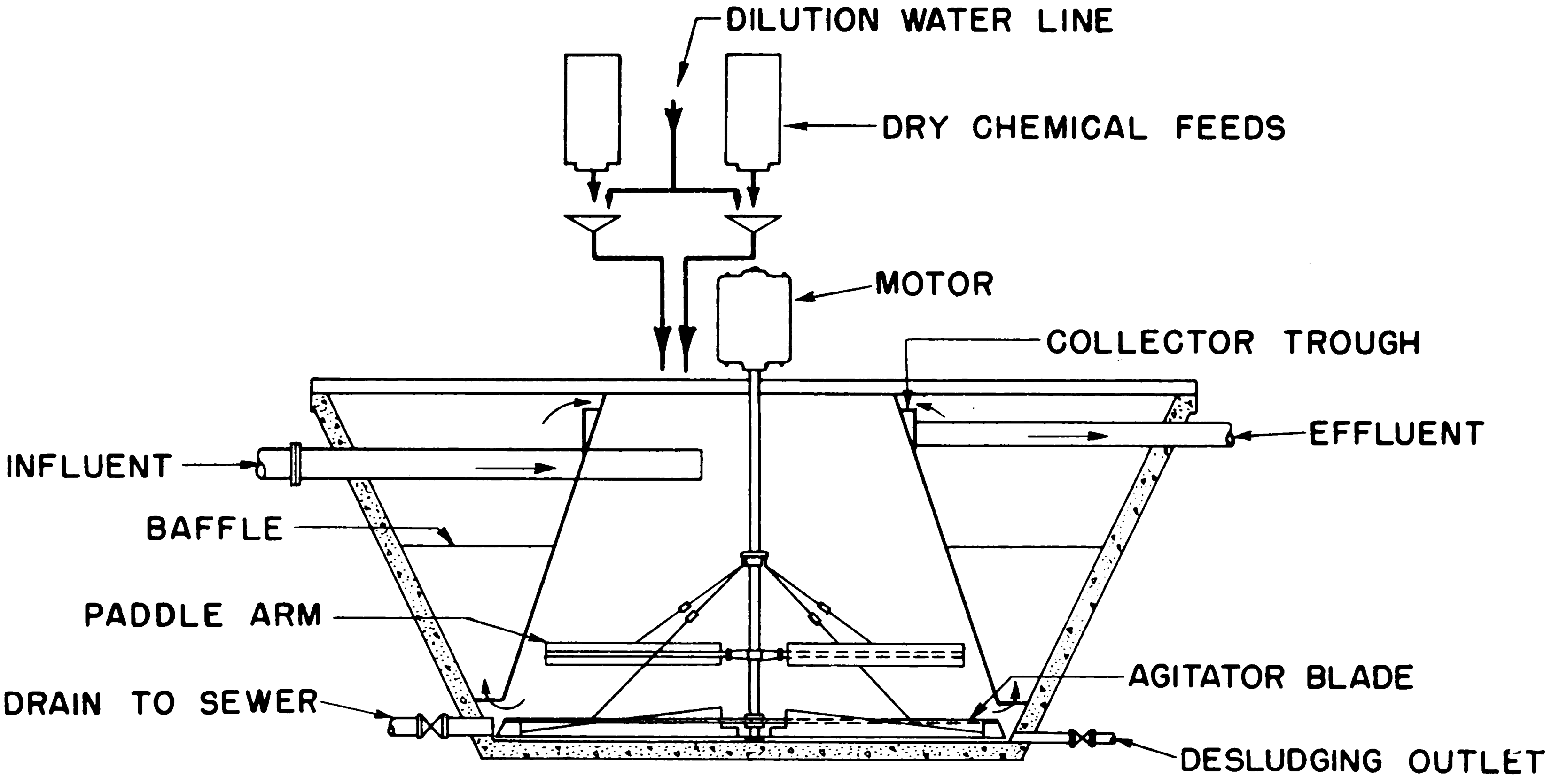


Figure 18. Sludge blanket settling basin.

is reduced to approximately 80 ppm. In the hot process and in the process utilizing the sludge blanket, the hardness can be reduced to between 20 and 40 ppm. In all types the final hardness depends on the amount of chemicals fed in excess of the theoretical requirements.

76. **Recarbonation.**— *a.* When water has been softened by the use of lime or by lime and soda ash, a part of the calcium carbonate remains in collodial dispersion (very fine state of division) and does not settle at once. When such water is filtered, much of this calcium carbonate will deposit on the sand grains of the filter. It may also deposit on the edges of orifices, on rough places in pipes, in elbows, tees, and valves, or in the distribution system itself. The tendency to deposit may be corrected by carbonation of the water, that is, by passing enough gaseous carbon dioxide usually in the form of flue gas into the water to convert the colloidal calcium carbonate into soluble calcium bicarbonate. If an excess of the carbon dioxide is used, there is possibility of the water becoming corrosive. The objective is, of course, to produce a balanced water, neither incrusting nor corrosive. The use of marble chip filters to prevent corrosive action by allowing excess carbon dioxide to act on the marble, or the use of certain phosphates such as sodium pyrophosphate and sodium hexametaphosphate to produce non-depositing calcium complexes, is also current practice.

b. The flue gas is first passed through a bed of lime-stone which is continually sprayed with water, then through an excelsior filter to a bed of steel turnings. It is then distributed to the water in a tank called a carbonation chamber by means of a perforated grid in the bottom of the tank.

77. **Softening by Ion Exchange.**— *a.* There are in general four types of ion exchange material as follows:

(1) The so-called natural sodium exchangers which are processed glauconite (green sand) or processed bentonite clay (kaolin). These materials are mined and then subjected to a processing consisting of washing, screening, and treatment with several chemicals to give them stability and long life. The exchange capacity of these materials ranges from 2500 grains of hardness removal per cubic foot of material to 5600 grains per cubic foot depending upon the origin and processing of the material. These and subsequent capacities which will be stated are not ultimate capacities, but since these are materials which obey the law of mass action, the capacities are those normally established in practice as being the most economical on the basis of the cost of regenerating material which will be discussed later.

(2) The synthetic exchangers are made either by a fusing process or by a precipitation process from such materials as caustic soda, aluminum sulfate, and sodium silicate. These materials have higher ca-

pacities, ranging in the neighborhood of 10,000 grains per cubic foot, but are more fragile; that is, they are more subject to deterioration, from suspended matter in the water, low pH, and iron, than are the so-called natural zeolites.

(3) The carbonaceous types are made from coal or other similar materials and can be operated on either the sodium or hydrogen cycle. They are quite rugged and have a nominal exchange capacity, which depends largely on the amount of acid or salt used to regenerate them.

(4) The so-called deacidizers are probably more nearly absorption materials than ion exchangers. They have the property of removing negative ions from the water.

b. The natural and synthetic sodium-aluminum silicates react to give up part of their sodium ions in exchange for calcium and magnesium ions in the water. When they have removed all the calcium and magnesium that is practical, they are revivified, or regenerated, by passing through them a solution of salt brine to which they give up the accumulated calcium and magnesium in exchange for the sodium of the brine. (Par. 74)

c. The carbonaceous exchangers operate in the same way on the sodium cycle, but are also capable of being regenerated with an acid, in which case they give up the accumulated calcium and magnesium as well as the sodium ions in exchange for the hydrogen ions of the acid, as follows:

Softening:

$$\left.\begin{array}{l} 2\ \mathrm{Na\,HCO_3} \\ \mathrm{Na_2SO_4} \\ 2\ \mathrm{NaCL} \\ \mathrm{Ca\ (HCO_3)_2} \\ \mathrm{Mg\ (HCO_3)_2} \\ \mathrm{Ca\ SO_4} \\ \mathrm{Mg\ SO_4} \end{array}\right\} + 7\ \mathrm{H_2Z} \longrightarrow \left\{\begin{array}{l} 3\ \mathrm{Na_2Z} \\ 2\ \mathrm{Ca\ Z} \\ 2\ \mathrm{Mg\ Z} \end{array}\right\} + \left\{\begin{array}{l} 6\ \mathrm{CO_2} + 6\ \mathrm{H_2O} \\ 3\ \mathrm{H_2SO_4} \\ 2\ \mathrm{HCL} \end{array}\right.$$

Regenerating:

$$\left.\begin{array}{l} \mathrm{Na_2Z} \\ \mathrm{Ca\ Z} \\ \mathrm{Mg\ Z} \end{array}\right\} + 3\ \mathrm{H_2SO_4} \longrightarrow \underbrace{\left\{\begin{array}{l} \mathrm{Na_2SO_4} \\ \mathrm{Ca\ SO_4} \\ \mathrm{Mg\ SO_4} \end{array}\right\}}_{\substack{\downarrow \\ \text{TO WASTE} \\ \downarrow}} + 3\ \mathrm{H_2Z}$$

d. When a water supply has been passed through a carbonaceous exchanger operating on the hydrogen cycle, the bicarbonates are converted to carbonic acid (carbon dioxide); the sulphates, to sulphuric acid; and the chlorides, to hydrochloric acid. If this water is then passed over an aerator the carbonic acid will be freed leaving only the sulphuric and hydrochloric acid. If it is not desired to remove the chlorides and sulphates, it is merely necessary to neutralize these acids with caustic soda, soda ash or other alkalies, or to mix some of the effluent of the hydrogen exchanger with the effluent of a sodium exchanger and allow the sodium bicarbonate of the latter effluent to react with the hydrochloric and sulphuric acid of the effluent of the hydrogen exchanger. If however, it is desired to remove the sulphates and chlorides as well, the effluent of the hydrogen exchanger is passed directly thru a deacidizer which absorbs the sulfates and chlorides leaving only traces in the water and giving an effluent equivalent to commercial distilled water.

e. The apparatus used to contain the ion exchange material and its operation follows filter practice. (Figs. 19 & 20)

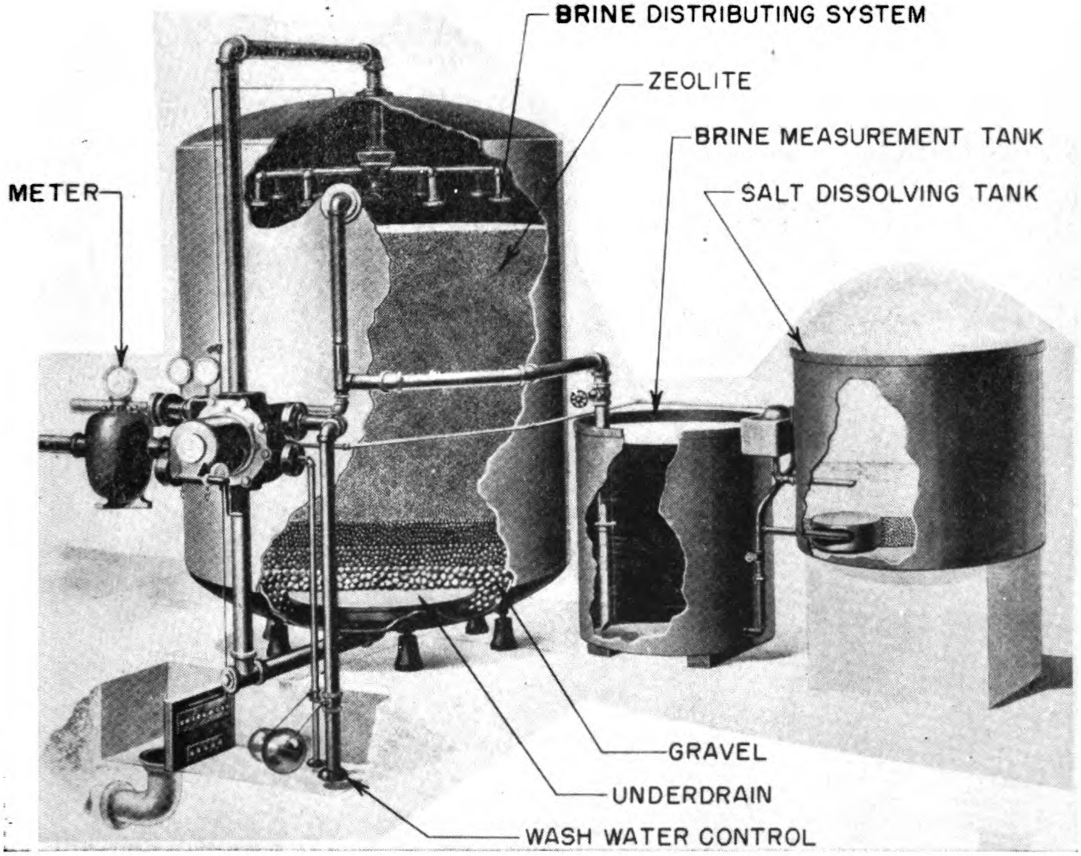


Figure 19. Sodium zeolite softener.

78. **Chemical Feeds.**— *a.* There are several types of apparatus that can be used for proportioning chemicals to water supplies. The simplest is the type used on the mobile and portable units which is generally known as a crystal pot feed. In this type, of feed, solid chemicals prepared in a way to make them dissolve relatively slowly are placed in the pot, and a small proportional amount of the main stream of water is by-

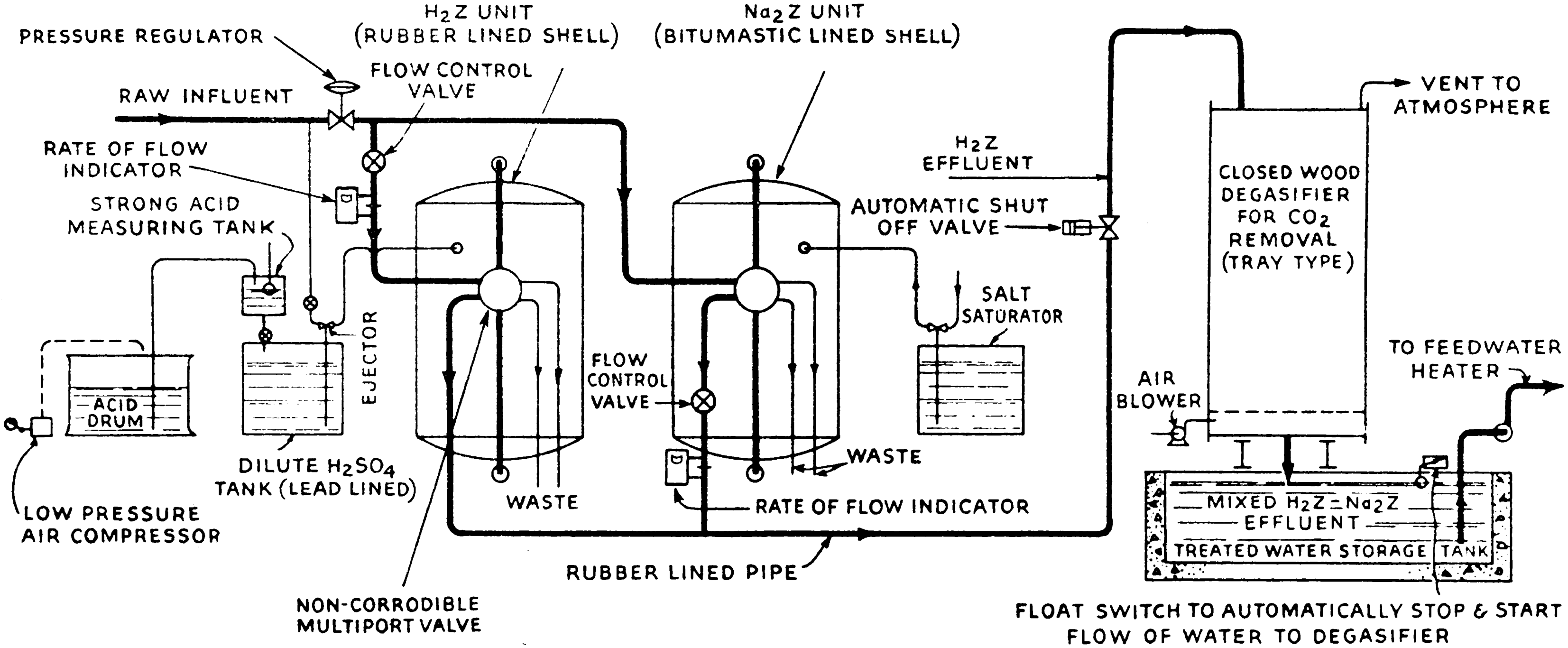


Figure 20. Flow diagram of hydrogen zeolite plant.

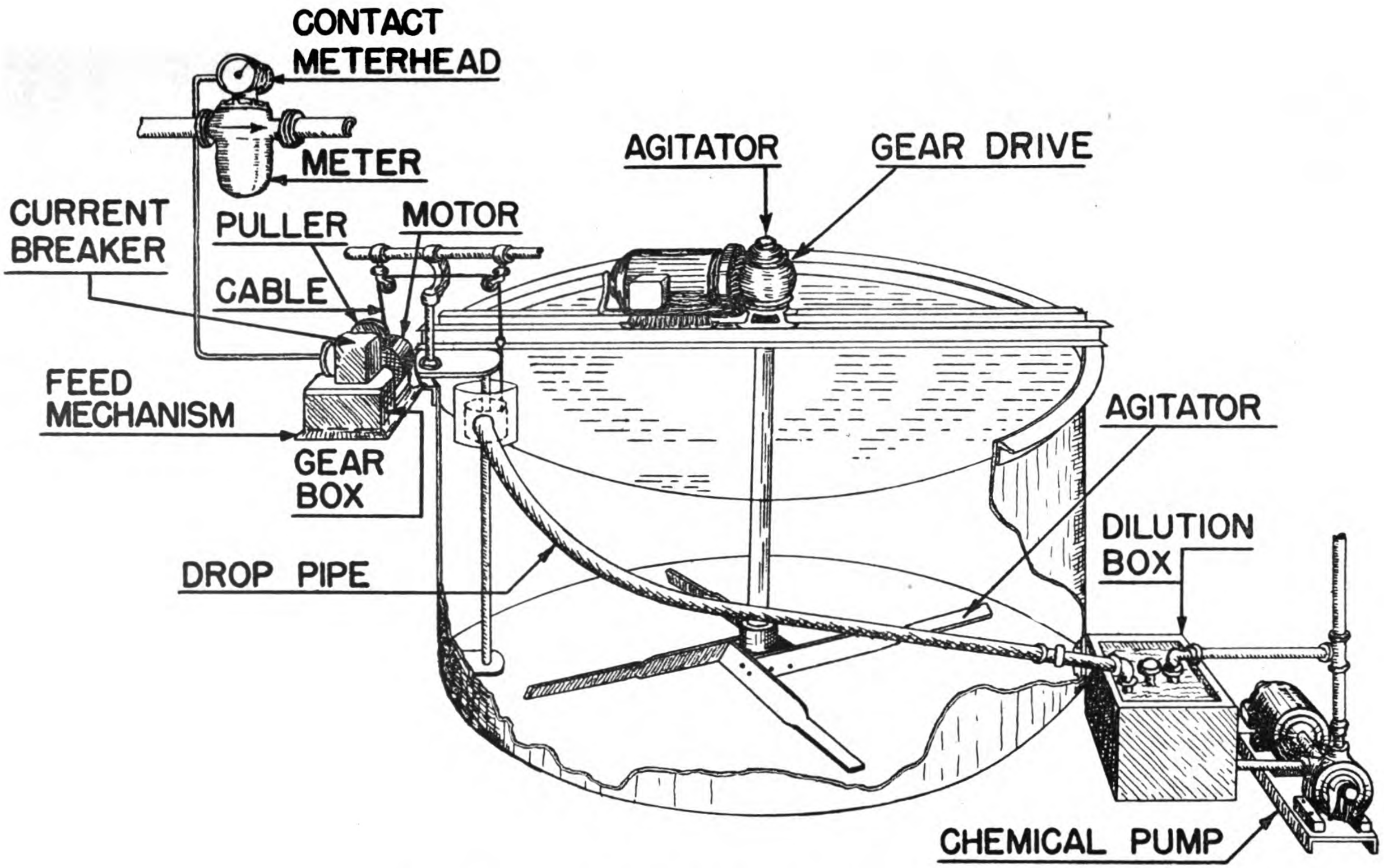


Figure 21. Gravity chemical solution feed.

passed by means of an orifice or a venturi, and a shunt through the pot and back into the pipe line. Care must be taken with this type of feed to check the dosage frequently for the concentration of the solution returning to the pipe line decreases as the quantity of chemical in the pot decreases. Other disadvantages are that chemicals suitable for use in the pot are relatively expensive and in addition are usually complex compounds containing a smaller percentage of the active ingredients than do other compounds which could be used for the purpose. For example, ammonium and potassium aluminum sulphate which are used in the pot feed contain relatively less aluminum than an equivalent amount of alum sulphate or filter alum, used in other types of feeds.

b. A similar feed, but a more accurate one, is the so-called pressure solution feed. In this feed a solution is prepared and placed in the pot. A portion of the main flow is diverted by means of an orifice and shunt through the high pressure leg to the pressure pot, and a part of this stream enters the top of the pot displacing the heavier chemical solution downwardly by a piston-like action. The remainder of the shunted stream passes through a secondary orifice and joins the flow of chemicals being pushed out from the bottom of the pot thereby diluting it. In this type of feed a more dilute solution reenters the main stream and on this account the distribution is more uniform.

c. There are also available gravity solution feeds of the constant rate and proportionating type. One type employs a head box with an orifice in the bottom. All the water entering the plant flows into the box and through the orifice. Since the head over the orifice depends on the rate of flow, a float placed in the head box raises and lowers a swivel joint pipe thereby increasing and decreasing the head of chemical solution over the outlet of the pipe.

d. Another type of feed (Fig. *21*) is actuated by a meter with a head which makes an electrical contact after each unit quantity of water passes through. These contacts actuate a motor or group of magnets which is geared to a pulley on which a cable is wound. By means of circuit-breaker the motor makes a definite number of revolutions for each contact, thus lowering the cable on the cable drum a definite amount for each contact. The cable lowers a drop pipe in the chemical solution tank, and therefore, each time a contact is made a certain definite quantity of chemical solution is discharged from the tank.

e. In larger plants where the quantity of chemicals used daily is large and the nuisance of making up a solution is undesirable, chemicals are fed by means of dry feeds of which there are several types. The dry chemical is fed into a hopper equipped with agitating devices to break up the lumps, and then is fed either at a constant rate or in proportion to the flow of water by means of rotating discs, knife edges, or other devices.

79. **Neutralization.—** If the water is acid, it may be neutralized with lime, soda ash, sodium silicate or some other alkali. If it is too high in caustic alkalinity, free carbon dioxide from flue gas or another source may be added to produce carbonic acid and convert the caustic alkalinity into bicarbonates and carbonates. In addition, acid waters or water containing free carbon dioxide can be filtered through broken limestone or marble chips to neutralize them by solution of the limestone.

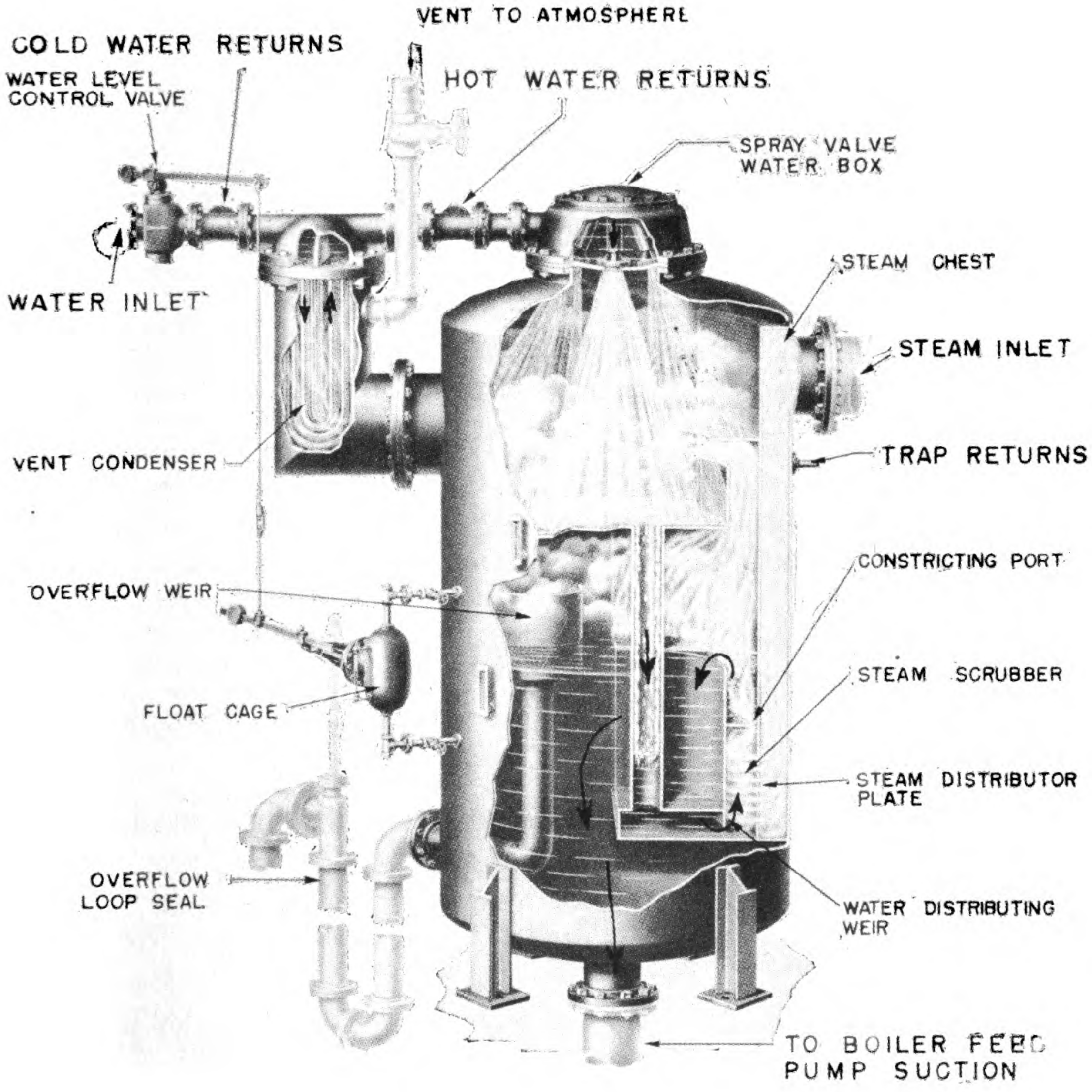


Figure 22. Deaerating heater.

80. **Deaeration.—** (Fig. 22) Gases are more readily soluble in cold water than in warm water. By raising the temperature of water to boiling, all traces of gases can be driven off. Breaking the water into fine droplets and heating is an accepted method of deaerating. Sometimes a partial vacuum is also used in connection with the heating.

81. **Distillation.**— *a.* Where it is impossible to obtain a potable water supply by other less difficult and less expensive means, distillation is used. Such instances would be where only brackish water or sea water is available.

b. Distillation is a process whereby water is evaporated into steam and this steam is condensed back into water. When the water changes into steam the solids dissolved in the water remain behind, so that when the steam is condensed, the water formed is practically free of solids.

c. Portable distilling equipment is being made available as an item of engineer supply to be operated by engineer distilling units.

d. The salt content of the sea water or other waters of high solid content may be reduced almost to zero by distillation. It is possible to introduce a certain amount of untreated water into distilled water in order to increase the volume, but since the solid matter in the sea water is about 37,000 parts per million and the maximum permissible amount of the sea water salts above which taste is evident is about 1000 parts per million it is obvious that dilution does not offer important possibilities of increasing the available supply.

82. **Addition of Salt to Water.**— When men are exposed to high temperature and strenuous exercise, sodium chloride, or common salt, should be supplied to the drinking water at the following rates, to make up for the salt lost by perspiration and to reduce fatigue:

10 pounds of sodium chloride (common salt) per 1000 gallons.
0.3 pound of sodium chloride per 36 gallons (contents of Lyster bag).
¼ teaspoonful of sodium chloride per quart (contents of canteen).
3 tablets of 5-grain sodium chloride per quart.
1 tablet 5-grain sodium chloride with alternate glasses of water.

This dosage with tablets produces a concentration of 1000 to 1200 parts per million of sodium chloride (or 600 to 750 parts per million of the chloride ion) in the water.

83. **Boiler Compound.**— Boiler compounds are mixtures of chemicals such as soda ash, sodium phosphate, caustic soda, sodium silicate, ferrous sulphate, sodium sulphite, tannin or other organic substances. They are used for the prevention of scale and the inhibition of corrosion in small boilers and at times, in hot water heaters although when they are used in hot water heaters, care must be taken to blow off the sludge frequently and to make sure the hot water is taken off from the top part of the heater and not from the bottom. Boiler compounds are less satisfactory in hot water heaters than in boilers, and it is preferable to remove the hardness from the water rather than to use boiler compound.

Chapter 6

STORAGE, DISTRIBUTION, AND MEASUREMENT OF WATER

84. **Storage Location.**— *a.* The location of the storage facilities, whether at or slightly below ground level, or elevated, will depend on the amount of cover available, the terrain, and the relative locations of the storage tank and the point of ultimate use. It will also be determined by the means of distribution, that is, whether by pipe line, railroad, or motor vehicle, and from a consideration of the ground about the proposed site and its bogging possibilities.

b. If the water is distributed to the point of use by means of a pipe line drawing from a tank, and the location of this storage tank is at a greater elevation than the distribution system, the tank need not be elevated above the ground unless the added pressure gained from raising the tank is required for fire protection or to overcome excessive friction in the distribution system. If it is not necessary to elevate the tank above ground, it should be buried and covered for concealment. If it cannot be buried, it should certainly be covered as a water surface is easily observed from above.

c. If the storage tank is to be used for filling tank trucks or railroad tank cars, and if it can be elevated and concealed, the resulting gravity flow is preferable to pumping because the pump engine is noisy. If the water is to be delivered from the storage tank to 5-gallon unit water containers it will be desirable to elevate the tank if possible for gravity flow in order to avoid splashing and overflow in filling the water containers.

d. When time permits, and the work involved and practical considerations do not interfere, gravity flow is preferable to the use of a pump.

e. Where the tank is placed below ground it should be constructed so that it is water-tight and so that it will not be subject to contamination from ground and surface water. The lip of the tank should be at least one foot above the ground and the tank must be covered to prevent the entrance of animals.

f. The advantage of a storage tank over direct pumping is that it permits operating the purification equipment at a lower average rate by "ironing" out the fluctuating demand which causes overloading of the equipment while it is producing.

g. Aside from the desire to obtain a concealed position, the location of the storage tank in a grove of trees is especially desirable, because of the elimination of the hazard of pollution from dust.

85. **Types of Storage.**— *a.* The simplest type of storage tank is a hole or hollow in relatively imperious ground. This has many disad-

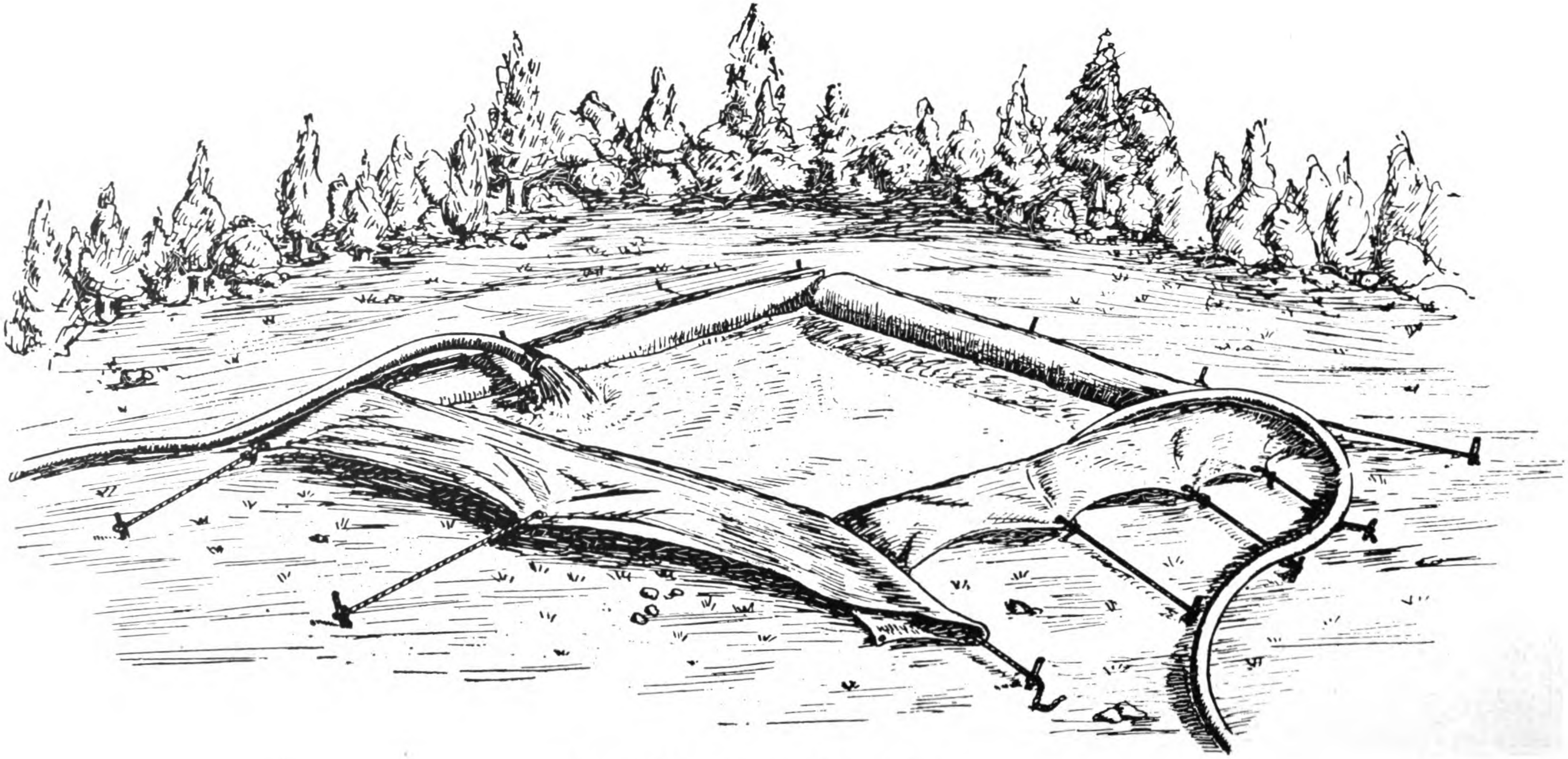
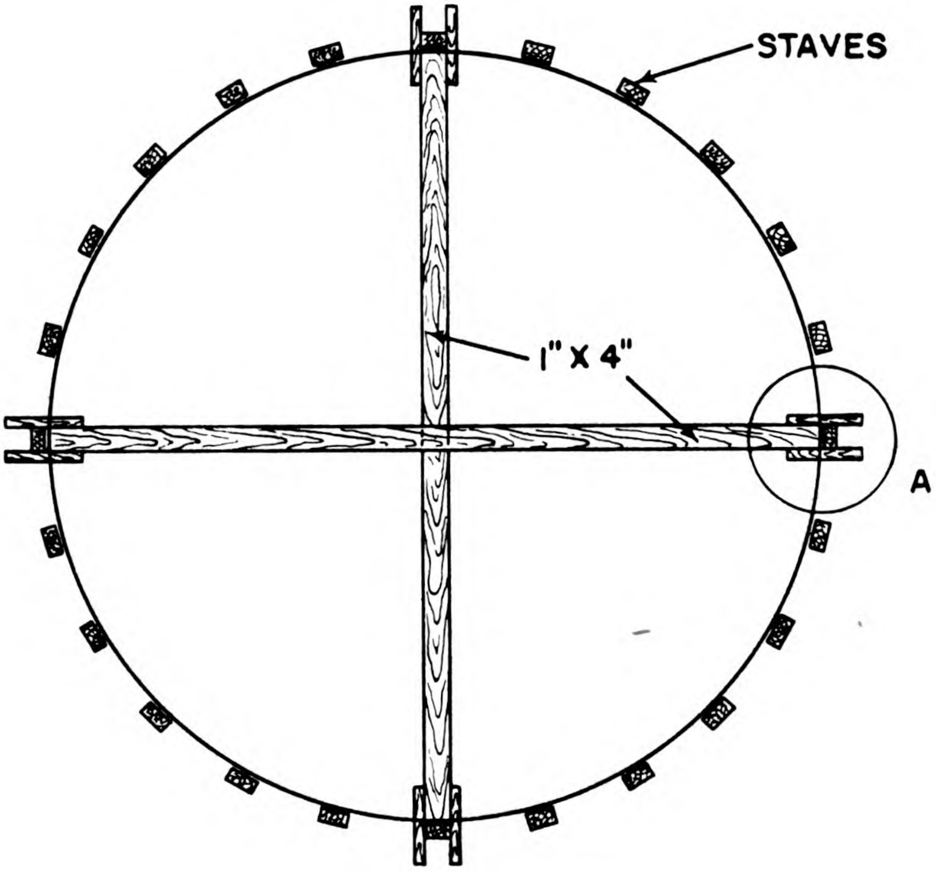


Figure 23. Canvas storage basin.

vantages and should never be used for treated water because surface run-off will contaminate the water. The next best is a similar hole lined with a tarpaulin but this is not much better. (Fig. 23)



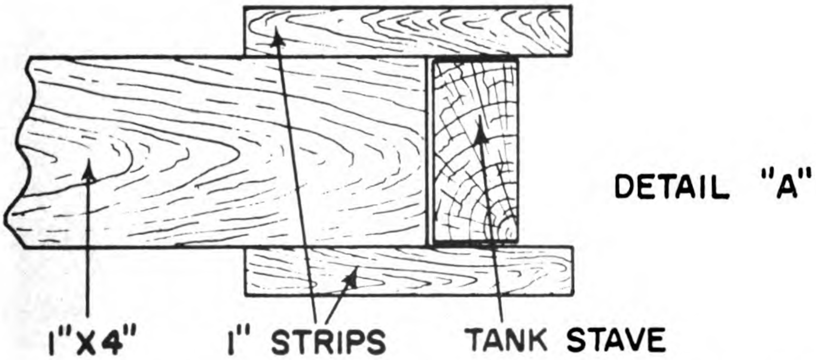


Figure 24. Suggested method of holding 3000 gallon canvas erect, eliminating use of guy rope and stakes. Will also prevent tank cover from sagging.

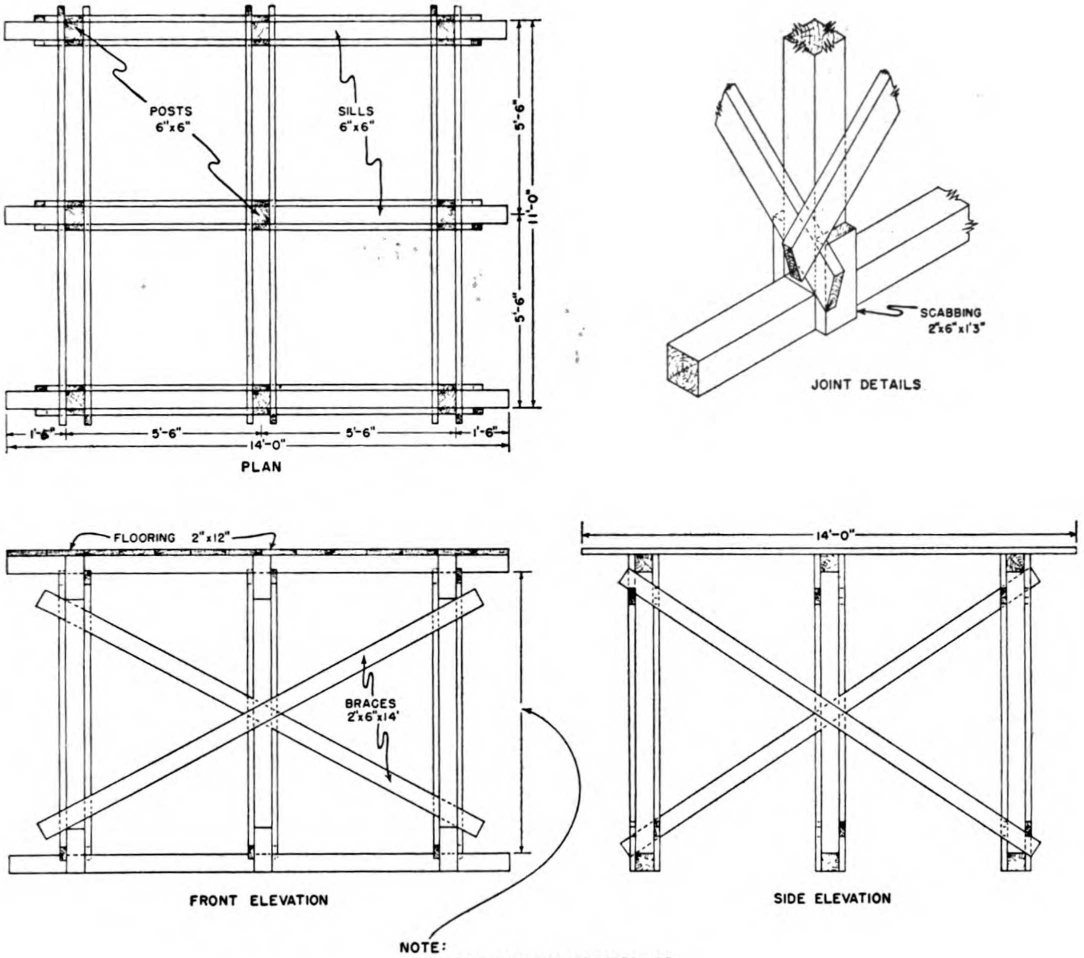
b. The 1500 and 3000 gallon canvas issue storage tanks are the most substantial temporary expedient. These tanks are equipped with three openings at the bottom and a tarpaulin cover for the top. They are erected on the ground, and the staves are guyed with improvised, wood or metal stakes and ropes during the filling. They can likewise be braced with 1x4's as shown in Figure 24.

c. Wooden tanks can also be used, but they must be maintained full of water at all times to assure the proper swelling of the wood. The tie rods should be taken up carefully and checked frequently for tightness.

Figure 25. Timber trestle platform (with canvas storage tank)

New wooden tanks, may give to the water color which will consume residual chlorine. It is not practical to knock down a wooden tank and transport it, even though the members are match-marked, for it is then difficult to get a tight tank when reassembled. Wooden tanks must be protected from rotting and from the action of bugs. In tropical countries wood, due to rapid deterioration, is not considered an economical means of storing water.

d. Steel tanks are quite satisfactory, but they must be painted with a non-poisonous paint inside and out to prevent corrosion. Bituminous materials are perhaps the best means of protecting these tanks.



NOTE:
MINIMUM ELEVATION OF BOTTOM OF
TANK ABOVE GROUND MUST EXCEED 8 FT.

BILL OF MATERIAL

NO PIECES	SIZE	LENGTH	ITEM
6	6" x 6"	14'— 0"	CAPS AND SILLS
9	6" x 6"	8'— 0"	POSTS
12	2" x 6"	14'— 0"	BRACES
14	2" x 12"	14'— 0"	FLOORING
36	2" x 6"	1'— 3"	SCABS
20LBS	30D	0'— 5"	NAILS

Figure 26. Timber trestle platform for the 3,000 gallon canvas storage tank.

e. When tanks are to be elevated above the ground level wood, angle iron or the proposed tubular steel towers can be constructed. (Fig. 25-27.)

f. In comparing the wooden tower with the tubular steel tower which is similar to the scaffolding employed by some contractors, it is seen that the tubular tower can be erected and knocked down more quickly and can be more easily transported. Pending issue of the tubular tower, or when wood is more readily available a wooden tower holds the advantage. Towers should not be erected, but the natural elevation of the ground should be employed whenever possible, because this eliminates construction, facilitates concealment and speeds up the preparation of the water point.

Figure 27. Steel trestle platform.

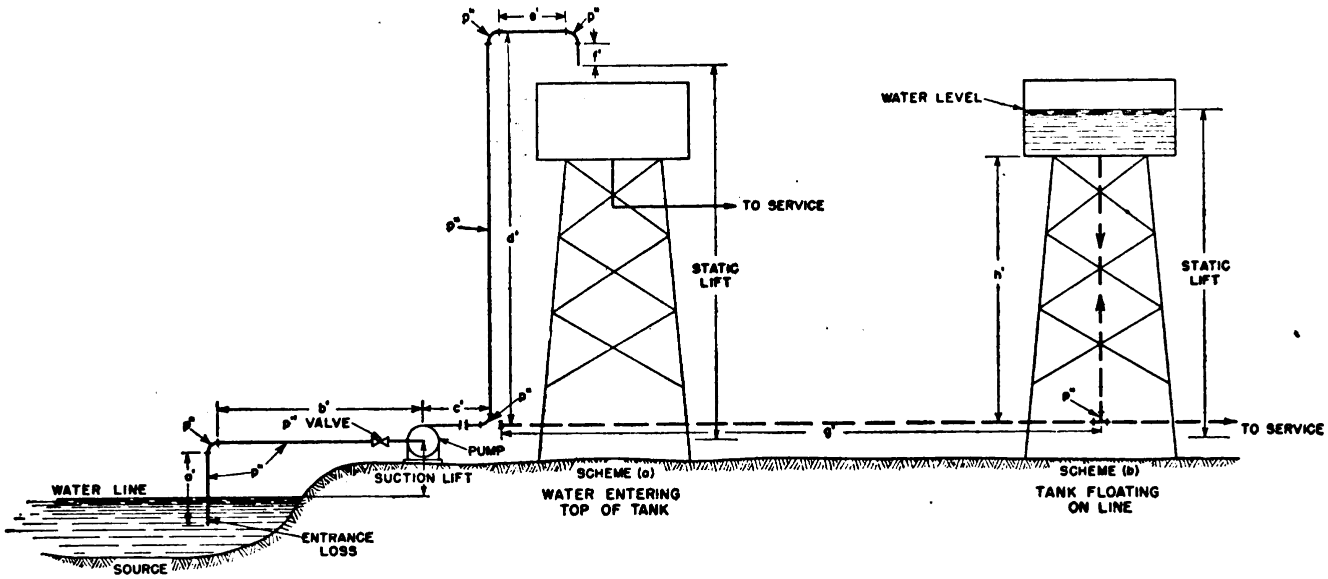
g. Stand pipes are storage tanks of relatively small diameter and considerable height, and rest on the ground.

h. Where existing facilities are taken over it is necessary for the military engineer to realize the care and maintenance that they must be given. This care consists chiefly in keeping the surfaces in contact with air and water well coated to prevent corrosion and adding inhibiting agents to the water.

i. Storage tanks in conventional plants are equipped with float valves when gravity flow is used, and float switches when pumps are used, to prevent overflow when filling or altitude valves, which close at a certain pressure head indicating that the storage tank or reservoir is filled and which open at a somewhat lower head, indicating that the tank is not full and it is advisable to allow water to flow in. These are generally used when there are several storage tanks at several different elevations. Storage tanks should be equipped with an overflow large enough to handle the maximum amount of water that could possibly enter the tank and direct this overflow to a point well away from the tank so that there is no danger of undermining the foundation.

j. Tanks should be covered not only to prevent the entrance of birds and animals, but also to prevent the entrance of sunlight which tends to heat the water and encourage the growth of algae.

k. In smaller installations it is common to employ a pneumatic tank. A full pneumatic tank contains approximately two-thirds water and one-third air. The air is introduced either by sniffling through the suction of the pump or by a separate compressor. When the tank is two-thirds full of water, the pressure in the system is at its maximum, and the pump delivering water to the tank is cut off. When the water level drops the air will expand, decreasing the pressure which will actuate the pressure switch and start the pump.



TOTAL HEAD = ENTRANCE LOSS + SUCTION LIFT + FRICTION LOSS + STATIC LIFT

FRICTION LOSS - SCHEME (a) = $\frac{(a+b+c+d+e+f)}{100}$ X FRICTION LOSS PER 100 FT FOR p" PIPE (FROM TABLES)

PLUS

4-p" ELBOWS X $\frac{\text{EQUIVALENT LENGTH OF PIPE PER p" ELBOW}}{100}$ X FRICTION LOSS PER 100 FT FOR p" PIPE (FROM TABLES)

PLUS

1-p" GATE VALVE X $\frac{\text{EQUIVALENT LENGTH OF PIPE PER p" GATE VALVE}}{100}$ X FRICTION LOSS PER 100 FT FOR p" PIPE (FROM TABLES)

FRICTION LOSS-SCHEME (b) $\frac{(a+b+c+g+h)}{100}$ X FRICTION LOSS PER 100 FT FOR p" PIPE (FROM TABLES)

PLUS

2-p" ELBOWS X $\frac{\text{EQUIVALENT LENGTH OF PIPE PER p" ELBOW}}{100}$ X FRICTION LOSS PER 100 FT FOR p" PIPE (FROM TABLES)

PLUS

1-p" TEE X $\frac{\text{EQUIVALENT LENGTH OF PIPE PER p" TEE}}{100}$ X FRICTION LOSS PER 100 FT OF p" PIPE (FROM TABLES)

PLUS

1-p" GATE VALVE X $\frac{\text{EQUIVALENT LENGTH OF PIPE PER p" GATE VALVE}}{100}$ X FRICTION LOSS PER 100 FT OF p" PIPE (FROM TABLES)

Figure 28. Diagram for calculating the head required in a pressure system.

86. **Transportation of Water.**— Water may be transported by means of a pump and piping system or by means of tank trucks or railroad tank cars.

87. **Pumps.**— *a.* Pumps are machines designed to pick up water (or other liquids) and deliver it through a system of piping at a given rate and with sufficient pressure at the pump discharge. They must develop sufficient pressure to overcome pipe line losses due to friction and to raise the water from its original elevation to the elevation at the point of delivery.

b. The total head (pressure) against which a pump must operate is made up of the following (see Fig. 28):

(1) The suction head — the distance from the level of the water being pumped to the center line of the pump (this may add to or subtract from suction head depending on whether center line of pump is above or below source water level) plus the friction head lost in the strainer and in the pipe and fittings of the suction line plus the entrance head into the suction line.

AIR CHAMBER DIMENSIONS

DIS-CHARGE LINE	INSIDE DIA OF AIR CHAMBER	TOTAL HEIGHT	a	b
2"	8"	3'-0"	4"	9"
2½"	8"	3'-6"	4"	12"
3"	10"	4'-0"	5"	15"
4"	10"	5'-0"	6"	21"
5"	12"	6'-0"	6"	27"
6"	16"	7'-0"	6"	33"

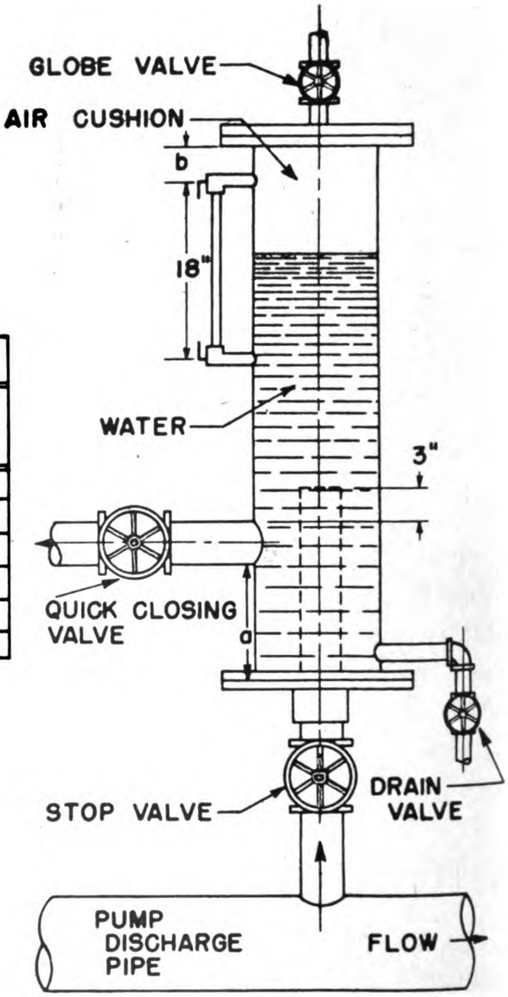
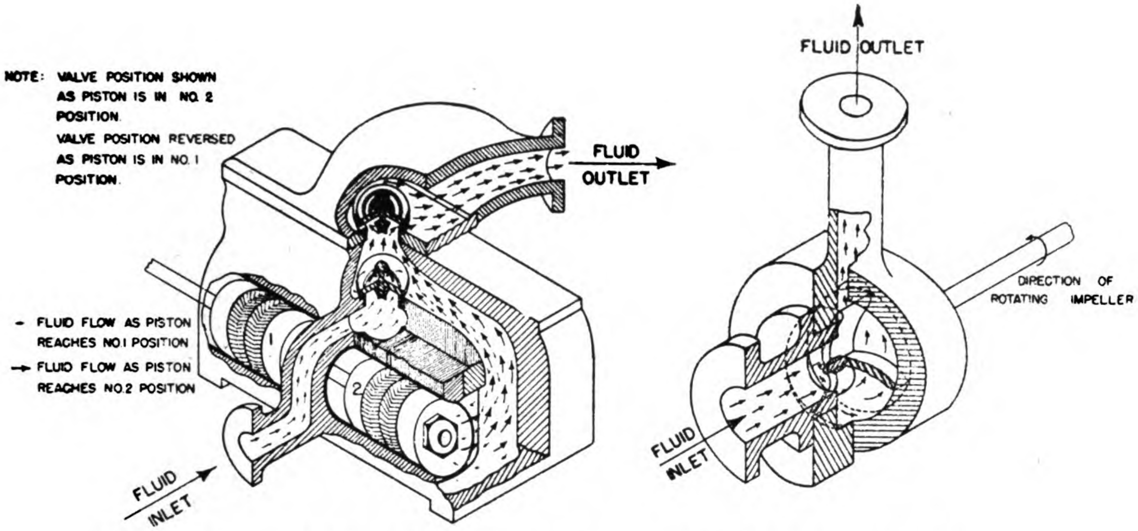
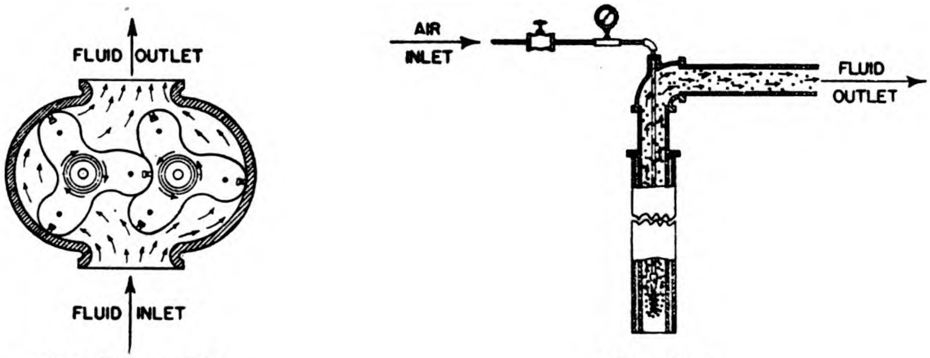


Figure 29. Air chamber.



SINGLE RECIPROCATING STEAM PUMP CENTRIFUGAL PUMP



ROTARY PUMP AIR LIFT

Figure 30.

(2) The static discharge head — the height from the center line of the pump to the maximum elevation to which the water is pumped. This also may add to or subtract from total head depending on the relative elevations of source and point of delivery.

(3) The friction head in the pipe, valves, and fittings from the discharge of the pump to the point of delivery.

(4) The pressure required at the point of discharge (for the operation of sprays, nozzles, or for other reasons).

c. In determining the head against which a pump will be required to work a diagram should be drawn showing elevation, pipe sizes, number and type of fittings, and the condition of discharge. (Fig. 28) *d.* Pumps may be classified as follows:

- Displacement
  - Piston or Plunger
    - Direct Acting Steam
      - Simplex
      - Duplex
    - Crank and Flywheel
    - Power
      - Simplex
      - Duplex
      - Triplex
  - Rotary
    - Cam
    - Screw
    - Gear
    - Vane
- Centrifugal
  - Single Stage
  - Multi Stage
- Deep well
  - Turbine

88. **Plunger Pumps.— (Fig. 30)** *a.* A plunger pump is a displacement type pump in which the liquid is drawn into a chamber or cylinder by the movement of a piston or plunger in one direction, and discharged by the movement of the piston in the opposite direction, the flow of the water from the source into the chamber and from the chamber into the discharge pipe being controlled by valves similar to the intake and exhaust valves in gasoline engines.

b. A direct acting steam pump is a reciprocating unit in which the steam piston is directly connected to the pump rod of the pump piston or plunger and the length of the stroke is regulated by adjustment of the steam valve. When it has one water piston it is called simplex and when it has two water pistons it is called duplex. A duplex pump discharges water on both forward and back strokes and hence has less of the pulsating flow which characterizes a simplex reciprocating pump. A triplex pump has still less pulsation. Direct acting steam pumps are durable, flexible and will operate against high heads.

c. Crank and flywheel pumps are reciprocating units with a crankshaft on which a flywheel is mounted to store energy during the first part of the stroke imparting the stored energy to the water piston during the latter part of the stroke. The length of the stroke is fixed by the throw of the main crank and is twice the distance from the center of the crankshaft to the center of the crankpin.

d. Power pumps are reciprocating pumps powered by an outside source such as an electric motor.

e. A single cylinder reciprocating pump should be equipped with an air chamber (Fig. 29) to protect the pipe line and pressure vessels in the line. The air in the chamber acts as a cushion which tends to smooth out the pulsation in flow.

89. **Rotary Pumps.**— A rotary pump is a displacement type pump in which the displacement of the liquid is brought about by the rotation of a cam, a screw, a gear, or a vane. (Fig. 30)

90. **Centrifugal Pumps.**— (Fig. 30) *a.* A centrifugal pump is one in which the water is drawn into the pump from the suction pipe at the center or eye of an impeller which, when rotated in a casing throws the water by centrifugal force outwardly from the center to the discharge. A deep well turbine pump is a centrifugal pump in which one or more impellers are located under the water surface of the well. The amount of water pumped by a centrifugal pump is proportional to the speed of the impeller; the pressure developed varies as the square of the velocity of the impeller.

b. If the head against which the water must be pumped is increased, the speed remaining constant, the quantity discharged will decrease and vice versa. If the head is increased beyond the head capacity of the pump (shut-off head) no water will flow.

c. If two centrifugal pumps are connected in series, that is, with the discharge of the first connected to the suction of the second, the flow capacity will be that of the first pump but the head will be the sum of the discharge heads of both pumps. The same effect is secured by placing two or more impellers in one casing (multi stage pumps). If, on the other hand, the two pumps are connected in parallel, that is, if both suctions are connected to the source and both discharges connected to the discharge line, the head will be the same as that of the individual pumps but the capacity will be the sum of the capacities of the two pumps.

d. Trouble shooting — centrifugal pumps:

(1) If no water is delivered check for the following causes:
  (a) Pump not primed
  (b) Speed too low
  (c) Discharge head too high
  (d) Suction lift too high
  (e) Impeller completely plugged up
  (f) Wrong direction of rotation

(2) If insufficient water is delivered check for the following causes:
  (a) Air leaks in suction or in stuffing box
  (b) Speed too low
  (c) Discharge head higher than anticipated
  (d) Suction lift too high
  (e) Impeller partially plugged up
  (f) Not enough positive suction head (for hot water)
  (g) Mechanical wear — rings, impeller, gaskets
  (h) Foot valve too small

  - *(i)* Foot valve or suction opening not submerged sufficiently

(3) If the pump does not deliver sufficient pressure:

  - *(a)* Speed is too low
  - *(b)* There is air in the water
  - *(c)* Mechanical wear — ring worn, impeller damaged, casing packing defective
  - *(d)* Impeller diameter too small
  - *(e)* Gland loose, drawing in air

(4) If pump works for awhile then loses suction look for

  - *(a)* Leaky suction line
  - *(b)* Plugged water seal
  - *(c)* Excessive suction lift
  - *(d)* Air or other gases in the liquid
  - *(e)* Loose glands drawing in air

(5) If pump takes too much power look for:

  - *(a)* Excessive speed
  - *(b)* Head lower than the rated head
  - *(c)* Mechanical trouble — Bent shaft, binding of rotating elements, tight stuffing boxes; wearing rings worn, improper casing gaskets

91. **Priming Centrifugal Pumps.**— *a.* The Centrifugal pumps issued are of the self-priming type; that is, they contain a priming chamber which when filled makes re-priming unnecessary until the priming chamber has been drained. If, however, the pump is not of the self-priming type, it is necessary to provide a foot valve on the suction line which closes when the pump is stopped, thus keeping the suction line filled with water.

b. (Refer to Fig. 31) Priming chamber F is filled with water. Trapped suction line E prevents water from draining out of pump. Pump is started and circulation of water starts downward through a flow control valve C into suction of pump and to impeller A, then outward through discharge B.

Flow of water out of B raises disc D (attached by arm G to flow control valve C), closing this valve. As supply is shut off at point C, suction energy immediately is transferred back through suction line E.

As air is drawn in through suction into impeller, the impeller becomes air bound and stops pumping water out of B. This permits discs D to drop and open flow control valve C, which supplies another charge of water downward into impeller A, displacing air and repriming pump. Air and water are thrown out through passage B into separation chamber F, the air passing off.

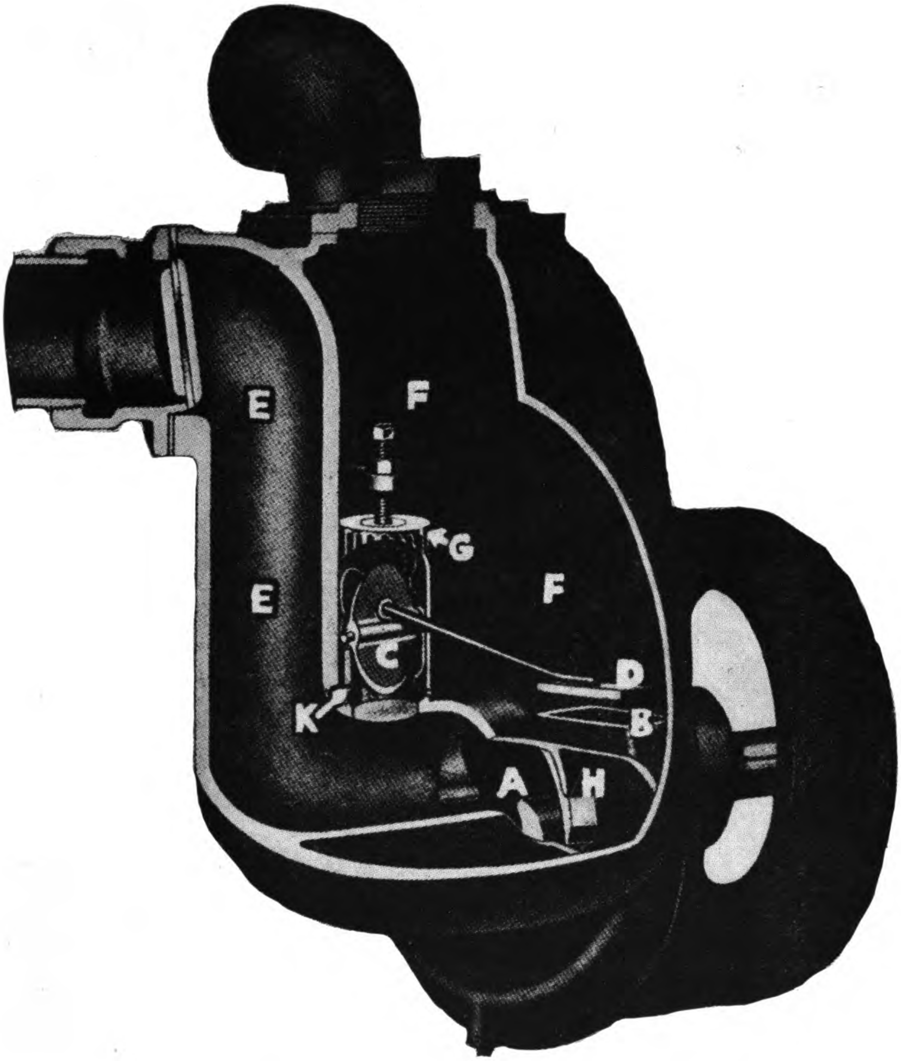


Figure 31. Priming chamber centrifugal pump.

This operation is repeated, each cycle expelling a portion of air from suction line, until water is drawn up through suction line and into pump.

c. Do not attempt to run a centrifugal pump when it is empty. Centrifugal pumps must be primed full of water and the air must be removed from the casing before starting. Any of the following methods of priming pumps which are not self priming may be used:

(1) The pump may be set below the water level, in which case the water will flow through the suction pipe into the pump by gravity, thus filling the case and forcing the air out through the cocks provided.

(2) A small by-pass pipe around the check valve in the discharge pipe may be used to fill the pump with water from the discharge pipe when the discharge pipe is kept full of water.

(3) A pitcher spout or cistern pump attached to the opening at the top of the casing can be used to exhaust the air from the casing so water will rise through the suction pipe. This is suitable for small pumps, up to 4 inches only, and short suction lines.

(4) Steam or compressed air ejectors can be used to exhaust the air from the pump casing.

(5) The pump can be filled from an independent source of supply such as a tank placed above the pump, or from city water supply pipes. In the later case be careful not to burst the pump casing with the city water pressure.

(6) A hand primer can be used. This consists of a suction hand pump so constructed that it can be connected permanently in the suction line between the pump and suction pipe.

d. When priming by methods (2) or (5) a foot valve should be placed on the end of the suction pipe. In case the pump is filled with water from an independent source of supply, a small valve should be placed in the priming line near the pump. If the pump is primed by filling it with water, as by any of the methods except (3) and (4), the air cocks must be opened and water should not be allowed to enter faster than the air is permitted to escape; otherwise, air pockets will form in the suction line.

e. After the pump has been primed by filling the casing with water, it can be started up, but no matter what method of priming has been used, the gate valve in the discharge line must be closed when starting. In order to allow any remaining air to escape, open the air cock on top of the casing after the pump has been started, and close the air cock as soon as a steady stream flows from it. When the pump is up to full speed, open the gate valve. Do not allow the pump to operate with the gate valve closed any longer than a few minutes at a time, since the churning water will heat up in a very short time and possibly cause the rotating parts to expand and bind.

92. **Pump Characteristics.**— *a.* The characteristics of a given centrifugal pump are expressed in a set of curves showing the change in efficiency with change in capacity, and the change of head with change of capacity.

b. For reciprocating pumps the quantity of water delivered depends upon the speed, cylinder size, and length of stroke and is varied in a given pump by adjusting the stroke. The maximum head against which it can pump depends upon the power of the driving engine or motor.

93. **Comparison of Pump Types.**— Table 1 shows the operating characteristics of various types of pumps.

TABLE I.—CHARACTERISTICS OF PUMPS

	PLUNGER (RECIPROCATING)			
	DIRECT ACTING STEAM	POWER	ROTARY	CENTRIFUGAL
FLOW	Pulsating	Pulsating	Even	Even
EFFECT OF INCREASING HEAD				
CAPACITY	Decrease	None	None	Decrease
POWER	Increase	Increase	Increase	Decrease
EFFECT OF DECREASING HEAD				
CAPACITY	Slight Increase	None	None	Increase
POWER	Decrease	Decrease	Decrease	Increase
EFFECT OF SHUTTING DISCH. VALVE		Pressure increases with violently destructive effect if no relief valve is used.		
INCREASE PRESS.	Increase			15 to 30%
POWER	Increase	Power increase to destruction.		Decrease 50 to 60%

94. **Air Lift.— (Fig. 30)** An air lift for raising water is an apparatus in which compressed air is conducted through an air pipe down into a well and discharged at the bottom. At this point it mixes with the water and causes the water to rise in the discharge pipe due to greater buoyancy.

95. **Strainers.—** *a.* With water from a stream which is likely to contain leaves, twigs, or other large solid particles which would clog the pump it is necessary to place a strainer on the end of the suction line.

b. Strainers are available commercially which can be screwed into practically all sizes of pipe or hose. However, if a standard commercial screen is not available, it is possible to construct a crib which consists of a wood or steel frame around which is placed wire netting of a mesh which will preclude the entrance of large particles and yet with sufficient area not to become clogged quickly by a large amount of small particles. Cribs can also be constructed by placing stones or gravel around the entrance of the suction pipe.

96. **Effect of Temperature and Elevation on Suction Lift.—** As the temperature of the liquid being pumped increases, the maximum suction lift possible decreases due to the fact that there is a greater tendency for vapor to form which will cause flashing and vapor lock. Table 29 in the

Appendix V shows the maximum suction lift for water at various temperatures and ground elevations. It will be noticed that when the temperature rises sufficiently, it becomes necessary to have a positive head on the suction of the pump; that is, the water level of the source must be above the center line of the pump.

97. **Pipe Friction.**— *a.* The friction in a pipe line depends on the type of pipe and its condition, or, in other words, the comparative smoothness of the surface of the pipe against which the water or other liquid impinges.

b. Table 16, Appendix V is based on ten year old steel pipe or eighteen year old cast iron pipe. Factors by which the friction given in the table should be multiplied to obtain the friction for other types and conditions of pipe are given. This table gives the friction loss in feet of head per thousand lineal feet of pipe for various quantities of water, stated in gallons per minute and gallons per 24 hours. The table also gives the velocity in feet per second. Pipe should be chosen so that the velocity does not exceed 7 feet per second, in which case the velocity head can be neglected. If this velocity is exceeded the velocity head must be considered.

c. (1) In addition to the friction in the straight pipe, the friction in the valves and fittings of the system must be included and in Table 17, Appendix V, is given the length of straight pipe producing a friction loss equivalent to that produced by given fittings. For example, a standard 2-inch elbow produces a friction loss equivalent to the loss in 5.5 feet of straight pipe and therefore if a pipe line is 94.5 feet long with one such elbow it should be considered as 94.5 + 5.5 feet or 100 feet long for the purpose of calculating the friction.

(2) Similarly, if the pipe size in a system is increased or decreased, a loss of pressure will occur, the amount of which is given in Table 18, Appendix V in terms or equivalent length of straight pipe.

(3) Finally, the loss when the water enters the suction line, when it is appreciable, should be determined and considered in the total loss. Entrance losses are also given in Table 18, Appendix V.

98. **Power Required.**— The power required to operate a pump is calculated by the following formula:

$$HP = \frac{D \times H}{3960 \times E}$$

where HP = Horse Power
D = Discharge (gallons per minute)
H = Total head (feet)
E = Pump efficiency (%)

99. Estimating Power, Capacity, Lift and Efficiency of Pumps.— *a.* Fig. 32 may be used when examining existing installations to find:

(1) The horse-power required, or

(2) The gallons of water a given pump will lift per minute against a given total head, or

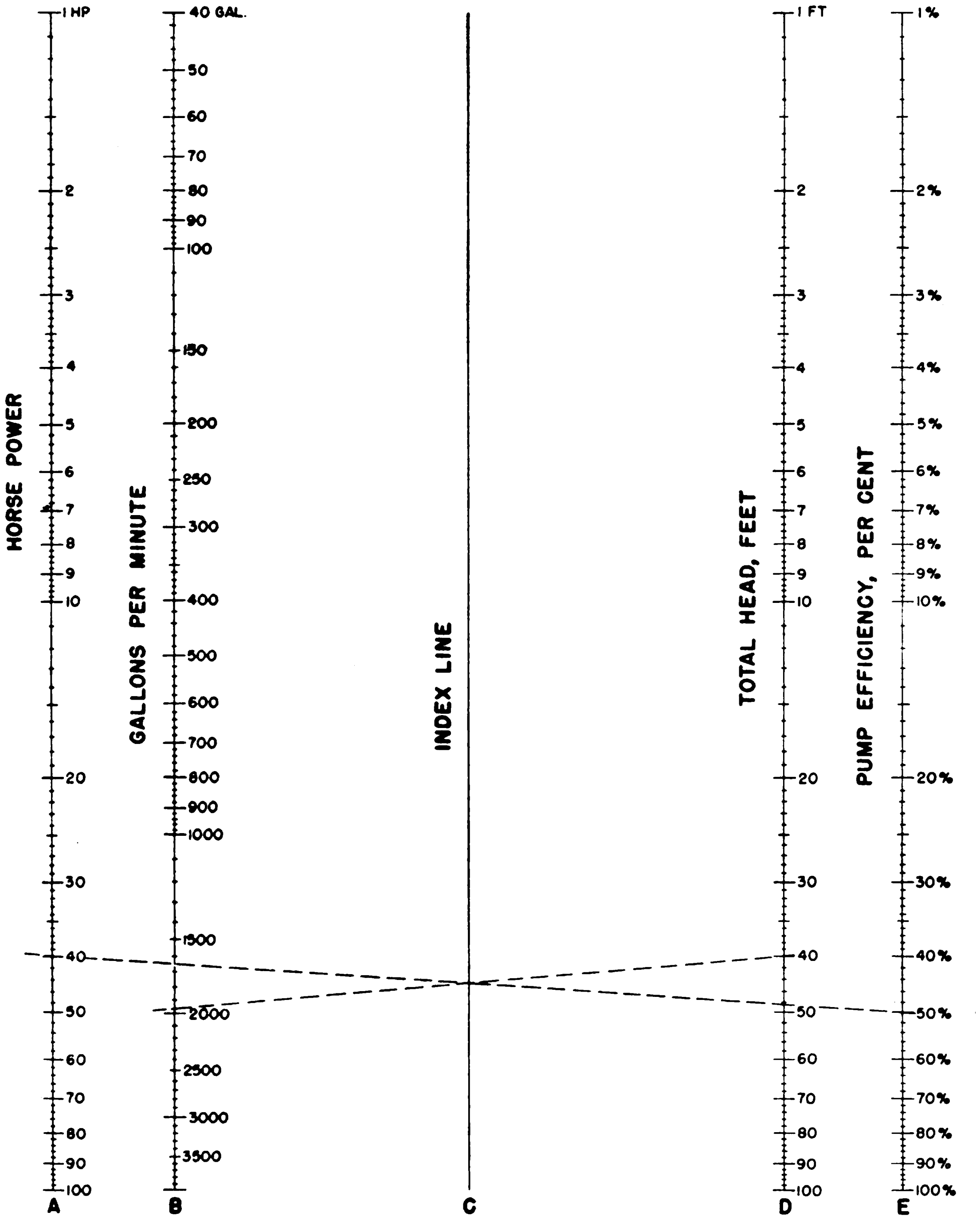


Figure 32. To estimate characteristics of a pump.

NOTE Always connect A and E, and B and D or vice versa

(3) The head against which it will deliver at a given rate, or

(4) The efficiency of a given unit.

b. This chart covers any motive power:— electricity, steam. diesel, gasoline, or water; and any type of pump:— duplex, triplex, centrifugal, or rotary.

c. *Sample Problem.* How many gallons per minute will be pumped by a pump equipped with a 40 H.P. motor against a total head of 40-ft., the efficiency of the pump being 50 per cent? Using a straight edge, folded paper, card, or ruler join 40 H.P. on scale A with 50 per cent on scale F, and locate the intersection on the index line. Pivot the straight edge about that intersection point to touch the 40 ft. head on scale D. The answer is found to be 1,950 gal. per minute on scale B. Always connect A with F and B with D. The two outside scales must be used together; the two inside scales, together. Knowing any three of the values A, B, D, or F, the fourth is found.

d. For average efficiencies use:

(1) For duplex, triplex, and reciprocating pumps in general about 80 per cent

(2) For good modern centrifugal pumps about 60 per cent

(3) For air lifts 40 per cent or less.

Higher efficiencies than these can be attained with all of the above types of pumps. For pumps that are old, worn, or otherwise in poor condition use smaller values. If the exact efficiency is known, use it.

100. **Kinds of Pipe.**— *a.* Water may be conducted from one place to another by means of canvas or rubber hose, or by one of the many types of pipe available, the more common of which are as follows:

(1) *Steel.*— Steel pipe is more readily available than pipe of other materials, and is less expensive. In oxygen laden water and in water of low pH, (Appendix I), it tends to corrode (rust) more readily than some of the other types of pipe.

(2) *Wrought iron.*— Wrought iron pipe is more expensive than steel and less commonly available, but is more resistant to oxygen corrosion, and to waters of low pH.

(3) *Galvanized.*—Either steel or wrought iron pipe can be purchased with a coating of zinc, in which case it is called galvanized steel or galvanized wrought iron pipe. The effect of the galvanizing is to slow down the initial rate of oxygen corrosion, but in some instances the galvanizing itself dissolves in a short time especially in the presence of "stray electric currents" leaving the bare steel or wrought iron exposed to the oxygen laden water.

(4) *Brass.—(a)* There are two types of brass pipe commonly called yellow brass (60% copper) and red brass (85-95% copper). The former is also known as beta brass and the latter, as alpha brass. Brass is an alloy of copper and zinc. It is much more expensive than many of the other types of pipe but it presents a smooth surface and hence has a low friction loss.

(b) Brass is also more resistant to oxygen corrosion than steel or iron, but in waters of relatively high alkalinity yellow brass tends to be dezincified, that is the zinc in the brass is dissolved, leaving the copper behind. In waters containing large amounts of carbon dioxide the copper in both types tends to dissolve.

(5) *Copper.*—Copper pipe has all the general characteristics of brass pipe but to a greater degree, except that it can not dezincify.

(6) *Cast Iron.*—Cast iron pipe is highly resistant to soil corrosion and therefore it is widely used for underground service in municipalities. It is, in general, more resistant to oxygen corrosion than is either steel or wrought iron. It is normally available only in larger sizes, and is generally furnished with either flanged or bell and spigot ends.

(7) *Asbestos Cement.*— This pipe of cemented asbestos is very smooth, giving low friction loss. It is resistant to corrosion but relatively soft water tends to leach out calcium carbonate from the pipe. No fittings are normally available for use with this type pipe and cast iron bell and spigot fittings are normally used. The successive lengths of pipe are coupled together by means of special saddle type couplings.

101. **Effect of Temperature on Pipe.—** In considering the desirability of the various pipe materials from the view of liability to corrosion, it should be remembered that the higher the temperature the faster the action takes place. Thus, pipes for use at high temperatures should have good corrosive resistance.

102. **Standard Pipe Sizes.—** *a.* ¾ inch, 2-inch, 4-inch, and 6-inch pipes will supply most military needs and are standard. (TM 5-280). The 4-inch size can easily supply 100,000 gallons a day, and by repumping the water can be carried forward indefinitely. The 2-inch and 1-inch sizes are suitable for laterals to water points and for other distribution. Occasional need may arise for 6-inch and in rare instances for larger sizes to bring water a considerable distance for a large installation. Universal joint and bell-and-spigot cast-iron pipe with lead-wool joints are used to some extent. Screw-joint pipe is generally satisfactory in smaller sizes but flanged pipe is easier to handle in the 4-inch size and larger.

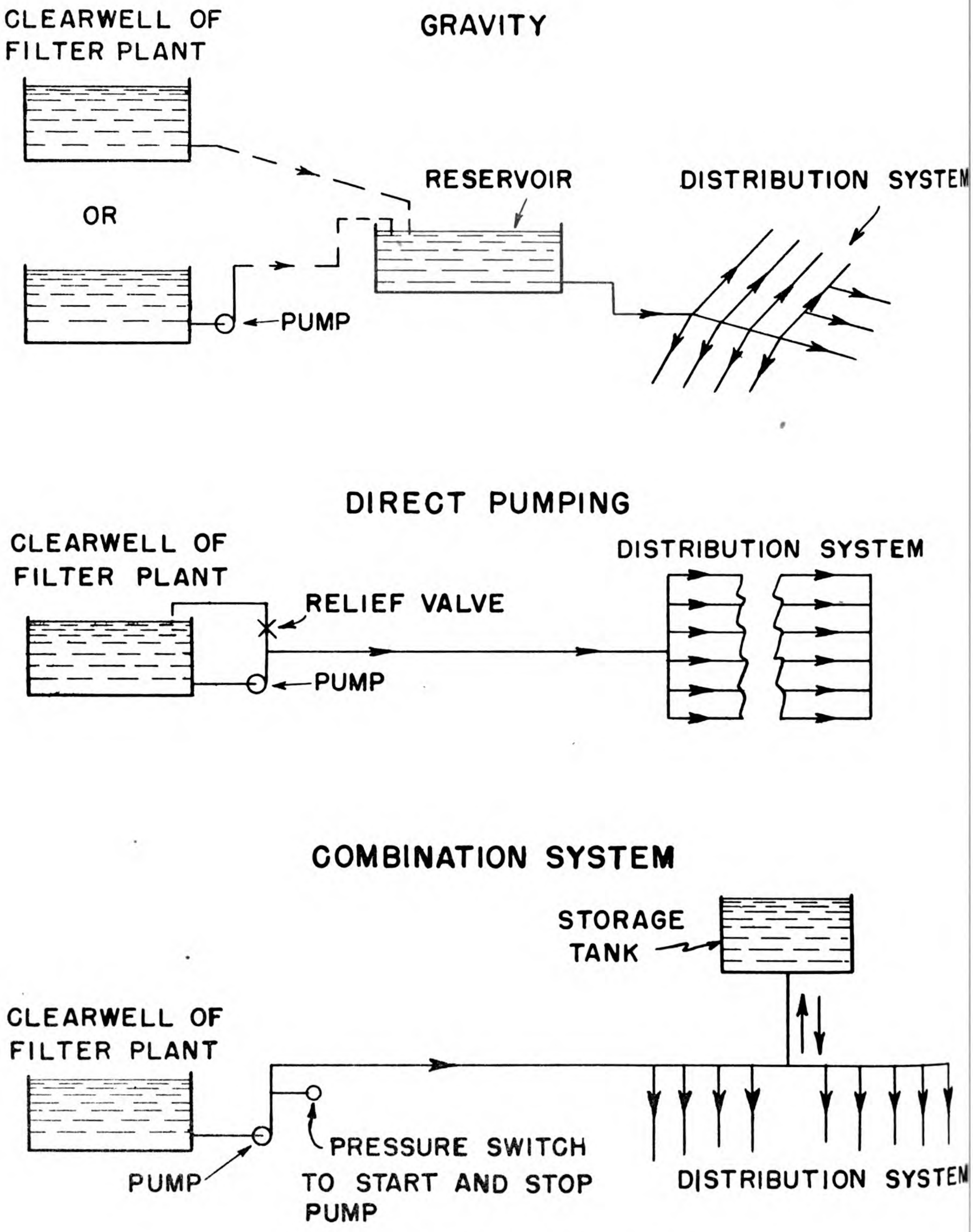


Figure 33. Types of distribution systems.

b. The need for fittings varies greatly with conditions, but should include 45° and 90° elbows, tees, bushings, plugs, nipples, valves, couplings, and saddles.

103. **Rate of Laying Pipe.**— This depends on the accessibility of the pipe line location to supply trucks. However, with a platoon of trained men, under good conditions, 4 miles of 4-inch screw-joint pipe can be laid in a day, assuming that the trench is dug and the pipe delivered by other troops.

104. **Pipe Distribution Systems.**— (Fig. 33) *a.* There are three general systems of pipe distribution:

(1) Gravity
(2) Direct pumping
(3) Combination

b. In the gravity system, mains are supplied by gravity alone, and no pumping is employed beyond the tank.

c. Direct pumping is usually undesirable because of the danger of pump failure. Where it is used, a relief valve must be placed at the pumping station to provide for the possibility of valves being shut on the line. Duplicate sets of pumps should be provided, when possible, for use in case of breakdown.

d. In the combination system the tank floats on the line as shown in Fig. 33c, that is, water enters and leaves the bottom of the tank through a common pipe which permits the distribution system to draw from the tank when the pump is not operating. When it is operating the line takes as much as is needed from the pump while the remainder of the pump discharge is delivered to the tank.

e. A comparison of the three systems of distribution will usually indicate the adoption of gravity or combination distribution where it can be utilized. Gravity and combination distribution provide the following advantages over direct pumping:

(1) Greater reliability.
(2) A constant head.
(3) Storage to provide for unexpected variations in demand.
(4) Less trouble from water hammer.

105. **Railroad Tank Car Distribution.**— Where it is necessary to transport water over long distances due to a scarcity of water in an area or for other reasons, railroad tank cars can be used. These tank cars may transport raw water but it is preferable to use them for only treated water, since they would have to be cleaned and sterilized if they were used for treated water after they had been used for raw water. These cars are usually made part of the daily train. In emptying, it is preferable to

draw the water by gravity from the bottom connection. If, for any reason, the water must be drawn through the dome, the dome should be kept as nearly covered as possible, and the suction line must be filled with water in order to prime the pump. If the water is to be pumped to a point some distance from the siding and pumps are not available, air can be used to discharge the water out of the bottom connection of the car by connecting a portable air compressor to the dome.

106. **Motor Vehicle Distribution.**— The Engineer Water Supply Battalion is equipped with 1500 gallon semi-trailer water tanks (tractor drawn) and 700 gallon tank trucks. Normally they deliver treated water to water distributing points, but can be used to haul raw water for treatment at the distributing point.

107. **Measurement of Water.**— *a.* There are several ways to measure the flow of water without meters. If the water is discharging from a hose or pipe line the time to fill a vessel of known size can be measured.

b. Orifice or Venturi Tube.— An orifice or Venturi tube can be inserted in the pipe line and, with the dimensions, and the difference in pressure across the orifice or between the inlet and the throat of the Venturi, the flow of water in the pipe can be determined. A straight length of pipe, 6 times as long as the diameter of the pipe should precede a Venturi.

c. The flow of water through an orifice can be calculated from the following formula:

$$Q = 4.84\, a\sqrt{h}$$

where Q = Flow in cu. ft. per second
a = area of orifice in sq. ft.
h = pressure loss across orifice in feet of water

d. The flow of water through a Venturi tube can be calculated from the following formula:

$$Q = \frac{a_1\, a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{64.4h}$$

where Q = Flow in cu. ft. per second
a_1 = area of pipe in sq. ft.
a_2 = area of throat of Venturi in sq. ft.
h = pressure differential from entrance to throat of Venturi in feet of water

e. If the water discharges from the hose or pipe line through a nozzle, the size of which is known, and if the pressure is measured just ahead of the nozzle, the flow can be determined from these data, using the formula in par. *d.* above.

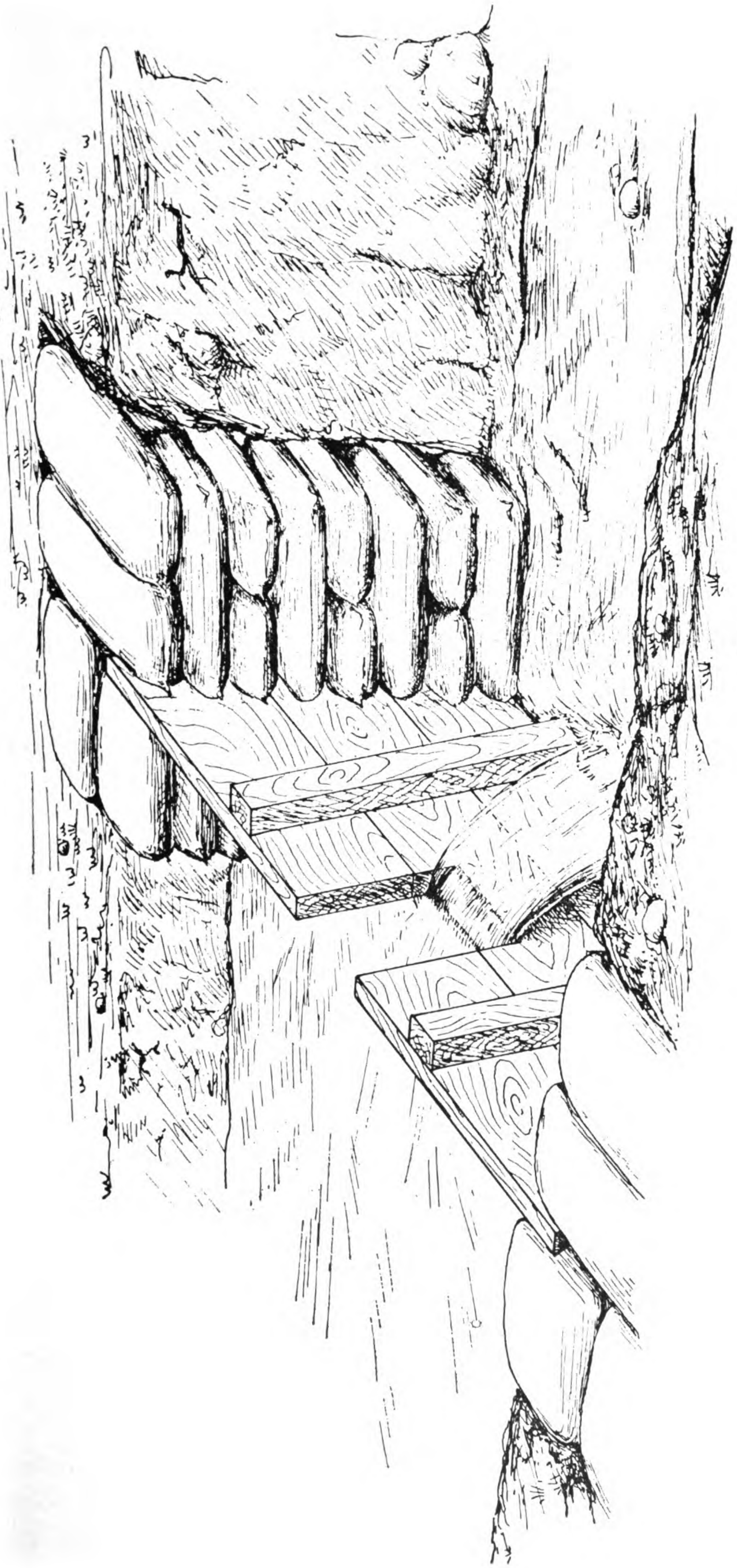


Figure 34. Improvised weir.

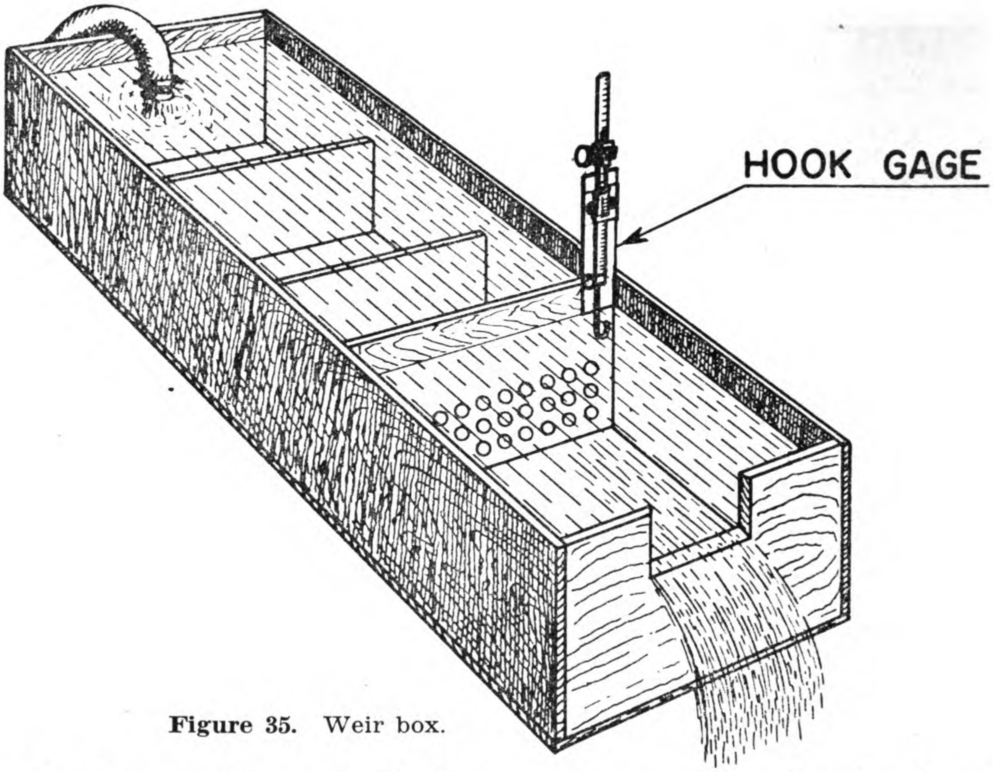


Figure 35. Weir box.

f. In streams, flumes, and other open waterways the simplest, but perhaps least accurate, method of measuring flow is to measure the cross-sectional area of the waterway and the time required for a chip or other light object to float a known distance. The rate of travel of the object should be multiplied by 0.75 in order to obtain the average flow of the stream. The area in sq. ft. multiplied by the average stream flow in feet per second gives the quantity flowing in cu. ft. per second.

g. Weirs. (1) Weirs are commonly used to measure flow. The discharge over the weir may be calculated or obtained from the table 25 in Appendix V. A weir consists of an opening of definite size and shape in an obstruction to the flow of water in an open waterway. The width of the weir can most conveniently be made a multiple of one foot and the depth of water over the crest of the weir, a foot or two upstream, can be measured. From these figures the flow can be determined from table 25, Appendix V, "Discharge over Rectangular Weirs."

(2) The length of the weir should be less than three-quarters of the width of the weir box or waterway; the depth of the weir box, or waterway, should be more than three times the depth of water over the crest of the weir; the fall from the crest of the weir should be at least half the head over the weir, or greater; and there should be free access of air below the crest of the weir. The weir can be constructed of wood and placed in the stream (Fig. 34) or a weir box can be made (Fig. 35). In either case the crest of the weir must be sharp, as shown in the illustrations, and the sharp edge should be upstream.

Chapter 7

OPERATION

Section I

GENERAL

108. **Basic.**— *a.* Water supply and purification in its simplest form consists of the individual soldier, on an isolated mission, filling his canteen from a spring or brook and adding 2 to 3 drops of tincture of iodine, or boiling the water for 30 minutes to disinfect it.

b. Lyster bag chlorination.— Companies and lower units when not supplied by higher echelons, take the clearest water possible from local sources, fill a Lyster bag (water sterilizing bag), Fig. 36, and chlorinate. The routine technique used in the chlorination of water in a water sterilizing bag is as follows:

(1) Fill the bag to the 36 gallon mark, or if the bag is not marked, to within four inches of the top.

(2) Draw a small quantity of water through one of the faucets into a canteen cup.

(3) Break an ampule of the calcium hypochlorite into the water in the cup and with a clean stick rub it into a thin paste containing no visible lumps. Then add sufficient water to fill the cup two-thirds full.

Figure 36.
Lyster Bag.

(4) Empty the solution of calcium hypochlorite from the cup into the water in the bag, and stir thoroughly with a clean stick which is long enough to reach the bottom of the bag. Then flush out each of the faucets.

(5) After the calcium hypochlorite has been in contact with the water in the bag for at least ten minutes, wash out one of the faucets by allowing a small amount of water to run through it onto the ground. Then fill a clean cup about two-thirds full of water from the same faucet.

(6) Add one c.c. (approxmiately 15 drops) of orthotolidine solution to the water in the cup and allow it to stand for about ten minutes so that the color will develop. Because of the reflected light, the color of the water in the cup is more intense than it would be if the same water were placed in a glass tube. A well marked yellow color indicates that the water contains about the proper amount of residual chlorine. An orange color is evidence of overchlorination.

(7) If no residual chlorine is present at the end of the ten minute contact period, the chlorination procedure, as outlined above, is repeated. If it is suspected that the calcium hypochlorite is inert, a preliminary test with orthotolidine should be made immediately after the addition of the calcium hypochlorite solution to determine if the water contains any free chlorine at that time. If no residual chlorine is shown by this test the calcium hypochlorite is deteriorated.

(8) As a factor of safety, the water should be allowed to stand for twenty minutes after the end of the contact period, or for thirty minutes after the addition of the calcium hypochlorite, before being used for drinking purposes.

109. **Emergency Chlorination.**— *a.* If water sterilizing bags are not available, the water may be chlorinated in other clean containers, such as galvanized iron cans, pails, or barrels. A proportional amount of calcium hypochlorite is used, and the method of chlorination is the same as with the water sterilizing bag.

b. If large containers are not available, canteens may be utilized. A pinch of chlorinated lime or Grade A calcium hypochlorite is dissolved in a canteen of water. This strong solution is then used to purify water in other canteens. The cap of a canteen is used as a measure and one capful of the strong solution is added to each canteenful of water to be treated. The water should be well shaken and not used until thirty minutes after chlorination.

c. Improvised Chlorinators.— (1) The chlorination of temporary water supplies with calcium hypochlorite may be accomplished by the use of improvised apparatus, such as that shown in Figure 37. A wooden barrel may be used as a combined mixing and solution tank. Where continuous application is necessary, the barrels should be in duplicate so that one can be used as a chlorinator while a solution is being prepared in the other. The flow can be controlled by a wooden spigot, but, if practicable, a solution feeder or an orifice box should be employed.

(2) Wooden barrels tend to deteriorate in a comparatively short time and, consequently, concrete tanks are better if the plant is to be used for any considerable length of time.

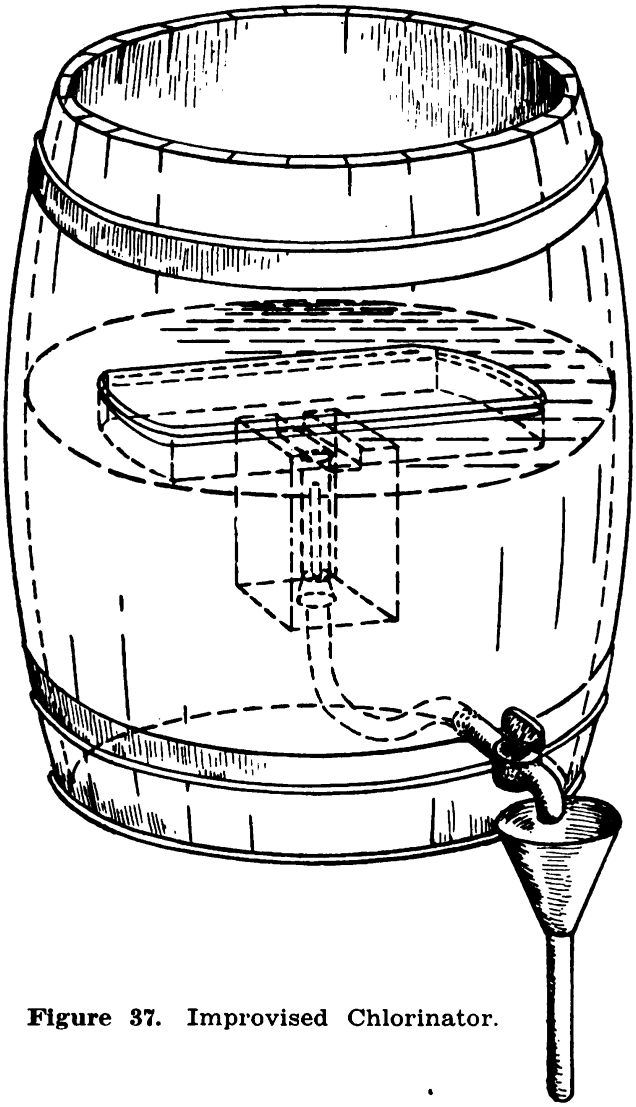


Figure 37. Improvised Chlorinator.

110. **Iodine Sterilization.**— Iodine may be employed as a disinfectant instead of chlorine. Ten c.c. (approximately one canteen capful) of the tincture of iodine are used to disinfect a water sterilizing bag of water (36 gallons). Iodine is expensive and the supply is limited during war. Further, in the treatment of some waters, iodine is apparently much less effective than chlorine. The water should not be used until thirty minutes after the iodine has been added.

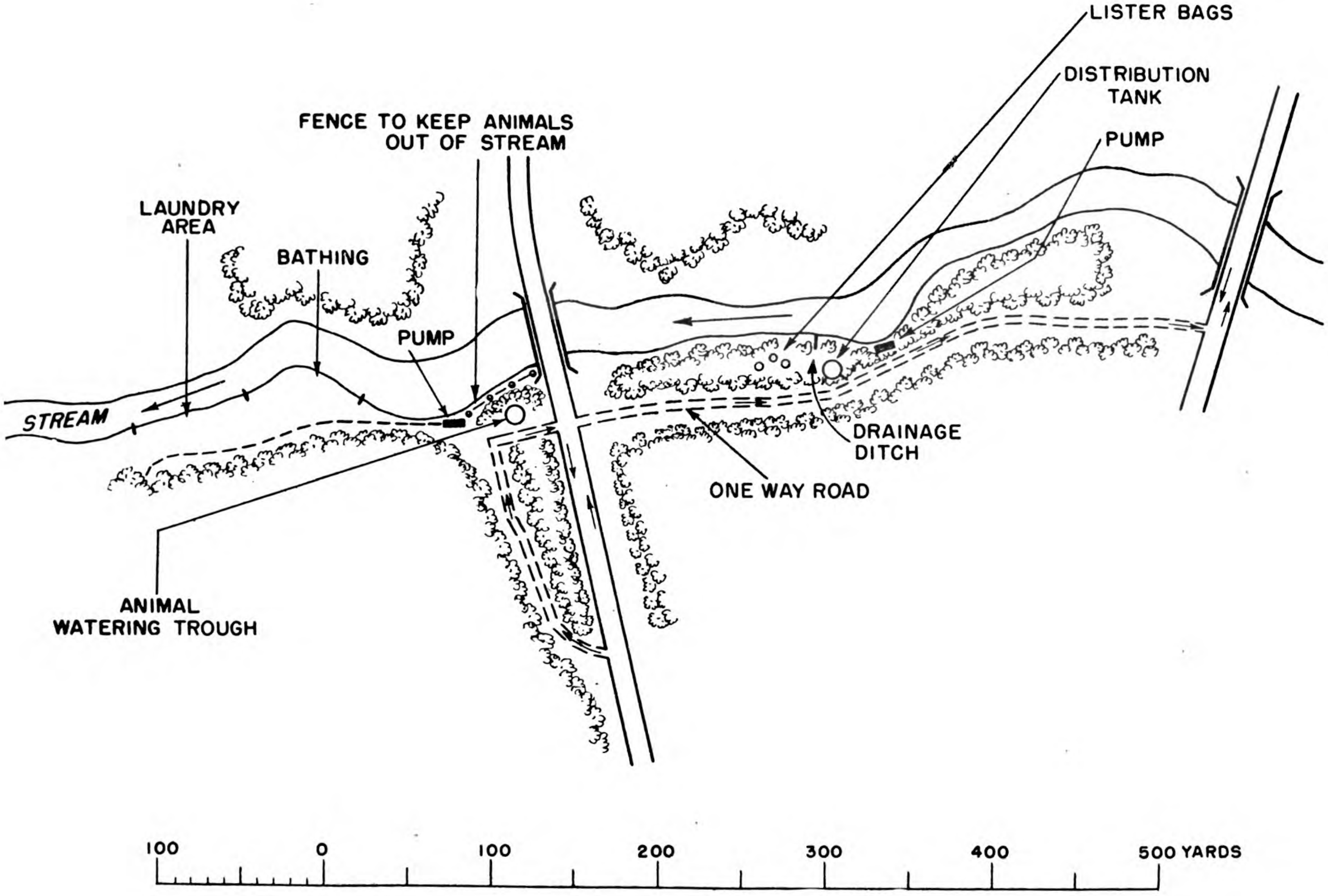


Fig. 38. Typical Water-Distributing Point

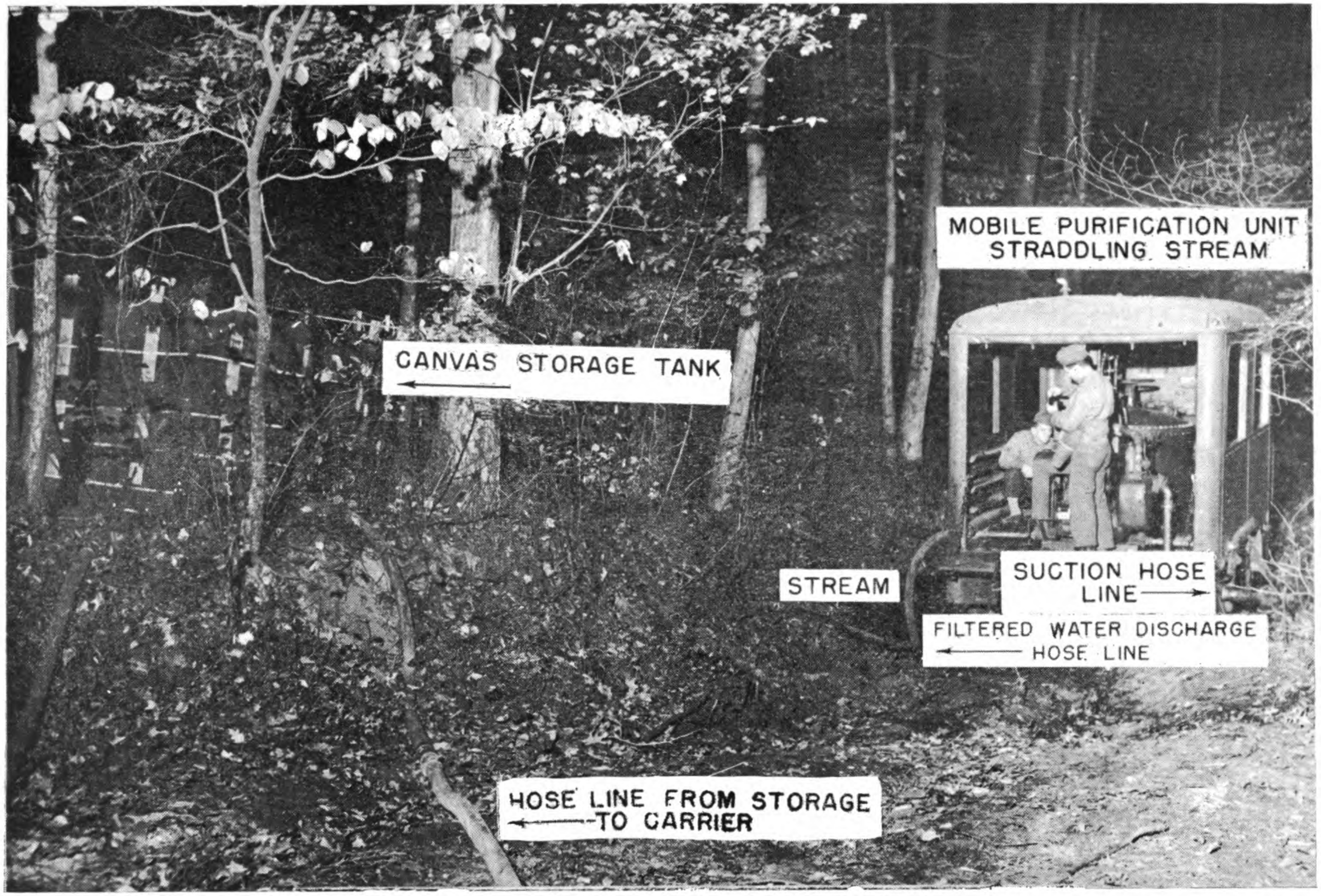


Figure 39. Water distributing point with mobile water purification unit.

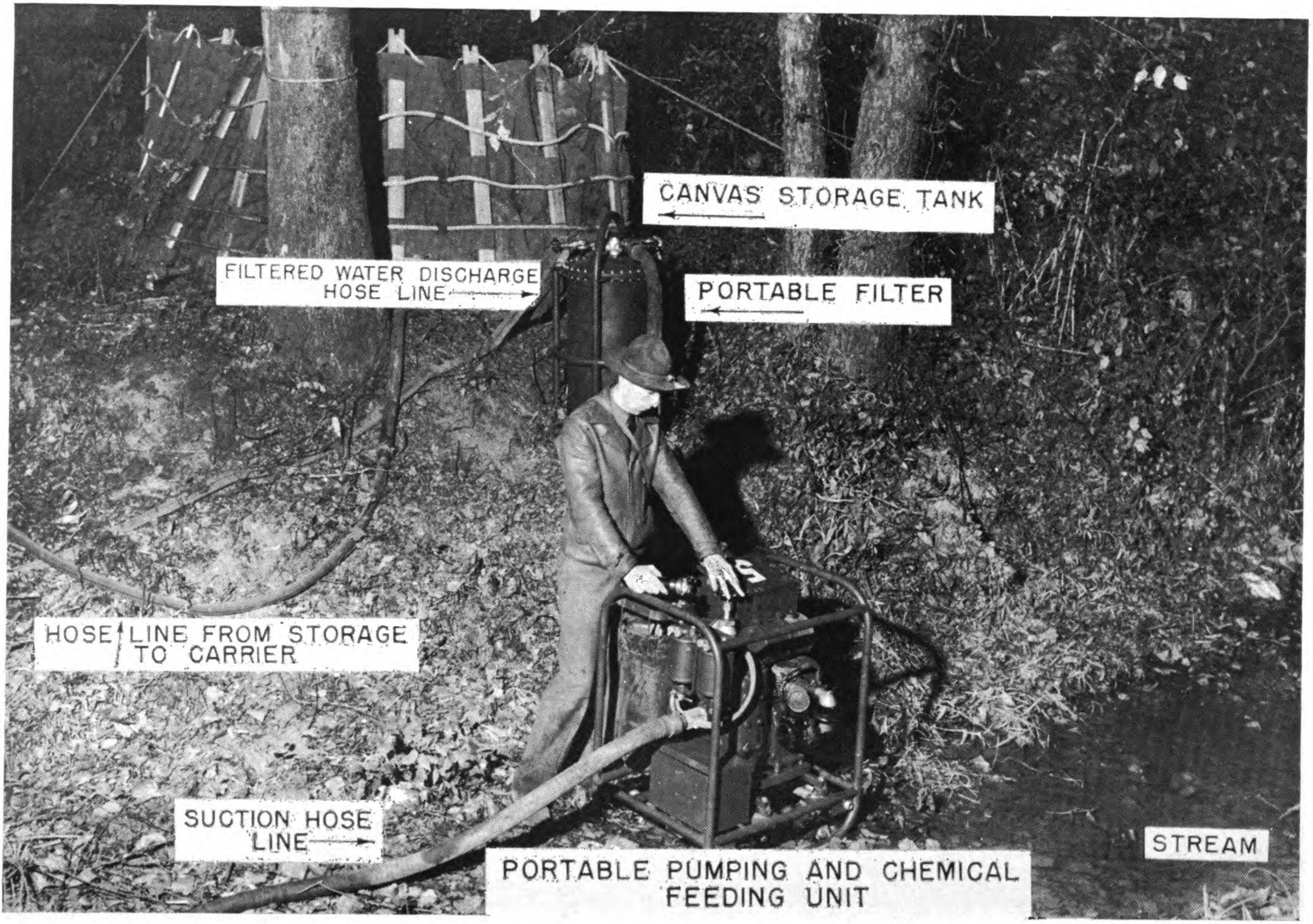


Figure 40. Water distributing point with portable water purification unit.

111. **Boiling.**— If neither calcium hypochlorite nor iodine is available, water may be purified by boiling for 30 minutes. This method should not be used by the individual soldier if avoidable, but the water should be boiled under supervision in comparatively large quantities, and then distributed to the troops. Water may be boiled in galvanized iron cans.

112. **Installations.**— *a.* Initial water supply installations in the theater of operations will generally be crude and will be designed to meet minimum requirements only. Local water sources and existing facilities will be used to the fullest extent possible.

b. Wide dispersion of water supply establishments is effected whenever possible, in order to limit and minimize hostile attack from the air.

c. Because of the difficulty of concealing water-supply establishments from enemy observation, extensive camouflage measures must be taken. Storage tanks are conspicuous by their shape; unless covered, they may be identified readily from the air by the reflection of light from the water surface. Railway tank cars and trucks are also very conspicuous, unless adequate concealment is available.

d. Water-supply work in forward areas is taken over by engineers of rear echelons as the situation permits.

113. **Water Supply Points.**— *a. Definitions.*— (1) Water supply points are establishments for the procurement, reception, storage, or delivery of water in the field. Facilities may be provided for one or more of the following functions: filling large containers, filling canteens, watering animals, bathing, or washing clothes. Water supply points are classified as watering points or water distributing points.

(2) *A watering point* is a place organized and operated by the consuming organization, at which it obtains water directly from the source with its own personnel and equipment. This method of supply is used whenever the quality of available water permits.

(3) *A water distributing point* (Fig. 38-40) is an establishment organized and operated by the Engineers at which one or more consuming organizations obtain water. This method of supply is used whenever the available supply is limited or badly contaminated, or whenever congestion would result from several organizations using the same watering point. It may be located at a natural source or water may be brought up by tank truck, railway tank cars, or pipe lines.

b. General.— (1) The number of water-supply points established depends upon the location and capacity of available sources and upon the number of troops to be supplied. Distributing points are generally installed at the rate of two or three per division or unit of similar size. As a rule, several small water-supply points will serve better than a few large ones.

(2) The order of taking water from a stream—from upstream downward—is as follows:

- (*a*) Drinking water for personnel.
- (*b*) Watering animals.
- (*c*) Bathing.
- (*d*) Washing clothes.

(3) Water for human consumption is chlorinated as a matter of protection. This will be accomplished by consuming organizations, using the issue calcium hypochlorite tubes if the water has not previously been treated, or if it may have become contaminated since treatment. In most cases the Engineers will provide purification, including chlorine treatment, at the distributing point or prior to receipt thereat, utilizing existing plants, small improvised fixed plants, or the standard portable or mobile purification units.

c. Control of traffic.— In order to prevent congestion, a carefully developed plan of traffic control must be enforced at water-supply points by the consuming unit or the engineer unit, whichever establishes them. It is essential that this plan be coordinated with the general scheme for traffic control within the area. In keeping with this plan, signs must be posted to guide vehicles, personnel, or animals to water-supply points and to direct them while passing through. Schedules alloting certain hours to each using-unit are prepared in order to smooth out traffic flow, and guards are posted to enforce the traffic plan.

d. Location and layout of water distributing points.— (1) The following desirable features are sought in locating a water distributing point:

- (*a*) Near kitchens and troops to be supplied.
- (*b*) Accessibility to water source.
- (*c*) Out of range of enemy light artillery.
- (*d*) Concealment from enemy air and ground observation.
- (*e*) Parking space for waiting vehicles.
- (*f*) Situated so as to fit into the general scheme for traffic control.
- (*g*) Existence of a natural elevation suitable for installation of storage tanks.
- (*h*) Hard ground with good natural drainage.
- (*i*) Suitable for the type of containers to be filled.

(2) Figure 38 shows a typical layout for a water distributing point.

(3) Tables 2 and 3 give data relative to the installation and operation of water distributing points.

TABLE 2—MAN HOURS FOR INSTALLING A WATER DISTRIBUTING POINT

Task	Man hours required	Size of party	Remarks
Erect timber trestle platform for 3000 gallon canvas tank	16	1 or 2 squads	Material at the site using power tools
Erect 3000 gallon tank	2	1 squad	After platform is constructed
Set up pump and hose	1	½ squad	
Install 260 gallon animal watering tank and hand pump	1	½ squad	
Set up mobile unit	2	½ squad	
Set up portable unit	2	½ squad	

TABLE 3—TYPE ORGANIZATION FOR OPERATING A WATER DISTRIBUTING POINT

Task	Size of party	Remarks
Filling water cans	1 squad	2 shifts of ½ squad each
Operating power pump	2 men	2 shifts of 1 man each
Traffic police	as required	3 shifts
Air guards	as required	3 shifts
Mobile and Portable Purification Units	3 men (each)	3 shifts of 1 man each

(4) Organizations are supplied with 5-gallon water cans for carrying water. A 1½-ton truck will carry 60 and a 2½-ton truck approximately 100. At the distributing point the cans may either be filled on the truck, or replaced from a reserve of filled cans.

e. Animal watering.— Animal watering basins should be used in preference to direct watering from a stream, unless the approaches are wide and open, the footing is hard, and the water downstream is not to be used by personnel. A fence should be improvised along the stream bank so as to make watering from the basin easier than from the stream. With the standard, circular 260-gallon basin, animals are led to the basin in groups of 10 and remain at the basin until all in the group are watered. Each group requires about 5 minutes at the tank. The hose supplying a watering tank should be buried to prevent damage by animals. Gravel should be spread and ditches dug to provide drainage and hard standings.

Section II

COAGULATION AND SEDIMENTATION

114. Determination of Optimum pH Range for Coagulation.— *a.* The need for establishing the optimum pH range for good coagulation and for maintaining the filtered effluent within that range is discussed under coagulation (Par. 63). In the laboratory or in a permanent filtration plant there will probably be found ample facilities for the necessary tests. In the field, however, expedients must be used. A proposed arrangement of 5-150 c.c. bottles, with bottles of the same size of standard alum and soda ash solutions and two-2½ c.c. medicine droppers in a block is shown in Figure 41. The alum solution should contain 0.102 grams of alum in 150 c.c. of water and the soda ash solution, the same. One-2½ c.c. dropper full of either in a 100 c.c. sample of water will give a dosage of 1 grain per gallon.

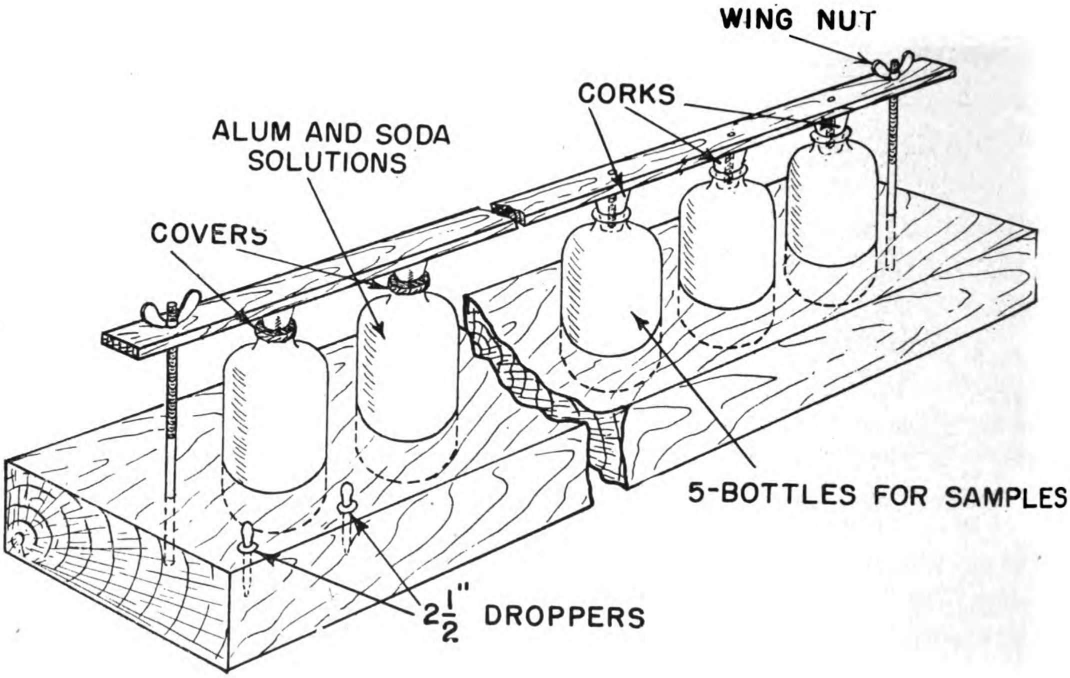
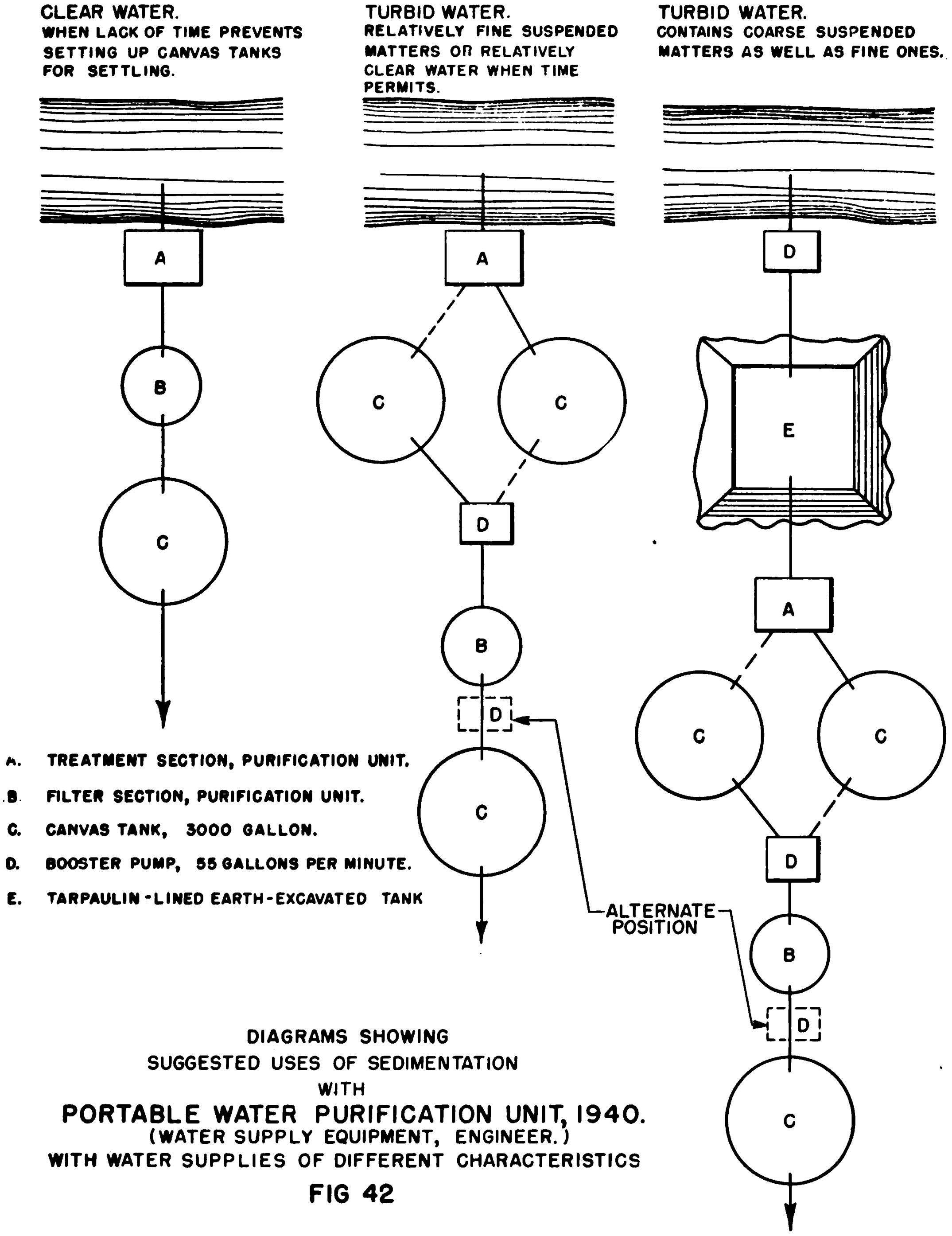


Fig. 41. Coagulation Test Set.

b. While filling and washing the filter, the 5-150 c.c. bottles should each be filled with 100 c.c. of the raw water; one, two and three droppers full respectively of the alum solution should be added to the first three bottles and two droppers full to each of the others, and in addition to the alum, two, and four droppers full of soda ash respectively should be added, to the latter two bottles. The contents of each bottle should be mixed by clamping the bottles in place as shown in Fig. 41 and shaking the group for a minute or two.

c. By the time the filter is filled and washed, the floc will have formed in the bottles to an extent sufficient to permit a preliminary selection of those containing the biggest and healthiest floc. Determine the pH of the contents of the bottles selected (see Appendix I) and thus, the optimum range. The feeds are then set during the rewash operation to establish this range.

d. Any small bottles will do until the set is available and if it is impossible to prepare or obtain standard alum and soda ash solutions, prepare rough solutions using a pinch of the alum and soda ash used in the purification unit for it is better to guess at the relative dosages than not to make the test. However, the solutions can probably be obtained from a Medical Corps field laboratory. If other bottles are used the amount of the solutions to be added must result in the proper proportion.



DIAGRAMS SHOWING
SUGGESTED USES OF SEDIMENTATION
WITH
PORTABLE WATER PURIFICATION UNIT, 1940.
(WATER SUPPLY EQUIPMENT, ENGINEER.)
WITH WATER SUPPLIES OF DIFFERENT CHARACTERISTICS
FIG 42

115. **Sedimentation.**— (Fig. 42) *a.* The following applies to portable and mobile units as well as to conventional filter plants.

b. Unless the suspended matter is removed as completely as possible before the water under treatment is put into the filter, there will be a tendency to clog the filter too quickly and reduce the time length of filter runs. This will also require more frequent shut-downs for backwashing the filter and a reduction in the daily capacity of the treatment plant.

c. Sedimentation is of two kinds, depending on the particle size.

(1) Without Coagulant.— Coarse suspended matter, such as sand, which will drop out quickly if the velocity of flow of water is reduced, should be presettled without coagulant by means of dams, ponds, canvas-lined or unlined pits, reservoirs, or any means of reducing velocity of flow.

(2) With Coagulant.— For fine suspended matter, often spoken of as colloidal material, which resists removal by plain subsidence a coagulant is necessary to gather the particles together into larger masses which will settle readily. Some of these fine colloidals will resist sedimentation for days unless a coagulant is used. Using the filter to strain all the particles of suspended material in their masses of coagulated matter is wasteful of time. It is preferable to use additional canvas storage tanks in which sedimentation can take place, and then filter.

d. Always consider each individual raw water condition. The same stream will not always carry the same kind of water. It may change quickly. Change the treatment procedure with it. Adapt the treatment to the water and alter the set-up, dosage of chemicals, and filter washing accordingly. *By ingenuity reduce the burden on the equipment to secure the best results with a minimum of effort, shut-down interruptions, time, chemical dosage and filter clogging.*

e. If handling clear water, special provision for sedimentation prior to filtration may not be absolutely necessary but will always be helpful.

f. If handling turbid water containing coarse sediments, let them settle out before beginning the actual treatment of the water. After pre-sedimentation, proceed to treatment with a period of settling after adding alum and before filtration. Sedimentation after adding the chemical coagulant will save time in filter washing and yield a better water.

g. If handling a water containing fine suspended matter in any considerable amount, introduction of settling tanks between the addition of chemicals and the filtration of the water is necessary. Ordinarily one sedimentation period is sufficient, but under exceptionally bad conditions a repetition of treatment and a second period of subsidence before filtration may be necessary to get satisfactory results. This is not likely to be necessary, except when a water contains very fine suspended matter, is high in organic coloring substances or is very cold. Do not make the treatment more complicated than circumstances demand.

h. Do not try to get a satisfactory water by merely raising the alum dosage. Addition of too much alum will result in precipitation of the chemical floc after the water has passed through the filter unit.

i. Careful preparation of the water for filtration yields the best returns in filtered water quality, and safety.

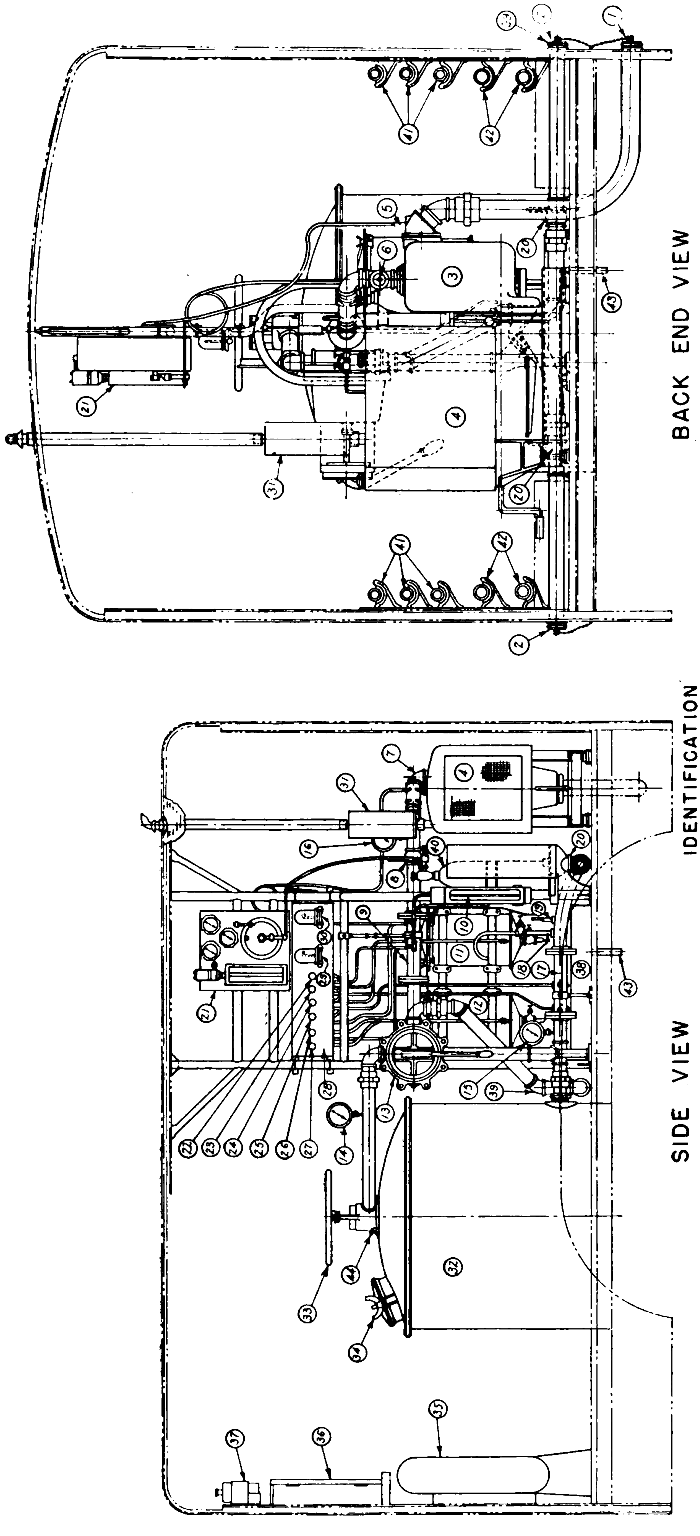
Figure 43.

Section III

MOBILE WATER PURIFICATION UNIT — M-3, MODEL 1940

116. **Description.**— The entire equipment of this unit is mounted on a 2½-ton, six-wheel drive truck chassis (Figures 43 and 44) and consists essentially of a single stage self-priming centrifugal pump with engine, a 42″ pressure type rapid sand filter with hand agitator, a three-position

valve for operating the filter, a standard dry feed chlorinator, an alum pot, a soda pot, a Venturi meter, and a simple test kit for determining Ph, and free chlorine. See Fig. 44 for sectional views and for the nomenclature of major parts.



IDENTIFICATION

1-2½" PUMP SUCTION
2-2" FILTERED WATER DISCHARGE
3-SELF-PRIMING PUMP
4-ENGINE
5-CHLORINE APPLICATION CONNECTION
6-2" BYPASS
7-2" PUMP DISCHARGE
8-PUMP DISCHARGE VALVE
9-INFLUENT VENTURI TUBE
10-FLOW MANOMETER
11-SODA TANK
12-ALUM TANK
13-CONTROL VALVE
14-INFLUENT PRESSURE GAUGE
15-EFFLUENT PRESSURE GAUGE
16-PUMP DISCHARGE PRESSURE GAUGE.
17-EFFLUENT VENTURI TUBE
18-FILTERED WATER SAMPLE BIBB
19-AUXILIARY CHLORINE APPARATUS CONNECTION
20-FILTERED WATER DISCHARGE VALVE
21-CHLORINATOR
22-H.P. SODA ASH VALVE (INF.)
23-L.P. SODA ASH VALVE (INF.)
24-H.P. SODA ASH VALVE (EFF.)
25-L.P. SODA ASH VALVE (EFF.)
26-H.P. ALUM VALVE (INF.)
27-L.P. ALUM VALVE (INF.)
28-CHEMICAL FEED CONTROL PANEL
29-ALUM FEED SIGHT GLASS
30-SODA FEED SIGHT GLASS
31-MUFFLER AND EXHAUST PIPE
32-FILTER
33-AGITATOR WHEEL
34-HANDHOLE CONNECTION
35-SPARE TIRE
36-TOOL BOX
37-BOTTLE RACK
38-CHEMICAL TANK DRAIN TROUGH
39-FILTER BACKWASH WASTE
40-CHLORINE CYLINDERS
41-2" HOSE AND RACKS
42-2½" HOSE AND RACKS
43-OUTLET FOR 38
44-AIR VENT

Figure 44. Mobile purification unit model M-3.

117. **Flow.**— *a.* (Refer to Fig. 44). Water is drawn in through the suction line (1) by the centrifugal pump (3). Chlorine is fed through the chlorinator (21) into the suction line (1) and is mixed with the water in passing through the pump (3).

b. A solution of alum is fed (12) from the alum tank in proportion to the rate of flow into the line beyond the pump by means of a Venturi tube (9). This Venturi tube (9) actuates a manometer (10) to measure the flow of water in gallons per minute. Entering at the top of the filter, and leaving at the bottom, when filtering, the water goes to the point of use. The discharge line from the filter is divided so that filtered water may be discharged at two outlets in the rear of the truck.

118. **Truck Body.**— The interior sides of the body carry the hose on racks and provision is made for four 10′ length of 2½″ suction hose (42), and six 10′ length of 2″ discharge hose (41). The tail gate is provided with hinges and chains fastened to the sides. The sides and rear are provided with glass windows and blackout shutters. The body is electrically lighted from the battery and plug-in sockets are provided for light extensions.

119. **Pump and Engine.**— The pump (3) is a self-priming, single stage, horizontal shaft, centrifugal type with 2½″ suction and 2″ discharge, direct connected to a 4 cylinder, four cycle, water cooled gasoline engine (4). The pump has a rated maximum capacity of 100 gallons per minute at 2000 r.p.m. against a total head of 90′, at least 20′ of which may be suction lift.

120. **Three-Position Valve.**— *a.* The three-position valve (13) is designed for convienent control of the flow of water through the filter. The valve may be set for washing, rewashing (filtering to waste) or service.

b. To by-pass the filter when chlorination alone is required, the hose to service is attached to the connection on the pump discharge which is normally capped (6). The water then by-passes the equipment and is not treated in any way except for chlorination. However, it is preferable to filter even clear water to remove amoeba which are not affected by chlorine.

121. **Filter.**— *a.* The filter (32) is of the pressure type, 42″ in diameter, designed for a hydrostatic pressure of 100 lbs. per square inch. It is provided with connections at the top and bottom, has a handhole, (34) in the top and a hand agitator (33). The agitator consists of a wheel on the outside of the filter which is connected by a shaft to vertical rake bars on the inside and is rotated to stir up the sand in the filter during the process of washing. At the bottom of the tank is the underdrain manifold embedded in a layer of 3/8″ to 5/8″ gravel 4″ thick. On top of this in succession, are 3″ of 3/16″ to 3/8″ gravel, 2″ of 3/16″ to No. 10 mesh gravel, and 18″ of filter sand of No. 30 to No. 45 mesh.

b. The pressure of the water is decreased due to friction as it passes through the filter, as indicated by the gauges (14) and (15) provided at the inlet and outlet of the filter. The normal pressure difference when the filter bed is clean is only a few pounds per square inch. When the filter bed becomes clogged with sediment this pressure difference increases and the flow of water is reduced. When the pressure loss exceeds 10 to 12 lb. per square inch it is necessary to wash the filter. This is accomplished by rotating the three-position valve to the wash position which reverses the flow of water through the filter and discharges it through the waste pipe. After washing, the filter is rewashed, that is, the water is filtered to waste, so that a new coagulant layer can be built up before the filter is placed in operation.

122. **Alum Pot.—** The alum pot (12) is filled with nut size ammonium alum. Dosage of alum is controlled by the needle valves (22) to (28) on the chemical control panel. The feeding of alum is automatic and proportional to the flow of water. Crystal alum must be used in this pot because commercial filter alum is too soluble for this type feed.

123. **Soda Pot.—** The soda pot (11) is filled with fused soda ash, in brick form, which dissolves slowly and uniformly in water. The feeding of soda ash is the same as for alum. However, the hook-up is such that soda ash solution can be applied to the pump discharge before entering the filter (9), or to the filtered water discharge (17) after the filter, to increase the pH of the filtered water.

124. **Venturi Tube and Manometer.—** (9) and (10). The purpose of this meter is to show the rate of flow of water. The manometer consists of a glass tube having its lower portion filled with mercury. The flow of water through the Venturi tube creates a differential pressure head corresponding to the rate of flow which causes the mercury to rise or fall, with the rate of flow. The scale of the manometer tube shows the rate of flow in gallons per minute. Shut-off valves are provided at the top of each manometer tube and a cross connection is provided to equalize the pressure in the manometer tubes.

125. **Test Set.—** The purpose of the test set furnished with the equipment is to determine the chlorine residual in the treated water, the pH value at which the raw water coagulates best, and the pH value of the treated water. This apparatus is of the colorometric type and very simple to operate. (See Appendix I).

126. **Piping and Connections.—** Red brass pipe is used throughout. The pump suction hose is 2½″ and the connecting lines are 2″, suitable couplings being provided for attaching the hose. There is also a pump suction strainer for attachment to the lower end of the suction hose.

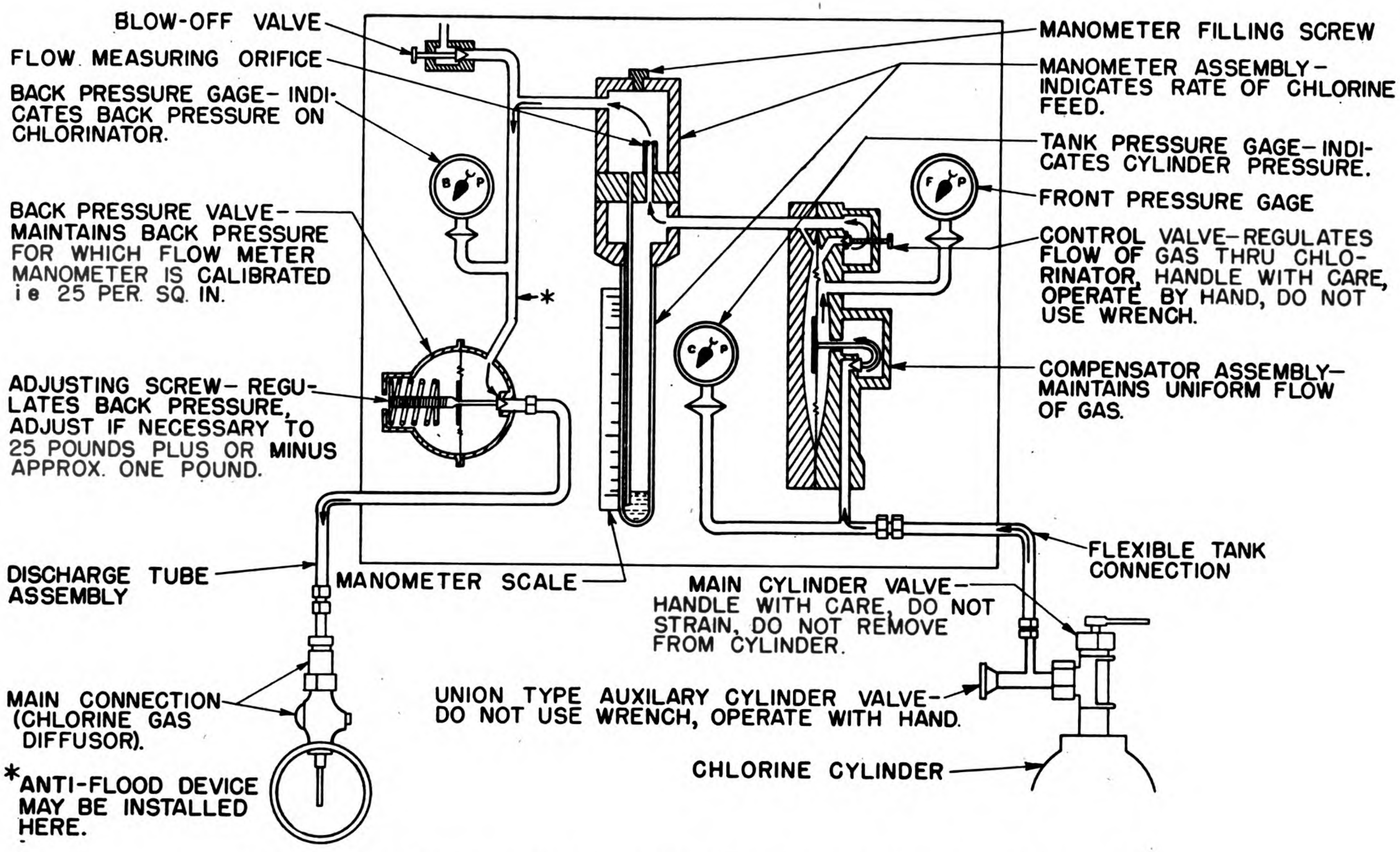


Fig. 45. Flow Diagram. Direct Feed Chlorine Control Apparatus—Type—M.T.D.

127. **Chlorinator.—** (Fig. 45) *a.* The chlorinator is of the dry gas feed type and has a maximum capacity of 10 lbs. of liquid chlorine per 24 hours. The chlorine gas is obtained from either of two 15 lb. chlorine cylinders and is fed to the chlorinator through silver tubing. The gas is conducted through silver lined copper tubing from the chlorinator to points of application.

b. The Chlorine Control Apparatus issued for measuring and applying chlorine gas directly to the flowing stream of water in the suction line. The apparatus consists of a pressure reducing and flow controlling compensator which has an integrally mounted control valve to adjust the rate of flow. Variations in chlorine cylinder pressure due to temperature changes are compensated for by this device. The chlorine flow is measured by an orifice and indicated on a manometer. The manometer is so calibrated with respect to the orifice that it reads directly the rate of flow of gas. A back pressure valve is included to keep a constant pressure on the equipment, a feature which is essential for accurate measurement. The discharge port of the back pressure valve is connected to the point of application of the chlorine gas to the suction line.

c. This apparatus will feed chlorine steadily and accurately at all rates within the limits of the particular orifice and scale. The flow of chlorine and the construction of the equipment is clearly shown in Figure 45.

d. Operation of Chlorinator.— (1) *To start:*

(a) See that the manometer liquid is at the proper level in the manometer.

(b) Be sure that the glass meter guard is in place.

(c) See that the blow-off valve is closed.

(d) Insert the diffusor tube assembly into the main so that the gas is delivered approximately in the middle of the flow.

(e) Open the main cylinder valve. One turn is usually sufficient.

(f) Open the auxiliary cylinder valve slowly, until the tank pressure gauge registers full tank pressure.

(g) Test for chlorine leaks (Par. 131 k, Testing for Chlorine Leaks). If a leak occurs, shut off the chlorine at the main cylinder valve and tighten up the union where the leak occurs, or renew the gasket. Leak of any description must be repaired at once.

(h) Set the control valve to the correct dosage required as determined by test of the effluent, the rate of flow being indicated on the manometer scale.

(i) Adjust the back pressure valve, if needed, to 25 lbs. pressure as indicated on the back pressure gauge. (Back pressure should be the same as that indicated for operating pressure on the orifice scale. This is sometimes other than 25 lbs.)

(2) *To stop:*

(a) Close the main cylinder valve.

(b) Close the auxiliary cylinder valve.

(c) If the shut-down is to be of brief duration and does not involve breaking any unions, nothing further is required. *Do not use control valve as a shut-off valve.*

(d) If the apparatus is to be out of service for any length of time, or if it is necessary to break any connections within the assembly, bleed the chlorine out of the apparatus by means of the blow-off valve. Second, the diffusor must be removed from the water completely. This makes it necessary, in pipe line applications, to pull the diffusor back into the receiving chamber, close the corporation cock, and disconnect the diffusor tube, opening same to atmospheric pressure.

(e) Plug all connections to prevent moist air or water entering the apparatus. Always store chlorinators and parts in a dry place.

e. The set-up of the truck at the selected pumping site should be so that it will give the least suction lift and maintain the truck as nearly level as possible. If necessary, blocking should be employed.

128. **To Start The Mobile Unit in Operation.**— *a.* Attach the strainer to one end of the 2½″ suction hose; attach the other end to the pump suction pipe. Support the strainer in the source of supply by tying it to a stake, midway between the surface and the bottom. Keep eel grass, floating leaves, and other debris away from the strainer to prevent clogging.

b. Connect the required number of 10′ lengths of 2″ discharge hose to the most convenient filtered water outlet connection on the side of the truck, and carry the free end to the point where purified water is to be delivered.

c. Connect the required number to 10′ length of 2″ hose and attach to the waste connection on the side of the truck, the free end to be carried to any suitable drain point downstream from the intake.

d. Fill the priming chamber of the pump.

e. Fill the alum and soda pots.

f. Open the valve in the pump discharge pipe slightly; close the valves in both branches of the filtered water discharge pipe. Set the lever of the control valve at "Washing." Open the air relief petcock on top of the filter tank. Close all valves in the chemical feed system. Close the three valves in the manometer connecting piping.

g. Check all chlorine connections, making sure all gaskets are in place and joints are tight (See "Testing for Chlorine Leaks", Par. 131 k).

h. Fill the gasoline tank on the engine and check the oil in the crankcase. Fill the radiator with water.

i. Open the test bibb in the pump discharge line. Start the engine. Do nothing more until water flows out of the test bibb, then close the test bibb.

j. Adjust the chlorinator to obtain a residual of 1.0 ppm in the effluent.

k. Water is now flowing to the bottom of the filter tank and displacing the air at the top *The filter tank should not be allowed to fill rapidly.* When water flows from the petcock on top of the tank, close the petcock slowly.

l. Adjust the manometer as follows: Open both air petcocks at the top of the manometer. If necessary, remove the plug in the mercury well at the back of the manometer and put mercury into the well until it shows zero on the scale. Replace the plug. Open the by-pass (equalizer) valve. Open the other two valves simultaneously, and slowly, allowing the glass tube and mercury well to fill with water. When it is certain that all air is out, close the petcocks. Close the by-pass (equalizer) valve slowly. The manometer is now in operation and the flow through the pump discharge will be indicated in gallons per minute. (Note:— All valves in the manometer piping should be closed before starting the plant in operation. Close all valves in the manometer piping after stopping the pump.)

m. Open the valve in the pump discharge pipe gradually until delivery is 100 gpm, and observe the water. If filter sand appears, throttle the valve in the pump discharge pipe until sand ceases to appear. Allow water to flow until it begins to clear. During this operation, turn the hand wheel on top of the filter tank to agitate the sand bed with the rake and break up any matted material or mud balls.

n. Throttle the valve in the pump discharge pipe until flow is approximately 10 gallons per minute, as indicated by the manometer. Set the control valve at "Rewashing." Open the valve in the pump discharge pipe gradually until the flow is 50 gallons per minute, as indicated by the manometer.

o. (1) Adjust the alum and soda feeds as follows.— Open the air cocks in the top of the chemical pots and open all chemical control valves.

Allow the pots to entirely fill with water; then close the control valves marked "high" on the panel and close the air cocks in the top of the chemical pots.

(2) To feed alum only, open the alum control valve marked "high" about half a turn. Determine the pH of the effluent; if it is greater than the optimum range previously determined, increase the alum dosage until the pH is within that range. If the pH is below the optimum range, add soda ash to bring it into range. Observe the water flow to waste and further adjust the control valves, if necessary, to obtain a crystal clear water, compensating with soda for each change of alum to keep within the optimum pH range.

p. Readjust the chlorinator, if necessary, to maintain 1.0 p.p.m. in the effluent after ten minutes of contact.

q. When the effluent comes clear, throttle the valve in the pump discharge pipe until the flow is approximately 10 gallons per minute, as indicated by the manometer. Set the lever of the control valve at "service", and open the valve in the pump discharge pipe. Open the valve in the filter discharge pipe slowly, as long as the effluent remains clear and until the flow is just sufficient for requirements over the period available, but not more than 100 gallons per minute, as indicated by the manometer. The plant is now in complete operation, and purified water is being delivered.

129. **To Wash.**— When the difference in pressure from inlet to outlet of the filter, as shown by the gauges, reaches between 10 and 12 pounds per square inch, it is necessary to wash the filter. To do this:

a. Throttle the valve in the pump discharge pipe to 10 gallons per minute. Close the filtered water discharge valves.

b. Shut off the alum and soda pots, but leave the chlorinator in operation.

c. Set the lever of the control valve at "washing", and slowly open the pump discharge valve sufficiently to obtain a flow of 100 gallons per minute, as indicated by the manometer. Observe the wash water, and if filter sand appears, throttle the valve in the pump discharge pipe until sand ceases to appear. Keep turning the rake handle in complete circles while washing. When the wash water effluent *begins* to clear, filter to waste, and return to service.

130. **Special Notes.**— *a.* After the final run in any one location, thoroughly wash the filter and completely drain all parts of the apparatus. Do not allow the inside of the filter to dry out if dirty. When draining, open all air cocks.

b. Examine chemical pots periodically. Keep all parts of pots and chemical piping clean. Flush out occasionally.

c. Do not open any valve quickly; sudden changes in direction of flow and surging in the filter should be avoided.

d. The chlorinator should not be shut down at any time when the plant is in operation, chlorinated water is desirable for backwashing and rewashing. The chlorine feed should be shut off only when the entire plant is shut down.

131. **Servicing Chlorinator.**— *a. Compensator.*— (1) The compensator can be tested readily by changing the inlet chlorine pressure or cylinder pressure, and observing that there is no change in flow of chlorine as indicated on the manometer until the cylinder pressure gets within 5 lbs. of the back pressure.

(2) The compensator which is a combined diaphragm-operated, pressure-reducing, control valve, is a delicate apparatus and should not be tampered with in the field. The control valve, however, can be readily disassembled for cleaning, and the chlorine pressure reducing valve seat can also be cleaned by removing the cap. This should be done only when all chlorine pressure has been removed from the apparatus.

b. Setting and Clearing Chlorinator Valves.— (1) *Setting the control valve.*— This control valve is a delicate metering valve and should be treated carefully. The valve stem does not rotate, but is moved in or out by the difference in the number of threads per inch on the stem and on the handle.

(2) After these valves have been disassembled for any reason, the adjustment often becomes disturbed. The valve is in correct adjustment when the handle just covers the threads on the valve body when the valve is closed. Note particularly, in this connection, that when the valve is closed, the handle should not cover the air vent hole in the valve body. If the valve handle screws down too far before the valve stem seats, readjustment is required. To do this, unscrew the valve handle until the threads on the handle are disengaged from those on the valve body. Then push the stem down through the packing a slight distance by exerting pressure on the valve handle. Then re-engage the threads on the valve handle with those on the body and close the valve, noting if the adjustment is correct.

(3) Should the above adjustment be carried too far and several of the threads on the valve body be exposed after the valve stem has reached the seat, the reverse adjustment should be made. The adjustment can be carried out to advantage by first removing the handle entirely from the stem, and then screwing it on in the reverse position until it bears against the packing nut, which will have the effect of withdrawing the stem.

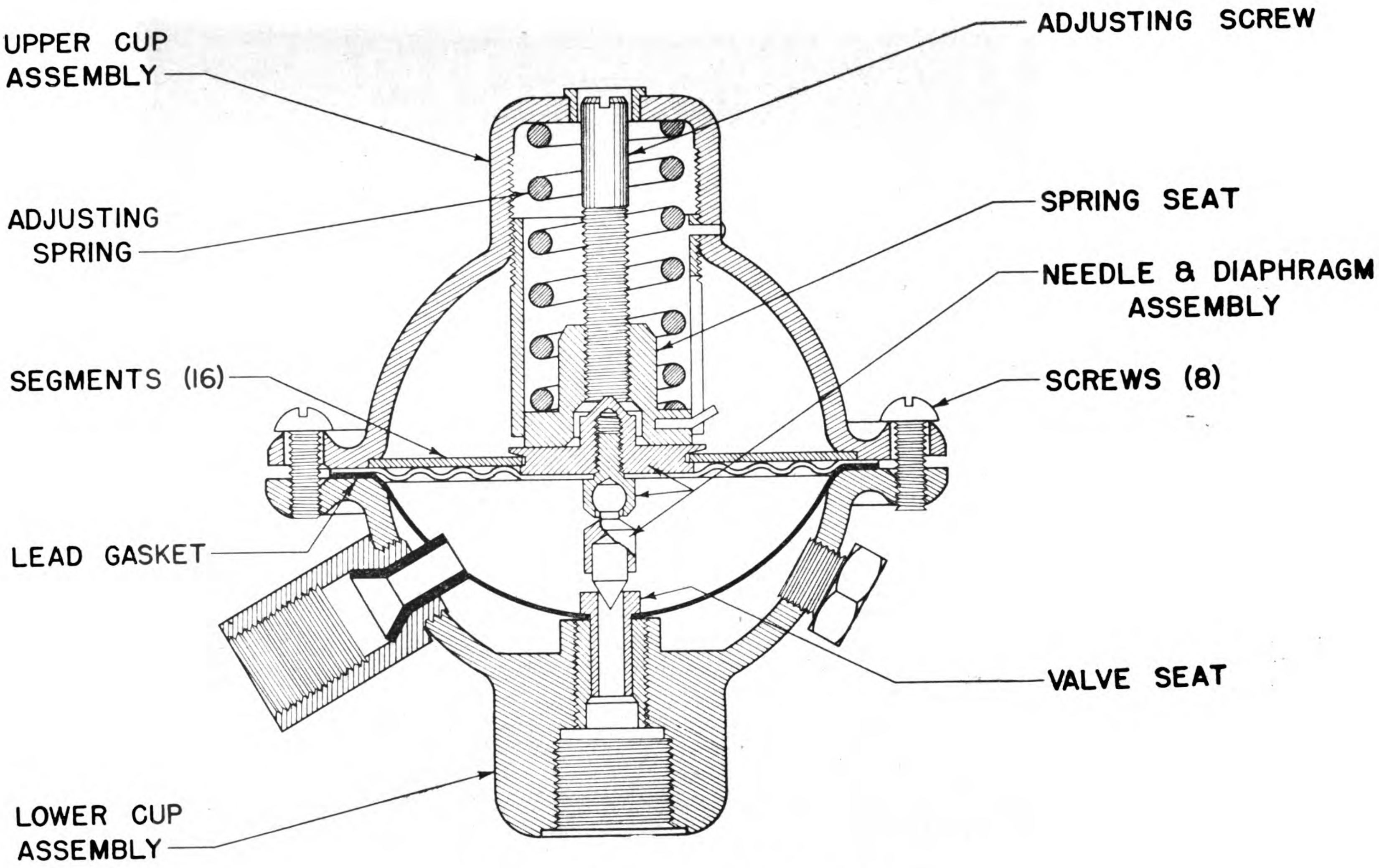


Fig. 46. Section Thru Back Pressure Valve.

(4) When replacing these valves on the machine, always see that the handle is backed off part way in order to open the valve, so as not to force the stem into the seat when the large union nut is tightened.

(5) These valves are provided with packing nuts having left hand threads, and consequently, when it is desired to take up on the packing nut, it should be screwed to the left.

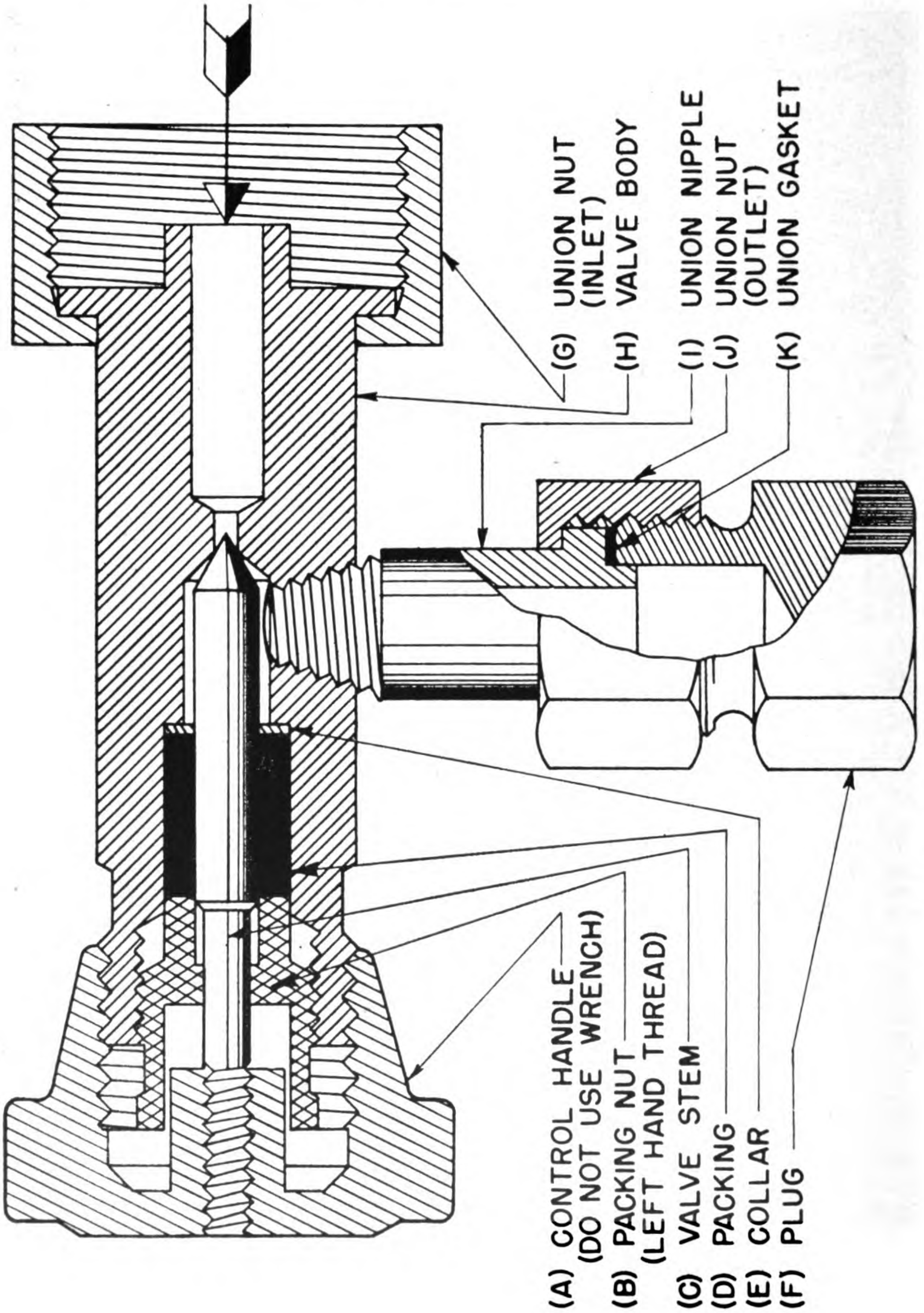


Fig. 47. Detail of Auxiliary Cylinder Valve.

c. Cleaning needle valve.—When it is necessary to remove the needle valve and lock nuts located under the compensator cap for the purpose of cleaning or repairs, do not remove or change the position of the two small, split, set nuts which are directly underneath the needle valve saddle. This will retain the original factory adjustment. If, however, they have to be removed on account of breakage of the pin itself, replace them in such a position that the point of the needle just enters the seat. This will be approximately the proper setting. It may be necessary to make this adjustment several times before the compensator operates properly. Both sides of the saddle, or bar holding the needle, should be the same distance from the face of the plate, so that the bar is parallel to the plate.

d. Back pressure valve.— (Fig. 46) (1) The back pressure valve consists of a diaphragm needle valve and spring, the tension of the spring, being such as to control the pressure at which the diaphragm needle valve opens. The spring tension is adjusted with a small screw driver, through a hole in the center of the top cap. The point of application of the chlorine is directly connected to the discharge of this valve, and in some instances, it will have to act as a check valve to prevent water backing into the apparatus. The valve is constructed of corrosion-resistant material.

(2) Should the back pressure gauge indicate a rising pressure above normal, throttle down on the control valve to hold it below the maximum indicated on the back pressure gauge. It is likely that the increase may be due to the presence of water in the back pressure valve, and the back pressure will not be restored to normal until the water has been forced from the line. When this occurs, the back pressure should fall to normal, and the control valve may then be readjusted to the proper setting. If, after allowing time for the water to be forced out, the back pressure does not fall, there must be a stoppage in the back pressure valve, the discharge line, or in the diffusor. This should be investigated as chlorination is impaired.

e. Auxiliary cylinder valve.— (Fig. 47) (1) Test the valve frequently for leaks (par. 131 k.) Should a leak develop around the valve stem, remove the control handle A, then tighten nut B by turning to the left (left-hand thread) until the leak is stopped. Use a wrench not over six inches long, and do not put excessive strain on the threads. Do not remove the packing nut B. Next, replace the control handle on the stem, and screw the handle down on the valve body until the valve is closed. Do not use a wrench on the handle of the valve.

(2) The above operation can be carried out while the equipment is in operation. In case the outlet union from the auxiliary cylinder valve is not connected up to the equipment, the plug F must be inserted in the outlet union, making sure that the gasket K is in place before the above adjustments are made.

f. Chlorine Orifice and Manometer Scale.— (1) Different orifices and scales are available for this apparatus to cover different capacities. The orifice screws into an adapter, inside the manometer orifice block. The scale is clipped lightly to the manometer tube and is adjustable for height.

(2) It will be noticed that at the bottom of the manometer there are two inner tubes. The shorter is the index tube, and the upper end of this should always be above the liquid level in the manometer. To insure accurate meter reading, and before any readings are taken, the zero of the scale and the meniscus, or liquid level, in the short index tube must be made to correspond by raising or lowering the scale on the manometer.

(3) The manometer liquid is added through the filling screw at the top of the manometer reservoir. It is occasionally necessary to add more liquid to the manometer. Normally there should be about 4 cc. of liquid in the manometer tube; this amount brings the level about half way up the index tube, but whenever the amount of liquid falls below the bend in the inside tubes, a sufficient amount should be added to bring the total quantity up to the desired level.

(4) The liquid in the manometer will not act normally on starting up until the back pressure has been built up, by the action of the back pressure valve, to the normal amount and gas is flowing steadily to the point of application. It is well to allow the back pressure to build up slowly to avoid a sudden increase in rate of flow when the back pressure valve opens. This sudden increase may be sufficient to blow the manometer liquid up into the manometer reservoir. When the rate of flow is restored to normal, this will drain back, usually with little or no loss of liquid. If some liquid is blown off, however, it will usually evaporate in other parts of the apparatus, doing no harm.

g. Liquefaction of chlorine gas in chlorinator.— Usually this is indicated by irregular and violent pulsations of the flow meter, and if permitted to continue, will cause stoppage of the valve ports. It is caused by the control apparatus being at a lower temperature than the chlorine cylinders, and may be eliminated by changing the heating arrangement to throw more heat to the control apparatus and less to the cylinders. Various methods are available for lowering the temperature of the chlorine cylinders. A jacket or covering of asbestos cloth or other insulating material can be made to fit over the chlorine cylinders and thus retard the absorption of heat from the surrounding air. This combined with a copper coil wrapped around the cylinder through which a small stream of cold water passes, makes an effective means of lowering the temperature and pressure within the chlorine cylinders.

h. General Service Notes.— (1) *Care of equipment.*— All connections should be tested each day for signs of chlorine leaks — NO LEAKS OF ANY KIND SHOULD BE PERMITTED. Green deposits or color on the metal parts of the equipment indicate the presence of free chlorine. There should be no odor of chlorine at the apparatus, except when a connection is broken for making changes. Test for the leaks with ammonia (par. 131 k). Stop every leak as soon as discovered.

(2) All openings in the apparatus should be plugged or closed up whenever any connection is broken, even for a short time. This will prevent dampness getting into the apparatus and causing trouble. Deposits form much faster in the presence of moisture.

(3) Do not damage the heads of screws or bolts. Use the proper size tool when removing screws or bolts. Since these are not removed often, any bolt or screw will freeze slightly, and if the head is deformed difficulty and delay will result.

(4) Use Dixon's Graphitoleo No. 692 on all hard rubber threads before assembling them, to prevent the parts freezing together. Do not use tools for tightening threaded hard rubber parts together. Hand tightness is all that is required.

(5) Do not use water when cleaning any part of the apparatus except glass parts, or parts normally in contact with water. This is important. Make sure that all metal parts which come in contact with chlorine are dry. When it becomes necessary to clean out deposits in any part of the apparatus use carbon tetrachloride (Carbona), chloroform, or wood alcohol. Do not use grain or denatured alcohol, ether, gasoline, or any petroleum distillates. Brown deposits of manganese dioxide can be removed by means of a strong solution of sodium bisulphite.

(6) Keep a plentiful supply of gaskets on hand in order to keep the union connections in good condition and tight without undue straining of the unions or fittings. Do not re-use gaskets.

(7) The unit should be drained whenever operations cease, even for a few hours. This not only eliminates the danger from freezing, but it considerably reduces the load on the truck when moving, and the air drawn into the system serves to aerate the filter. Drains have been provided at all the low points, but drainage is most effective when the truck is moving on the road, due to the accidental variations in level. The filter requires several hours to drain completely.

(8) Good lubrication of all moving parts, particularly of the pump, is essential.

i. Emergency Precautions.— (1) Physiologically, chlorine is a powerful respiratory irritant. However, in concentrations far below injurious ones it gives warning of its presence. In any atmosphere containing chlorine, short or shallow breathing should be used. Low concentrations in enclosed spaces sometimes cause nausea and coughing because workmen do not realize that it is impossible for them to become hardened to continued exposure. Chlorine produces no cumulative effects, and complete recovery from mild exposure usually occurs. As chlorine is particularly irritating to persons afflicted with asthma and certain types of chronic bronchitis, such persons, especially, should avoid exposure.

(2) It is important that some form of protection be provided for emergencies. For this purpose, a suitable gas mask should be at hand and located at a readily accessible point outside of the area likely to be affected in case of accident.

(3) The instructions accompanying a mask concerning its care and use should be obeyed implicitly. Everyone who is in danger of being accidently exposed to high concentrations of chlorine should be provided with a gas mask, preferably to be used by no one else. He should be familiar with the instructions accompanying it and trained to hold his breath and to put the mask on quickly and properly. Periodic strict inspection and maintenance of approved gas masks are essential.

(4) When chlorine is noticeable in the atmosphere, either by sight or smell, the following immediate precautions should be taken:

Close the tank valve promptly.

Avoid panic. Warning of the presence of chlorine is given immediately by its pungent odor and greenish-yellow color.

Refrain from coughing.

Keep the mouth closed.

Avoid deep breathing.

Keep the head high as chlorine seeks the lowest possible level.

Withdraw from the affected area. The odor of the gas is so disagreeable in minute quantities that all persons in the affected area would be aware of its presence.

If a leak develops in a cylinder valve, be sure the leaking cylinder is upright. This will prevent the escape of liquid and under these conditions vaporization diminishes rapidly as natural chilling will take place and the escape of chlorine into the air will then be slow.

Remove persons affected by chlorine to the open air and away from all chlorine gas. Place the patient flat on his back. Keep patient warm and have his head slightly elevated.

Call Hospital immediately.

j. Chlorine valves.— (1) The proper handling of chlorine valves is of vital importance in all installations. When the container is in operating service for several days or more, open and close the valve once each day to prevent the threads on valve stem from becoming set in any one position. Failure to rotate the stem frequently will cause the threads, to freeze in the valve body, and if stem is forced at this stage, damage to the valve may result.

(2) When opening a valve, do not give the valve stem more than 1¼ turns, and do not make a habit of using a wrench longer than 6 inches. It is unnecessary to use much force in closing valves.

(3) *Warning:* Never remove the fusible metal plug in the cylinder valve body or in the ton-container head. A core of fusible metal is poured in the plug, which has a melting point of between 157° and 162° F. The fusible safety plug is designed to release the cylinder pressure in case of fire.

(4) In making connections to chlorine valves and flexible connections, always use the proper lead gasket to the union or yoke type joints.

k. Test for Chlorine Leaks.— To locate a leak, remove the stopper from the bottle of ammonia which is shipped with the apparatus, and hold the open bottle near all joints, piping and valves. White fumes of ammonium chloride indicate the location of the leak.

Section IV

THE PORTABLE WATER PURIFICATION UNIT

132. **Description.**— *a.* The Unit (see Figure 48), consists essentially of a (Fig. 49) Gasoline Engine Driven Centrifugal Pump, a Chlorinator, a chemical feed tank, and a (Fig. 50) Pressure Filter with interconnecting piping. Suitable suction hose and discharge hose is provided to carry the water to and from the Unit.

b. The filter consists of a closed monel metal tank with inlet and outlet piping, control valves which control the flow of water for all operations, and internal collecting and distributing system located at the bottom of the tank, and contains, from the bottom up, a 4 inch layer of fine gravel and an 18 inch layer of selected and graded sand.

c. Any portable water purification unit is limited by the allowable weight of the assembled equipment. The principal capacity-determining item is the filter. Because of both size and weight, a filter not over four feet high and about 18 inches in diameter is the largest that is practicable. It often becomes necessary to deliver as much water as possible through the filter and to the troops, even to the extent of sacrificing physical ap-

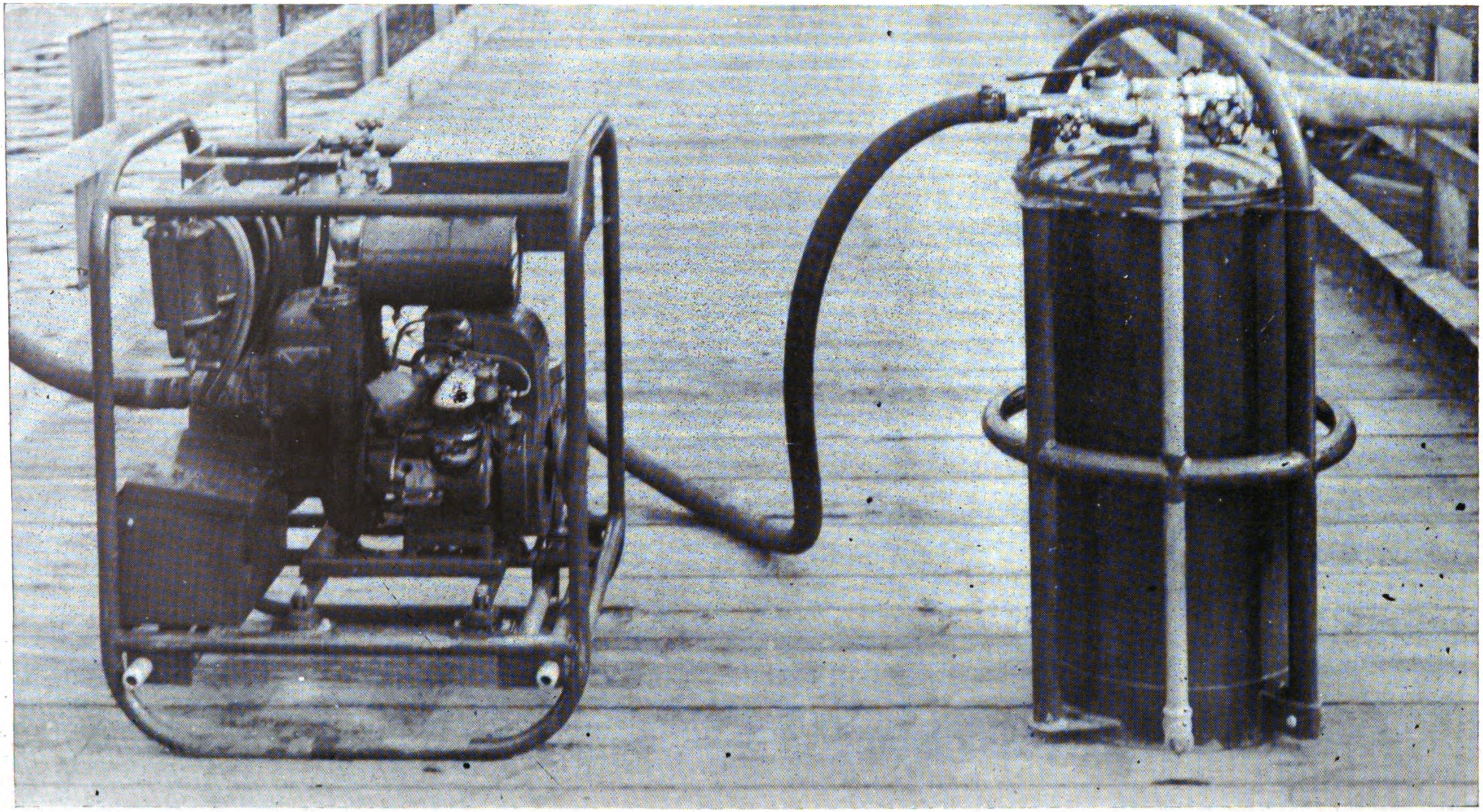
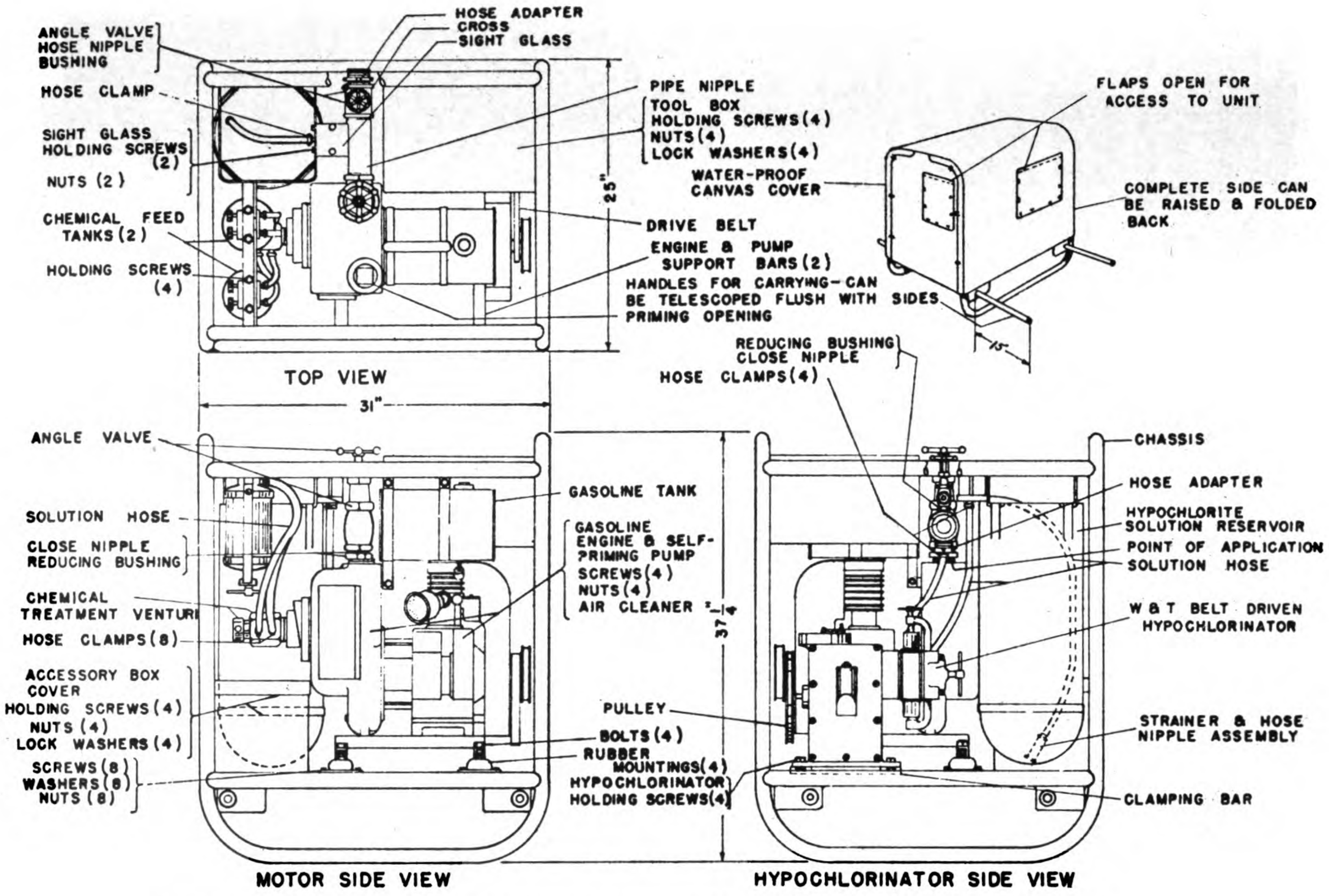
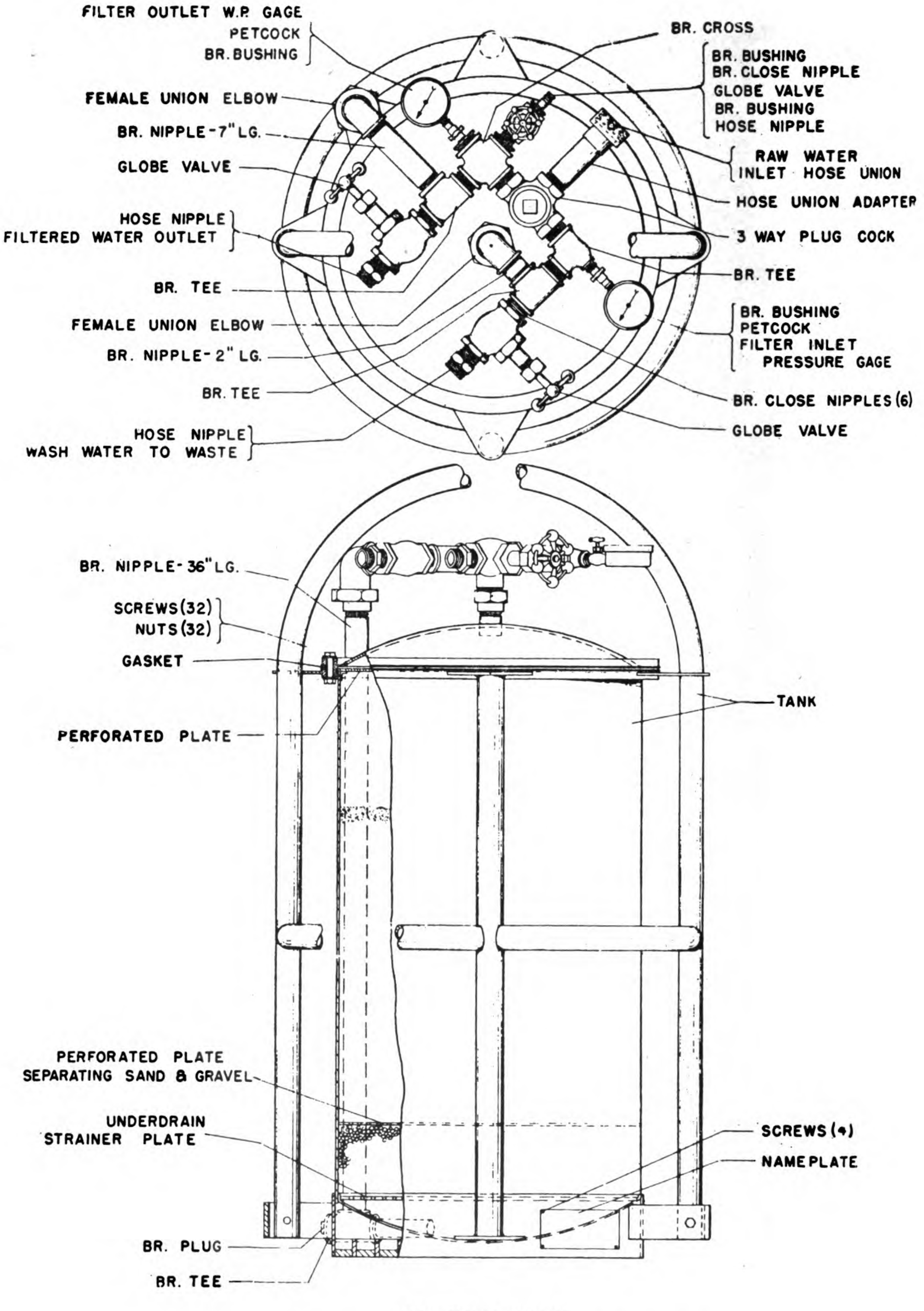


Figure 48. Portable Water Purification Unit.



PORTABLE PUMPING, STERILIZATION AND CHEMICAL TREATMENT PLANT

Figure 49.



FILTER UNIT
FOR USE WITH PORTABLE PUMPING,
STERILIZATION & CHEMICAL TREATMENT PLANT

Figure 50.

pearance of the water. If 15 g.p.m. is delivered through the present portable filter, it will be operating at a rate of 10.4 gallons per square foot of filter area per minute, which is roughly four times the usual rate for rapid sand filters.

133. **Filter.**— (Fig. 50) The rate at which the filter is operated should therefore be governed by the character of the raw water and the requirements of the troops. If the raw water is relatively clear, the filter can be operated at a high capacity for a considerable period of time. If the water is turbid, the rate should be reduced by throttling the pump discharge valve until a rate is found at which a clear effluent can be obtained. Except when pressed for a greater delivery of filtered water it is good practice to operate the unit at less than half the maximum capacity and never operate at a capacity higher than necessary to obtain the daily requirement in the time allotted.

134. **Chlorinator.**— The chlorinator for this unit is designed to pump hypochlorite solution. Best results will be obtained by making solutions from a high test hypochlorite, which is a dry powder, packed in small containers which give instructions for preparation of the solution. Only part of the hypochlorite in a container will be used for each batch. It is important to store the extra chemical in dry, air-tight containers. Mason jars with gaskets are suitable.

135. **Operating Procedure.**— *a.* Attach the strainer to the suction hose and connect the hose to the pump suction, making sure that gaskets are in place in all couplings and that all joints are made tight. Select a good spot, preferably a deep one, in the stream or pond and fix the strainer to a stake midway between the surface and the bottom. The suction line should be no longer than necessary and should be laid on a steady down grade from the pump to the strainer to avoid air pockets and relieve extra load on the pump.

b. Connect the pump discharge to the filter unit with a 10-ft. length of suction hose. Connect from the filter outlet to the tank with the discharge hose.

c. The suction hose, the discharge hose, and the waste hose are all furnished in short lengths so that no greater hose length than is actually required need be used.

d. Connect the waste hose to the waste discharge pipe, and arrange it so that the waste water will be carried away from the unit down stream from the intake.

e. Open the pump discharge valve very slightly, and set the filter control valves for the washing operation. This setting permits the filter to fill from the bottom, and the air to discharge upwards through the gravel and sand and out through the waste line. (Air is lighter than water.)

f. Never fill the filter from the top as the incoming water will dig holes and ridges in the surface of the sand bed and interfere with proper operation.

g. Fill the pump engine crankcase with proper grade of oil and make sure that pump bearings are properly lubricated.

h. Fill the pump priming chamber with water and start the pump in operation. If the pump fails to pick up its suction within a few minutes, check the suction line joints for possible leaks and reprime the pump.

i. Allow the filter to fill slowly, without increasing the opening of the pump discharge valve, while preparing the hypochlorite solution as follows: Add 6 ounces (about 6 "mess kit" spoonfuls) of powdered hypochlorite to the rubber hypochlorite solution bag about one-third full of water and stir with a clean stick. Adjust chlorinator by turning stroke control handle until the effluent water has a residual chlorine content of 1.0 p.p.m. If sufficient residual chlorine can not be obtained at maximum adjustment of the chlorinator, increase the strength of the solution. In testing for chlorine, allow the water sample to stand for 10 minutes before adding orthotolidine. Allow 5 minutes between the time orthotolidine is added and chlorine content is read with the comparator (Appendix I). These periods should be increased if the water temperature is below 60° F.

j. After all the air is expelled from the filter and water flows from air cock in the top of the filter, close the air cock and continue to wash until the effluent starts to clear, then set the control valves for "Filter-to-waste", and see that the alum and soda pots are filled. This operation displaces raw water from the strainer system and permits a coating of floc to form on the sand grains because the alum and soda feeds are filled and adjusted to the correct dosage and the optimum pH range, determined as described in Sec. 2 this chapter, while filtering to waste.

(2) To fill feed tanks close the regulating valves on each tank, and remove feed tanks.

(3) After full feed tanks have been replaced, open wide the regulating valves on the line from the inlet side of the Venturi to the feed tank, and adjust the valves on the line from the feed tank to the outlet side (nearest pump suction) of the Venturi, a little at a time, to the desired dosage.

k. When the chemical dosages have been properly adjusted and the effluent (water leaving filter) becomes clear, shift the discharge so that it delivers the filtered water to service. If the filter fails to deliver a clear or satisfactory water, check up on the coagulant feed lines and connections since clogged lines would prevent proper application of coagulants.

l. Continue to deliver water to service until the pressure loss between the inlet and the outlet of the filter increases to 10 lbs. per sq. in., then wash by setting filter valves as in filling, and filter to waste (as described above). If, before that pressure loss is reached, the filter fails to deliver clear water or floc appears in the water in the storage tank check to determine if the chemical dosage is still correct. (Sec. 2 this Chapter).

m. Always backwash with the chlorine feed operating, but with valves and the alum and soda feeds closed. *Always* start backwashing with the pump discharge valve opened only slightly and slowly increase the rate to the maximum permissible without loss of sand.

n. Chlorinator notes: (1) *Mixing Sterilizing Solution.*— When the water used to mix or dilute sterilizing solution for the chlorinator contains "hardness", (Par. 44) it will be necessary to precipitate as much as possible of this "hardness" previous to passing the solution through the chlorinator. Soda ash should be added to the water and all precipitate allowed to settle before adding hypochlorite. The amount of soda ash to be added can be determined experimentally by observing the precipitate. A slight excess is not in any way harmful.

(2) *Cleaning Chlorinator.*— If difficulty is observed in pumping the chlorine solution under circumstances where hard water is known to exist, the diaphragm and valves may be removed for cleaning. The effects of hard water are indicated by a white coating on all parts in contact with the sterilizing solution. This is most easily removed by soaking the parts in 5% hydrochloric acid, which may be obtained in any drug store. The commercial form of hydrochloric acid, known as muriatic acid, is acceptable.

Section V

ROTARY DRILL RIG

136. **Rotary Drill Rig.**— *a. Description.*— (1) The rig consists of a truck mounted drill-frame, rotary type drill head assembly, hoist assembly, golding mast, slush pump, oil pump for the hydraulic system, oil storage tank, tool box, supply chest, and an independent gasoline power unit (see Fig. 51). It is equipped with sufficient drilling tools and accessories to drill a 5″ well 1000 feet deep. (Fig. 52).

(2) *The power unit* is a 217 H.P. Buda, water cooled, gasoline engine equipped with magneto ignition, electric starting system, and a built-in governor. The starter button and ignition switch are mounted on the rear panel section of the drill frame at the driller's platform. An auxiliary starter button and ignition switch are mounted on the engine housing.

(3) *The slush pump.*— *(a)* A Gardner-Denver Model pump FF-FXF is mounted in front of the engine on the drill frame. It is a gear driven, reciprocating pump with 4-inch cylinder and 5-inch stroke. It will deliver at pressures from 50 to 300 lb./sq. in. depending on the depth

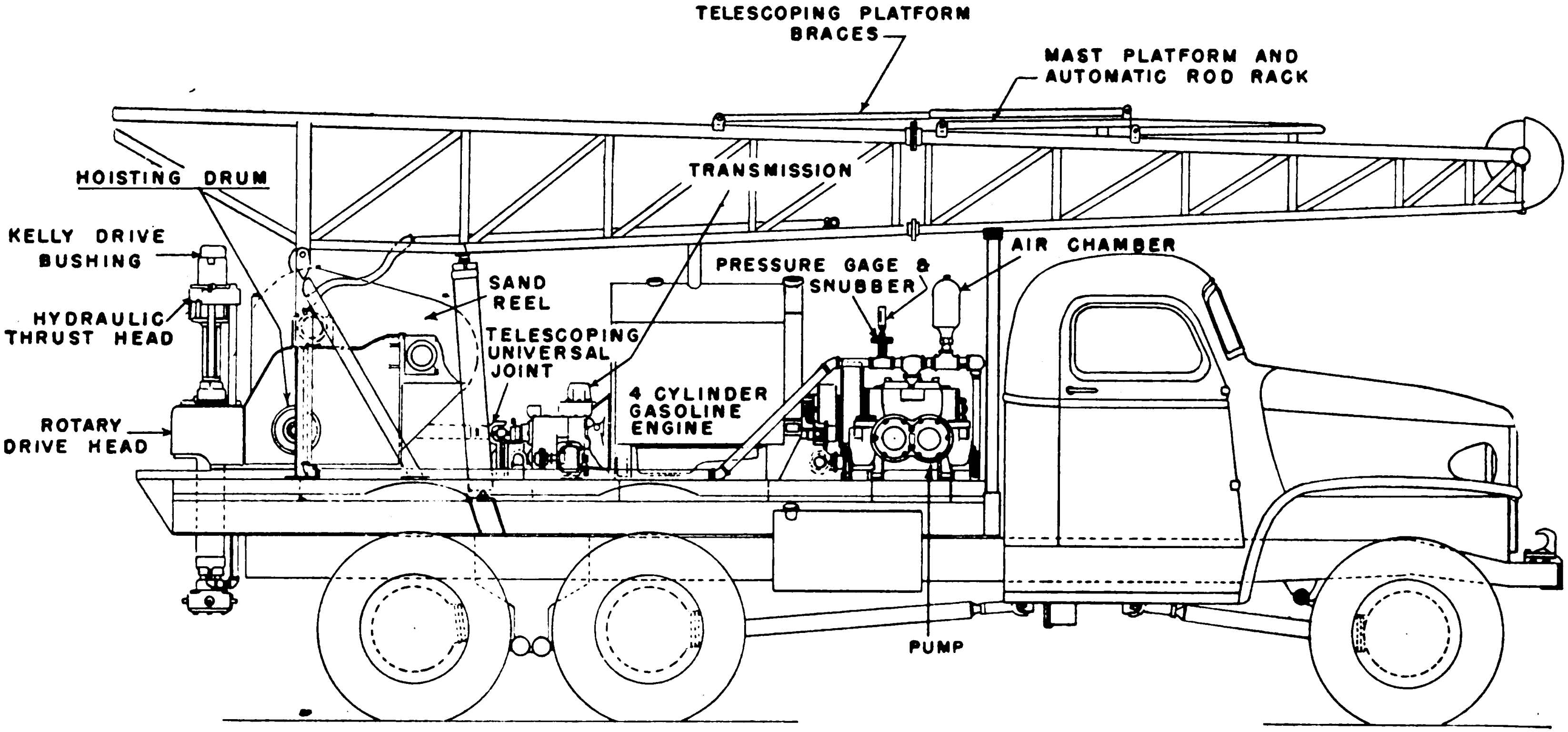


Figure 51a. Rotary Drill Rig in Traveling Position

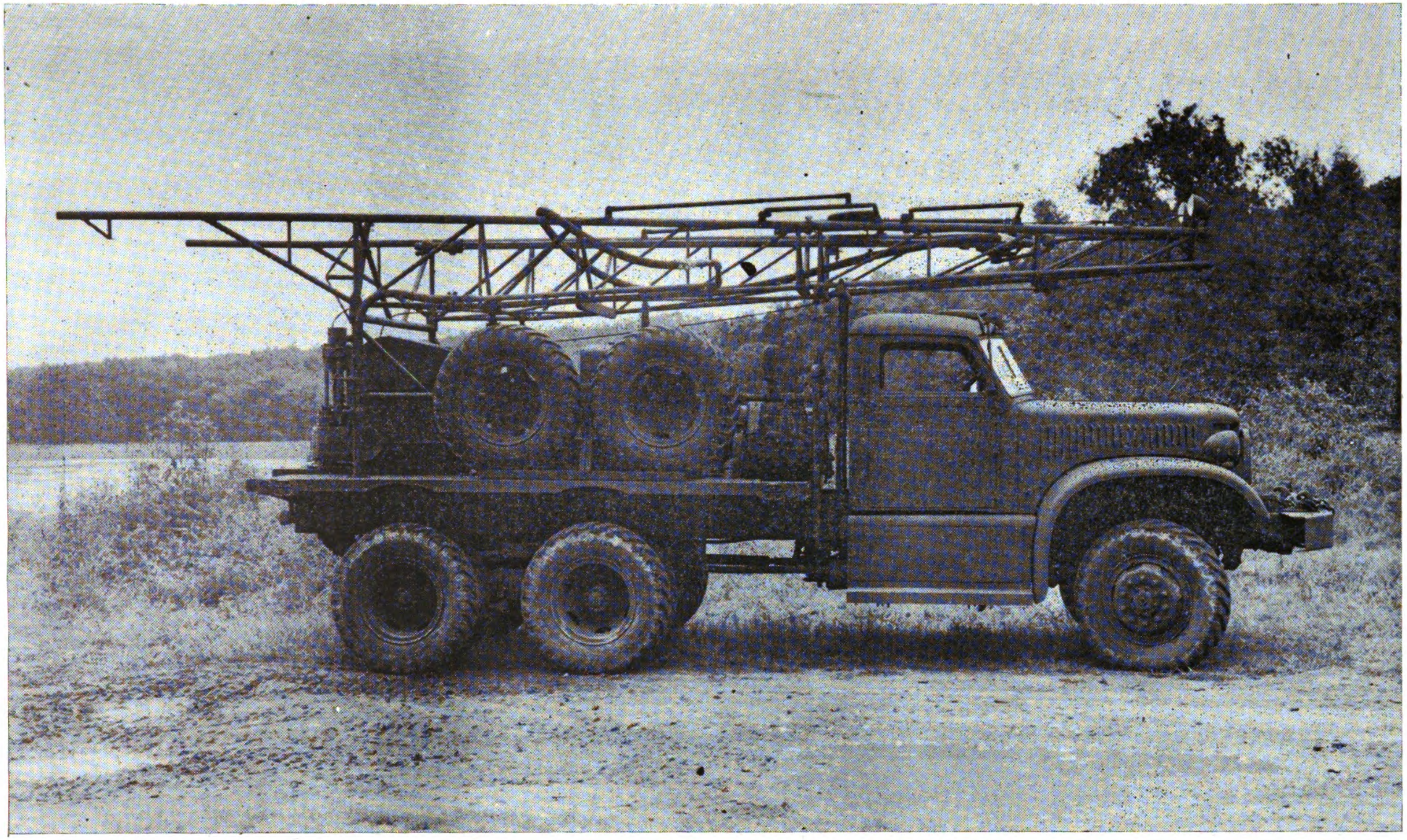


Figure 51b. Rotary Drill Rig in Traveling Position

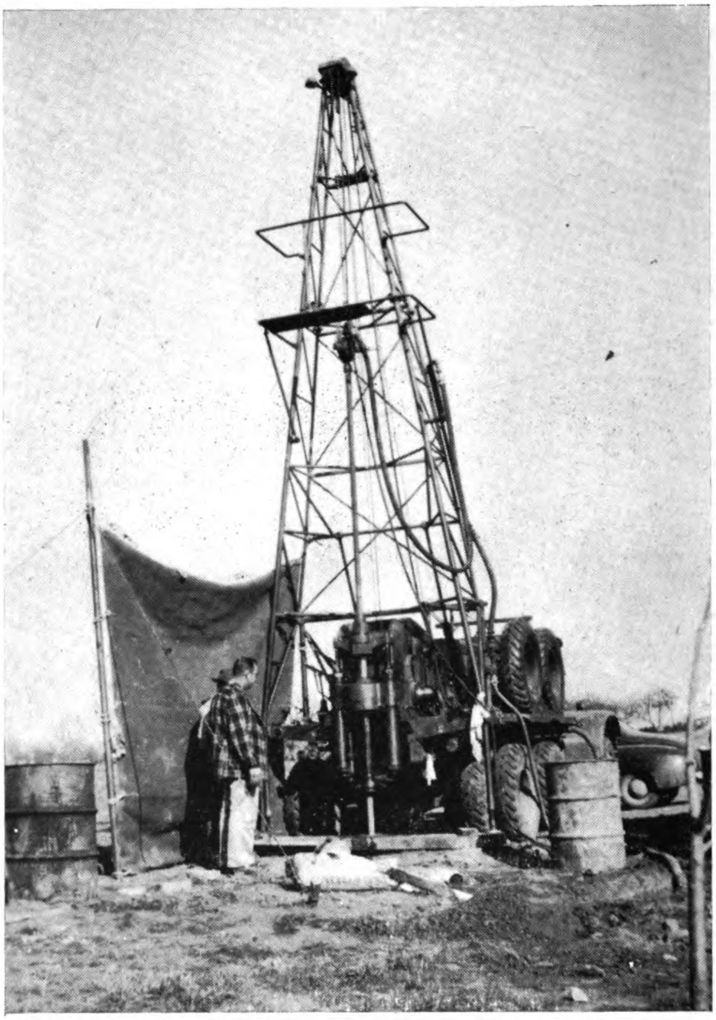


Figure 51c. Rotary Drill Rig in Operating Position

of the well. The maximum pressure for which this pump is designed is 900 lb./sq. in., but the engine has only sufficient power for operation pressures below 500 lb./sq. in. when the engine also drives the drill. This pump is equipped with a relief valve adjusted to relieve at about 500 lb./sq. in. All pipe fittings are tested at 2000 lbs./sq. in.

(b) The pump drive consists of a universal joint from a flange on front of the motor crankshaft, and an oil sealed chain drive case to the jack shaft on the pump. A friction clutch is mounted on the jack shaft of the pump, with the control lever at the rear of the drill frame near the driller's platform.

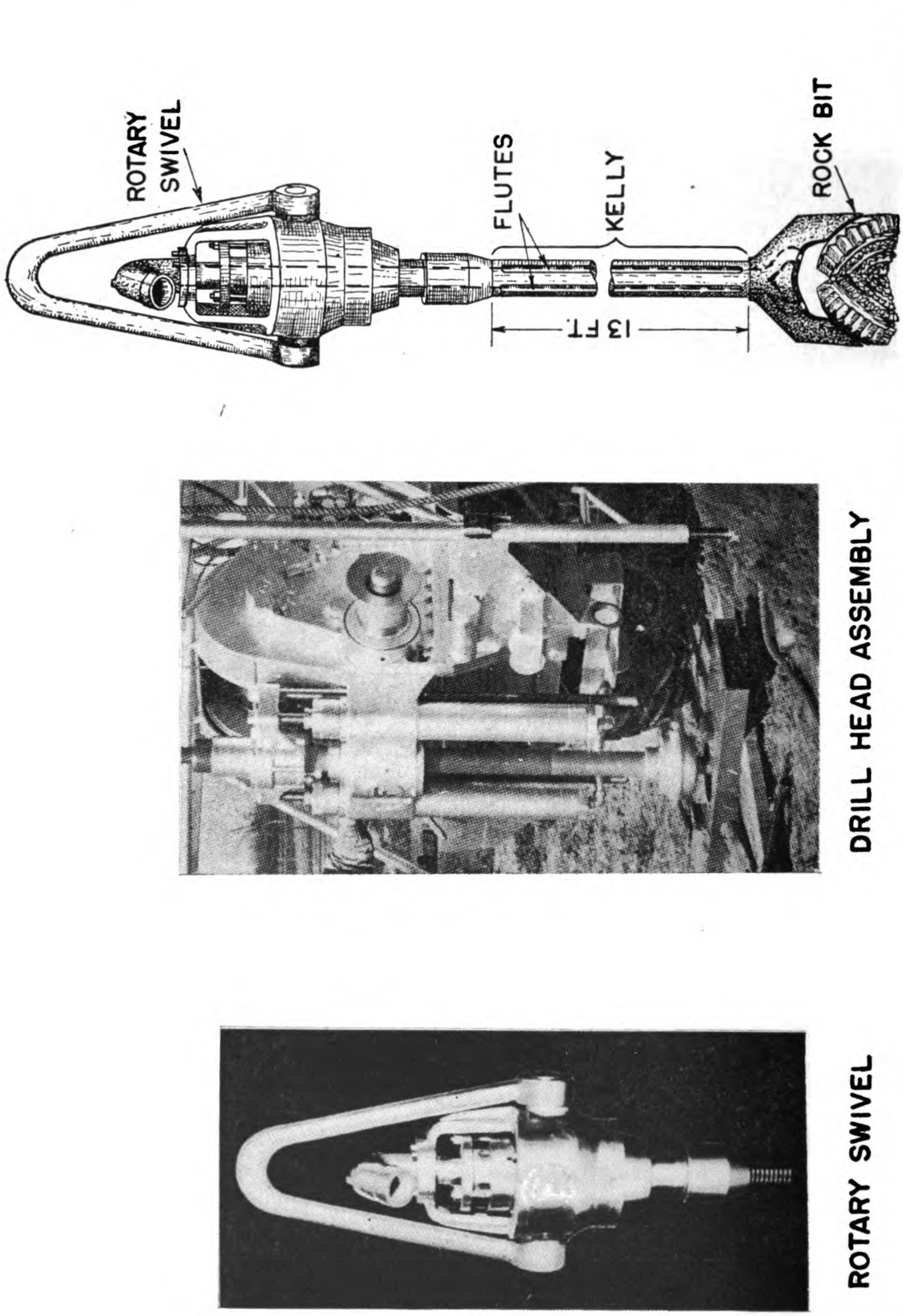
(c) The pump should be checked at each well site for worn valve inserts, valve seats, piston cups, and liners. Worn parts in the fluid end will cause the pump to buck and run unevenly. Mud with high sand content will wash out any of these parts, and if not replaced, the effic-

Figure 52. Rotary Well, Rig Tools.

iency of the pump will be reduced. Packing glands should be tightened firmly but not solidly. Worn or leaky packing causes excess wear on pump rods.

(4) *The mast assembly* is a 26-foot four-leg tubular steel structure, fitted with extensions and jack feet on the rear legs. It is built in two sections with flanged couplings in the center, and is equipped with

three sheaves, one each for the hoisting drum, sand reel drum, and catline, and hangers for the kelly and swivel (Fig. 53) during operations. It has a folding rack on the rear for a crew member to stand on while removing the drill stem from the hole. The gross capacity of the mast is 40,000 lbs. It is raised and lowered by two hydraulic lift cylinders operated by a four-way control valve from the right side of the drill frame.



KELLY, SWIVEL, & BIT ASSEMBLY

DRILL HEAD ASSEMBLY

ROTARY SWIVEL

Figure 53. Details of Rotary Well Rig.

(5) *Oil pump assembly.*— The oil pump is a Vickers Model V-134-X vane type for 1000 lb./sq. in. pressure. The hydraulic system is designed for a working pressure of 300 pounds per sq. in. The pump is chain driven, with power from the front of the power unit on the same shaft that drives the slush pump. It is equipped with a relief valve adjusted for 300 pounds per sq. in. and all necessary fittings for operating the hydraulic system.

(6) *Hoist assembly.— (a)* The hoist assembly consists of a main hoist, sand reel hoist, and cathead. The unit is sectionalized to permit repair or replacement without dismantling the entire assembly, and component parts of the unit are interchangeable.

(b) Main hoist.— The main hoist consists of a drum, friction clutch and brake. The drum is constructed of steel, with a spool 7 inches in diameter and 18½ inch flanges. Line capacities for the drum are:

½″	wire	rope	550 ft.
9/16″	″	″	435 ft.
⅝″	″	″	360 ft.

It is chain driven with reduction gears in the engine transmission located on the power unit. The drum is equipped with a two-plate disc type friction clutch and a friction type brake having approximately 220 square inches of braking surface. It has four speeds with maximum bare drum line pull of 22,750 pounds in first gear and 3,590 pounds in fourth gear. All controls are mounted at the rear of the assembly near the driller's platform.

(c) Sand reel.— The sand reel is mounted forward of the main hoist assembly and consists of a drum, clutch, and brake. It is chain driven with the same source of power as the main hoist, and is equipped with a jaw type, undercut tooth clutch and friction brake having approximately 150 sq. in. of braking surface. Real line capacities are:

⅜″	wire	rope	1,650 ft.
7/16″	″	″	1,200 ft.

All controls are mounted on left side near the driller's platform.

(d) The cat head.— The cat head, of cast iron construction, is keyed to the main hoist drive and mounted on the right side of the hoist assembly. It can operate independently of the main hoist and sand reel.

(7) *Rotary Drill head assembly.— (a)* The rotary drill head consists of a rotary table, drill rod, "kelly" (Fig. 53) and rod chuck, and hydraulic feed system mounted within a reinforced recess on the rear center of the drill frame.

(b) The rotary table is driven by a main drive shaft from the engine with a jaw type clutch mounted between the rotary table and main hoist power take-off. Rotary speeds for the table, at 1600 engine R.P.M., are:

First	38.2 R.P.M.
Second	73.8 R.P.M.
Third	146.6 R.P.M.
Fourth	242.0 R.P.M.

(*c*) *Hydraulic.*— The hydraulic feed system consists of two hydraulic cylinders having a feed stroke of 30″, two guide rods, and four-way valve control for operating.

(*d*) All controls for the drill head assembly are mounted on the left rear at the driller's platform.

(8) *Drill Frame.*— The drill frame is electric welded of 4-inch channels and covered with 1/8″ non-skid floor plate. It is angle-iron reinforced and is bolted to the frame of the truck. It can be used as a foundation for the drilling unit when the unit is removed from the truck.

b. *General information.*— (1) The entire unit, less the truck, but complete with tools, "kelly", swivel, spider mat, and suction and swivel hoses, weighs approximately 8,650 pounds. It has an over-all width of 8 feet and over-all height with mast folded of approximately 9 feet 8 inches.

(2) The rig uses a water-mud circulation system for cleaning the bit, clearing the cuttings from the hole, and sealing the walls of the hole to prevent cave-ins, thus the casing does not have to be placed while drilling. The fluid (mud) acts as a lubricant for the bit and as a jet to cut away soft formations, and speed up the drilling.

137. **Crew.**— For normal operations, a three-man crew is required, consisting of a driller and two helpers. The driller operates the rig and supervises the drilling operation, is responsible for the care of the equipment, and must be experienced in drilling and formation testing with rotary equipment. The two helpers, who act as assistants should have a general knowledge of mechanical equipment and be able to make repairs to the equipment.

138. **Procedure.**— *a*. The steps in the drilling procedure are (1) setting up; (2) drilling; (3) testing; and (4) completion of the well.

b. (1) The drill unit is set up on a solid foundation. Footings placed under the wheels will keep the foundation from settling under the weight of the drilling equipment and surface water should be ditched away from the well site to prevent washing away the foundation.

(2) A suction pit at least 4′ x 4′ square and 3′ deep is dug as near to the pump as possible and filled with water transported to the site. A settling ditch is dug from the well to the suction pit. This ditch should be deep enough to carry the flow of drilling fluid and should have as little slope as is necessary to carry the fluid into the suction pit. It should be cleaned frequently to prevent the bit cuttings from filling in the suction pit and plugging the suction hose and valves on the slush pump.

(3) Most surface formations contain enough clay deposit to build up a drilling fluid and it is not necessary to mix mud before the drilling starts. Water is circulated as the well is spudded in and gradually conditioned. If the body of the fluid needs to be increased, commercial fluid conditioners and weighting material may be added by pouring them into

the suction or mixing pit and jetting. By digging a mixing pit in the circulation ditch and jetting the fluid as it flows through this pit, the fluid will build up a high clay content. It is necessary for the fluid to have body so that it can carry the cuttings away from the bit. Adding water in the ditch near the outlet at the well will not only reduce the weight of the fluid but will also drop out the sand and cuttings. The desired weight for drilling fluid is between eight and twelve pounds per gallon.

(4) Before the unit is operated, lubrication should be checked, and while operating, the lubrication chart should be followed. To avoid accidents, lubricate only while the machinery is stopped. Check to see that all clutches are disengaged before starting the engine.

c. The drilling operation.— This is a general procedure and will not apply directly to all situations. Only experience can determine the proper steps to take. The operations are as follows:

(1) The first step is known as "spudding in." To spud in, start the "kelly-joint" through the drill rod and connect a bit to the bottom. Drop the bit to the ground through the hole in the center of the spider mat.

(2) *Start the pump.* Before starting a new pump, or a pump that has been overhauled, check all bolts and nuts for tightness. To prevent wear on packing and fluid pistons, prime the pump by filling the intake valve chambers with water. If the pump does not pick up soon after starting, check the suction line for air leaks and see that the discharge line is open. Circulate the fluid slowly at first, and at the same time rotate the "kelly-joint" and put weight on the bit. It may be necessary to apply weight to the bit for the first few feet to force the bit into the formation by locking the "kelly-joint" to the drill rod and forcing the drill rod down with the hydraulic rams. When the hole reaches the depth of the "kelly-joint", the "kelly" is pulled out and the bit removed. The pump is not stopped until the lower "kelly" connection clears the spider mat, when making connections.

(3) The next step is to screw the bit on the drill collar and lower the section into the hole. Connect the "kelly" to the drill collar and continue drilling.

(4) A well of any desired depth may be obtained by adding joints of drill stem between the drill collar and the "kelly." After the weight of the drill stem becomes sufficient, it is not necessary to use the hydraulic rams. The weight of the drill stem increases as new joints are added until it becomes necessary to support most of the weight on the blocks, slacking off only the desired amount.

(5) Casing, larger than the bit size to be used, is run in the hole as soon as the porous surface formations have been drilled through. This is necessary to stop loss of circulation through gravel, sand, or quicksand formations found in the surface strata. This surface string of casing

need only be as deep as the surface strata, usually 10 to 20 feet. All drill tools that are in the hole are removed to run this surface string.

(6) To continue drilling, after the surface string is placed, the drill collar and bit are lowered into the hole and a joint of drill stem is connected onto the drill collar. This is lowered into the hole and the "kelly" is connected to the drill stem. The drill stem is 10 feet long and weighs 5 pounds per foot. The drill collar, which is 10 feet long, 3½ inches in diameter, and weighs 25 pounds per foot, is used as a coupling between the bit and drill stem. A special lifting plug is used to raise and lower the drill stem when not attached to the "kelly". This plug fits in the drill stem or drill collar and either wire rope or catline can be attached. Slips are used in the bushing in the spider mat, to wedge and hold the drill stem when new joints are added or as the drill stem is taken out of the hole. chain tongs are used to make up or break drill stem connections and all drill stem threads are cleaned and lubricated before connecting. This prevents galling the threads and having to use extensions on chain tong handles. Up to 75 foot lengths of drill stem can be raised or lowered in the hole with the catline. Wire line and hook attachments are used on depths greater than this and when the bit is stuck in the hole, or binds as it is removed.

(7) To change bits it is necessary to pull the drill stem out of the hole, racking it in the mast or laying it down on the ground; replace the worn bit, and run the drill stem back into the hole. The drill stem is broken into 20 foot joints when rocking the mast.

(8) When drilling in clay or soft shale formations, the cuttings may ball up and form a large knot on the bit. Increased pump pressure and decreased weight on the bit will usually prevent balling in these formations. If not, it may be overcome by holding the pipe off bottom and letting the pump wash the bit clean; by raising the pipe as high as the mast permits and dropping it close to the bottom without hitting; and by spinning the pipe at varied speeds. If these methods fail to clean the bit, it will have to be pulled and cleaned by hand. The bit will bind and cause considerable back-lash in the drill stem when drilling in these formations and bit cuttings will be large clay-like chunks.

(9) Some type of rock bit is best suited for drilling hard rocks or hard formations such as limestone, sandstone, and hard shale. The bit will bounce, giving a jarring affect, when drilling in hard formations and worn bits will turn hard and bind, as in clay formations. Bit cuttings will be fine chips in limestone and hard shale, and fine sand in sandstone. Care must be taken that bearings in the cutters of the bit do not become so worn that they will fall off. Recovery of lost cutters requires special tools and a considerable length of time.

(10) Care must be taken when using the "cat head" to move equipment with the "catline" or other ropes. The rope should be coiled

evenly on the cat head and overlaps should not be used at any time. "Surging" the rope on the cat head should be held to a minimum with heavy weights. If the rope becomes fouled on the cat head, stand clear until the cat head has been stopped.

139. **Testing for Strata.**— The principal means of testing for water bearing formations is by washing and analyzing bit cuttings from the circulation ditch, called ditch sampling, and by checking drilling fluid for loss of fluid through circulation or loss of weight caused by dilution from water in the formation.

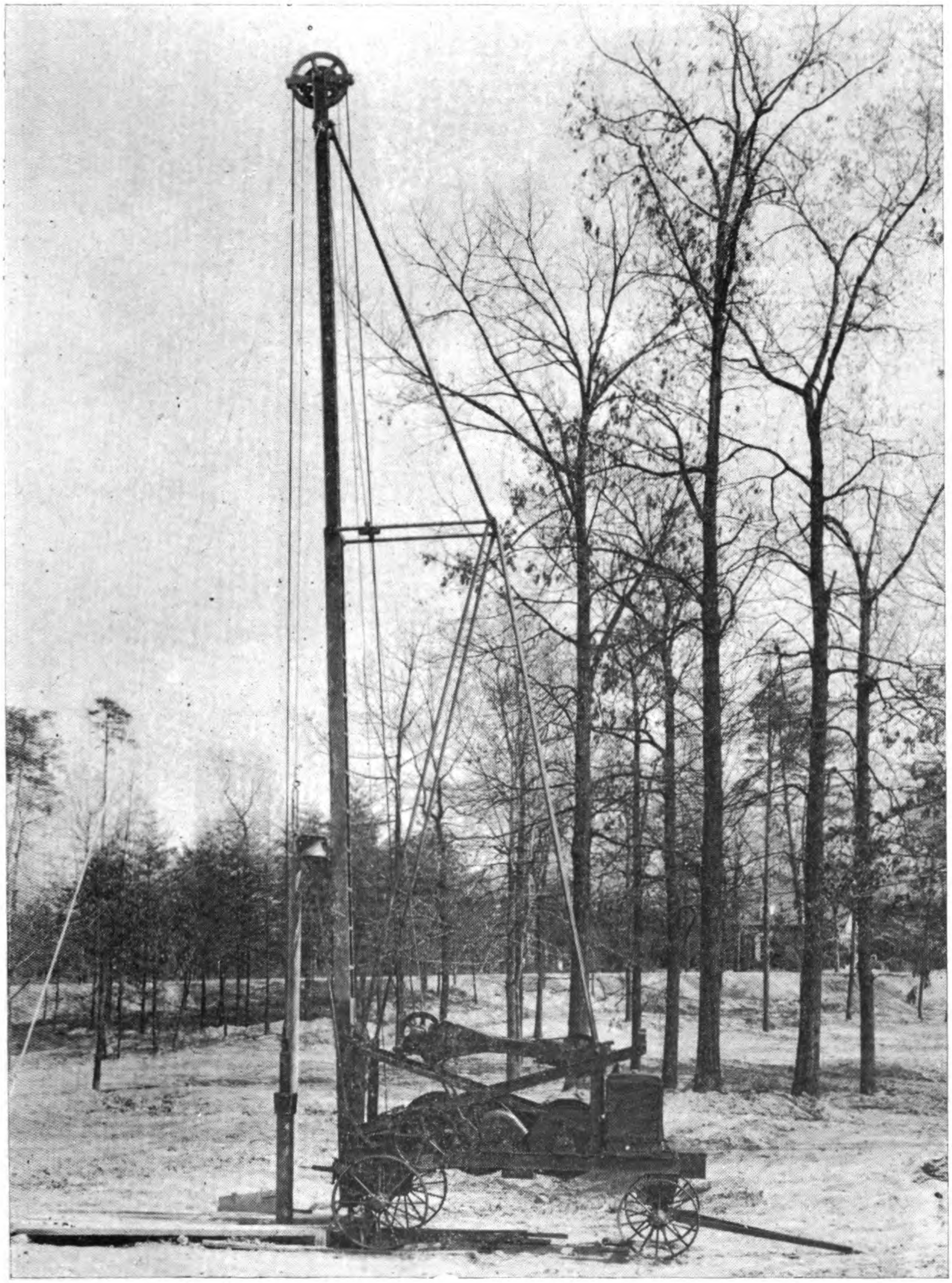


Figure 54. Percussion Well Rig in Operating Position

Figure 55. Closeup of Percussion Well Rig in Operating Position

Section VI

PERCUSSION WELL RIG

140. **Description.**— *a.* The rig (Figs. 54 & 55) consists of a wheel and spring mounted drill frame, telescoping mast, hoist assembly, spudder assembly, power unit, necessary tools (Fig. 56), and equipment for handling tools, weighing 1400 to 1600 pounds, to a depth of about 600 feet.

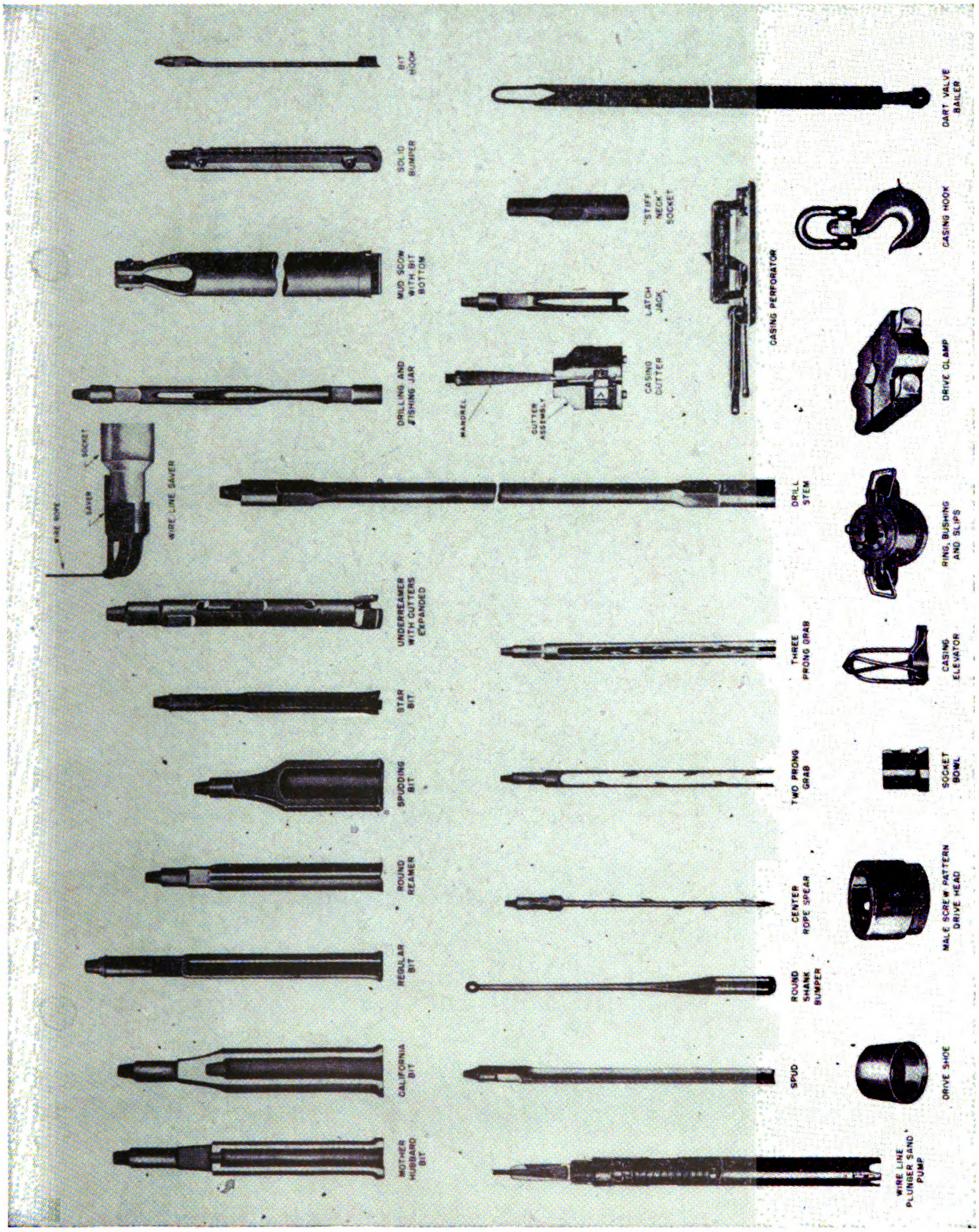


Figure 56. Percussion Wheel Rig Tools and Accessories.

Figure 57. Percussion Well Rig in Traveling Position

b. The power unit is a four cylinder, water cooled, Continental gasoline engine equipped with clutch, transmission, and pulley attachments for driving the rig. It has a magneto ignition system but no electric starter system. Before starting and at regular intervals the engine should be checked for lubrication.

c. The spudder assembly consists of a spudder arm with line sheave, main shaft, clutch, and shock absorbers. It is belt and gear driven, direct, from the engine pulley.

d. The 40′, telescoping, tubular steel mast is raised by a main cable hand hoist, and an auxiliary hand hoist for the upper section. The upper section is held in place by shear pins. In transit (Fig. 57) the mast is clamped to a rest, on the front of the unit, in a horizontal position. It is equipped with two sheaves, one each for the drilling cable and sand reel line.

e. The hoist assembly consists of a bull reel, controlled by a brake and a friction clutch, for handling the drill cable; a sand reel, controlled by a combination brake and clutch, for handling the sand reel line; and controls for the entire unit located at the rear of the rig within reach of the drillers platform.

f. Regular inspection and lubrication should be made of the entire rig. Lubrication charts should be followed, and to prevent accidents all lubrication must be performed while the rig is stopped.

141. **Drilling Tools and equipment.**— (Fig. 56) *a. Bit.*— the cutting tool which loosens, cuts, and pulverizes the material to be removed from the hole.

b. California Bit.— Has a long shank tapering to round shoulders, and a deep, wide course. It is used for drilling holes larger than 8″ in hard formations, such as sandstone and limestone, and for drilling ahead of the casing.

c. Mother Hubbard Bit.— Has a sharp shoulder just below the wrench square, making it easy to remove the drill from the hole when the mud from drilling shale has built up on the sides of the hole, above the drill.

d. Spudding Bit.— Has flat, thin body section and is used on portable rigs for starting holes in soft formations, such as sand and clay, or where a regular bit of suitable diameter would make the tool string too unwieldly for the machine.

e. Star (4 wing) Bits.— Has a star shaped cutting end used for drilling fissured formations which tend to deflect the tools.

f. Round Reamers.— Used to enlarge a hole already drilled.

g. Underreamer.— Used to ream below the casing to increase the size of hole to permit lowering the casing.

h. Drill Stem.— Steel rod which, when attached to the bit at one end, and the cable at the other, furnishes the weight to drive the bit.

i. Drill and Fishing Jar.— Used between the cable socket and drill stem only when there is danger of the tools becoming fast in the hole. It is composed of two telescoping reins. When running fishing tools the drill jar is placed below the stem, next to the fishing tool to give greater jarring action.

j. Cable Sockets.— Means for attaching cable to the drill stem.

k. Bailer.— Consists of casing with dart valve which opens when bailer hits bottom and closes as bailer rises, and is used to remove cuttings and water from the hole.

l. Sand Pump.— Used to remove sand and heavy sediment from close to the bottom of the hole.

m. Mud Scow.— Used in place of a regular bit, for drilling in sand and gravel formations, the same as with a string of cable tools. The churning motion causes a pumping action to be set up in the hole which agitates the material and forces it up into the barrel through a valve in the bottom of the scow. It is then hoisted out of the hole and emptied like a bailer.

n. Drive Clamp.— Attached with nuts and bolts to the square of the stem, at the pin end, and used to drive pipe by striking the drive head, or coupling, on the top of the casing.

o. Drive Head.— Used at the top end of the upper joint of casing to protect the threads from the driving blows of the drive clamps.

p. Drive Shoe.— Attached to the lower end of the casing to prevent collapsing or crumpling in formations where the casing is subject to damage by driving.

q. Casing Rings with slips.— (Also called "spider with slips").— Used for setting and pulling casing with elevators, screw jacks and hydraulic jacks.

r. Casing elevators.— Used for raising or lowering casing.

s. Casing.— Tube of steel or other material used to prevent walls of the hole from caving and to prevent flow into the well from undesirable starta above that from which water is desired.

t. Screen.— A perforated section of casing to be located in the train of casing in the water bearing strata.

u. Spud.— Used for straightening a string of tools in the hole and for loosening sediment or cavings around a bit or other tools, so a fishing tool may be run.

v. Socket Bowls.— Used on slip sockets, combination sockets, and horn sockets to adapt a socket to a larger size hole.

w. Bit hooks.— Used to straighten lost tools that have fallen over in an enlarged or caved hole, so fishing tools can be run.

x. Jar bumpers.— A jar bumper, or jar knocker, is used to loosen jars that have become locked, or to loosen tools that are stuck in the hole. It is operated on the sand or bumper line, and is "U" shaped to fit around the cable where it is guided by a detachable pin and roller.

y. Casing Cutters.— Used to cut casing while in the hole at any desired depth when the casing cannot be removed. It is lowered on the tubing; the jars and mandrel run in; and by jarring downward, the cutters are forced out against the wall of the casing; at the same time, the tubing is revolved by use of tongs or some other method.

z. Fishing.— Recovery of tools lost in the hole.— (1) When tools are brought onto the job, accurate measurements of each should be taken and placed on file, to be referred to in an emergency. These are: size and length of the cable socket; diameter and length of cable socket neck; length and stroke of jars; length and size of stem and bit; sizes of taper joint on each tool.

(2) When cable breaks or parts in the hole and the tools are not fast, the proper fishing tool to use is a cable spear or grab, run with cable socket stem and jars. The spear is driven into the cable, and when lifted, the prongs take a secure hold.

(3) The center spear is used in small diameter holes, the two prong cable grab for 8¼ inch holes and smaller, and the three prong cable grab in larger than 8¼ inch holes.

aa. Screens.— (see also Sec. IX). Screens can be obtained factory made or can be made on the job from casing, with a casing perforator.

ab. Latch (or boot) jacks.— Used to fish out bailers, sand pumps, broken jars, and other tools lost in the hole.

ac. Casing spears.— Used to fish out loose pipe which has parted in the hole.

ad. Casing swedges.— Used to open a free passage or expand collapsed or indented casing in the hole.

ae. Thread protectors.— Used on tool joints when not in service to protect them from damage and rust.

af. Wire line savers.— Used on cable to fit over the socket, protecting cable from kinks and breaks, when picking up or laying down tools.

ag. Setting a wire line socket.— See TM 5-225, Rigging.

ah. Care, splicing, and handling of wire cable.— See TM 5-225, Rigging.

142. **Crew.**— For normal operations a three-man crew consisting of a driller and two helpers, is required. The driller operates the rig, supervises drilling operations, is responsible for care of equipment, and must have experience in drilling with percussion type equipment. The two helpers act as assistants and should have a general knowledge of the mechanical equipment and be able to make repairs to the equipment.

143. **Procedure.**— *a.* The general procedure in drilling a water well with the percussion rig is (1) setting up; (2) drilling; (3) testing and completion.

b. Setting up.— (1) The rig is set up on a solid foundation with drainage to carry surface waters away from the rig site. Footings placed under the wheels of the rig help to floor the foundation and keep the rig from settling under the weight of the tools during drilling operations.

(2) The mast is raised into position and a mud sill is placed under it. The extension joint and mast jack are screwed down against the mud sill, giving the mast a solid foundation. Jacks are placed between the rig frame and mud sill to level the rig and take the weight off of the springs. The telescope mast is raised and guyed from the top, at an angle of 45 degrees, to deadmen or other holdfasts. Guy lines from the joint of the mast are only used on deep wells or when the mast will be used in the raised position for any length of time.

(3) A platform is built around the hole to the rear of the rig, for the driller and men to stand on while working. This should be high enough for the driller to be on a level with the control levers. A sluice box with a drain leading away from well is built to carry off bit cuttings and water as it is bailed from the well.

c. Drilling.— (1) The drill tools, consisting of swivel socket, drill stem, and drill bit, are assembled and inserted in the drill stem guide. When assembling the drill tools, the wire line saver (Fig. 56) should be used to prevent breaking or kinking the drill cable at the swivel socket. The drill stem guide may be used in starting the hole until the tool buries itself, but it is better to start the hole with an earth auger if one is available.

(2) The functions of the bit are penetrating, crushing, reaming, and mixing. Water transported to the site from another source is added to the hole to speed these functions and so that the cuttings can be cleaned from hole with the bailer. The bailer, which is operated by a separate cable, should be used frequently to prevent the cuttings from settling

around the tool and causing the bit to stick in the hole. When it is used, the drill line is held back out of the way, and when the drill line is being used, the bailer is held back out of the way.

(3) A drive shoe is attached to the lower end of the first length of casing. This length of casing is lowered into the hole as soon as the hole reaches a depth equal to one length of casing.

(4) Continue drilling through the shoe-length of casing until the hole is deep enough to hold the second length. Then screw the second length to the shoe-joint length and lower it into the hole. If the casing does not lower to the bottom of its own weight, it is driven with the drive head and drive clamps. This operation of drilling and driving casings is continued until desirable water strata are found, or until the well is abandoned.

d. A bit drills a hole from one to two inches larger than its own diameter, therefore casing should not be more than one inch larger in diameter than the bit. Using dull bits causes the hole to become cone shaped and will collapse the casing when driving it into the hole. Bits are replaced and dressed when they have worn away ¾ inches of diameter.

e. When drilling in quicksand or similar formations, it is necessary to keep the casing driven into the bottom of the hole as it is cleaned to prevent submining of the formation. The best means of penetrating quicksand is by flushing and bailing continuously, at the same time driving the casing into the formation.

144. **Testing and Completion.**— The principal means of testing for water bearing formations is by sampling bit cuttings as they are bailed from the well and by checking on amount of fluid in the hole. Usually, water will build up in the hole, forming a column, and if the capacity of the well is nearly sufficient for use, this water column will rise and maintain a stable level while bailing. After the capacity of the well is tested (Sec. 9), the casing is perforated and pumping equipment is installed.

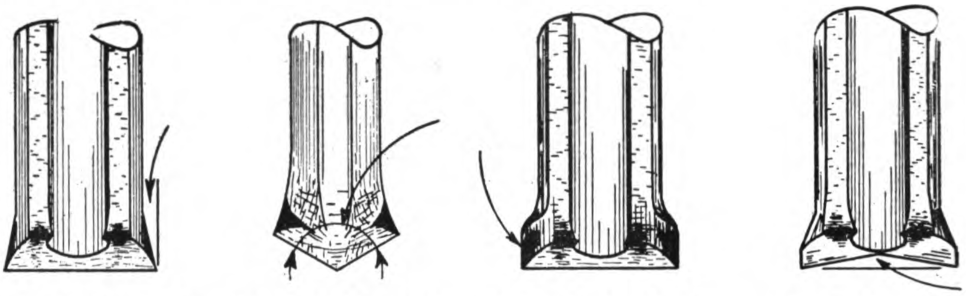
145. **General Information.**— *a.* "Left-lay" drilling cable is best suited for use as a drilling line. The swivel action of this type cable keeps the connections in the drill stem tightened and prevents back-offs and loss of tools. Socket connections on the sand reel line or drilling cable should be cut and reset at the first sign of wear or kinking.

b. The hole is drilled by the action of the spudder arm on the drilling cable to raise and drop the tools in the hole with a pounding motion. This is called the stroke.

c. The stroke of the spudder arm varies with the type formation and depth of the hole. Most rigs are equipped with means of adjusting the length and speed of stroke. In hard formation drilling a fast, short stroke is best, while in soft or sticky formations a longer and slower stroke is best. For average drilling the stroke is set at 30 to 35 inches. For better drilling, the stroke and speed should be as great as will permit the machine to run smoothly and the tools to drop clean and hit hard. The following serves as a guide for the length and number of strokes per minute.

Strokes / Minute	Length of Stroke
60-65	20 inches
55-60	25 ”
50-55	30 ”
45-50	35 ”
40-45	40 ”

d. Back lash or whip should be eliminated from the drilling cable to keep tools from leaning in the hole and drilling out of line. By holding the cable the operator can judge the amount of weight to pay off to prevent slack line at the end of the stroke.

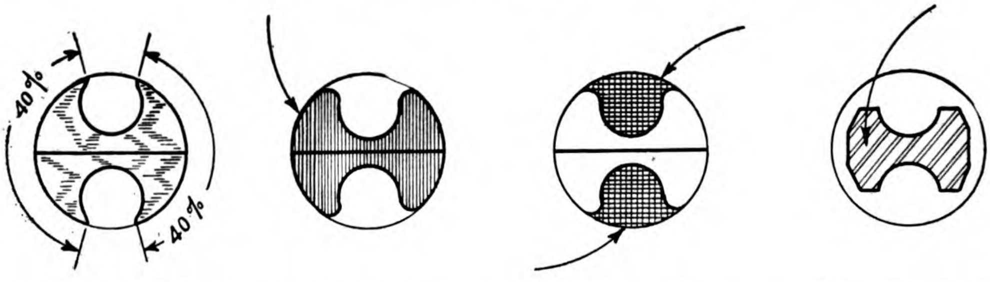


The Angle of Clearance is the taper on the outside or reaming edges. Drawing shows drill bit having wide ***angle of clearance*** and no ***wearing surface.*** Arrow points to ***angle of clearance,***

The angle of penetration is the bevel on the cutting edge which penetrates or breaks up the material in the bottom of the drill hole. Drawing shows drill bit having a ***penetrating angle*** of 120°. Arrow points to the ***angle of penetration.***

The Wearing Surface is the area which has no clearance and is in actual contact with the wall of the drill hole. This drill bit has a large area of ***wearing surface*** and no ***angle of clearance.*** Arrow points to ***wearing surface.***

The Contour of Penetrating Edge on a drill bit may be concaved, straight or convex, and the degree of ***contour*** is measured by the change in angle from a square line across the bottom of the bit. The drawing shows a concaved ***penetrating edge.***



The Reaming Edge is the outside edge of the bit and is measured as a part of the full circumference. Drawing shows drill bit having 80 per cent ***reaming edge*** — 40 per cent ***reaming edge*** on either side of the water courses.

The Crushing Face is the area of surface on the bottom of the bit and is compared by measuring its percentage of the total area of the drill hole. Arrow points to ***crushing face*** —the shaded portion of the drawing. ***Water courses*** shown in white.

The Water Course is that portion of the hole which is not filled by the bit and through which the water or cuttings must pass when the bit is moved up or down in the hole. Arrows point to water courses, crosshatched in black in this drawing.

The Cross Section of a drill bit is the size of the body at a point back from the end when it is not upset. Arrow points to ***cross section.*** The drawing shows the cross section of a drill bit back a few inches from the cutting edge.

Figure 58. Suggestions for Shaping Drill Bits.

146. **Instructions for Dressing and Hardening Drill Bits.**— (Fig. 58) *a.* The proper heating of a drill bit is very important, regardless of the method used in forging or sharpening. Whether the bit is sharpened by hand or machine, if it is improperly heated the grain structure of the steel will be damaged and the final results will not be satisfactory.

b. Do not heat the steel too rapidly and be sure to heat uniformly. A cold drill bit should be heated slowly at the start and until it starts to show a red color, after which it may be brought to a forging temperature with a hotter fire.

c. The minimum time required to heat a 6-inch bit should be about 25 minutes and the bit should be turned frequently to prevent heating one side more than the other. If a drill bit is heated to a red color on one side while the other side is allowed to remain cold or black, the uneven expansion will cause internal strains which may rupture or crack the bit.

d. A furnace having an arch or hood over the top is the best heating equipment because it holds the heat and prevents cold air from chilling the heated steel. When such a furnace is not available an open forge may be used, if fitted with an arch or cover constructed of fire brick. It is always advisable to have a deep fire pot in order to prevent holes burning through the fuel bed and allowing the air blast to strike against the steel. A depth of from 7 inches to 10 inches of fuel bed should be provided between the drill bit and the pipe where the air blast enters.

e. For forging, the steel should be heated to a temperature above the magnetic stage which exists up to about 1470° F. This can be determined by the use of a small "horse shoe" magnet fastened to a stiff wire handle about two feet long. The magnet should be fastened loosely on the end of the handle so it will swing freely. By bringing the magnet in contact with the point of the bit, it is very easy to determine the temperature at which the magnet is not attracted to the steel.

f. Heat to a bright red color just changing to yellow, or about 1800° F., on the first forging heat and do not forge or hammer the steel after the temperature drops to the magnetic stage. In other words, "when the magnet works the operator should rest" and reheat the bit. On the last, or finishing heat the temperature should not be allowed to run up to a yellow heat, but the bit should be forged when at a bright red color. Again, never forge or hammer after the heat drops below the non-magnetic stage.

g. When a drill bit has been sharpened and is ready for hardening it should be allowed to cool until it turns black before reheating for hardening. If allowed to cool, the steel will normalize and forging strains will be relieved. Reheat the bit uniformly, turning it frequently to prevent heating one side faster than the other. Heat it to just above the magnetic stage only as far back as it is to be hardened; for a six-inch bit this is about four inches from the end or 1½ inches from the corners. The upper critical point (the point of complete magnetic change) will be at about 1470° F. and the bit should be heated only until the magnet fails to attract and then quenched immediately "on a rising temperature." The bit should be quenched only as deep as the hardness is required, or from 1½ inches to 2 inches for 6-inch bits. A half barrel with about 10 to 15 gallons of water (rain water preferred) may be used for a quenching tub.

h. Hold the bit in a vertical position and move it around freely when quenching. The amount of water in the tub should be regulated before immersing the bit so that the water level will cover the end of the bit as far as the steel is to be hardened.

i. Suggestions for sharpening bits.— (1) There are eight important features in the design and method of dressing a drill bit to suit the formation being drilled and secure most effective penetration: (1) angle of clearance, (2) angle of penetration, (3) wearing surface, (4) reaming edge, (5) area of crushing face, (6) area of water course, (7) contour of penetrating edge, and (8) cross section of drill bit.

(2) Each of the eight features are equally important in the proper forming of a drill bit to produce the maximum efficiency of operation in the different formations to be drilled. By a careful study of operations it is possible to arrive at a shape of bit which will give maximum drilling speed, increase the footage which can be drilled between dressings, and decrease the time and labor required to keep the bit in proper condition.

147. **What A Drill Bit Does.**—*a.* A drill bit has four important functions to perform: (1) penetrating, (2) crushing, (3) reaming, and (4) mixing.

b. The character of the formation to be drilled will always determine which of the four functions of the drill bit is most important.

148. **Drilling in Hard Limestone.**— *a.* In hard limestone the most important function is penetration. If the limestone has a high silica content, it will be abrasive and, in this case, the function of reaming must also be considered.

b. Hard, solid limestone which has no vertical seams or open fissures to deflect the drill hole may be drilled with a bit having a sharp angle of penetration. The contour of the penetrating edge should be slightly concaved, and if the formation is not abrasive, a wide angle of clearance should be used. If seams or fissures are encountered, the penetrating angle should be greatly increased. This makes the bit very blunt and brings the corners and reaming edges nearer to the penetrating edge so the reaming edges can cut into the slanting side of a seam and carry the hole down without deflection. Should the guage size of the bit be worn away rapidly and the size of the hole become reduced so that difficulty is encountered when a fresh bit is run into the hole, it will be necessary to reduce the angle of clearance and allow wearing surface on the bit to resist the abrasion.

149. **Drilling in Soft Limestone.**— *a.* Soft limestone requires special attention to the function of crushing, and if the limestone has a noticeable amount of clay mixed with it, there should be some attention given to the function of mixing.

b. Soft limestone with open seams, fissures, and hard spots requires a drill bit with the maximum reaming edge, a liberal angle of clearance, and ample crushing face area. The angle of the penetrating edge should be very flat, but the contour of the penetrating edge should be concaved about 3/8 inch on a 6-inch bit.

150. **Drilling in Quartzite or Granite.**— *a.* Quartzite and granite are hard and abrasive, therefore the most important functions of the drill bit are to penetrate and ream. In this case the functions of crushing and mixing are less important than reaming.

b. Granite, quartzite, or trap rock with vertical seams and fissures require a drill bit with a wide angle of penetration which will form a thick, heavy cutting edge to withstand the impact of heavy tools on hard rock. The reaming edges must be kept out to full gauge size and not more than 1/2 inch back of the penetrating or cutting edge. The contour of the cutting edge should be slightly concaved. Most important is the wearing surface, which should be as near straight as possible, allowing a very small or no angle of clearance. The cross-section or body size of the bit should be large in order to guide the tools in the hole and prevent offset when fissures are encountered.

151. **Drilling in Soft Formations.**— *a.* Shale, clay, or very soft limestone formations require that special attention be given to the function of mixing and in many cases it is necessary to retard penetration in order to secure maximum mixing results.

b. This character of formation requires a drill bit with entirely different features to perform the important function of mixing. Very little, if any penetrating angle is necessary. The greatest possible angle of clearance should be used and the cross-section or body size of the bit should be small. A large area of crushing face should be given the bit for the purpose of retarding penetration and at the same time packing the material in the bottom of the hole to prevent the tools from driving and sticking.

c. To analyze any certain drilling problem it is necessary to know the physical character of the formation. The most important function of the drill bit can then be determined, and the features of the bit can be worked out to give best results.

Section VII

DRIVE POINT (DRIVEN) WELLS

152. **Typical Locations.**—*a. General.*— Successful drive point wells frequently may be constructed in the following situations:

(1) Deltas of large rivers.

(2) River valleys, stream beds, plains in which rivers meander, lake plains, and river valley terraces.

(3) Beaches and dune country.

b. Deltas of large rivers.— These usually contain a considerable proportion of sandy deposits, although sometimes clays and sandy clays are present to such an extent that water at shallow depths is obtainable only in negligible amount. Owing to the variable conditions under which deltaic deposits accumulate, water-bearing deposits of sand or gravel are usually to be found, and initial *failure* to find water at any one place or depth *should not discourage further search.* In some deltas, considerable quantities of mineral salts have been precipitated; a condition probably due to the concentration of mineralized water by evaporation, or to sea invasions in isolated areas subject to subsequent evaporation and deposition. Nevertheless, even in such places, there exist main drainage channels from which the accumulations of the salts have been wholly or partially removed by leaching, and search should be made for these places. In many deltas shallow artesian supplies may be tapped by means of drive point wells.

c. River Valleys.— (See Figure 59) In most countries river valleys frequently present favorable conditions for drive point wells. The sandy or gravelly character of the ancient river terraces fringing the valleys frequently affords an indication as to the type of deposit that may be expected below the level of saturation. Where the rocky sides of the valleys contract to form gorges there is usually little or no water-bearing deposit laid down. Valleys of medium width which enable floods to pass without great scouring action, but nonetheless possess a current strong enough to carry away all the finer silts, are nearly always underlain by beds of sands and gravels through which sub-surface water may flow quite independently of the flow of water above the ground. Drive point wells sunk into such valley formations may tap copious supplies of clear water isolated from the turbid and polluted stream. If driven deeply enough into highly porous strata, there is little chance of the upper stream water being drawn in, particularly when fine sediments cut off the more porous water yielding deposits below. Slow-running streams flowing in wide valleys may deposit large quantities of silt that is useless as a source of water supply, but even here, careful examination or systematic tests, may reveal sandy zones from which useful supplies of water can be drawn.

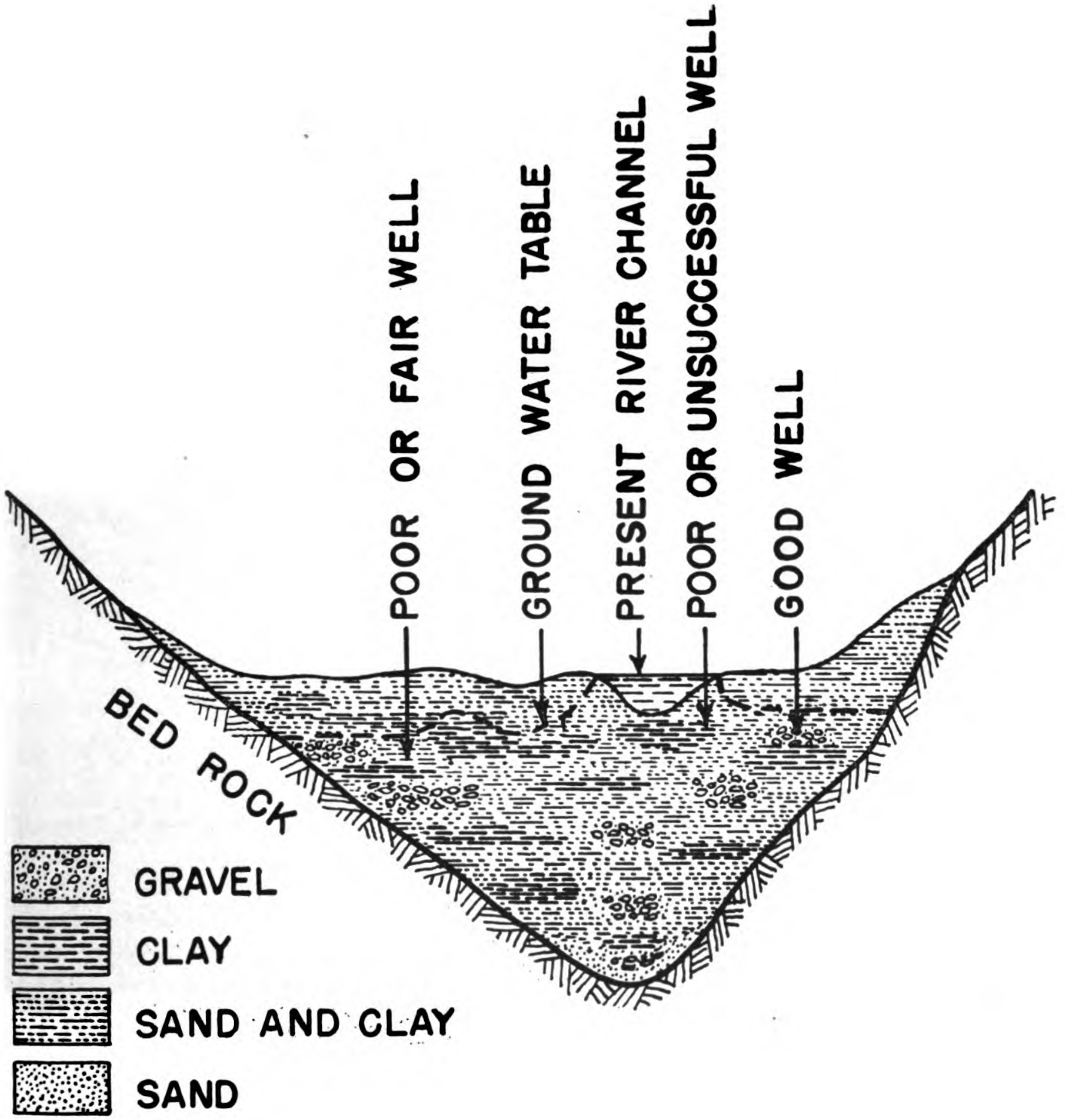


Figure 59. Section of a River Valley Illustrating Interlocking, Lenticular Beds of Sands, Gravels and Clays.

d. Beaches and coastal dune areas.— (1) These areas frequently yield good supplies of water, even from below sea level. This is due to the slow movement of fresh water down the slope of the water table toward the sea. Drive point wells may be successful in many of these areas, particularly where the elevation of the ground surface does not involve sinking the well more than 15 to 20 feet to reach sea level. They may often be sunk within a few yards of high-tide level without suffering much in quality, unless too heavily drawn upon. (See Figure 60.)

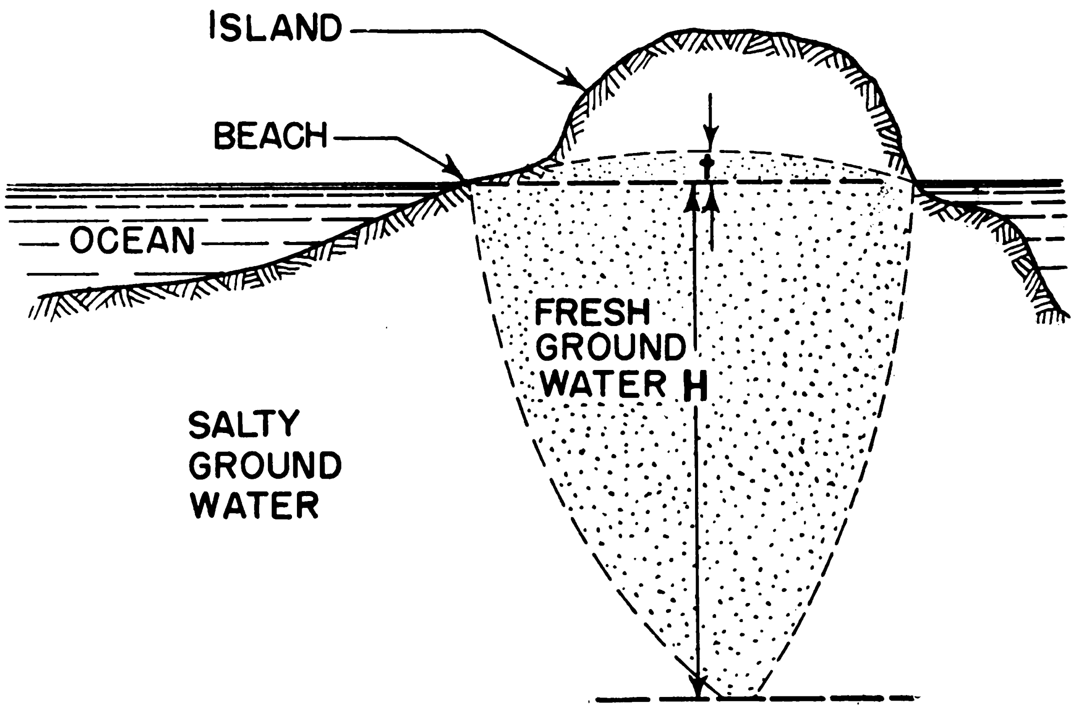


Figure 60. Section Through an Island Showing Fresh Ground Water Floating on Salty Ground Water.

(2) In Gallipoli, limited quantities of water have been obtained from the beach sands at Anzac, even where a very narrow margin separated the hills from the beach, and at Helles, where gullies cut channels into the cliff. Along the Sinai and Palestine coastline, drive point wells have been successfully driven in the dune areas. But many of the wells throughout the Palestine coastal area contain enough mineral matter to be brackish, even some distance from the actual coast.

(3) The specific gravity of fresh water being less than that of salt water, it tends to float on top of salt water. Fresh water is often available on islands and along the shore lines of mainlands, even when the pervious material containing the fresh water extends out to sea and contains salt water in its seaward extension. A shallow well on an island or sea coast may yield fresh water when a deeper well will yield only salty

water. For this reason, a large number of small fresh water wells along a coast line are often more desirable than a smaller number of wells with greater discharge and drawdown effect.

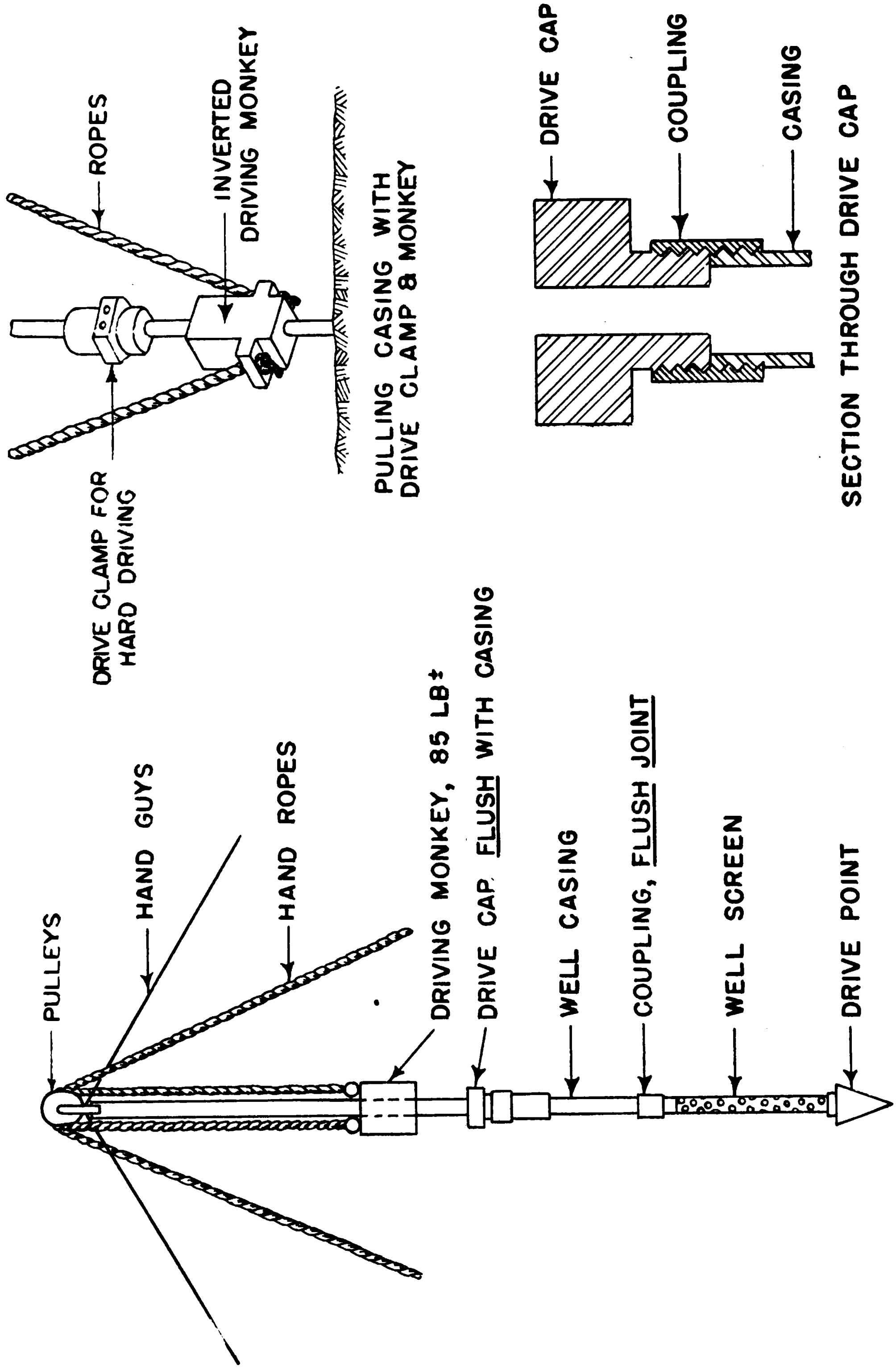


Figure 61. Drive Monkey Rig.

153. **Equipment.**— *a.* A portable and simple arrangement for constructing drive point wells is illustrated in Figure 61. A hollow, mild steel monkey slides over a pulley bar or pipe which is supported vertically by the well pipe itself. By means of two ropes passing over pulleys at the top of the pulley bar the drop weight may be alternately raised and allowed to fall upon a clamp or cap fitted to the upper length of casing. In this way the well is driven into the ground.

b. A drive monkey can be made to slide over the well casing; instead of supporting the pulleys and rope on a pulley bar, provide a clamp which can be attached to the extended well casing and to which are attached the pulleys and rope used to raise the monkey. A drive head cannot then be used, the blow of the monkey being delivered to a drive clamp attached to the well casing.

c. A tripod outfit is suitable, but it lacks the portability and simplicity of the other driving methods and possesses few compensating advantages.

d. In the absence of mechanical driving apparatus, a sledge hammer or a mallet may be used if a suitable platform is arranged upon which to work, and a drive head or other protection provided to prevent damage to the top of the pipe being driven.

e. The construction of drive point wells can be facilitated if compressed air and an air hammer is available for use in place of the drive monkey used for hand driving.

154. **Operation.**—*a.* If possible, the well should be started with an earth auger or a small post-hole auger by boring a preliminary hole about the same diameter as the outside of the well casing to be used. Care should be taken to insure that the hole is vertical. This makes for easier driving, especially in dry earth, and it also facilitates the withdrawal of the casing, if it is decided to pull the drive pipe for future use. However, the drilling of the preliminary hole with the auger has the disadvantage that the upper portion of the drive pipe is looser and surface water can enter around the outside of the well casing, and contaminate the supply.

b. The well-point, with its screen and with the first section or two of the drive pipe attached, can then be lowered into this hole, and driving can proceed.

c. In soft ground the descent of the drive point will be from two to three inches per blow, and it takes about five minutes to drive a well under best conditions. Driving in compact clays is often facilitated by introducing a little water into the pipe, or around its exterior to obtain a lubricating effect. In hard ground the pipe should be rotated in a clockwise direction to avoid loosening the couplings a fraction of a turn at each blow by means of a heavy pipe wrench. In very tough clays many heavy blows may fail to drive the pipe down more than an inch. Under such conditions the pipe is apt to break near the upper couplings. When driving in wooded country, large tree roots may completely stop the progress of the drive pipe, and may force the pipe to one side so that deeper driving is impossible.

d. Too much stress cannot be laid upon the importance of making air-tight joints in drive point wells. In the process of driving, all joints should be screwed tightly, after carefully cleaning, oiling, removing burrs and bruises, and applying a light coating of white lead. Protection of the threads by caps or couplings during transportation and storage is advisable. When the pipe is being driven with difficulty, the whole string of pipe should be twisted at frequent intervals to tighten up the couplings.

e. It is essential that the well pipe be kept vertical. Until the first two sections of the drive pipe are in place, this should be constantly checked by means of a plumb-bob held at arm's length from the well pipe, and from two directions at approximately right angles to each other. If the pipe is slightly out of vertical during the early part of the driving, it can generally be pushed into place by pressure exerted on the pipe while the blows are being delivered. Unless it can be straightened, the pipe should be withdrawn and started again in a new place.

f. Interpretation of the character of materials penetrated.— Successful construction of drive-point wells depends upon close observation and the correct interpretation of events while driving. Accurate interpretation of such details as the penetration made with each blow, the drop and rebound of the monkey, the sound of the blow, the resistance of the pipe to rotation, all provide information which will enable the experienced well driver to obtain an idea of the character of the materials being penetrated. An approximation of the geological section of the well can be obtained by recording these observations. Study of the logs for successive wells, coupled with a study of the results obtained from each well, soon makes intelligent operating personnel into experienced drive-point well men.

g. The following will serve as a guide:

(1) *Soft clay* gives an easy driving, rapid descent, a dead blow without rebound, a dull-sounding blow, and a slight but decided and continuous resistance to rotation.

(2) *Tough indurated clay* gives hard driving, slow progress, but appreciable descent at each blow, no resonance, considerable but silent continuous resistance to rotation, and causes frequent rebounding of the monkey.

(3) *Fine sand* is usually very hard to penetrate, whether wet or dry, and gives fair resistance to rotation, accompanied by a slight gritty sound transmitted up the pipe. It causes frequent rebound of the monkey with dull resonance.

(4) *Coarse sands* are often easily penetrated, especially when saturated with water. Progress is often unsteady, with irregular penetration for successive blows. Rotation is easy, and is accompanied by a very gritty sound. There is no rebound of the monkey after a stroke.

(5) *Gravels* generally give easy driving, but irregular penetration for successive blows. Rotating the pipe gives a gritty sound with irregular resistance as pebbles are pushed aside. The pipe is generally quite free after a few revolutions.

(6) *Boulders and rock* give little or no progress, and cause rebound of the monkey and sometimes of the pipe. Rotation is easy unless the pipe is out of plumb. There is loud resonance at each blow.

(7) When a depth of about 50 feet has been reached, or the stratum is too hard to safely drive further owing to the distance from the blow to the drive-point, the blow may be applied by letting a steel bar, attached to a rope, fall freely upon the base of the point inside the casing (Fig. 62).

(8) If the lower part of the pipe is choked with fine detrital matter which might prevent the water from entering, it can be cleared out by one of the following methods:

Method I. Attach a hand pump to a string of ½ inch pipe which has been lowered inside of the well pipe and clamped in position with the lower end of the small pipe resting on the obstruction. Run water into the well between the drive pipe and the ½ inch pipe, and start the hand pump. By steadily lowering the ½ inch pipe and adding water while continuing pumping, material which obstructs the free entrance of water into the casing may be removed.

Method II. Insert a string of ½ inch pipe, fill the well with water, and repeatedly raise and lower the ½ inch pipe sharply by hand. By holding the thumb over the top of the ½ inch pipe during the upward movement, and removing it during the downward movement, a jet of muddy water can be expelled at each downward stroke. When the material has been broken up and put into suspension, the muddy water can be pumped out.

Method III. Water pumped into a string of ½ inch pipe reaching down to the obstruction, will rise and escape from the top of the drive pipe, acting as a water jet to break up and remove the obstruction. This procedure requires the use of an auxiliary motor-driven or hand force pump.

155. **Development and Testing.**— Entry into a water-bearing stratum is usually indicated by an immediately increased rate of descent, sometimes as much as 6 inches at a single blow, but when the water-bearing sands are fine-grained, there may be little or no increase in speed of pene-

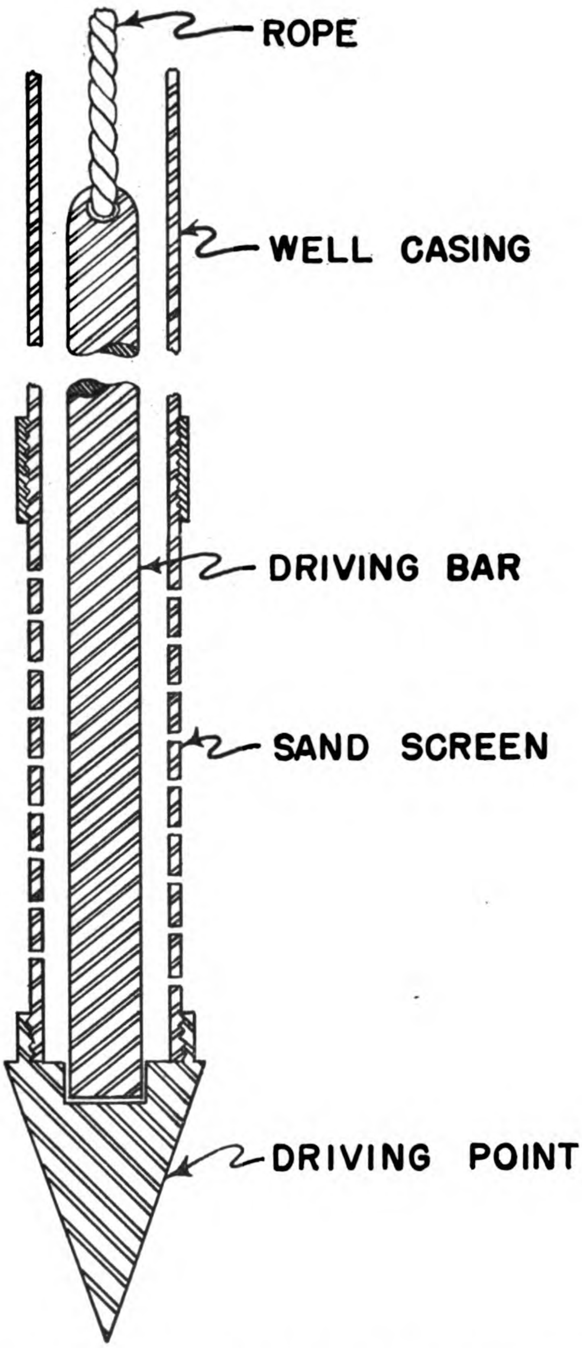


Figure 62. Driving Deep Drive Point Well With Driving Bar Which Delivers Blow on Drive Point.

tration. On entering a suspected water-bearing sand, driving should be stopped and a plumb-bob lowered to ascertain if water has entered the tube. If little detritus is found in the pipe, and the level of water stands well above the perforations of the screen, and within 15 to 20 feet of the surface, the pitcher pump may be attached, and a test may be made to determine the yield.

156. **Pulling the Well.**— Drive-point well pipe may be withdrawn by upward blows with the monkey applied to a pipe clamp attached firmly to the well pipe. Levers or jacks working against a pipe clamp may also be used. A chain wound around the drive pipe and connected to the short arm of a long lever operating against a solid fulcrum will also raise the pipe in short lifts. After the pipe has been raised a few feet, the remainder of the lift can often be accomplished by hand, and in general, the withdrawal is assisted by turning the well pipe.

Section VIII

JETTED WELLS

157. If water from another source, under sufficient pressure and in sufficient quantity is available, wells can be constructed by the use of a water jet. This method is best suited to driving in soft materials, such as unconsolidated sands, sandy clay, etc., which is capable of being broken up by a jet of water. The use of a chisel-like bit on the end of the jetting pipe will aid in breaking up the more solid materials. In this method the well is sunk by forcing water down a small pipe inside the well pipe, and the drillings are carried away by the water rising up between the two pipes. The well pipe may itself be used as the jetting pipe. The lower, open end of the pipe should be reduced in diameter and a serrated cutting edge or chisel-like bit attached or formed on the lower edge of the pipe. Turning or raising and lowering the pipe as the hole progresses in depth aids in breaking up the materials penetrated. The cuttings are then carried away by the water rising between the pipe and the sides of the hole produced by the jetting. The method is quick and inexpensive for sinking a large number of shallow wells.

Section IX

SCREENING, TESTING, AND DEVELOPMENT OF WELLS

158. **Well Screens.**— *a. Functions.*— Well screens should not be considered simply as strainers, though they are often so called. Rather, they should be thought of as first providing ready access of water to the well casing, at the same time serving as stabilizers, allowing a portion of the sand to pass into the well and be removed while they hold back just enough of the coarser sand and gravel of the formation to support the remainder, and prevent caving during development and pumping of the well. When a sand of mixed particle sizes is tapped and pumping is begun, the finer sand particles are first drawn in with the water, then coarser and coarser particles appear until a natural filter is produced by the retention around the screen of grains that cannot enter the opening of the screen. The finer particles are removed from between the larger ones, increasing the size

of the passages in the sand outside of the casing, thus reducing the resistance to the passage of water through a volume of the formation outside of the casing. The further this area of fine-sand removal extends, the larger is the perimeter of the volume through which the passage of water is facilitated by the development of the well. (See Figures 8 and 9.) The coarser the particles left around the well screen, the more freely the water enters.

b. Size of apertures.— Each one of the apertures leading into the well casing has its own part in determining the entrance loss into the casing. This loss is increased if the area of the individual openings is reduced, even though the total aperture area remains the same. The loss can be decreased by increasing the number, and particularly by increasing the size, of the apertures. This can be done by widening the slots, or increasing the diameters of holes bored in the casing where it will be in contact with the water-bearing formation. However, these openings must not be so large that they admit all or most of the sands and gravels of the aquifer, or water-bearing formation. If this removal of sand and gravel occurs to too great an extent, there will be continued or successive cavings of the formation around the perforated casing, with resultant plugging of the well, or the procurement of muddy water. The opening in the pipe must be sufficiently small to hold back about 70% of the material from the water-bearing formation, or the openings must be screened to achieve the same result. Well screens have been designed with apertures of almost any selected size, while at the same time giving a maximum opening into the well casing without causing the caving of the water-bearing formation. These screens can thus be obtained in screen sizes adapted to almost any size of sand and gravel, and for almost any diameter well casing.

c. Determining the size of aperture.— Driven well construction does not lend itself to the securing of samples of material from the formation penetrated so readily as do methods which allow removal of material from known depths with the mud, as in a rotary well or by means of the bailer, or sand bucket in percussion wells. If samples of material from the formation are available, the screen size to be used may be easily determined by a mechanical analysis of the sand, using a series of sieves. The series of sieves is assembled in order of aperture sizes, with the largest-mesh screen at the top. A weighed sample of the air-dried sandy material is then placed upon the coarsest screen and the material is allowed to pass on down through the progressively smaller-mesh sieves. After shaking the sieve nest until the separation is complete, the material passing through the finest sieve is placed on a balance and weighed. The material on the next finest sieve is added, and the whole weighed, and so on, for the rest of the screened material. The cumulative weights, which represent 100% of the material, are plotted on coordinate paper, giving a characteristic curve for the sand specimen. From this curve, the size of grain such that 30% is finer and 70% coarser, can be determined. If the diameters of the sieve apertures are calculated in inches, or some other convenient unit, the diameter of the optimum screen aperture is thus determined.

d. Design.— (1) Well screens of various designs are available. They may be divided into 3 classes: wire wrapped, perforated pipe, and slotted openings, and are constructed by perforating a length of pipe with holes of such size, and so spaced, as not to weaken materially the compressive strength of the pipe along its length. In coarse gravel, such a perforated pipe may be used, in some instances, without further protection. Generally, the perforated pipe is encircled by a finely perforated or slotted brass plate or tube, or with wire guage through which only very small sand grains can pass. The perforated pipe may also be wrapped with a spirally wound small-diameter wire.

(2) More highly improved and more satisfactory types of well screens are designed to have self-cleaning slots, increasing in diameter toward the interior of the tube. These are made by cutting V-shaped slots in the screen plate or tube from the inside, producing a cut with the narrow point of the V toward the outside of the screen. They may also be made by electrically welding a specially-formed, V-section wire in a spiral around a series of upright strips, or rods.

(3) It is the obvious advantage of these improved screens that they do not allow sand grains to catch in the openings, bridging them and plugging the screen, as may happen with other types of screens, since in the improved screens, any sand grain which will enter the opening will pass on through into the well and be pumped out. The improved screens are also much less likely to be damaged when the drive point is driven or pulled, and in addition, the possibility of the screen being stripped from a supporting pipe is eliminated because small stones and gravel are less likely to lodge in the openings and hold the screen when the casing is moved.

e. Perforating casing.— (1) Casing is ordinarily perforated in place, although more satisfactory results usually can be obtained when it is perforated before it is placed in the well, if the locations of the water-bearing strata are definitely known. There are various methods of perforating casing in place, but the Mill's knife which cuts rings of vertical slots in the pipe at the points desired is most often used.

(2) The Mill's knife (fig. 56) consists of a frame that carries the perforating knife, a string of pipe for pulling the lever that forces the knife through the casing and a cable for holding the perforator in place. This device has an indicator on the pipe which shows where the perforations are being made.

(3) The star perforator is also used to some extent. It makes the perforations by means of four star-shaped cutters held in a frame which is froced down by means of a special hammer on the end of a drill stem. The star perforator does not have an indicator to show where the slots are being made.

(4) Casing is also perforated by ripping long slots in it with a device called a ripper. These long slots weaken the casing and may cause it to collapse.

(5) The Mill's knife starts at the bottom of the well and works toward the top. The other devices start at the top and work down. If there is much sand coming into the well as the result of perforating the casing, the accumulation of sand in the bottom of the well will interfere with the operation of the devices which have to be driven downward.

(6) Another type of perforator, developed recently, is operated by hydraulic presure through pistons that cut shutter-shaped perforations in the casing. Like the Mill's knife, the position of this perforator can be accurately controlled, and very satisfactory results are obtained.

159. **Testing and Developing the Well.**— *a.* When the presence of water in the formation is suspected, and the casing is clear to the bottom, a simple test is to run water into the well and observe the result. If the well is in dry sand, the water will all run away, whereas in a free yielding, water-bearing sand, the level of the added water remains almost stationary, or quickly sinks to a fixed level after the addition of water to the casing is stopped. The value to this test depends upon the fact that the quantity of water which can be run into the well pipe is essentially a measure of the well's capacity on pumping, for the sand bed, when saturated, will yield its contents as freely as it will absorb water. Also, an air lift produced by running the hose from an air compressor down into the well will remove water at controllable rates so the draw-down can be measured at these rates. Often raising or lowering the screen a foot or so will bring a greater length into contact with the water-bearing formation and away from a layer of clay which has been covering the apertures.

b. The purpose of development is to remove fine sand and drilling mud from around the screen. Even when the selection of the well site has been good, the pipe accurately driven, the strata correctly interperted, and the presence of water correctly diagnosed, wells may fail to yield water merely because they have not been systematically pumped to remove the fine sediment from around the screen.

c. Development is best accomplished in the field by surging with air. This can be done by capping the casing and connecting the portable air-compressor to a connection in the cap, allowing the pressure to build up so that some of the water standing in the well is forced back into the water-bearing formation.

d. Another method of surging consists of the rapid up and down movement of a plunger which draws water and fine materials into the well when raised and forces the water out again when the plunger is lowered. Surging is also accomplished by attaching a mud scow to the drilling line and giving it an up and down movement with a long stroke, with the valve in the mud scow closed by filling it with gravel or by placing a strut between the valve and the bail. Another method is to use a surge block consisting of a circular wood disc several inches thick attached to a metal stem which is raised and lowered by the rig.

e. (1) The common pitcher-mouthed kitchen pumps, usually supplied for drive-point wells can be used for development. They are of the suction type, with a lower valve which can be tripped by raising the pump handle high enough to cause a projection on the bucket to strike the hinge side of the suction valve. It is then possible not only to prime the pump, but to run water into the tube itself through the tripped lower valve. By alternately applying a heavy suction on the well and suddenly tripping the suction valve, to allow the water to rush back down the well pipe, it is possible to create a disturbance which will suspend muddy material and permit its removal through the pitcher pump. Even if only a tiny inflow of water manifests itself at first, the stratum from which it flows will tend to break down as the repeated alternation of pressure and suction gradually induces the admission and escape of small quantities of water, removes the smaller sand grains, and finally breaks down the sand body about the screen. This break-down is at once followed by an inrush of muddy liquid in which the silts and finer sand particles predominate. A few minutes of continued hard pumping generally causes a continued inrush of sand and water, during which the sand grains steadily increase in size. It is very important at this time to *maintain a rapid rate of pumping* by relays of men, for otherwise the sand will settle and plug the lower part of the well pipe. In due course, the water will flow easily, and will be free from sediment. The well will then be ready for use.

(2) Failure of a well to develop may be due to the fact that the sand bed is composed of closely compacted grains of ungraded size, which do not break down readily and classify themselves, even though the formation is saturated with water. The packing induced by forcing the drive-point or the bit pipe into the formation, may also be responsible, in part, for this result, since the original closely packed grouping is further consolidated and wedged in place.

160. **Cementing (Grouting).**— When, in drilling, the desired water-bearing formation is reached, a wood plug drilled to take the grout pipe is placed in the bottom of the first length of casing and the casing is placed in the hole just above the bottom. A grout of neat cement and water (one bag of cement to 4½ gallons of drinkable water) is pumped through the

grout pipe until grout appears around the annular space at the top of the casing. Some grout is wasted to eliminate loose material from caving. The casing is lowered to the bottom of the hole, the group pipe is raised a few inches and flushed to remove remaining grout from it and the casing pipe. It is then withdrawn and the grout allowed to set for 3 to 7 days. The plug is then drilled out and drilling continued into the water-bearing strata and the screen placed.

161. **Increasing Yield of Wells.**— *a.* An inadequate yield usually results from insufficient supply or from the slowness with which water is given up by the water-bearing strata. In clay and the denser varieties of soil, water is given up slowly, and the amount of water in a well is more or less proportional to the area of surface exposed. Consequently, in such formations, large wells are desirable. Large wells are also desirable in rocks in which water occurs in pores, rather than open passages. In some cases, where the water table has sunk, deepening alone will increase the yield sufficiently.

b. In deep wells the use of explosive shatters the surrounding rock and may result in opening other water-bearing crevices. Explosives are most effective in hard, brittle rocks, such as limestone, and least effective in soft, tough shales. Relatively small charges should be placed and tamped opposite the strata to be opened.

c. Packing with gravel is useful when the material surrounding the well is so fine as to clog the flow. Pebbles may sometimes be dropped into the well and forced out into the surrounding clay with a drill, until a pocket permitting flow is produced. The yield of wells in unconsolidated sands may often be increased by removing sand from around the strainer and substituting selected, graded gravel. A coarse strainer is required, and the effective diameter of the well becomes that of the gravel pocket. The usual method of packing with gravel consists of removing the screen, pumping out sand through an inner casing and simultaneously feeding in gravel between an inner and outer casing. This means of increasing yield is most applicable to shallow wells in fine sands.

d. If, in measuring the static level of an existing well, it is found to be less than the original static level, the pump may be lowered or a larger one installed.

e. If sand has packed around the screen it may be jarred loose and dislodged by exploding blasting caps inside the screen at vertical intervals of two feet.

f. If the screen is encrusted with iron deposits or calcium carbonate and the screen is constructed of brass, bronze or stainless steel the encrustations may be removed without too much harm to the screen by treatment with an inhibited acid, such as muriatic acid, by placing a solution of sufficient acid in the well to make a 10 to 25% solution when mixed with the water in the hole. This can be done by lowering a pipe to just above the lower screen and pouring or pumping the acid through the pipe. This is a dangerous operation and about six gallons of sodium bicarbonate solution should be kept at hand to neutralize acid spilled on the hands, clothing or on the pump. After about five hours, assuming a 15% acid solution was used, the pipe used to place the acid in the well should be removed but care should be taken to spray it with water as it is removed. The well should then be pumped until the pH value (Appendix I) of the water approximates the pH value before the treatment was begun, or at least until

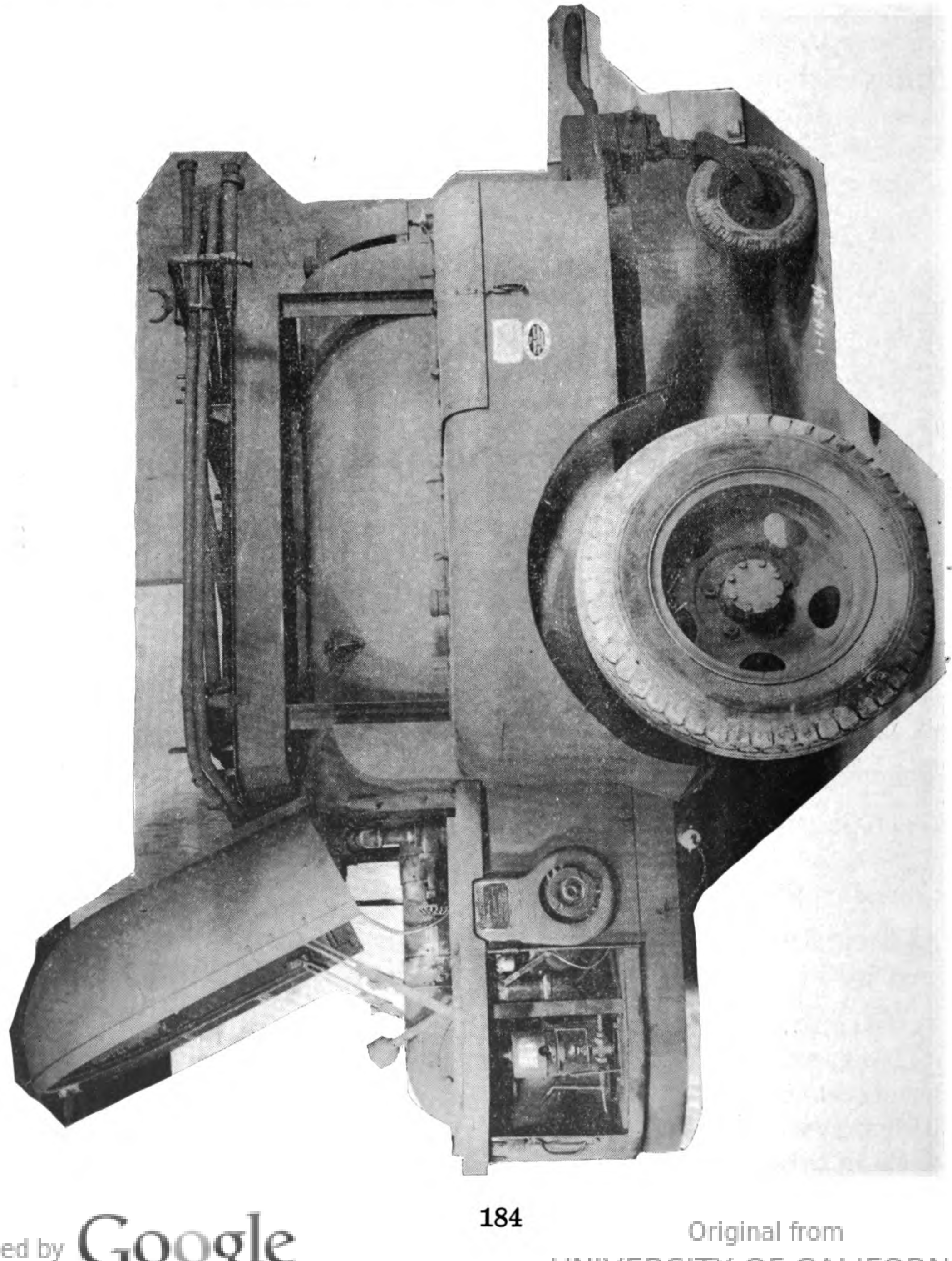


Figure 63. Portable Field Bathing Unit in Traveling Position.

the pH is close to 7.0. If one or more of the frequent bacterialogical tests that should be made on all wells by the Medical Corps shows the presence of contamination, the source of contamination should be sought out, and in addition, the well should be disinfected as described for new wells, in paragraph 28.

162. **Protection of Wells.**— Wells should be located if possible at local high points where drainage is away from well and remote from any possible contaminations, such as latrines. The well casing should extend well above the ground surface and precaution should be taken to prevent the entrance of animals and insects. Gravel used for gravel packing should be chlorinated. After developing the well a solution of sodium hypochlorite should be pumped into the well to a point near the bottom. The amount of hypochlorite should be sufficient to give a residual of five parts per million. After remaining in contact with the water for thirty minutes the hypochlorite can be removed by pumping the well.

Section X

PORTABLE FIELD BATHING UNIT

163. **Description.**— *a.* The Portable Field Bathing Unit (Figs. 63 & 64) consists of a water pump, a heater, and a set-up for 8 showers mounted on a two-wheel trailer.

b. The equipment for setting up the shower heads is carried in a compartment over the heater.

c. The heater is of fire tube construction and designed to burn No. 3 fuel oil (Viscosity = 50 seconds saybolt Universal at 100° F) in warm weather, No. 2 oil in cold weather, or a mixture of kerosene and light lubricating oil (a cup of lubricating oil to 5 gallons of kerosene) in emergencies, but kerosene will burn less readily and hence heat less water than fuel oil. The fuel oil pump is V-belt driven from the blower shaft.

d. The water pump is a self-priming, centrifugal pump with a maximum capacity of 45 gallons per minute against 50 feet of head and a maximum suction lift of 25 feet.

e. A gasoline engine drives the water pump, the heater blower, and fuel pump by means of a belt drive.

f. *Operation.*— (Fig. 65) (1) Set up the unit so that it is as near the source of water as possible and the heater level with all tubes covered with water.

(2) Connect the suction hose with strainer attached from the water supply to the pump suction, making sure all joints are tight, and connect the discharge hose from the heater to the showers. Fill the priming chamber if it has been drained.

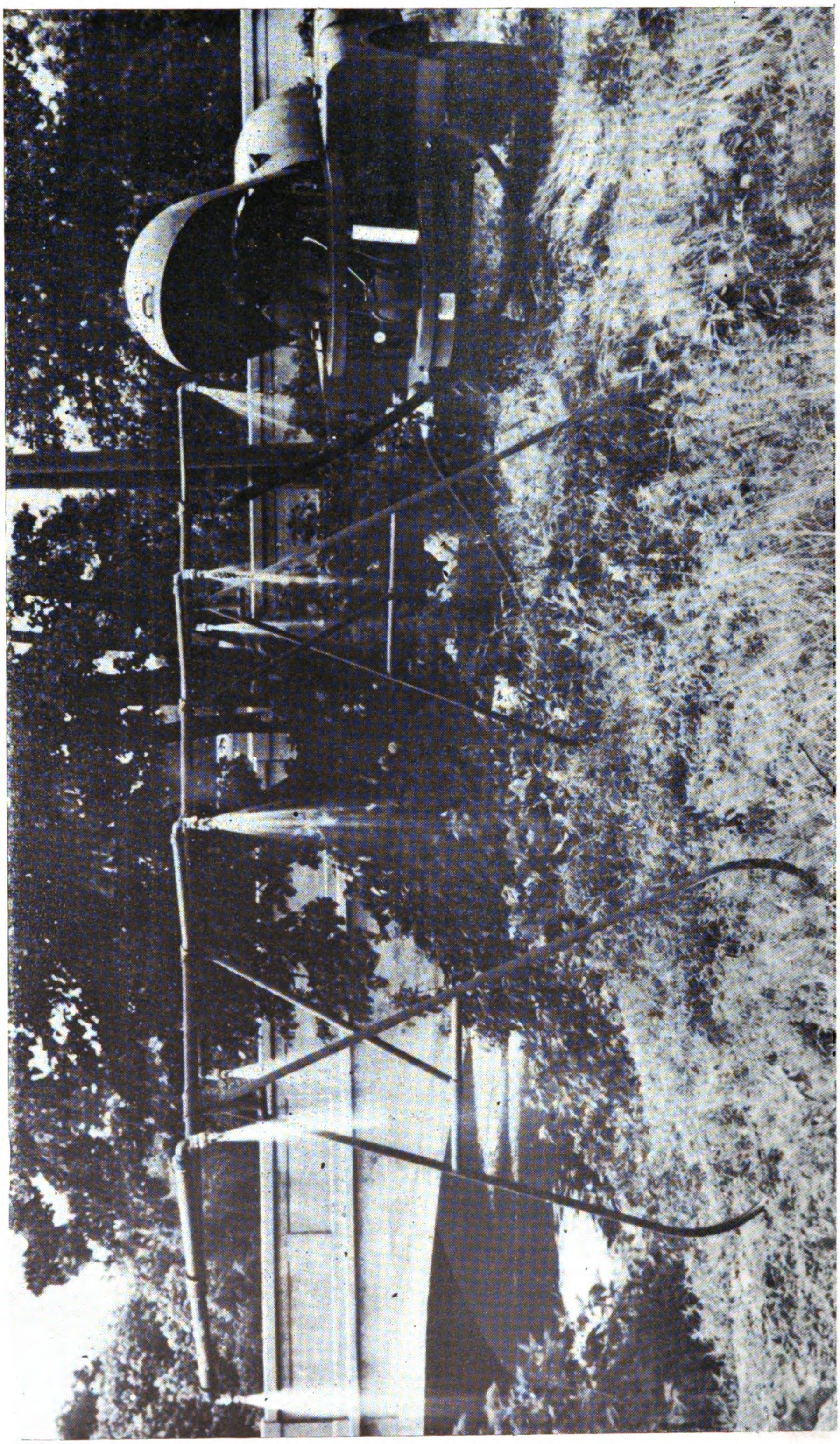


Figure 64. Portable Field Bathing Unit in Operation.

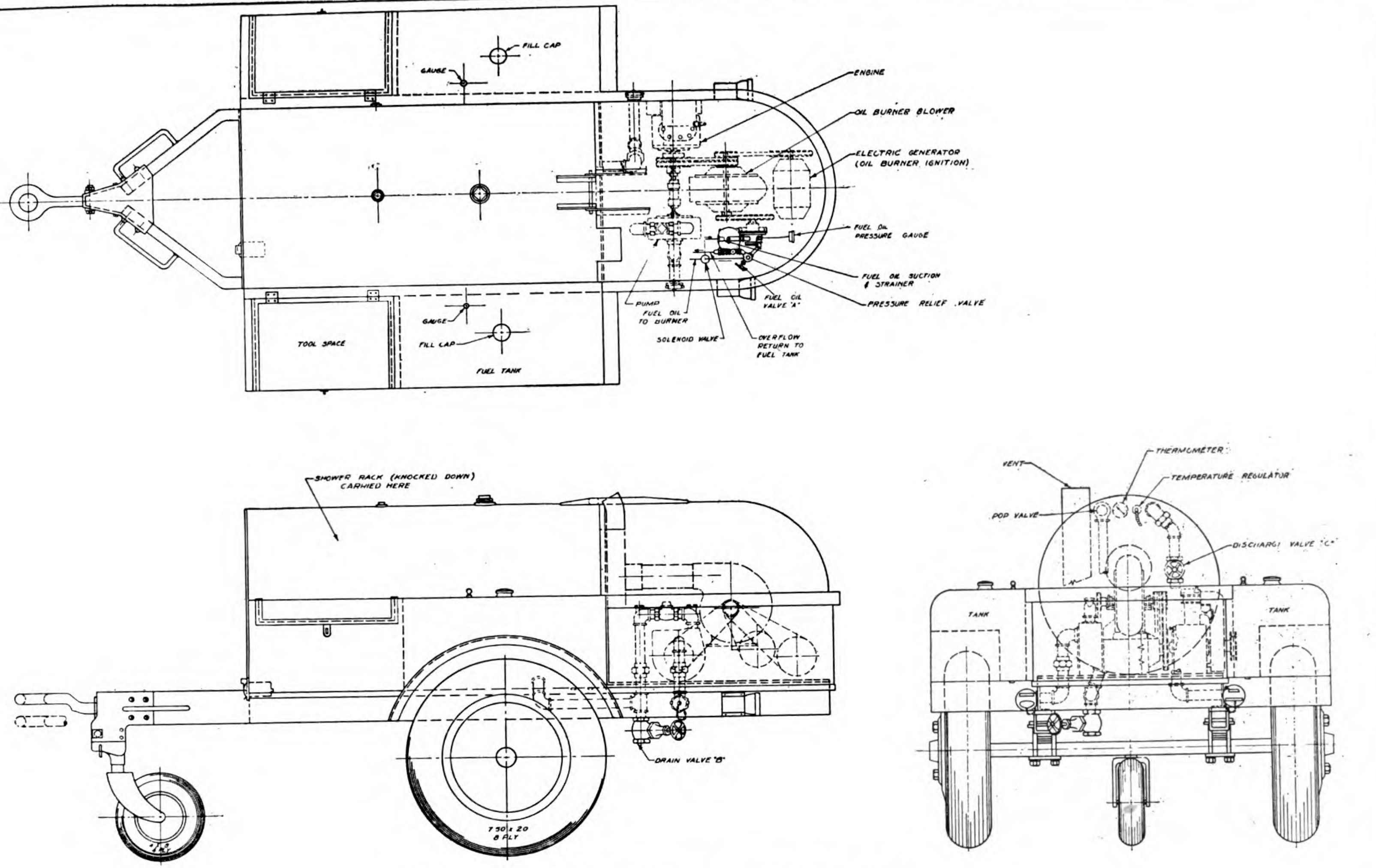


FIG. 65 PORTABLE FIELD BATHING UNIT (8 SHOWER HEAD TYPE)

(FROM MANUFACTURES DRAWING F 1-17)

(3) Close valve "B", fill the heater with water, and when full, close valve "C".

(4) Close the fuel oil valve (A) between pump and burner and the butterfly valve on the blower, and prime the fuel oil pump.

(5) Turn the flexible coupling on the water pump to insure that the impellor is free, then start the engine.

(6) Check the fuel oil pressure, it should be between 100 and 120 lb. per square inch. If the pressure is outside this range remove the cap from the pressure regulator and adjust the regulating screw. Check the fuel oil suction lines for leaks.

(7) Open the fuel oil valve (A) and set the butterfly valve on the blower about one quarter open.

(8) When the water in the heater reaches the desired temperature open valve "C" and adjust to the desired flow.

(9) To shut down, close the oil valve (A), and when the fire is out, cut off the engine. Drain the pump casing if there is danger of freezing.

g. Precautions.— (1) Do not close globe valves in the fuel oil suction or return lines at any time unless the fuel tank is damaged.

(2) Keep the grease cup on the water pump seal filled with grease (equal to Mobilgrease No. 4) at all times, and before starting, screw down the cross-bar on the grease cup stem to the end of the stem.

Section XI

PORTABLE DISTILLATION UNITS

164. **The 50 GPH (1000 Gallons Per Day) Unit.—(Fig. 66)** *a. Description.*— This unit is a single effect evaporator designed to produce 50 gallons per hour of distillate and consists essentially (Fig. 67) of a pump, an oil fired boiler, an evaporator and a condenser mounted on a trailer.

(1) The boiler is the fire tube type in which the hot gases formed by the combustion of the fuel pass through tubes or flues, and the water to be heated and changed into steam is around the tubes. The design of the boiler is known as 4-pass in which the hot gases pass back and forth through the flues four times before passing out to the atmosphere through the stack. It is equipped with an oil burner of the conventional type and its own boiler feed pump.

(2) The evaporator consists of coils immersed in sea water contained in the shell of the evaporator through which the steam formed in the boiler passes, evaporating the sea water. The steam is condensed in

evaporating the sea water and is returned to the boiler by the boiler feed pump. The steam from the evaporator passes through the shell of the condenser around a coil through which cold water is pumped. This causes the steam to condense, the heat from the steam being absorbed by cold sea water, part of which then passes to the evaporator to supply its requirements. Since more cooling water than evaporator feed is required, a part of the water leaving the condenser is discharged to waste.

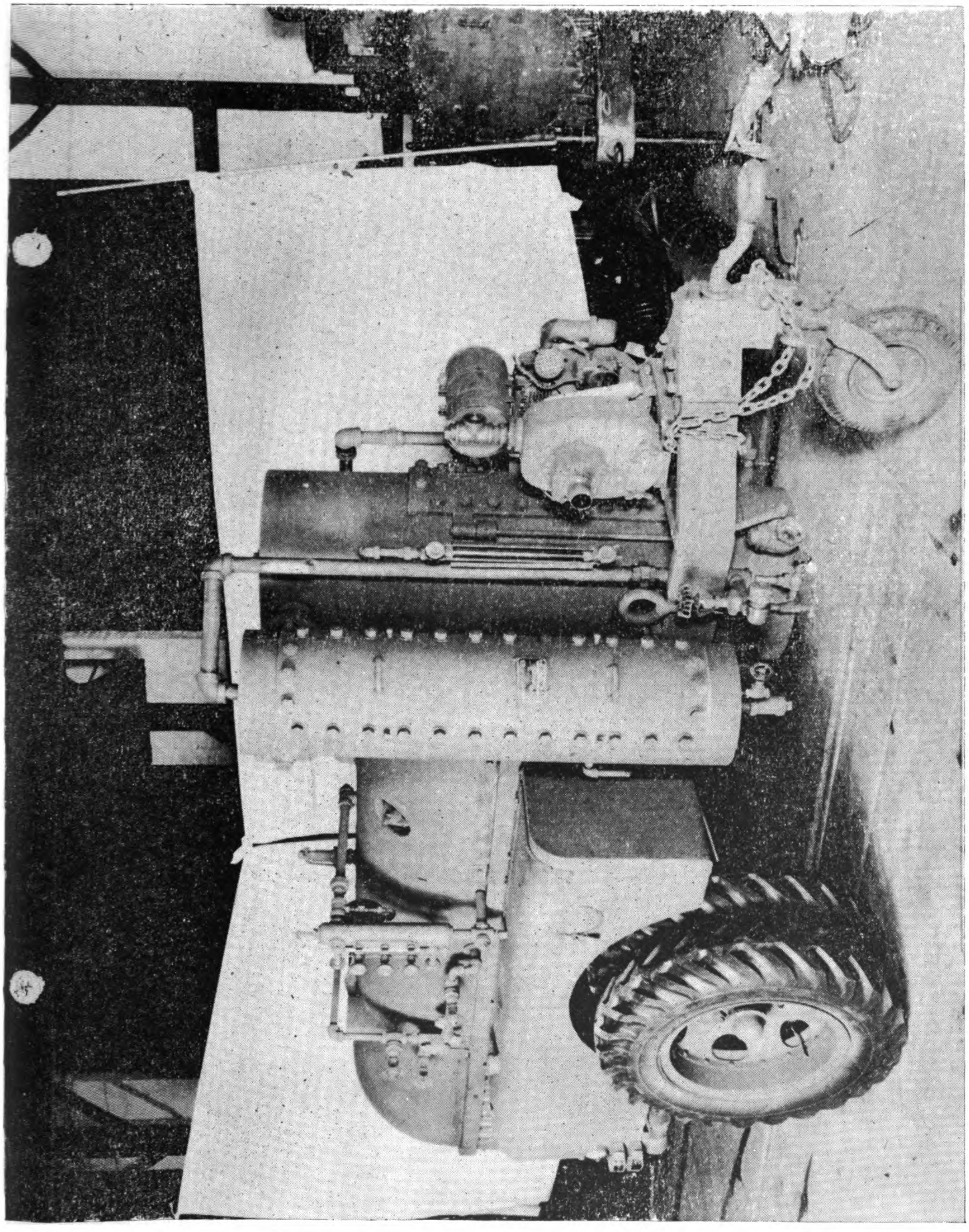
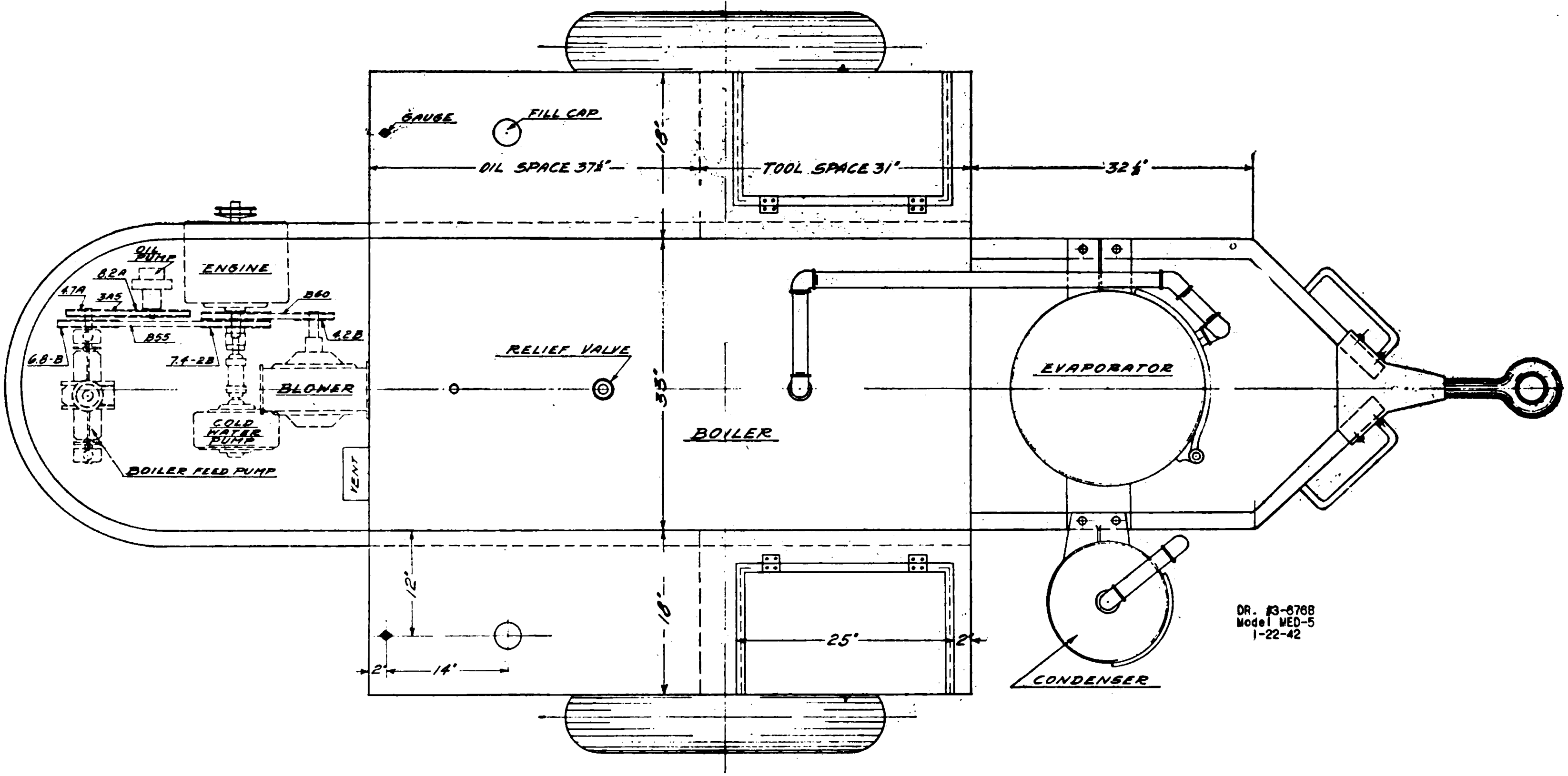
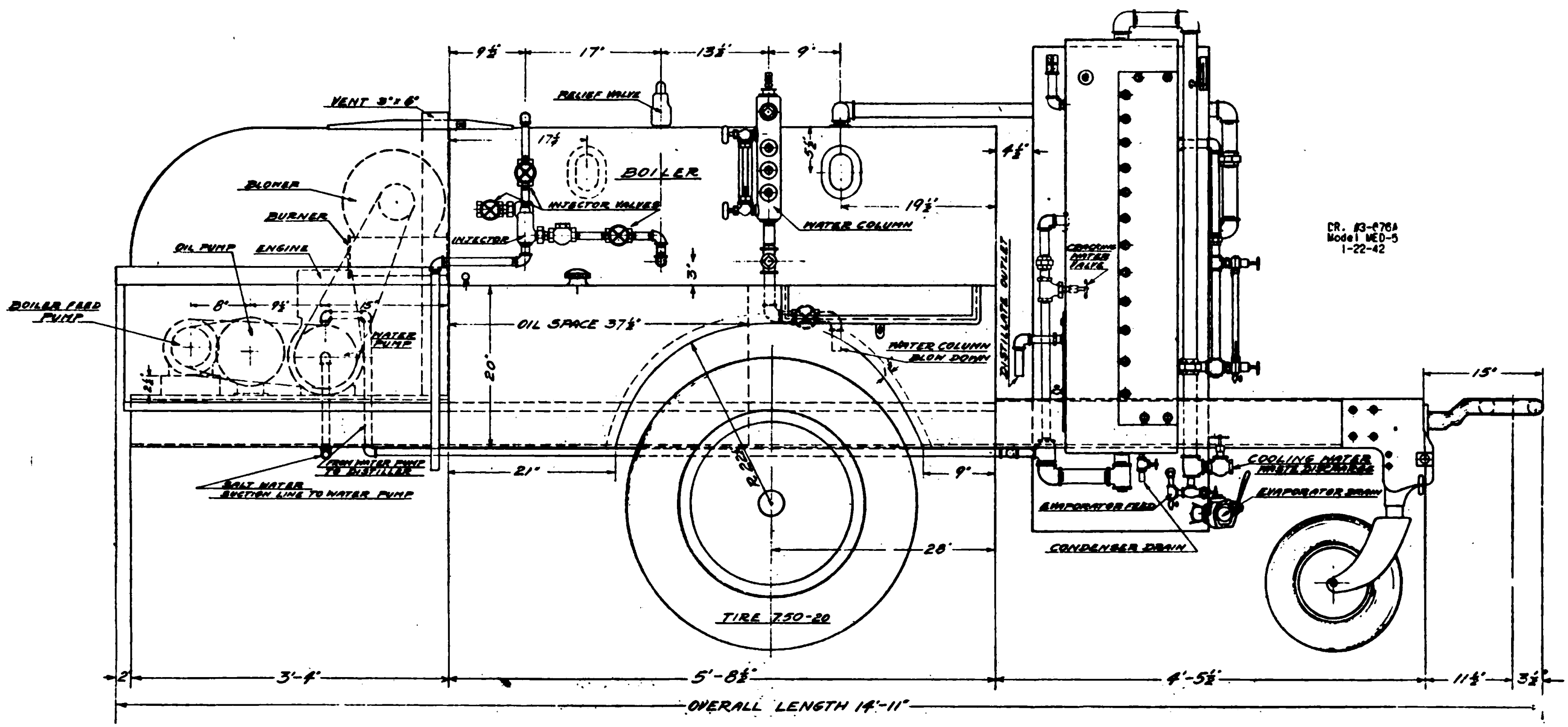


Figure 66. 50 G.P.H. (1000 G.P.D.) Portable Distillation Unit.



TOP VIEW

Figure 67A.



LEFT SIDE VIEW

Figure 67B.

(3) The unit is equipped with a sea water pump, a boiler feed pump, a fuel oil pump which delivers the fuel oil to the burner, and a blower which furnishes the air for combustion of the fuel oil, which are all driven by a gasoline engine.

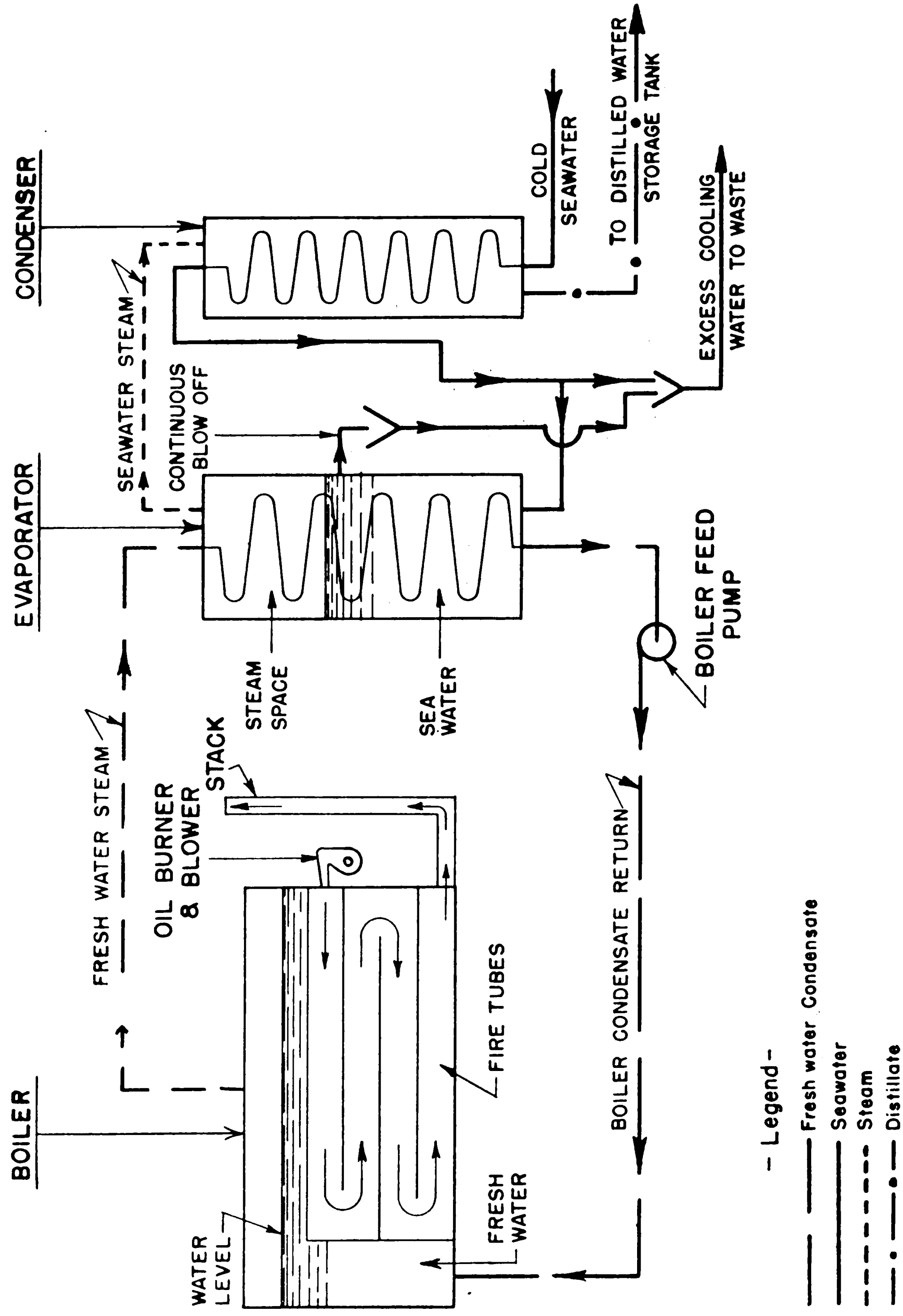


Figure 68. Flow Diagram 50 GPH Portable Distillation Unit.

b. Operation.— (See Par. 25, Fig. 6 and Fig. 68) (1) Make sure the unit is level and the boiler filled with fresh water or preferably condensate until two inches of water shows in the guage glass. In operation the expansion of the water will result in a rise to about three inches which should be maintained. If it is impossible to obtain fresh water with which to fill the boiler, operate with salt water until sufficient distillate is produced, then drain the boiler and refill with this distillate.

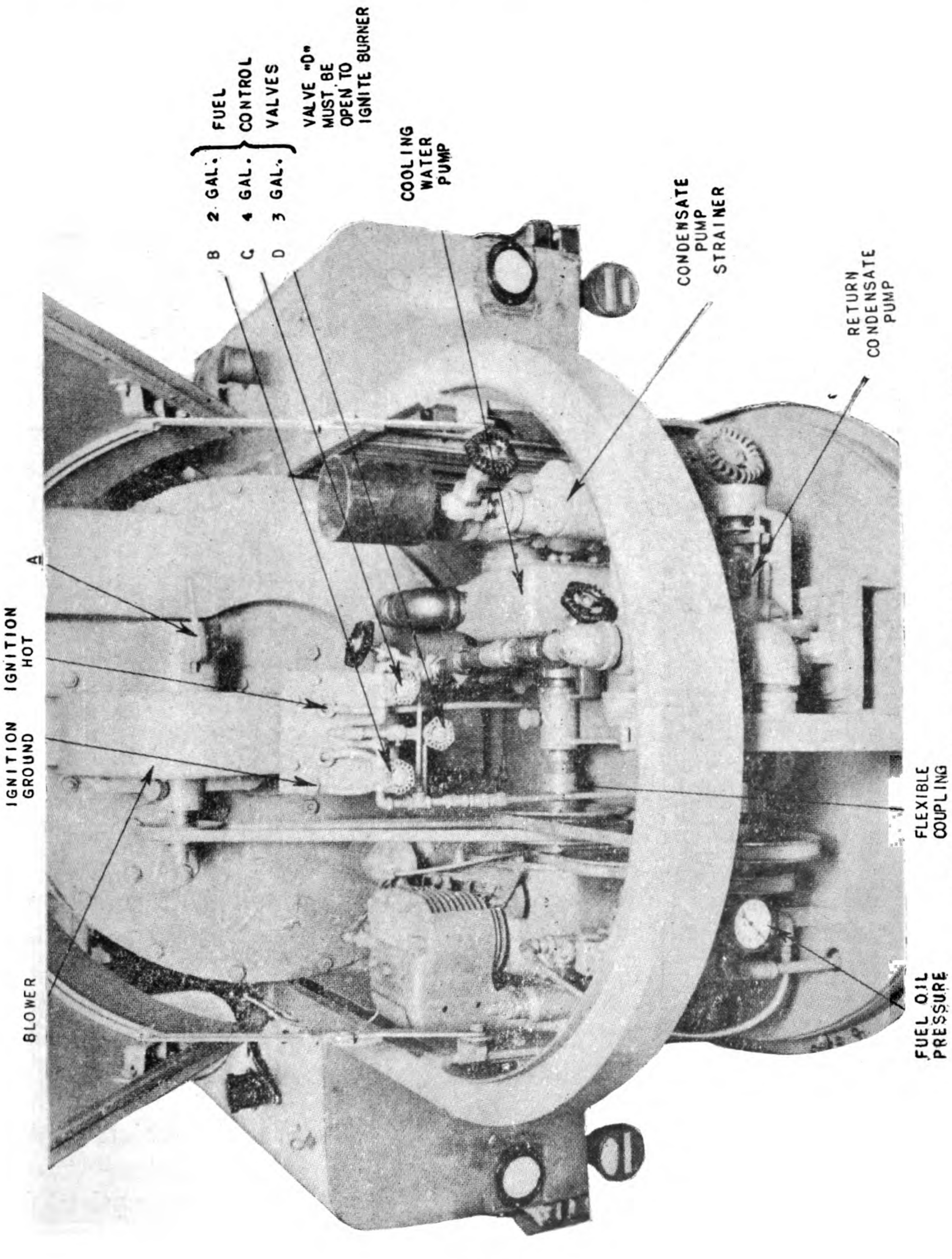


Figure 69. Operating platform 50 G.P.H. still.

(2) Fill the fuel oil tanks with oil no heavier than No. 3 in warm weather and No. 2 in cold weather. If it is necessary, because of the absence of any other fuel, to use kerosene, a cupful of light lubricating oil should be added to each five gallons of kerosene. The use of kerosene will result in a lower output.

(3) Close the fuel oil valve and the damper on the blower. (Fig. 69) Warm up the gasoline engine. Check fuel oil lines for leakage. When the engine is warm and its operation, as well as the operation of the oil pump, has been checked (the oil pressure should read between 100 and 120 pounds per square inch), stop the engine. Open the fuel valve and set the damper on the blower about one-quarter open. Start the engine again. See that the valves leading to the 2-and 3-gallon burner nozzles are open and that the valve to the 4-gallon nozzle is closed. If, after the unit is in operation, this does not produce sufficient distillate, try operating with the 2 and 4 gallon nozzles or the 3 and 4-gallon nozzles.

(4) The oil should ignite at once from the electric spark produced by the magneto. When the oil has ignited reset the damper so that just a haze of smoke comes from the stack, then open the damper until this has just disappeared. If oil does not ignite from the electric spark it may be lit by means of the asbestos torch furnished with the apparatus. If the fuel oil pressure is less than 100 pounds per square inch or more than 120 pounds per square inch, remove the cap from the pressure regulator and adjust the small screw, which will be found under it, with a screwdriver.

(5) Open wide the steam valve to the evaporator and the valve on the condensate return line to the boiler feed pump and open the petcock on the air chamber on the line to the boiler feed pump until all the air has been discharged and water flows. Gradually close the circulating valve on the line which discharges the excess cold water to waste until the temperature of the cold water is 175° F as shown on the thermometer.

(6) *(a)* As the water in the evaporator changes into steam the solids (salts) dissolved in the sea water remain behind and concentrate. If this concentration is allowed to continue a point will be reached when sea water with its dissolved material will be entrained with the steam and carried over to the condenser. These salts carried over will result in solids in the distilled water (see par. 47c).

(b) Since the boiler is fed with distillate which contains no dissolved matter and as this water is condensed and returned to the boiler by means of the boiler feed pump, no blow-down is required from the boiler and the only make-up water necessary for it is that to replace

the small losses which occur from leaks in the steam lines. Once the distilling unit begins to operate this make-up water can be supplied from the distillate produced by the unit.

(c) The blowdown from the evaporator is automatic in that all the feed water in excess of that evaporated overflows to waste. Therefore, to maintain the proper blowdown, open the evaporator feed valve sufficiently so that the overflow is approximately one gallon in seventy-five seconds.

c. Scale removal.— To remove the scale (reference par. 37) which will form on the coils in the evaporator, drain the evaporator every 24 hours by opening the 2-inch quick opening valve and when the evaporator is completely drained, open the cracking valve wide for 30 seconds and then allow the evaporator to drain completely. The boiler should be operating while this operation takes place. Repeat the cracking operation three times, then close the quick opening valve and restore the water to the evaporator.

d. Burner failure.— If the burner fails to light or goes out while operating, check:

(1) Oil supply.

(2) Oil pressure. If it is impossible to regulate relief valve as described above, determine whether the relief valve or the pump is giving difficulty and make unit replacement.

(3) Cleanliness of fuel oil strainer.

e. Sea water pump failure.— Check to see:

(1) If pump is primed.

(2) If there are air leaks in suction line.

(3) If suction lift too great.

f. Boiler feed pump failure.— Check to determine:

(1) If pump is primed.

(2) Air leaks in the return line.

(3) If return line or strainer clogged.

(4) For air leaks through stuffing boxes.

(5) That engine speed is 2340 rpm.

g. To add make-up to the boiler.— Locate a vessel of distillate as close to the unit as possible and connect to the injector by means of pipe or hose with a strainer on the end. Open the steam line to the injector full and the discharge of the injector to the boiler about 2 turns.

165. **100 GPH (2000 Gallons Per Day) Unit.**— (Fig. 70) *a. Description.*— (1) This unit (Fig. 71) is a double effect evaporator designed to produce 100 gallons per hour of distillate and consists of a pump, an oil fired boiler which is the first effect, an evaporator which is the second effect, a condenser, and a distillate cooler.

(2) (Figs. 72 & 73) Sea water which has been partially heated in the cooler and condenser is pumped to the boiler or first effect where it is heated by means of an 8-pass fire tube boiler. The steam formed in the first effect goes to the second effect where it passes through coils immersed in sea water bled from the first effect. This sea water is evaporated into steam and passes to the condenser where the steam from the first effect, now partially condensed, mixes with the steam produced in the second effect as it enters the condenser. The combined effluents are changed from steam to distillate in the condenser by sea water which has been partially heated in the cooler. The distillate passes to the cooler where it is further cooled and then passed to the distillate storage.

(3) The cold sea water is pumped through the cooler and condenser. The partially heated sea water leaving the condenser is vented to the atmosphere in the aerating pan of the condenser to eliminate part of the dissolved gases and the fishy odor often present in sea water. Since the amount of water necessary for chlorine is less than that required for feed water a part of the effluent is allowed to pass to waste while the remainder is pumped to the boiler.

(4) Blow-off (See Par. 164 *b* (6) (a)) is provided for in this apparatus from the second effect which is equipped with two weir cups one of which receives the distilled water flowing out of the cooler and the other the continuous blow-down. Both cups are exactly alike, the water entering at the bottom of one compartment of each cup and flowing to the other compartment through a horizontal and vertical weir so proportioned that when the rate of flow is 100 gallons per hour the height of water in the vertical weir opening will be 1 inch about the horizontal slot. To maintain the blow-down at proper rate the height of water over the horizontal slot in the blow-down cup should be the same as in the distillate cup.

b. To operate.— (1) Fill the engine gasoline tank. Fill the fuel oil tank with oil no heavier than No. 3 in warm weather and No. 2 in cold weather. (See Par. 164 *b* (2) above regarding use of kerosene.) Remove the portable pump from the trailer and site it near the source of salt water.

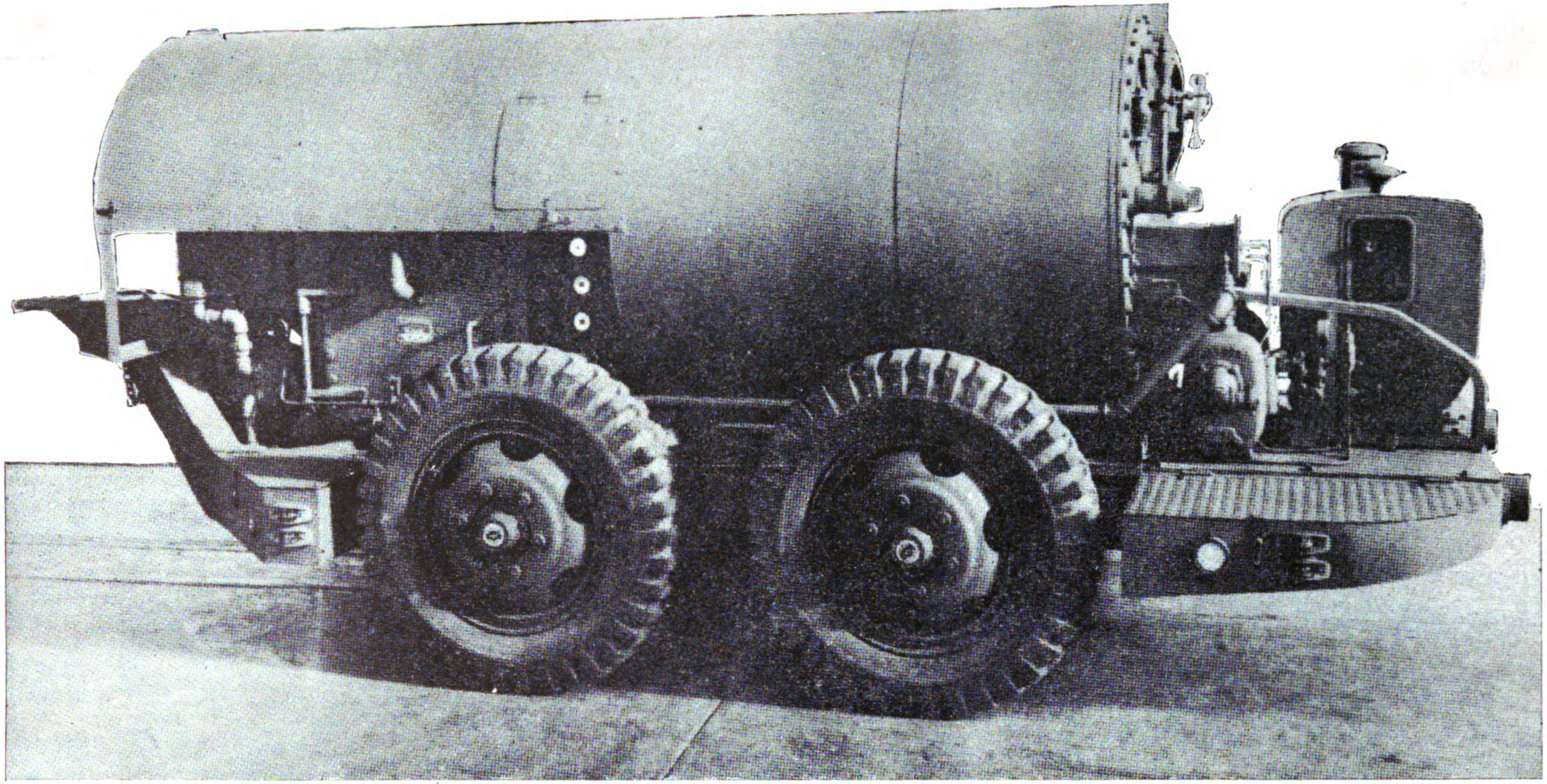


Figure 70. 100 G.P.H. Distilling Unit.

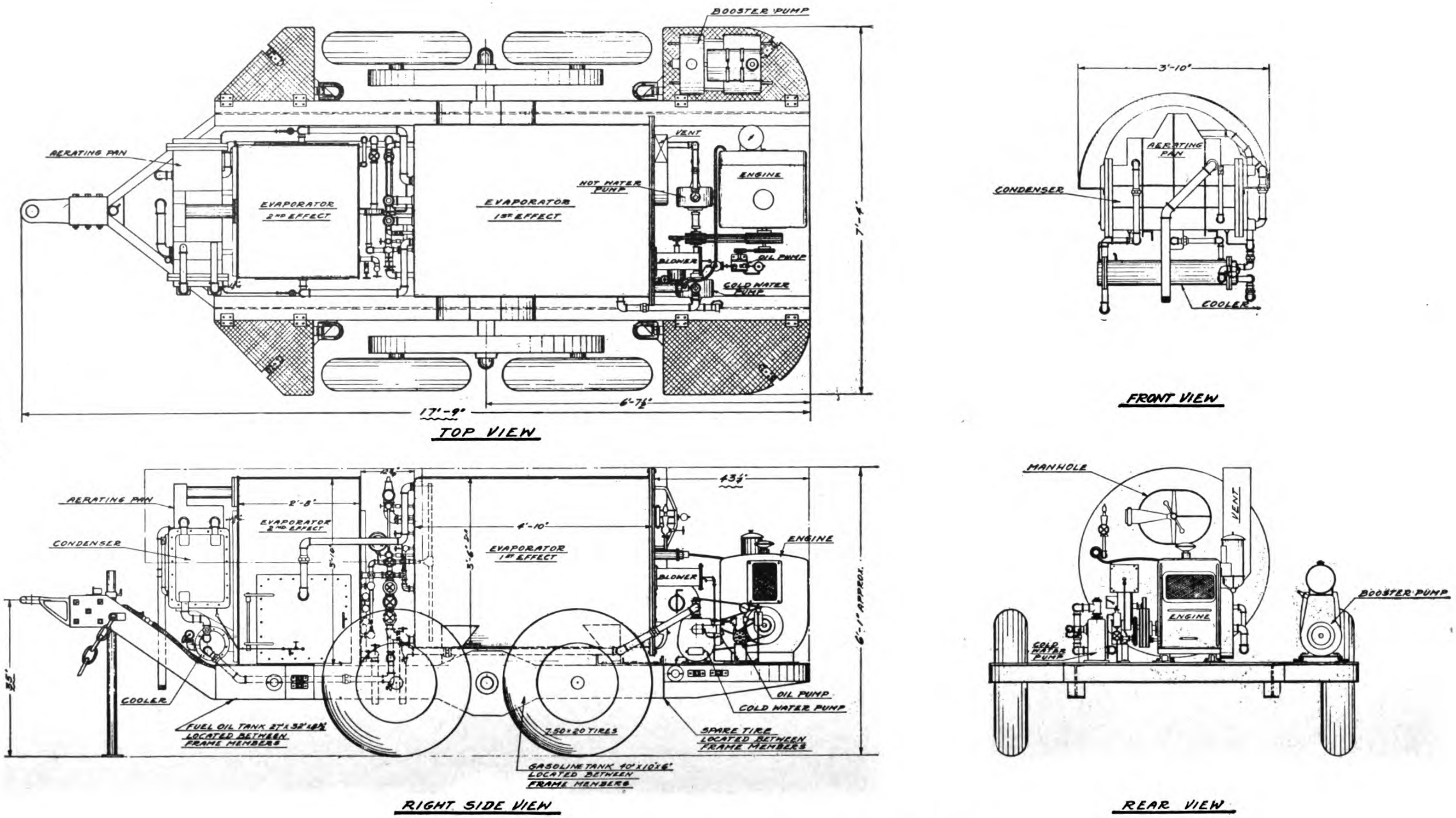


Figure 71. 100 G.P.H. Portable Distillation Unit.

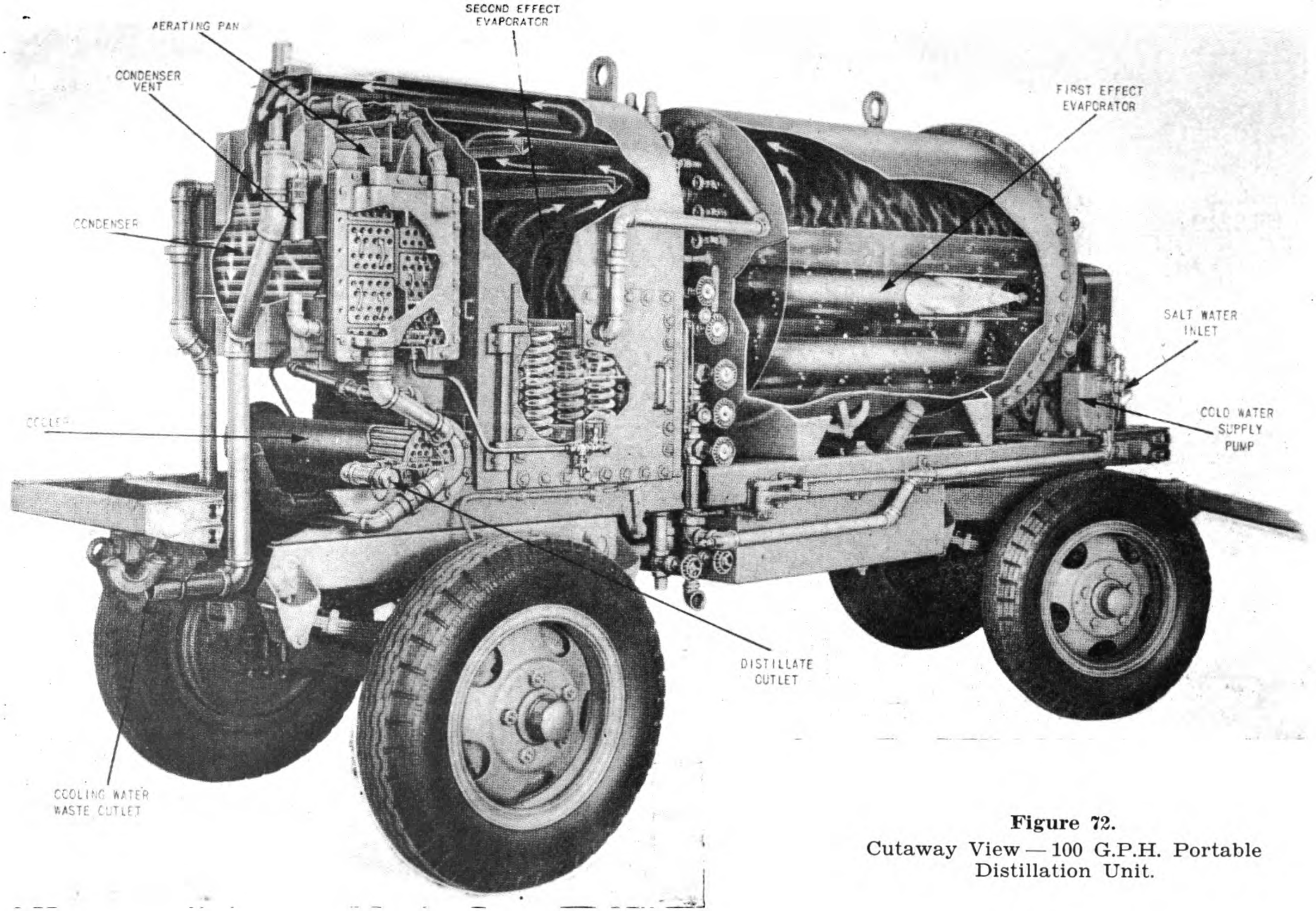


Figure 72.
Cutaway View — 100 G.P.H. Portable Distillation Unit.

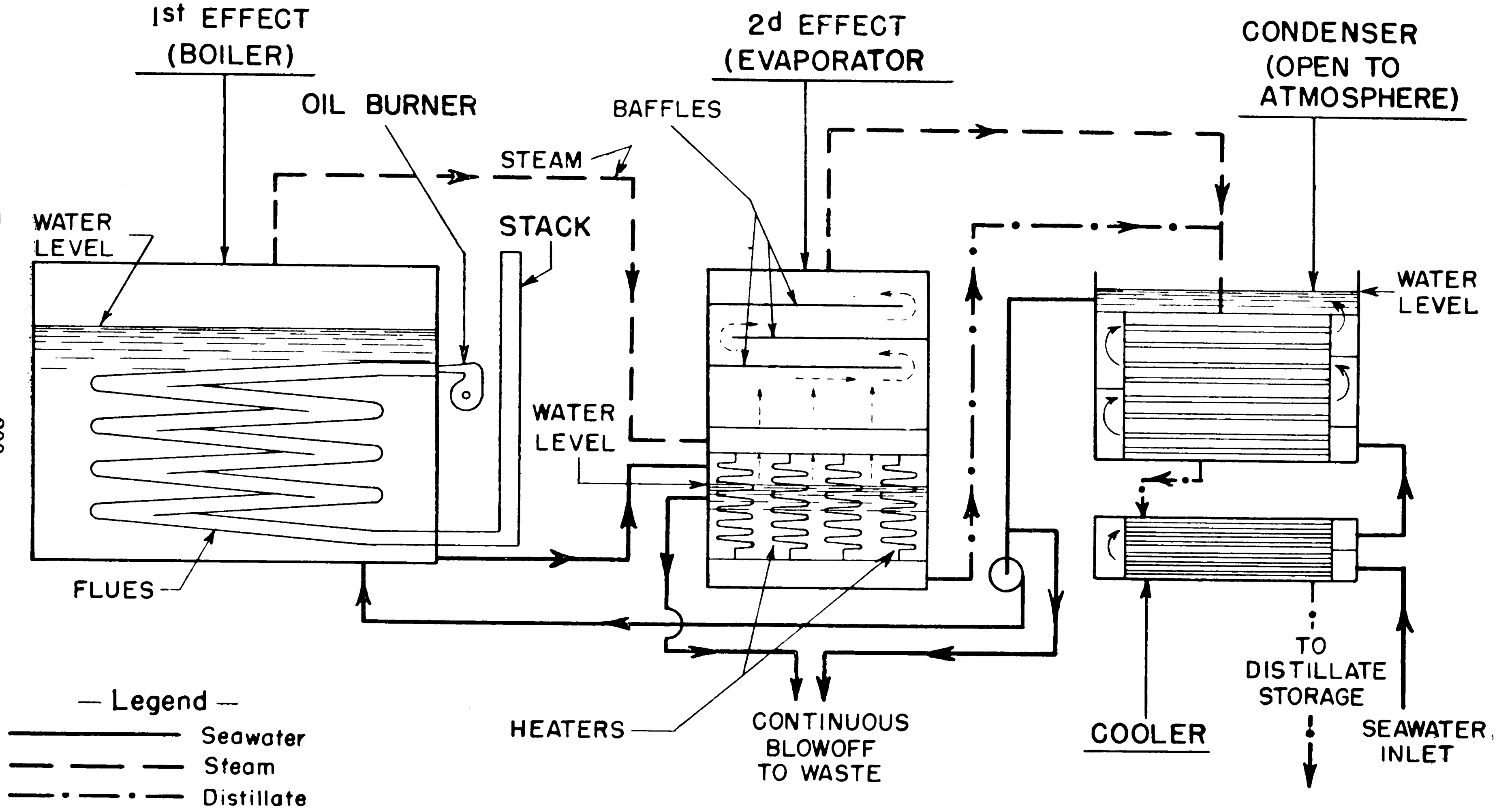


Figure 73. Flow Diagram 100 GPH Portable Distillation Unit.

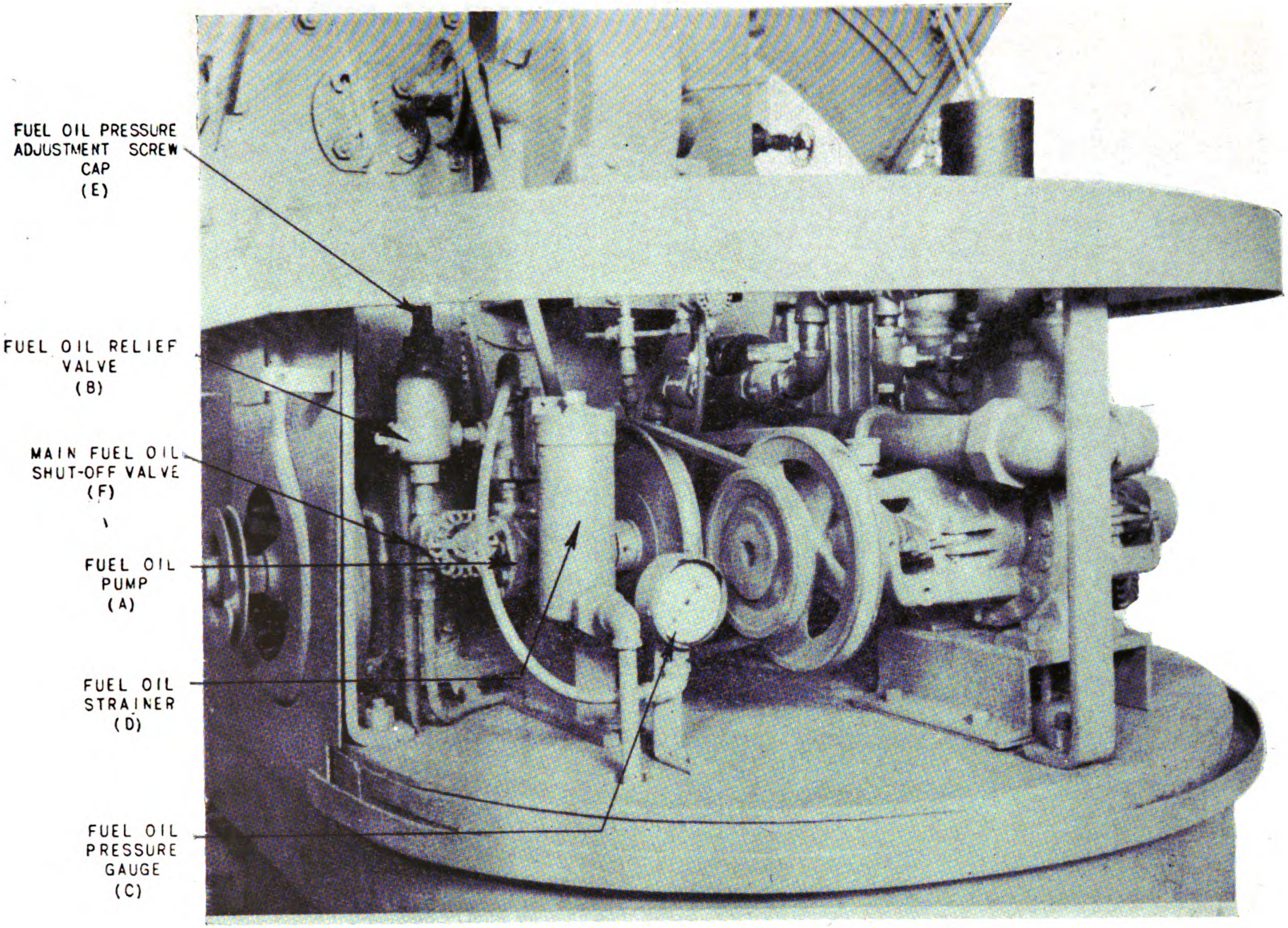

FUEL OIL PRESSURE ADJUSTMENT SCREW CAP (E)
FUEL OIL RELIEF VALVE (B)
MAIN FUEL OIL SHUT-OFF VALVE (F)
FUEL OIL PUMP (A)
FUEL OIL STRAINER (D)
FUEL OIL PRESSURE GAUGE (C)

Figure 74.

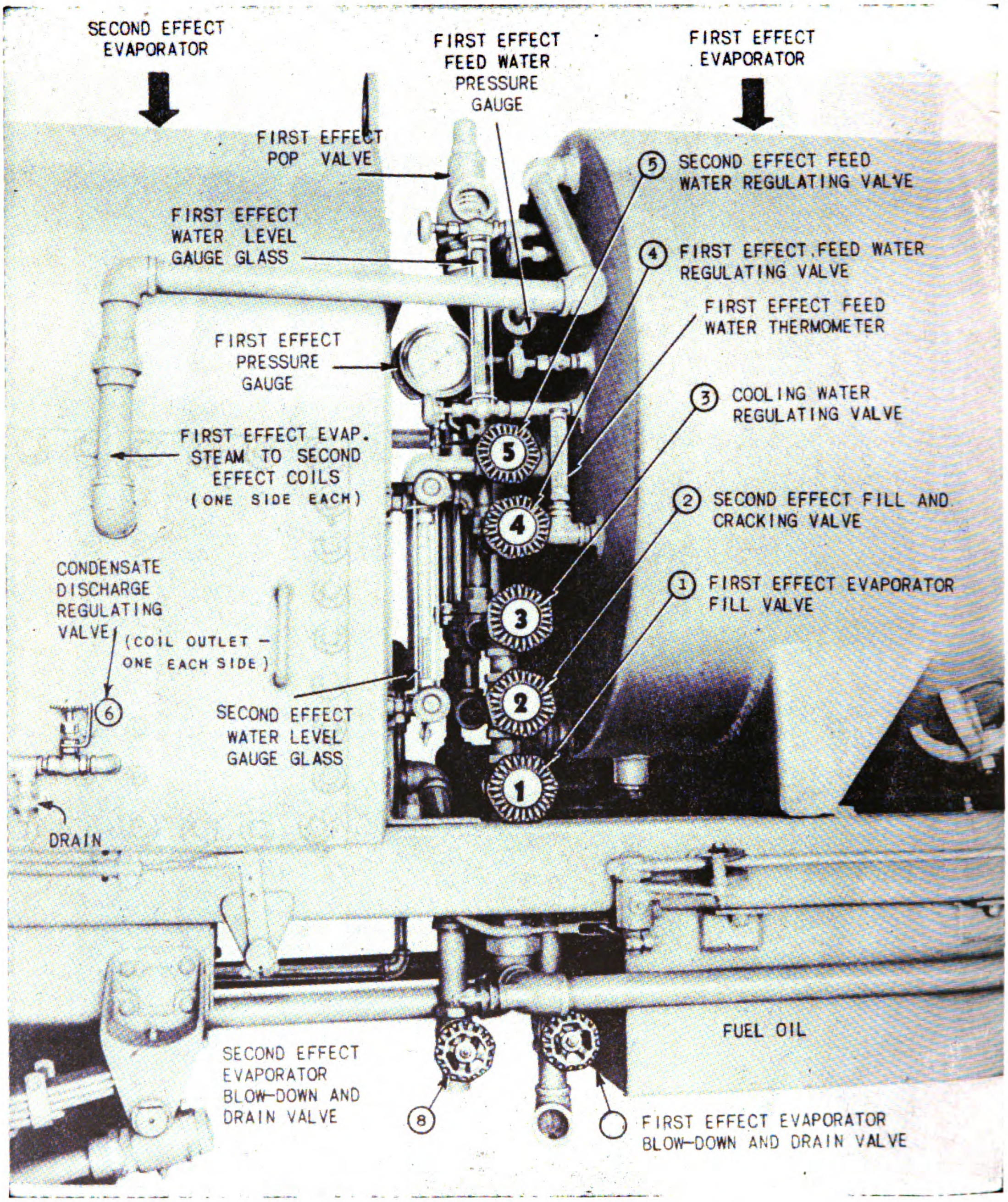


Figure 75. Water Valve Control Station 100 G. P. H. Portable Double Effect Distillation Unit.

(2) Start the pump (Fig. 74) delivering to the storage tank to be used to eliminate the sand and oil from the sea water (see Par. 25 and Fig. 6). This pump can also be used when storage is not available to jet (wash down) a beach well (see Par. 33 *b* (1)).

(3) Fill the low water alarm on the boiler. Close all water valves 1 to 5. (See Fig. 75)

(4) Open top and bottom water glass gauge cocks of the first and second effects and close all drain cocks in water lines and at the bottom of both the cold water pump on the unit and the boiler feed pump. Fill the priming chamber of the cold water pump and connect the cold water pump to the storage tank or beach well.

(5) Start the engine and open the fill valve No. 1 to first effect evaporator. Close this valve, and gauge cocks when two inches of water show in the gauge glass and open the second effect valve No. 2. Close this valve and gauge cocks when two inches of water show in the gauge glass. Light the ignition torch previously dipped in gasoline, close air damper in blower inlet, insert flaming end of torch into lighter hole so it rests on the bottom of the fire tube directly in front of the burner and then open the fuel oil supply valve fully and when lit quickly remove the lighter. Open air damper sufficiently to just eliminate smoke from the stack.

(6) When steam pressure has been generated in the first effect, open needle valves 6 and 7 in the coil outlet lines about one and one-half turns each to permit distillate to pass to the condenser.

(7) Open cold water feed valve No. 3 about a half turn and observe the vapor, discharged from the condenser for water bubbles. If water bubbles appear in the vapor increase the opening of valve No. 3.

(8) As the steam pressure rises evaporation of water from the first effect lowers the water level and the feed valve No. 4 should be opened to permit water to pass from the aerating pan to the first effect. The second effect feed valve No. 5 is then opened and allows feed water to flow from the bottom of the first effect to the second effect.

(9) After the flow of distillate has started cold water valve No. 3, valve No. 4 and valve No. 5 should be adjusted to establish constant levels. Valve No. 3 should be opened only sufficiently to produce cold water to condense all the vapors and give the feed water to the first effect a temperature between 180 to 200° F. as shown by the thermometer above valve No. 4. Valve No. 4 is adjusted to maintain a constant water level in the first effect and valve No. 5 is adjusted to keep a constant level in the second effect at the same time permitting the proper amount of blow-down to be discharged.

c. To test;— Fill one of the beakers furnished with distillate and add two or three drops of the silver nitrate furnished. If the distilled water is of satisfactory quality the silver nitrate will cause the color of the water to change slightly but if it is salty a white cloud will form on the surface of the water.

Note: Silver nitrate is poisonous. If taken internally, administer a solution of table salt or soap in water to induce vomiting and follow with one tablespoonful of mustard in warm water and a dose of epsom salts.

d. Scale removal.— (1) Once every twenty-four hours, during the period set aside for maintenance, drain the second effect by opening the bottom drain valve No. 8 and then fill to the proper level through the second effect fill valve No. 2, keeping the coils full of steam by operating the boiler with the drain valve open. This will send a jet of cold water against the coils causing contraction of the expanded coils and the scale to crack off. After about 30 seconds close valve No. 2 and when the evaporator has drained, repeat the operation twice again. Then close drain valve, refill evaporator, and proceed.

(2) At least once every two hundred hours of operation the operator should enter the first effect through the upper manhole in the back plate to inspect and remove scale by scraping or chipping. The unit should be allowed to cool before the operator enters.

166. **To Shut Down (Either 50 or 100 GPH Unit).**— Close oil supply valve to the burner but continue the engine in operation to circulate cool water until the flow of distillate is stopped, then shut off engine. Do not drain immediately after shutting down but allow the unit to cool thoroughly.

167. **Fusible Plug (Either 50 or 100 GPH Unit).**— If the boiler is accidently fired with low water the fusible plug provided will melt and warn the operator by the fact that vapor is emitting from the stack. If the plug fuses it should be replaced and the water level restored.

168. **Improvised Distillation Setup.**— Figure 76 illustrates an emergency still constructed of gasoline drums and pipe. The drums should first be freed of gasoline fumes by heating and of traces of tetraethyl lead by repeated rinsing followed by heating. One drum is set on its side over a fireplace of stone or brick and a pipe welded into it as shown; a second drum is filled with water and the pipe run through it and welded to the heads so that it inclines from inlet to outlet. A third drum is filled with water, set on end and a length of coiled pipe placed in it running to a catch basin. Capacities of from 3 to 5 gallons per hour have been reported with similar arrangments.

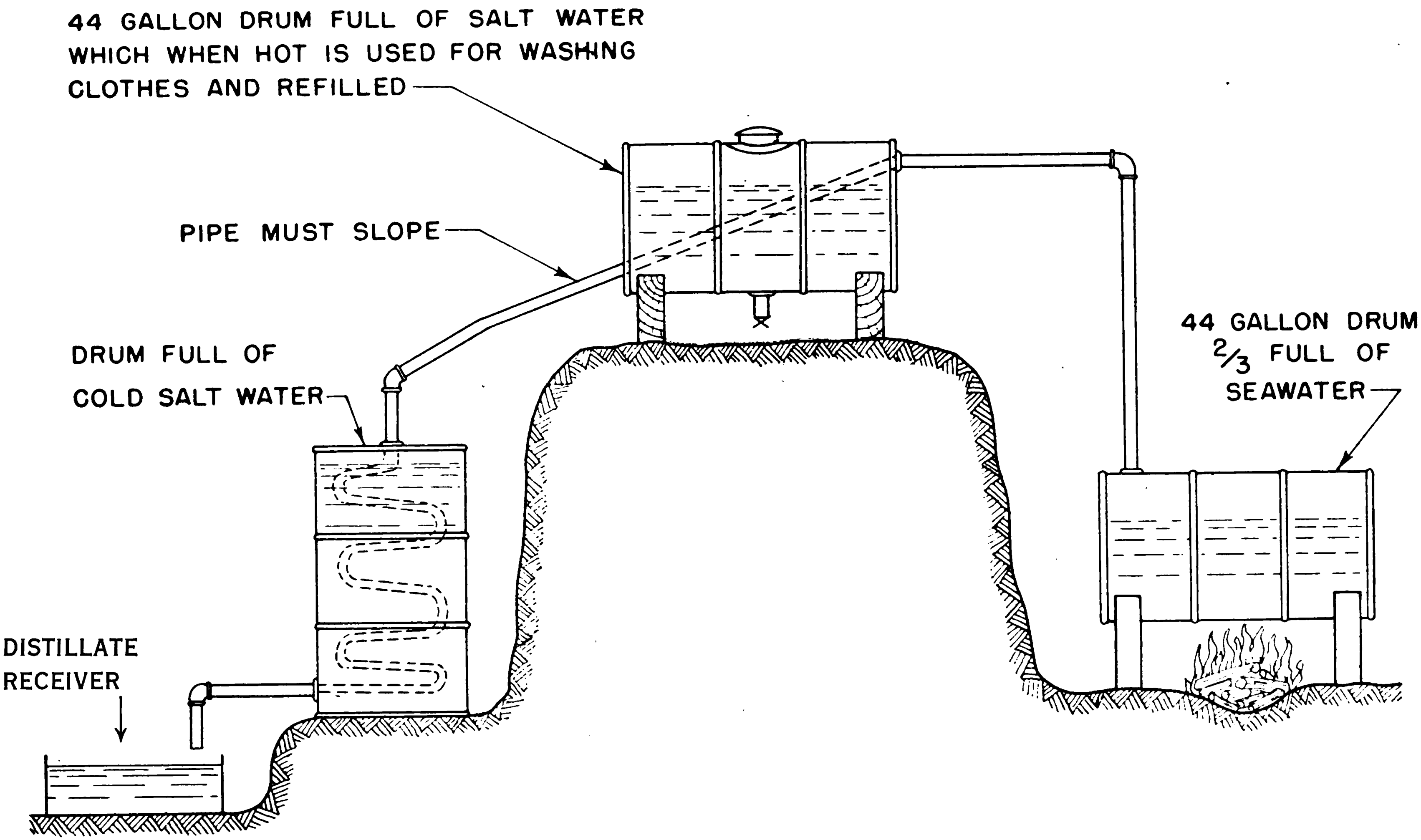


Figure 76. Improvised Still.

APPENDICES

Pressure and Volume Conversion (Tables XXII and XXIII and Figure 3)

Miscellaneous Data

Boiler Evaporation

Pump Power Requirements
Table of Daily Water Consumption in Gallons (Table XXIV)

Discharge Over Weirs and from Artesian Wells (Tables XXV and XXVI)

Areas and Capacities Per Foot of Depth of Tanks (Table XXVII)

Units of Measurements (Table XXVIII)
Suction Head Required with Hot Water at Various Altitudes (Table XXIX)

VI. BIBLIOGRAPHY

Appendix I

WATER ANALYSIS

Appendix I

SAMPLING AND ANALYSIS OF WATER

1. **Time Interval Between Collection and Analysis.**— *a.* In general, the shorter the time elapsing between collection and analysis of a sample, the more reliable will be the analytical results. Under some conditions analysis in the field is necessary to secure accurate results because the composition of the water will change before an analysis can be made in the laboratory.

b. The time that may be allowed to elapse between collection of a sample and the beginning of its analysis cannot be definitely stated. It depends upon the character of the sample, the examinations to be made, and other conditions. Changes incident to activities of organisms present may be greatly retarded if samples are kept at a low temperature until they are examined. The following are suggested as fairly reasonable maximum limits:

Physical and Chemical Analysis	
Unpolluted waters	72 hours.
Fairly pure waters	48 hours.
Polluted waters	12 hours.

If a longer period elapses between collection and examination, the time should be stated. If sterilized by addition of acid or a germicide, samples for sanitary chemical examination may be allowed to stand for a longer period than above indicated, but no definite procedure can be recommended.

c. Determination of dissolved gases, especially oxygen, hydrogen sulphide, and carbon dioxide, should be made at the source in order to be reasonably accurate, in accordance with directions given hereafter in connection with each determination.

2. **Expression of Chemical Results.**— *a.* The results of chemical analyses shall be expressed in parts per million, assuming that a liter of water measured out for analysis weighs 1 kilogram. When the error introduced by this assumption exceeds ∓ 3 parts in a thousand, the specific gravity of the sample (referred to water at 4° C.) shall be determined and results obtained with measured samples shall be divided by this specific gravity to give correctly, parts per million. A liter of pure water at 25° C. weighs 0.997 kilograms in air, and a liter of water containing 6573 milligrams of sodium chloride at 20° C. weighs 1.003 kilograms.

b. The following general rules shall govern the use of significant figures in the expression of results:

(1) If the results show quantities greater than 10 parts per million, use no decimals: record only whole numbers.

(2) If the results are between 1 and 10 parts, do not retain more than one decimal place.

(3) If the results are between 0.1 and 1 part, do not retain more than two decimal places.

TABLE I. — FACTORS FOR TRANSFORMING RESULTS OF ANALYSES

Unit	Equivalents			
	Grains per U. S. gallon	Grains per Imperial gallon	Parts per 100,000	Parts per million
1 grain per U. S. gallon	1.000	1.20	1.71	17.1
1 grain per Imperial gallon	0.835	1.00	1.43	14.3
1 part per 100,000	0.583	0.70	1.00	10.0
1 part per million	0.058	0.07	0.10	1.0

3. **Turbidity.**— *a.* The turbidity of water is due to suspended matter, such as clay, silt, finely divided organic matter, microscopic organisms, and similar material. The terms "Turbidity" and "Suspended Matter" do not represent chemical equivalents. "Suspended Matter" is that portion of the residue on evaporation not in solution in the sample. "Turbidity" is an expression of an optical approximation of the suspended matter, based upon the similarity of interference to the passage of light rays through a water sample when compared with standard samples of recorded turbidity.

b. The standard unit of turbidity is considered as that produced by one part per million of silica (diatomaceous earth or fuller's earth) in distilled water.

4. **Turbidity Measurements—General.**— *a.* Turbidity measurements are based on the depth of suspension required for the image of the flame of a standard candle to disappear when observed through the suspension. The standard instrument for making such measurements shall be the Jackson candle turbidimeter, which consists of a graduated glass tube, a standard candle, and a support for the candle and tube. The glass tube and the candle shall be supported in a vertical position so that the center line of the tube passes through the center line of the candle, the top of the support for the candle being 7.6 centimeter (3 inches) below the bottom of the tube. The glass tube shall be graduated, preferably to read direct in turbidities, and shall have a flat polished bottom. Most of the tube should be enclosed in a metal or other suitable case when observations are being made. The candle support shall have a spring or other device so as to keep the top of the candle pressed against the top of the support. The candle shall be made of beeswax and spermaceti gauged to burn within the limits of 114 to 126 grains per hour.

b. To insure uniform results, it is desirable that the flame be kept as near constant size and constant distance below the glass tube as is possible. This will require frequent trimming of the charred portion of the candle string and frequent observations to see that the candle is pushed to the top of its support. Each time before lighting the candle remove such portion of the charred part of the string as is very easily broken off with the fingers. Do not keep the candle lighted for more than a few minutes at a time, for the flame has a tendency to increase in size.

c. The observation is made by pouring the suspension into the glass tube until the image of the candle flame just disappears from view. Pour very slowly when the candle becomes only faintly visible. After the image has disappeared the removal of one per cent of the suspension from the tube should make it again visible. Care should be taken to keep the glass tube clean on both the inside and the outside. The accumulation of soot or moisture on the lower side of the glass bottom of the tube may interfere with the accuracy of the results.

TABLE II. — GRADUATION OF CANDLE TURBIDIMETER

Depth of liquid (cm.)	Turbidity (parts per million)	Depth of liquid (cm.)	Turbidity (parts per million)
2.3	1000	11.4	190
2.6	900	12.0	180
2.9	800	12.7	170
3.2	700	13.5	160
3.5	650	14.4	150
3.8	600	15.4	140
4.1	550	16.6	130
4.5	500	18.0	120
4.9	450	19.6	110
5.5	400	21.5	100
5.6	390	22.6	95
5.8	380	23.8	90
5.9	370	25.1	85
6.1	360	26.5	80
6.3	350	28.1	75
6.4	340	29.8	70
6.6	330	31.8	65
6.8	320	34.1	60
7.0	310	36.7	55
7.3	300	39.8	50
7.5	290	43.5	45
7.8	280	48.1	40
8.1	270	54.0	35
8.4	260	61.8	30
8.7	250	72.9	25
9.1	240		
9.5	230		
9.9	220		
10.3	210		
10.8	200		

d. The figures in Table 2 give the turbidities for the depth at which the image of the candle flame just disappears.

e. Observations should be made in a darkened room or with a black cloth over the head. It is allowable to substitute for the standard candle other forms of light, but the instrument must be calibrated to give turbidity readings that correspond with the standard candle.

5. **Turbidity Measurements—Above 100.—** *a.* The standard method of measurement of turbidities from 100 to 1000 parts per million shall be the use of the candle turbidimeter as described in the preceding section. Alternate procedures involving the use of standard suspensions in bottles may be followed if the frequency of tests requires the use of such equipment, and further, provided that the readings obtained by the use of such suspensions are checked at least once daily with the candle turbidimeter.

b. Samples having a turbidity above 1000 parts per million shall be diluted with one or more equal amounts of turbidity free water, until the resultant turbidity falls below 1000 parts per million. The turbidity of the original sample should be computed from the reading made on the dilute sample. For example, if the reading on the dilute sample is 500 and the amount of the original sample in the dilute sample is 1 part in 6, the turbidity of the original sample is 3000.

6. **Turbidity Measurements—Between 5 and 100.—** *a.* Samples having a turbidty of from 5 to 100 parts per million may be estimated by comparison with standard suspensions in bottles.

b. Samples having a turbidity between 25 and 100 may be estimated by the use of the candle turbidimeter.

c. Preparation of standards.— (1) Add about 5 grams of fuller's earth to 1 liter of distilled water, thoroughly agitate intermittently for an hour and then allow to stand 24 hours. Withdraw the supernatant without disturbing the sediment in the bottom and test the turbidity with the candle turbidimeter. Take successive portions of the suspension and dilute with distilled water until the mixtures resulting correspond to the depth of liquid reading of the various turbidity standards desired in the 5-100 range, using the candle turbidimeter for making the readings.

(2) If fuller's earth does not produce a suspension the color of which is reasonably similar to the suspended matter in the water under examination, suspended matter or bottom sediments from a stream may be acid treated to remove soluble constituents, washed by decantation and adjusted as above directed.

(3) The standards, when prepared, shall be placed in clean resistant bottles of 1 liter capacity or greater. Enough free space at the top of the bottle shall be left to allow adequate agitation when readings are being made.

(4) The standards shall be made fresh at least every month and shall be kept tightly stoppered.

(5) In order to prevent bacterial or algae growths from developing, a small amount of mercuric chloride may be added to the standards.

d. Procedure.— (1) The sample, contained in a bottle of the same type as the standards, and the standards shall be well shaken. The comparison shall be made by viewing the sample and the standards sidewise, looking through both at some object and noting the distinctness with which it can be seen. The turbidity of the sample shall be recorded as that of the standard bottle which produced the visual effect most closely approximating that of the sample.

(2) Readings will be facilitated if a series of black ruled lines on white paper be the objects viewed, and further, if the light, preferably electric, illuminates both sample and standards from above while the comparison is being made, with no direct rays from the light reaching the eye.

7. **Turbidity Measurements—Less than 5.**— *a.* When the turbidity of a sample is less than 5, estimations are best made with an interferometer of the Baylis or the St. Louis type. These instruments make use of the Tyndall effect produced by rays of light striking particles at an angle to the line of vision, the effect increasing as the density of suspended particles increases. Estimations are made by comparison with standard suspensions. The sensitivity of such instruments may decrease in the range of 2-5 parts per million. If so, the sample must be diluted with zero turbidity water before the estimation is made.

b. Preparation of standards.— (1) Dilute a suspension (the turbidity of which has been observed by the use of the candle turbidimeter to be any recorded amount above 25 and not over 100) with zero turbidity distilled water until the computed turbidity is 10 parts per million. This stock suspension should be made fresh at least every month. Bacterial and mold growths may be prevented by adding a small amount of mercuric chloride.

(2) Dilute standards of 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, etc., should be made weekly. With a stock suspension having a turbidity of 10, one milliliter made up to 100 milliliters with distilled water will have a turbidity of 0.1 part per million. The dilute standards should be made up in amount large enough to fill the comparison tubes, but are preferably stored in resistant glass bottles when not in use.

c. Procedure.— (1) The comparison tubes of the particular type adapted to the interferometer being used shall be made of clear white glass. They shall be kept scrupulously clean, both inside and out, and should be discarded when scratched or etched. Do not handle the tubes below the point where the light strikes them.

(2) Fill a series of tubes to the mark with the dilute standards and the samples—all thoroughly agitated. Allow air bubbles to escape. View from above and match the sample with the standard giving the same or approximately the same interference effect. Record in terms of the turbidity of the matched standard.

d. Recording Turbidity Readings.— The results of turbidity observations shall be expressed in whole numbers which correspond to units of turbidity as follows:

Turbidity between	0	and	1	recorded to the nearest	tenth
” ”	1	”	10	” ” ” ”	unit
” ”	11	”	100	” ” ” ”	5
” ”	101	”	400	” ” ” ”	10
” ”	401	”	700	” ” ” ”	50
” ”	701	”	greater	” ” ” ”	100

8. **Coefficient of Fineness.**— The quotient obtained by dividing the weight of suspended matter in the sample by the turbidity, both expressed in the same unit, shall be called the coefficient of fineness. The samples shall be filtered through a fine alundrum crucible or some suitable filter that will remove all suspended matter. The crucible shall then be dried to constant weight in an oven at 103° C.

9. **Color.**— *a.* The "color" or the "true color" of water shall be considered the color that is due only to substances in solution; that is, the color of the water after the suspended matter has been removed. The accurate determination of color in water containing matter in suspension is impossible. The removal of suspended matter by centrifuging before the color observation is made gives the best results. No filter shall be used since filters exert marked decolorizing action.

b. The "apparent color" shall be considered as including not only the true color, but also any color produced by substances in suspension. The apparent color, if determined, shall be determined on the original sample without filtration.

c. The platinum-cobalt method of measuring color shall be considered as the standard, and the unit of color shall be that produced by 1 milligram of platinum per liter. The ratio of cobalt to platinum may be varied to match the hue in special cases. The proportion given below is usually satisfactory. The true and apparent color of clear water or waters with low turbidities is substantially the same.

d. The results of color determination shall be expressed in whole numbers and recorded as follows:

Color between	1	and	50	recorded to nearest	unit
” ”	51	”	100	” ” ”	5
” ”	101	”	250	” ” ”	10
” ”	251	”	500	” ” ”	20

e. Comparison with platinum—cobalt standards.— (1) *Preparation of standards.*— *(a)* Dissolve 1.245 grams of potassium chloroplatinate (K_2PtCl_6) containing 0.5 grams of platinum, and 1 gram of crystalized cobaltous chloride ($CoCl_2.6H_2O$) containing about 0.248 grams of cobalt, in water with 100 milliliters of concentrated hydrochloric acid, and dilute to 1 liter with distilled water. This solution has a color of 500.

(b) In the absence of a reliable supply of potassium chloroplatinate, chloroplatinic acid may be substituted, as follows: dissolve 0.5 grams of metallic platinum in aqua regia; remove nitric acid by repeated evaporation to dryness after adding an excess of hydrochloric acid. Dissolve this product with 1 gram of cobalt chloride as directed in *(a).*

(c) To prepare standards having colors 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, dilute 0.5 1, 1.5 milliliters etc. of the above solution with distilled water to 50 milliliters in standard Nessler tubes. If 100 milliliters standard Nessler tubes are used, colors of 5, 10, etc. are obtained by diluting, 1, 2, etc. milliliters of the standard solution to 100 milliliters with distilled water. Protect the tubes from evaporation and from dust when not in use.

(2) *Procedure.*— *(a)* Waters having a color greater than 70 shall be diluted with distilled water before making the comparison, in order that no difficulty may be encountered in matching hues.

(b) The color of a sample shall be observed by filling a standard Nessler tube to a height equal to that in the standard tubes with the water to be examined and by comparing it with standards. The observation shall be made by looking vertically downward through the tubes upon a white or mirrored surface placed at such angle that light is reflected upward through the column of liquid.

(c) Inasmuch as the proportions of the standard color solution in the comparison tubes are such as to represent an aliquot part of a liter, the readings are direct as parts per million.

f. Comparison with glass discs.— Since the platinum-cobalt standard method is not well adapted for field work, the color of water to be tested may be compared with that of glass discs held at the end of metallic tubes through which they are viewed by looking toward a white surface. The glass discs are individually calibrated to correspond with colors on the platinum scale. Experience has shown that the glass discs used by the United States Geological Survey give results in substantial agreement with those obtained by the platinum determinations, and their use is recognized as a standard procedure.

10. **Odor.**— *a.* Odors in water may be associated with the presence of polluting or otherwise objectionable substances, such as decomposing organic matter, plankton organisms, and odorous chemical compounds.

Determination of odor quality and intensity will assist in interpreting the results of a water analysis and in indicating the degree of consumer acceptance of the supply so far as its odor is concerned. The determination may facilitate the search for plankton organisms and may point out the need for special tests, such as those for hydrogen sulfide, free chlorine, and phenol. Since heat usually intensifies odor, the determination may be made on hot as well as cold samples of water.

b. Odors in water are due to the presence in the water of volatile substances in concentration, generally, too small to be detected by ordinary analytical procedures. Hence the sense of smell must be employed to ascertain their presence. Individuals vary in their sensitivity to odor stimuli and the sense of smell is quickly fatigued. These limiting factors must be recognized in connection with the methods of determining the quality and intensity of odors hereinafter outlined. Fatigue must be avoided, and the tests must be carried out in a room free from interfering odors.

c. Reagents and Apparatus.— (1) *Odor-free water.*— Add 0.5 grams powdered activated carbon to 1 liter of tap water. Stir at intervals for 30 minutes. Filter through well washed filter paper into a clean glass-stoppered bottle. Protect the funnel and bottle against absorption of odors from the air. Store the water in completely filled bottles. If odor-free water cannot be satisfactorily prepared as above indicated, distilled water may be boiled until all odor has been driven off and used as odor-free water.

(2) *Glassware.*— Use glass-stoppered bottles and flasks, or flasks covered with inverted beakers or small Petri dishes. It is preferable to reserve a sufficient number of flasks, bottles, etc. exclusively for this determination. Glassware must be cleansed frequently with cleaning solution and immediately before each determinatin with boiling odor-free water. Avoid the use of rubber or cork stoppers unless completely covered with tinfoil or equivalent material. The success of the determination depends upon keeping all glassware employed absolutely free from odor. As a precaution, apparatus when not in use may be kept immersed in tap water containing granular activated carbon. As an alternate procedure, glassware, after cleansing with cleaning solution and rinsing with distilled water, may be made odor-free by baking on a hot plate.

(3) *Osmoscope.*— In order to draw the odor from a flask or bottle directly into the nose without admixture of air at the nostrils, a glass osmoscope may be prepared from a ¾-inch glass tube, 8 to 12 inches long, open at the lower end and either terminating at the other end in two acorn-shaped nosepieces to be inserted in the nostrils or in an enlarged section that will cover the outside of the nostrils. Since the nostrils and nostril distances of different observers vary greatly, the osmoscope must either be fitted to the observer, or made adjustable. An adjustable double-nose-

piece osmoscope is obtainable commercially. Instead of a single tube, two tubes about 3/8-inch in diameter and held the proper distance apart by a metal clip or other spacing device may be employed.

d. Procedure.— (1) *Cold Odor.*— If the temperature of the sample is less than 20° C. allow it to stand quietly in the laboratory until this temperature is reached. Shake the sample violently in one of the collecting bottles which is not more than 2/3 full. Remove the stopper and lightly sniff the odor at the mouth of the bottle. Repeated shaking and smelling will reduce the odor of the sample and should be avoided.

(2) *Hot Odor.*— Pour about 200 milliliters of the sample into a 500 milliliter Erlenmeyer flask. Close the mouth of the flask with a glass stopper, a well fitting watch glass, or a small Petri dish. Heat the water to approximately 65° C., agitate it with a rotary movement, slip the cover to one side and quickly sniff the odor.

(3) *Odor concentration.*— *(a)* If an odor is detected in the sample, add to 200 milliliters of the sample in a 500 milliliter Erlenmeyer flask 200 milliliters of odor-free water, representing a 1 in 2 dilution. Mix without undue agitation or exposure to the air, and withdraw 200 milliliters into a second 500 milliliter flask. To this flask add 200 milliliters of odor-free water, representing a 1 in 4 dilution. Mix, withdraw, and dilute as before to obtain dilutions of 1 in 8, 1 in 16, etc., continuing to the second dilution below which odor is no longer readily detectable. If it is known that the odor concentration of the sample will be in the higher dilutions, the laboratory worker may omit such lower dilutions as he has reason to believe are unnecessary for the precise performance of the test.

(b) Then, starting with the flask containing the greatest dilution of the original sample, shake long enough to saturate the air within the flask with odor, insert an osmoscope deep into the flask, but not into the water, and observe the presence or absence of odor by sniffing lightly. Examine the flasks in order, proceeding from the greatest dilution until an odor is just detectable in one of the flasks. This is the threshold odor, and shall be recorded as the "Odor Concentration." The latter term is defined as the volume to which the sample must be diluted with odor-free water in order to reduce odor to a just perceptible value, or volume of mixture of sample and odor-free diluting water in which one volume of sample will produce a just perceptible odor.

(c) If it is desired to determine the "hot" odor concentration, dilutions must first be made in the cold and the flasks then brought to the proper temperature before the observations are made. The same dilute portions cannot serve for both cold and hot determinations.

(d) Precision of observation will be increased if a blank of odor-free water is smelled alternately with the various dilutions. Fatigue of the sense of smell must be avoided.

(e) Air dilution method. The odor concentration may be determined directly by drawing the odor-saturated air above the original water sample into a measuring device, such as the "odor meter," in which the odor is diluted with odor-free air in the ratios given above. Use of the air-dilution method for determining the odor concentration is optional.

e. Expression of results.— (1) Express the quality of characteristic of the cold or hot odor by the descriptive term assignable from the following list. For record purposes the code letters may be used.

TABLE III. — ODOR CHARACTERISTICS

Code		Nature of Odor	Description
A		Aromatic (Spicy)	Such as odor of camphor, cloves, lavender and lemon
	Ac	Cucumber	Such as odor of Synura
B		Balsamic (Flowery)	Such as odors of geranium, violets and vanilla
	Bg	Geranium	Such as odor of Asterionella
	Bn	Nasturtium	Such as odor of Aphanizomenon
	Bs	Sweetish	Such as odor of Coelosphaerium
	Bv	Violets	Such as odor of Mallomonas
C		Chemical	Such as odors due to industrial wastes or chemical treatment
	Cc	Chlorinous	Odor of free chlorine
	Ch	Hydrocarbon	Such as odors of aoil refinery wates
	Cm	Medicinal	Such as odors of phenol or iodoform
	Cs	Sulfuretted	Odor of hydrogen sulfide
D		Disagreeable	Pronounced unpleasant odors
	Df	Fishy	Such as odor of Uroglenopsis and Dinobryon
	Dp	Pigpen	Such as odor of Anabaena
	Ds	Septic	Such as odor of stale sewage
E		Earthy	Such as odor of damp earth
	Ep	Peaty	Such as odor of peat
G		Grassy	Such as odor of crushed grass
M		Musty	Such as odor of decomposing straw
	Mm	Moldy	Such as odor of a damp cellar
V		Vegetable	Such as odor of root vegetables

(2) Express the quantity of odor either as "odor concentration," "odor intensity" or as the "pO" value. The "odor concentration" is the reciprocal of the dilution. The "pO" value is the number of successive dilutions required to reach the odor concentration.

TABLE IV. — EXPRESSION OF ODOR QUANTITY

No. of Successive Dilutions	pO Value, or Odor Intensity	Odor Concentration
*	(None)	(0)
0	0	1
1	1	2
2	2	4
3	3	8
4	4	16
5	5	32
etc.	etc.	etc.

* No odor perceptible in undiluted sample.

(3) If no odor is detected in the undiluted sample, the designation "absent" should be employed.

11. **Chloride.**— *a.* The method of determining chloride here described is based upon the fact that in a solution containing chloride and chromate, silver reacts with all the chloride and precipitates before reaction with the chromate begins. The appearance of the red color of the silver chromate precipitate is the end point of the titration.

b. Cyanides and thiocynates react with the silver nitrate and increase the apparent chloride reading. CN and CNS may be estimated separately and correction made for them. Sulfites react similarly and correction must be made.

c. Reagents.— (1) *Standard sodium chloride solution.*— Dissolve 16.4858 grams of pure fused sodium chloride in distilled water and make up to 1 liter. Dilute 100 milliliters of this stock solution to 1 liter. 1 milliliter of this standard solution contains 1 milligram of chloride radical.

(2) *Standard silver nitrate solution.*— *(a)* Dissolve about 2.4 grams of silver nitrate crystals in 1 liter of distilled water. Titrate against the standard salt solution, correct for the error due to variations in the volume of the liquid by means of the formula $X = 0.003 V + 0.02$, in which $X =$ the correction in milliliters to be deducted from the volume of silver nitrate solution used, and $V =$ milliliter of liquid at the end of the titration. Adjust the solution so that 1 milliliter will be exactly equivalent to 0.5 milligrams of chloride radical.

(b) Final adjustment of the silver nitrate solution should be made against a known volume of the sodium chloride solution made up with distilled water to 50 milliliters — the standard titration portion for this determination.

(3) *Potassium chromate indicator.*— Dissolve 50 grams of neutral potasium chromate in a little distilled water. Add silver nitrate to produce a slight red precipitate; after a day or two, filter and dilute the filtrate to 1 liter with distilled water.

(4) *Aluminum hydroxide.*— Electrolyze ammonia-free water using aluminum electrodes. Wash the precipitate until it is free from chloride, ammonia, and nitrate. Or, dissolve 125 grams of potassium or ammonium alum in 1 liter of distilled water. Precipitate the aluminum by cautiously adding ammonium hydroxide. Wash the precipitate in a large jar by successive additions and decantations of distilled water until free from chloride, nitrate, and ammonia.

d. Preparation of the sample.— (1) If the sample has a color greater than 30, decolorize by shaking it thoroughly with washed aluminum hydroxide (3 milliliters to 500 milliliters of the sample), and allow the precipitate to settle. Make the determination in an aliquot portion of the clarified sample, filtered if necessary.

(2) Before titrating the chloride, add 2 or 3 drops of phenolphtalein indicator. If a red color appears, neutralize with N/50 H_2SO_4. If the water is acid to methyl orange, neutralize with N/50 Na_2CO_3. If the sample contains H_2S, acidify with H_2SO_4, boil a few minutes, cool, neutralize with $NaHCO_3$ and restore the original volume of sample.

e. Procedure.— (1) If the chloride present amounts to more than 50 parts per million, use 25 milliliters or less of the samples, diluting the volume taken to 50 milliliters with distilled water.

(2) If the chloride present amounts to less than 10 parts per million, a previously measured amount of standard sodium chloride solution may be added to the sample and correction made therefor before computing the result.

(3) After preparations, samples of either of the above classes, as well as samples of a chloride range between 10 and 50 parts per million, may be titrated as directed below.

(4) Add 1 milliliter of potassium chromate indicator to 50 milliliters of the prepared sample in a 6-inch white porcelain evaporating dish or a 150 milliliter Erlenmeyer flask over a white surface. Titrate with standard silver nitrate solution under similar conditions of volume, light and temperature, as were used in standardizing the silver nitrate until a faint reddish coloration is perceptible. The detection of the end-point is facilitated by comparison of the color in the dish or flask with that in a similar vessel containing the same quantity of indicator in 50 milliliters of distilled water. Make the titration in a darkened room provided with yellow light. The end-point is very sharp by yellow electric light and also by daylight with yellow photographic glass.

(5) Make corrections for the error due to variations in volume as directed above. The correction to be deducted is 0.2 milliliters unless unusual accuracy is required.

(6) Chloride in p.p.m. = 1000 ÷ (2 x milliliter of sample titrated) x corrected milliliters of silver nitrate solution used.

12. **Fluoride.**— *a.* The fluoride estimation by the following procedure, is made after determinations of calcium, magnesium, sodium, chloride, and sulfate have been concluded, so as to enable the preparation of the synthetic water for the standards. In many cases, however, fairly close results are obtained, which may be useful for most practical purposes, by taking into consideration in the preparation of the standards, the sulfate content only. In general, the latter simplification may be considered applicable to potable waters showing total solids of not more than about 500 pars per million, which are free from appreciable quantities of phosphate, and where there is no reason for suspecting the presence of

constituents that are usually not found in potable waters, or the presence of ordinary constituents in unusual concentration. A sulfate solution of convenient concentration for use in the preparation of standards is listed amoung the reagents. Similar stock solutions of known concentration of $CaCl_2$, $MgCl_2$, Na_2SiO_3, NaCl, $FeCl_3$, $AlCl_3$, etc., may be kept on hand for convenience in the preparation of standards with water containing also other constituents of the sample in addition to sulfate. When a large number of samples of water of essentially similar characteristics are being examined for flouride, the method of Sanchis may be found useful.

b. Regeants.— (1) *Zirconium oxychloride solution.*— Dissolve 0.5 grams zirconium oxychloride ($ZrOCl_2.8H_2O$) in distilled water and make up to 100 milliliters.

(2) *Alizarin sodium monosulfonate solution.*— Dissolve 0.1 grams alizarin sodium monosulfonate in distilled water and make up to 100 milliliters.

(3) *Zirconium-alizarin reagent.*— To a chosen volume (50 milliliters) of (1), add slowly, drop by drop, with stirring, an equal volume (50 milliliters) of (2). If a turbidity remains after the final mixing, allow to stand for a few hours or over night until it clears. Finally, dilute the mixed solutions with double their volume (200 milliliters) of distilled water.

(4) Keep solutions (2) and (3) in a cool dark closet.

(5) This reagent, applied in accordance with the following procedure, is most sensitive to flouride when freshly prepared. Hence, when dealing with waters containing only about 1 part per millon of flouride (F), it should be used before it is more than a few days old.

(6) *Standard sodium flouride solution.*— Dissolve 0.2210 grams sodium flouride (NaF) in distilled water and make up to 100 milliliters. From this stock solution prepare the standard solution by diluting 5 milliliters to 100 milliliters with distilled water. 1 milliliter is equivalent to 0.05 milligrams of flourine.

(7) 5 N hydrochloric acid.

(8) *Sodium sulfate solution.*— Dissolve 14.8 grams flouride-free anhydrous sodium sulfate (Na_2SO_4) in distilled water and make up to 1 liter. 1 milliliter is equivalent to 10 milligram sulfate (SO_4).

c. Procedure. (1) To 50 milliliters of the sample of water, or a smaller quantity diluted to 50 milliliters with distilled water, and to each of 50 milliliters of standard containing known amounts of flouride in water of similar composition as the sample used (prepared on the basis of the analysis), add 5 milliliters of 5 N HCl and 1 milliliter of the zirconium-alizarin reagent, mixing well after each addition. Allow to stand at room temperature over night (about 18 hours) and then compare the color of the sample, in standard Nessler tubes, with the colors of the flouride standards.

(2) The flouride standards are prepared so that neighboring tubes in the series vary from each other by 0.01 milligram of flourine. Depending on the concentration of flouride in the sample under examination and on the sensitivity of the available zirconium-alizarin reagent, the flourine quantities of suitable series may be 0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, and 0.07 milligrams respectively, or 0, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11, and 0.12 milligrams respectively. These are obtained by measuring out, from a finely graduated 1 milliliter pipette, the corresponding volumes of the standard sodium flouride solution and diluting with synthetic water of similar composition as the sample to 50 milliliters, or diluting with a volume of the synthetic water equal to that of the sample used and distilled water to 50 milliliters.

(3) Erlenmeyer flasks of about 125 milliliters are convenient for the preliminary mixing. The mixed solutions should, however, be transferred to the Nessler tubes as soon as practicable. The solutions should also be mixed well immediately before the colorimetric comparisons, since there appears a tendency for the coloring matter to precipitate on standing.

(4) The calculation to parts per million is made as usual and the results are expressed in terms of flourine (F).

13. **Hydrogen Sulfide.**— *a.* The instability of standard solutions used in this determination makes it imperative that the entire process, including titration of the iodine solution outlined below be carried on in the field.

b. *Reagents.*— (1) Sodium thiosulfate. N/100 solution.

(2) Standard iodine solution (N/100) prepared with potassium iodide, and standardized against the thiosulfate solution thus: To 500 milliliters of boiled distilled water add, after cooling, 10 milliliters of iodine solution and about 1 gram of potassium iodide; titrate with N/100 thiosulfate in the presence of starch indicator. One milliliter of N/100 solution is equivalent to 0.1704 milligrams of hydrogen sulfide.

(3) Potassium iodide crystals.

(4) Starch indicator, freshly prepared.

c. *Procedure.*— (1) Add 500 milliliters of the sample to 10 milliliters of standard iodine solution and 1 gram of potassium iodide in a glass-stoppered bottle or flask. If the sample is to be collected from a tap or pipe, lead the water into the bottle through a rubber or Z-shaped glass tube inserted well into the tap and extending to the bottom of the bottle, in order to eliminate errors due to aeration. Stopper and shake the bottle, allow it to stand a few minutes, and titrate the excess of iodine with thiosulfate solution in the presence of starch indicator.

(2) The difference in milliliter of thiosulfate solution used in titration of the standard iodine solution in *b.*-(2) and in the back titration of the sample multiplied by 0.3408 is equal to the parts per million of hydrogen sulfide, free and combined.

(3) This method does not give satisfactory results in sewage analysis and should not be used for this purpose.

14. **Hardness.**— *a.* Hardness, like alkalinity, is expressed in terms of calcium carbonate. The calcium carbonate equivalent of the calcium and magnesium content, and sometimes with that of iron and aluminum, is a measure of the *total hardness* of a water. The soap and soda reagent methods given below are but approximate field or technical tests for estimating this value; ordinary quantitative methods are more realiable. When the total hardness is greater than the carbonate and bicarbonate alkalinity, the amount of hardness equivalent to the alkalinity is called *carbonate hardness* and the amount of hardness in excess of this is called *non-carbonate hardness.* When the total hardness is equal to or less than the sum of the carbonate and bicarbonate alkalinity, there is no non-carbonate hardness; all the hardness is carbonate hardness.

b. Total hardness by soap method.— (1) The determination of hardness by the soap method roughly approximates the amount of calcium and magnesium in a water, though it actually measures the soap-consuming power of the water.

(2) *Reagents.— (a) Standard calcium chloride solution.*— Dissolve 0.5 grams of pure calcite (calcium carbonate) with a little dilute hydrochloric acid, being careful to avoid spattering. Wash down with carbon dioxide-free distilled water and neutralize it with ammonium hydroxide to slight alkalinity, using litmus as an indicator. Make up to 500 milliliters with carbon dioxide-free distilled water and store in a glass stoppered bottle. One milliliter of this solution is equivalent to 1 milligram calcium carbonate.

(b) Standard soap solution.— Make up "stock solution" by shaking vigorously approximately 100 grams of pure powdered castile soap in one liter of 80 per cent grain alcohol. Let this solution stand at least over night and decant. The stock soap solution is approximately 9 to 10 times as strong as the dilute standard soap solution. Take a portion of the stock solution, dilute with 80 per cent grain alcohol, until

when titrated against $CaCl_2$ solution, 1 milliliter of the resulting dilution is equivalent to 1 milliliter of the standard calcium chloride solution, making allowance for the lather factor of the adjusted soap solution from at least five determinations. The lather factor will vary from 0.5 to 1.4 milliliter with different soaps. The term lather factor may be defined as the amount of standard soap solution required to produce a permanent lather in a 50 milliliter portion of distilled water. Carbon dioxide-free water should be used for lather factor determinations and standardization of the solution. One milliliter of this solution after subtracting the lather factor is equivalent to 1 milligram calcium carbonate.

(c) N/50 sulfuric acid (H_2SO_4).— Dilute to approximate final volume A. C. S. reagent grade sulfuric acid (not less than 94 per cent H_2SO_4 by weight) with freshly boiled and cooled distilled water, adding the acid slowly to the water. (To check the strength of the acid, take 25 milliliters, add 4 milliliters concentrated HCl, dilute to 300 milliliters with distilled water, heat to boiling, add while boiling 10 milliliters of 10 per cent $BaCl_2$ (A. C. S. reagent grade) solution drop by drop, stirring as the addition is made. Let settle at about 100° C. for ½ hour, cool, filter through double ashless filter paper, ignite and weigh. 1 milliliter of N/50 H_2SO_4 will produce a precipitate of .002336 h. $BaSO_4$.

(d) N/50 sodium carbonate (Na_2CO_3).— Dry A. C. S. reagent grade anhydrous sodium carbonate for an hour at 103° C. Place until cool in a weighing bottle in a desiccator. Weigh precisely 1.059 grams and dissolve in 1 liter of freshly boiled and cooled distilled water.

(e) Phenolphthalein indicator.— Dissolve 5 grams of a good quality phenolphthalein in 1 liter of 50 per cent alcohol. Neutralize with N/50 sodium hydroxide. The alcohol should be diluted with boiled distilled water.

(f) Methyl orange indicator.— Dissolve 0.5 grams of a good grade of methyl orange in 1 liter of distilled water. Keep the solution in the dark.

(g) Erythrosine indicator.— Dissolve 0.1 grams of erythrosine (the sodium salt) in 1 liter of freshly boiled distilled water.

(h) Methyl red, with a significant color change at pH 5.1, should not be substituted for erythrosine.

(3) *Procedure.— (a)* Measure 50 milliliters of the water to be examined into an 8 ounce bottle. Add the "standard" soap solution in small amounts at a time, shaking vigorously after each addition, until a strong permanent lather is secured which will stand for five minutes with the bottle laid on its side. A lather thus persisting, indicates the *"true end-point.* It is usually satisfactory to add amounts of soap solution

equal to the lather factor as the first additions and then, as the end-point is approached, to cut the additions of soap solution to 0.1 to 0.2 milliliters, depending upon the accuracy desired and the experience of the manipulator. Note and record, if desired, any false end-point (transient lather or ghost point) which may be assumed to be the dividing line between the calcium and magnesium salts. The final burette reading after deducting the lather factor and multiplying by 20, gives the total hardness (H) in terms of calcium carbonate as parts per million.

(b) (In determining the hardness of acid waters, they should first be rendered neutral to methyl orange by addition of N/50 sodium carbonate solution.) The difference between the false end-point and the true end-point (total hardness) may be taken to indicate the amount of magnesium salts, the balance being calcium salts. All, when multiplied by 20, gives results as parts per million in terms of calcium carbonate. If the water has a temperature below 10° C., this test tends to give high results. If the hardness test requires more than 15 milliliters of soap solution, take an aliquot portion and dilute to 50 milliliters with carbon dioxide-free distilled water so that the final lather point will be less than 15 milliliters. After deduction of the lather factor, multiply the result accordingly to obtain correct hardness value.

(Note: If it is desired to express results in terms of grains per gallon, use a 58.3 milliliter sample of water and the results can be read direct as grains per gallon in terms of calcium carbonate after substracting the lather factor.)

(c) To avoid mistaking the false or magnesium end-point for the true one when adding the soap solution to waters containing magnesium salts read the burette after the titration is apparently finished and add about 0.5 milliliters more of soap solution. If the apparent end-point was due to the presence of magnesium the lather will disappear on the addition of more soap. Soap solution must then be added until the true end-point is reached. Usually the false lather persists for less than five minutes.

15. **Alkalinity.** *a.* The alkalinity of a natural water represents its content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is determined by titration with a standard solution of a strong acid to certain standard datum points or hydrogen ion concentrations. Indicators are selected which show definite color changes at these points.

b. *Reagents.*— (1) *Sulfuric acid.* N/50 solution.—

(2) *Phenolphthalein indicator.*— Dissolve 5 grams of a good quality phenolphthalein in 1 liter of 50 per cent alcohol. Neutralize with N/50 sodium hydroxide. The alcohol should be diluted with boiled distilled water.

(3) *Methyl orange indicator.*— Dissolve 0.5 grams of a good grade of methyl orange in 1 liter of distilled water. Keep the solution in the dark.

c. Procedure.— (1)--*With phenolphthalein.*— *(a)* Add 4 drops (0.1 milliliter) of phenolphthalein indicator to 50 or 100 milliliters of the sample in a white porcelain casserole, or an Erlenmeyer flask over a white surface. If the solution becomes colored, hydroxide or normal carbonate is present. Add N/50 surfuric acid from a burette until the coloration disappears.

(b) The phenolphthalein alkalinity in parts per million of calcium carbonate is equal to the number of milliliters of N/50 sulfuric acid used multiplied by 20, if 50 milliliters of the sample were used, or by 10 if 100 milliliters were used. Procedure with cresol phthalein and thymol sulfon phthalein is similar to that with phenolphthalein.

(2) *With methyl orange.*— Add 2 drops of methyl orange indicator to 50 or 100 milliliters of the sample, or to the solution to which phenolphthalein has been added, in a white porcelain casserole or an Erlenmeyer flask over a white surface. If the solution becomes yellow, hydroxide, normal carbonate, or bicarbonate is present. Add N/50 sulfuric acid until the faintest pink coloration appears; that is, until the color of the solution is no longer pure yellow. The methyl orange alkalinity in parts per million of calcium carbonate is equal to the total number of milliliters of N/50 sulfuric acid used multiplied by 20 if 50 milliliters of the sample were used, or by 10 if 100 were used.

d. Expression of results.— (1) Results are to be expressed as parts per million of calcium carbonate (assume molecular weight of 100 instead of 100.08) and may be given as phenolphthalein alkalinity and methyl orange alkalinity, substituting for these names the names of other indicators if others are selected, or the results may, in cases where the alkalinity is due to bicarbonate, carbonate and hydroxide, be calculated to these radicals. The assumptions upon which such calculations are made are given in Table V.

TABLE V. — RELATIONS BETWEEN ALKALINITY TO PHENOLPHTHALEIN AND THAT TO METHYL ORANGE IN PRESENCE OF HYDROXIDE, CARBONATE, AND BICARBONATE.

Result of titration.*	Value of radical expressed in terms of calcium carbonate		
	Hydroxide	Carbonate	Bicarbonate
$P=O$	O	O	T
$P<\frac{1}{2}T$	O	2P	T-2P
$P=\frac{1}{2}T$	O	2P	O
$P>\frac{1}{2}T$	2P-T	2(T-P)	O
$P=T$	T	O	O

*T = Total alkalinity in presence of methyl orange or indicator of similar range.
P = Alkalinity in presence of phenolphthalein or indicator of similar range.

(2) Since methods of expression other than in terms of $CaCO_3$ are in use the factors for converting to the other systems are given.

(a) *Normal carbonate.*— Normal carbonate is present if the alkalinity to phenolphthalein is greater than zero but less than the alkalinity to methyl orange. If the phenolphthalein alkalinity is exactly equal to one-half the methyl orange or erythrosine alkalinity, it is due entirely to normal carbonate. If the phenolphthalein alkalinity is less than one-half the methyl orange alkalinity, normal carbonate expressed in terms of calcium carbonate is equal to twice the phenolphthalein alkalinity. If the phenolphthalein alkalinity is greater than one-half the methyl orange alkalinity, the normal carbonate is equal to twice the difference between the methyl orange alkalinity and the phenolphthalien alkalinity. The carbonate, carbon dioxide as carbonate, and bound carbon dioxide can be calculated as follows:

Carbonate (CO_3) = 0.6 times the normal carbonate expressed in terms of calcium carbonate.

Carbon dioxide (CO_2) as carbonate = 0.44 times the normal carbonate expressed in terms of calcium carbonate.

Bound carbon dioxide (CO_2) is the sum of the carbon dioxide as carbonate and one-half that as bicarbonate.

(b) *Hydroxide.*— If hydroxide or caustic alkalinity is present, the alkalinity to phenolphthalein is greater than one-half the alkalinity to methyl orange; the alkalinity is due entirely to hydroxide, if the phenolphthalein alkalinity is equal to the methyl orange alkalinity. If the phenolphthalein alkalinity is more than half and less than all the methyl orange alkalinity, hydroxide, expressed in terms of calcium carbonate, is equal to twice the phenolphthalein alkalinity minus the methyl orange alkalinity.

(c) *Bicarbonate.*— Bicarbonate is present if the alkalinity to phenolphthalein is less than one-half the alkalinity to methyl orange. The alkalinity to methyl orange is due entirely to bicarbonate, if there is no phenolphthalein alkalinity. If there is phenolphthalein alkalinity, the bicarbonate is terms of calcium carbonate is equal to the methyl orange alkalinity minus twice the phenolphthalein alkalinity. Bicarbonate, carbon dioxide as bicarbonate, and half-bound carbon dioxide can be calculated as follows:

Bicarbonate (HCO_3) = 1.22 times the bicarbonate expressed in terms of calcium carbonate.

Carbon dioxide (CO_2) as bicarbonate = 0.88 times the bicarbonate expressed in terms of calcium carbonate.

Half-bound carbon dioxide (CO_2) = 0.44 times the bicarbonate expressed in terms of calcium carbonate.

16. **Acidity.**— *a.* The acidity of a natural water represents the content of free carbon dioxide, mineral acids, and salts (especially sulfates of iron and aluminum) which hydrolyze to give hydrogen ions. It is determined by titration with a standard solution of a strong alkali to certain arbitrary standard datum points, or hydrogen ion concentrations. Indicators are selected which show definite color changed at these points.

b. Reagents.— (1) *Sodium hydroxide, N/50.*— This solution should be carbonate-free. A solution sufficiently free from carbonates can be prepared by first preparing a saturated solution of sodium hydroxide and allowing it to stand stoppered for some time in a Pyrex flask. Sodium carbonate, being insoluble in saturated sodium hydroxide solution, will settle to the bottom. The strength of the supernatant liquid can be estimated by a preliminary titration, and the solution then diluted to the proper strength with water which has been freed from carbon dioxide by boiling and cooled in an atmosphere free from carbon dioxide. This solution should be preserved in containers of resistant glass, protected from the air by tubes filled with soda-lime. It should be standardized by titration against weighed portions of pure benzoic acid which has been recently fused. The benzoic acid is dissolved in a small quantity of alcohol and the titration made, using phenolphthalein as an indicator. If preferred, the sodium hydroxide may be standardized by titrations against weighed portions of acid potassium phthalate. In order to prevent interference of carbon dioxide of the air, the titration should either be made rapidly, or a stream of carbon dioxide free air should be kept passing through the titration flask. A blank titration should be made on the alcohol and correction made for any acidity found. One milliliter of the solution is equivalent to 1 milligram of $CaCO_3$.

(2) *Sodium hydroxide, N/44.*— Prepare as in (1), adjusting the concentration by titration; 1 milliliter of this solution is equivalent to 1 milligram of CO_2.

(3) Phenolphthalein indicator.

(4) Methyl orange indicator.

c. Procedure.— (1) *Free carbon dioxide.*— *(a)* Carbon dioxide may exist in water in three forms: free carbon dioxide, bicarbonate, and carbonate. One-half the carbon dioxide as bicarbonate is known as the half-bound carbon dioxide. The carbon dioxide as carbonate plus one-half that as bicarbonate is known as the bound carbon dioxide.

(b) Pour 100 milliliters of the sample into a tall narrow vessel, preferably a 100 milliliter Nessler tube. Add 10 drops of phenolphthalein indicator, and titrate rapidly with N/44 sodium hydroxide, stirring gently, until a faint but permanent pink color is produced. The free carbon

dioxide (CO_2) in parts per million is equal to 10 times the number of milliliters of N/44 sodium hydroxide used. Free carbon dioxide in terms of parts per million $CaCO_3$ may be determined by multiplying parts per million of free carbon dioxide by 2.272.

(c) Because of the ease with which free carbon dioxide escapes from water, particularly when the gas is present in large amounts, a special sample should be collected for this determination, which should preferably be made at the time of collection. If the analysis cannot be made at the time of collection, approximate results with water not too high in free carbon dioxide may be obtained on samples collected in bottles completely filled, so as to leave no air space under the stopper. Bottled samples should be kept, until tested, at a temperature lower than that of the water when collected. If mineral acids or certain salts are present, correction must be made. At best, the results of the titration are uncertain because the proper end-point for correct results differs in color with different types of water.

(2) *Total acidity.*— *(a)* Add 10 drops of phenolphthalein indicator to 50 to 100 milliliters of the sample in a white porcelain casserole or an Erlenmeyer flask over a white surface. Add N/50 sodium hydroxide until the solution turns pink. The total acidity in parts per million of calcium carbonate is equal to the number of milliliters of N/50 sodium hydroxide used multiplied by 20 if 50 milliliters of the sample were used, or by 10 if 100 milliliters were used. In the presence of aluminum sulfate and certain other salts of this nature this determination is of little value as its true end-point is reached with extreme slowness or not at all.

(b) In the examination of mine waters, the volume taken should be such that on diluting to 100 milliliters with recently boiled distilled water and titrating with N/50 sodium hydroxide, not more than 15 milliliters is required. The end-point should be taken as a faint pink only, otherwise partial re-solution of aluminum hydroxide occurs.

(3) *Free mineral acids.*— *(a)* Add 2 drops of methyl orange indicator to 50 or 100 milliliters of the sample in a white porcelain casserole or an Erlenmeyer flask over a white surface. Add N/50 sodium hydroxide from a burette until the pink coloration of the solution disappears. The acidity due to free mineral acids, expressed in terms of calcium carbonate, is equal to the number of milliliters of N/50 sodium hydroxide used multiplied by 20 if 50 milliliters of the sample were used, or by 10 if 100 milliliters were used.

(b) In the presence of appreciable amounts of ferric and aluminum salts this procedure gives results which are too high. In such cases more accurate estimations of the free mineral acids can be made by

subtracting the acidity due to salts of iron and aluminum (calculated from the determined amounts of these substances) from the acidity due to free mineral acids and sulfates of iron and aluminum as determined by the procedure given below.

(4) *Mineral acids and sulfates of iron and aluminum.— (a)* Modify the method for free mineral acids by titrating the sample at boiling temperature in the presence of phenolphthalein indicator. The acidity due to free mineral acids and sulfates of iron and aluminum, expressed in terms of calcium carbonate, is equal to the number of milliliters of N/50 sodium hydroxide used, multiplied by 20 if 50 milliliters of the sample were used, or by 10 if 100 milliliters were used.

(b) The acidity due to sulfates of iron and aluminum is equal to the acidity due to mineral acids and sulfates minus the acidity due to mineral acids. In the presence of ferric and aluminum salts the determination of free mineral acid by titration is not reliable. In such cases the acidity due to ferric and ferrous iron and aluminum should be calculated from determinations of these substances.

(5) Acidity shall be reported in parts per million of calcium carbonate ($CaCO_3$). Sulfate (SO_4) equals calcium carbonate multiplied by 0.96.

17. **Iron.**— *a.* (1) In natural waters and in those receiving industrial wastes iron may be in the ferric or ferrous condition, soluble, colloidal or insoluble. Ferric iron is rarely found in solution in appreciable quantities except in acid waters. Insoluble or colloidal iron is likely to be all ferric. Colorimetric methods for ferric and ferrous iron are especially applicable to samples of low content; gravimetric or volumetric methods, to water of high iron content. Total iron is determined in unfiltered samples; dissolved iron determined after filtration; the difference is equivalent to the suspended iron. Ferrous iron may be determined in filtered and unfiltered samples. The content of ferric iron is the difference between total iron and ferrous iron.

(2) In colorimetric estimations of iron, the specific reagent (thiocynate or ferricynide) shall be added to each of the iron standards at the same time that it is added to the prepared samples of water under examination. Comparison of color developed in both standards and samples shall be in matched Nessler tubes in the presence of equivalent concentrations of acid, immediately after the reagent is mixed with the solutions, since the color is deepened by an excess of the reagent, is diminished by an excess of acid, and fades quickly on standing.

b. Total iron.— (1) *Reagents.— (a) Standard ferric iron solution.*— Dissolve 0.7022 grams of crystallized ferrous ammonium sulfate ($FeSO_4(NH_4)_2SO_4.6H_2O$) in 50 milliliters of distilled water and 20 milliliters of concentrated sulfuric acid. Warm the solution and add potassium permanganate solution until the iron is completely oxidized as evidenced by the persistence of a faint pink color. Dilute to 1 liter; 1 milliliter contains 0.1 milligram Fe.

(b) Potassium (or ammonium) thiocyanate.— Two grams dissolved to make 100 milliliters of solution.

(c) Dilute hydrochloric acid.— One volume concentrated acid (specific gravity 1.2) to 3 volumes of distilled water. Approximately 3. N.

(d) Potassium permanganate, approximately N/5.— Dissolve 6.3 grams in distilled water and make up to 1 liter.

(e) Hydrochloric acid.— Concentrated, free from iron.

(f) Nitric acid.— Specific gravity 1.42, free from iron.

(g) Nitric acid.— Specific gravity 1.195; 382 milliliters concentrated acid (specific gravity 1.42) in 1 liter. Approximately 6 N.

(2) *Procedure.*— *(a)* Evaporate 100 milliliters or less of the sample to dryness or use the residue on evaporation. (With silt-bearing waters the quantity of iron is sometimes so great that it is necessary to use as little as 10 milliliters of the sample. With such waters evaporation should be in the presence of 5 to 10 milliliters of concentrated hydrochloric acid. If the sample contains much organic matter, destroy this by ignition, taking care not to prolong ignition so as to render the iron too difficultly soluble.)

(b) Heat the dish to drive off excess acid, if the residue was not ignited. Cool the dish and add 0.8 to 1 milliliter of 3 N hydrochloric acid. Warm on the water bath, taking care to avoid evaporation to dryness by adding small quantities of distilled water. Rinse the hot solution into a 50 milliliter Nessler tube, filtering if necessary. Add a drop or two of patassium permanganate solution; if the color of the permanganate does not persist for at least 5 minutes, add more, drop by drop. Cool and dilute to the mark with distilled water. With iron standards in readiness (see below), add 5 milliliters of thiocyanate solution to the sample and to the standards, mix and compare immediately. With permanent standards (see below) comparison must immediately follow the addition of thiocyanate.

(c) If low in organic matter, boil 50 milliliters of the sample with 5 milliliters 6 N nitric acid for 5 minutes, add 3 drops of permanganate solution, and cool. Add 5 milliliters of thiocyanate and compare immediately with standards prepared from the standard iron solution with 6 N nitric acid instead of 3 N hydrochloric acid.

(d) Surface waters of slight organic content may be tested as follows: Take a portion which contains at least 0.5 milligrams of iron. Concentrate in a beaker with 2 to 3 milliliters of concentrated nitric acid, with addition of permanganate if necessary to destroy organic matter,

until a volume of about 50 milliliters remains. To the hot liquid add ammonia in very slight excess and warm until the odor of ammonia is hardly discernible. Filter and wash with water at 70° to 80° C. containing a little ammonia. Dissolve the precipitate on the filter and in the beaker in 5 milliliters of concentrated hydrochloric acid, collecting the filtrate in a 50 milliliter Nessler tube. Cool, dilute to the mark, add 5 milliliters thiocyanate and compare at once with standards.

(3) *Preparation of iron standards.*— Place in matched Nessler tubes measured volumes (0.05 to 4 milliliters) of standard iron solution (1) *(a)* covering the range of standards required for the determinations at hand; dilute to about 40 milliliters, add 0.5 milliliters of 3 N hydrochloric acid and 1 or 2 drops of potassium permanganate solution to each tube; dilute each to the mark. To each of these tubes and to those containing the prepared samples to be tested, add 5 milliliters thiocyanate solution, mix and compare immediately the color developed. These standards are not permanent.

(4) *Preparation of permanent standards.— (a) Potassium chlorplatinate,* K_2PtCl_6. Dissolve 4 grams in distilled water, add 200 milliliters of concentrated hydrochloric acid and dilute to 1 liter with distilled water.

(b) Cobaltous chloride, $CoCl_2.6H_2O$.— Dissolve 48 grams in distilled water, add 200 milliliters of concentrated hydrochloride acid and dilute to 1 liter with distilled water. It is essential that the cobaltous chloride contain the proper amount of water of crystallization.

(c) Place in 50 milliliter Nessler tubes the volumes of platinum and cobalt solutions specified in Table 6 and make up to the 50 milliliter mark with distilled water. The iron equivalent of these standards is shown in the first column.

TABLE VI. — PREPARATION OF PERMANENT STANDARDS FOR THE DETERMINATION OF IRON

Milligrams of Iron	No. of milliliters Platinum Solution	No. of milliliters Cobalt Solution
0.0	0.0	0.0
0.01	1.00	0.60
0.02	2.25	1.20
0.03	3.30	1.85
0.04	4.65	2.75
0.05	5.75	3.65
0.075	8.85	6.60
0.10	11.30	10.00
0.125	14.70	12.80
0.15	16.85	15.10

c. Ferrous iron.— (1) *Reagents.— (a) Potassium ferricyanide* $K_3Fe\ (CN)_6$. Dissolve 0.5 grams of crystals in 100 milliliters of distilled water. The solution must be freshly prepared.

(b) Dilute sulfuric acid.— One volume of iron-free, concentrated acid (specific gravity 1.84) to 5 volumes of distilled water.

(c) Standard ferrous iron solution.— Dissolve 0.7022 grams of crystallized ferrous ammonium sulfate in a large volume of freshly boiled distilled water to which 10 milliliters of dilute sulfuric acid has been added, and dilute to 1 liter. This solution must be freshly prepared; 1 milliliter contains 0.1 milligram of Fe.

(2) *Procedure.*— Add 10 milliliters of dilute sulfuric acid to 50 milliliters of the sample, remove the suspended matter by filtration if necessary, and add 15 milliliters of potassium ferricyanide solution. Dilute to the mark in a 100 milliliter Nessler tube with distilled water that has been freshly boiled and cooled. Compare the color developed in the sample with that in standards made at the same time from the ferrous iron solution, in this way: Place in 100 milliliter Nessler tubes, in the following order, 75 milliliters of distilled water, 10 milliliters of dilute sulfuric acid, and 15 milliliters of ferricyanide solution, and mix well the content of each tube. Add various volumes of standard ferrous iron solution to several tubes, mix well, and compare immediately the resulting colors with that of the sample.

18. **Manganese.**—*a.* If the sample contains less than 10 parts per million of manganese, use a colorimetric method in which the manganous salt is oxidized to permanganate and the color produced thereby is compared with that of a standard solution similarly treated. Either the periodate or the persulfate method is suitable. If manganese be present in very small amount, the periodate method is preferable. If the sample contains more than 10 parts per million of manganese, it is sometimes preferable to use a volumetric or gravimetric method.

b. Periodate method.— (1) *Reagents.*— *(a) Standard manganous sulfate.*— Dissolve 0.1438 grams of C.P. potassium permanganate in distilled water to which has been added 2 to 3 milliliters of 2 N sulfuric acid. Reduce by adding 0.4 grams of sodium bisulfite. Boil off the excess sulfur dioxide and dilute to exactly 1 liter.

(b) Sulfuric acid reagent.— Prepare a sulfuric acid solution (6 per cent by volume) by adding 120 milliliters of concentrated C.P. sulfuric acid to 1500 milliliters of distilled water and diluting to 2 liters. Add 2.4 grams of sodium paraperiodate ($Na_2H_3IO_6$), heat to boiling, and place, for 30 minutes, in a boiling water bath.

(c) Color Standards.— Add 1.2 milliliters of concentrated C.P. sulfuric acid and 30 milliliters of sulfuric acid reagent (1)-*(b)* to exactly 20 milliliters of standard manganous sulfate (1.1). After thoroughly mixing, add 0.3 grams of sodium paraperiodate ($Na_2H_3IO_6$), heat to boiling, and place, for 30 minutes, in a boiling water bath. Cool and dilute to 1 liter with sulfuric acid reagent. This standard contains 0.001

grams of permanganate manganese per liter. Prepare a series of color standards in accordance with Table 7 and store in glass stoppered bottles which have been cleaned with hot dichromate cleaning solution, washed and dried.

(2) *Procedure.*— *(a)* Add 3 or 4 drops of concentrated C.P. sulfuric acid to 100 milliliters of the water sample and evaporate to dryness in a porcelain or glass dish. Measure out 100 milliliters of sulfuric acid reagent (1)-*(b)*. With this, moisten the residue and transfer it to a 250 milliliter Erlenmeyer flask. Then wash the dish thoroughly by repeated use of all the remaining acid reagent, pouring the washings into the flask. Add 0.3 grams sodium paraperiodate, heat to boiling, and place the flask in a boling water bath for 30 minutes. Cool to room temperature and transfer the solution to a 100 milliliter Nessler tube. Compare with standards and read directly in parts per million provided a 100 milliliter portion of the sample was used for the test.

(b) In all cases prepare a comparison tube containing no permanganate manganese, but 100 milliliters sulfuric acid reagent as a blank, as this reagent has a color greater than that which might be interpreted as zero manganese.

TABLE VII. — COLOR STANDARDS FOR DETERMINATION OF MANGANESE. USE 100 MILLILITER COMPRESSION TUBES.

Permanganate manganese. milliliter.	Sulfuric acid reagent. milliliter.	P.p.m. of Mn. when 100 milliliter sample is used.
0.0	100.0	0.0
2.5	97.5	0.025
5.0	95.0	0.05
7.5	92.5	0.75
10.0	90.0	0.1
20.0	80.0	0.2
30.0	70.0	0.3
40.0	60.0	0.4
50.0	50.0	0.5
60.0	40.0	0.6
70.0	30.0	0.7
80.0	20.0	0.8
90.0	10.0	0.9
100.0	0.0	1.0

c. Persulfate method.— (1) *Reagents.*— *(a) Nitric acid.*— Dilute concentrated nitric acid with an equal volume of distilled water. Free the diluted acid from brown oxides of nitrogen by aeration.

(b) Silver nitrate.— Dissolve 20 grams of silver nitrate in 1 liter of distilled water.

(c) Standard manganous sulfate.— Dissolve 0.2873 grams of purest potassium permanganate in about 100 milliliters of distilled water.

Acidify the solution with sulfuric acid and heat to boiling. Add slowly a sufficient quantity of dilute solution of oxalic acid to discharge the color. Cool and dilute to 1 liter; 1 milliliter of this solution contains 0.1 milligram of manganese.

(2) *Procedure.*— Use an amount of the sample which contains not more than 0.2 milligrams of manganese. Add 2 milliliters of nitric acid and boil down to about 50 milliliters. Precipitate the chloride with silver nitrate solution, adding at least 1 milliliter in excess. Shake and heat to coagulate the precipitate, and filter. A sample which contains much chloride should be evaporated with a few drops of sulfuric acid until white fumes appear and then diluted before the nitric acid and silver nitrate are added as directed above. If the sample is highly colored by organic matter, it should be evaporated with sulfuric acid, and the residue ignited and dissolved in dilute nitric acid. Add about 0.5 grams of ammonium persulfate crystals, and warm the solution until the maximum permanganate color is developed. This usually takes about 10 minutes. At the same time prepare standards by diluting portions of 0.2, 0.4, 0.6 milliliters and treating them exactly as the sample was treated. Transfer the sample and the standards to 50 milliliters Nessler tubes, and compare the colors immediately.

19. **Field Test for pH and Free Chlorine.**— *a.* The pH is a measure of the degree of acidity or alkalinity of a solution.

b. pH Scale.— The pH scale may be compared to a thermometer scale. On the Fahrenheit thermometer scale as the temperature increases above 32° we consider that heat is increasing, and that cold increases as the temperature decreases below 32°. On the pH scale, with neutrality at 7.0, acidity increases below 7.0, and alkalinity increases as the pH rises above 7.0 to a maximum of 14.0.

c. Comparator.— (1) The pH of a substance may be determined in a number of ways among which is by the comparator. For each range of pH values there is available a dyestuff which changes color as the pH changes. By adding this dye to a sample to water of unknown pH and comparing the color with samples of known pH called standards to which the same dye has been added, it is possible to find the one which matches the unknown closest, thus finding the pH of the unknown.

(2) In the comparator used by the army in the field, colored glasses embedded in a plastic disc have been substituted for the standard solutions. This disc is rotated in the comparator so that successive colored glasses pass alongside the unknown, to which the appropriate indicator (dyestuff) has been added, in front of an eyepiece, until the color of a glass most nearly matches the color of the sample. The pH is then read on the face of the comparator.

d. Residual free chlorine is similarly determined in the comparator using an indicator known as orthotoludine and a disc suited to that indicator.

20. **Relation of Alkalinity-Free Carbon Dioxide Ratio to pH Value.—** When there are no carbonates or hydroxides present in a water sample, or in other words if there is no phenolphthalein alkalinity present, the pH value can be determined from the ratio of methyl orange alkalinity to the free CO_2 (carbon dioxide) content by reference to Table VIII below:

TABLE VIII

Ratio- $\frac{\text{Alkalinity}}{CO_2}$	pH	Ratio- $\frac{\text{Alkalinity}}{CO_2}$	pH
No CO_2	8.3	1.3	6.5
200	8.25	0.8	6.2
110 to 180	8.2	0.5	6.0
70 to 100	8.1	0.4	5.9
35 to 50	7.9	0.32	5.8
23 to 30	7.7	0.25	5.7
16 to 22	7.5	0.20	5.6
12 to 15	7.4	0.15	5.5
10 to 11	7.3	0.12	5.4
7 to 9	7.2	0.10	5.3
6	7.1	0.077	5.2
5	7.0	0.062	5.1
4	6.9	0.05	5.0
3	6.8	0.04	4.9
2.5	6.7	0.03	4.8
2	6.6	0.02	4.7

21. **Sampling of Water Supplies.—** *a.* All determinations of water quality rely for their accuracy on how samples of the water are taken. Unless the quality of the water at the points where the samples are taken is accurately representative of the water supply, the results of the examination may lead to erroneous conclusions.

b. Foreign material in the orifices of faucets is a frequent cause of contaminated samples. Spattering or leaky taps may allow polluting substances to get into a sample bottle.

c. Where freezing winter temperatures are prevalent, hydrants are likely to yield unrepresentative specimens as a result of contamination of the barrel of the hydrant through the drip cock. Drip cocks should be provided at the bottom of the barrels of hydrants which are to be exposed to severe winter weather, in order that the water left in the barrel after each use, may drain away into the earth. If this were not done, the next user in winter time might find the water passage blocked with ice. Foreign matter, including living worms, may sometimes be injected or carried into the barrel through the drip-cock opening and then delivered from the outlet with the water.

d. Dipping specimens from open bodies of water, or from streams, must be done in such a manner as to avoid the introduction of surface scums or bottom sediments into the bottle. Water which has passed over the collector's hand, or which is collected in an improperly prepared bottle, is obviously unfit for examination, especially a bacterial examination.

e. Water samples change in character while in storage. The more organic matter, or the more of the various gases a sample contains, the more rapid the changes to be expected. Keeping the temperature of the specimen low reduces the rate of chemical change and also retards bacterial multiplication and the metabolic chemical changes that this increase involves. Sometimes chemicals are added to preserve specimens. The influence of the preservatives on the examination must then be considered.

f. The glass of which the sample bottle is made may also have an influence on the results of an analysis. Sometimes the glass is soluble, enough to materially affect the results of a mineral analysis of the water.

g. Deliberate falsification of water samples is sometimes encountered in civilian practice. The idea which inspires such a deed as the submission of a false sample is usually based on a misconception of the functions of the water laboratory and of the matters sought in routine work. Sometimes it is inspired by a desire to test the ability of the analyst. Sometimes it is intended to insure a particular sort of result. Usually the falsification is so clumsily done that it defeats itself, but it can be done in such a way as to mislead the analyst to report values which would in turn mislead anyone depending upon his results. Only water samples collected by persons who can be trusted to collect them intelligently and accurately according to directions should be considered worthy of examination and of being used as a basis for the choice of treatment and type of equipment.

22. **Conversion of the Form of a Water Analysis.**— *a.* There are a number of ways in which a water analysis may be expressed. Most often the form used depends on the use to which the analysis is to be put or the method of treatment employed.

b. One form commonly used expresses the hardness and alkalinity as $CaCO_3$; the free carbon dioxide as CO_2; the sulfates as SO_3; the chlorides as Cl; and the nitrates as NO_3.

c. Another expresses all substances in the terms of their ions, that is, as Ca, Mg, Na, SO_4, HCO_3, Cl, CO_3, and NO_3.

d. Still another way, less commonly used now, is to set up hypothetical combinations, such as, $Ca\ (HCO_3)_2$, $Mg(HCO_3)_2$, $Ca\ SO_4$, $Mg\ SO_4$, $Na_2\ SO_4$, NaCl, and so on.

e. To convert an analysis in one form to another form, the factors in Tables IX, below, can be used.

TABLE IX. — FACTORS FOR CONVERTING FORM OF EXPRESSION OF ANALYSES

A		B		TO CONVERT A TO B MULTIPLY BY	TO CONVERT B TO A MULTIPLY BY
NAME	FORMULA	NAME	FORMULA		
Calcium	Ca	Calcium Carbonate	$CaCO_3$	2.50	.400
″ Bicarbonate	$Ca(HCO_3)_2$	″ ″	″	.617	1.62
″ Chloride	$CaCl_2$	″ ″	″	.902	1.11
″ Hydroxide	$Ca(OH)_2$	″ ″	″	1.35	.740
″ Nitrate	$Ca(NO_3)_2$	″ ″	″	.610	1.64
″ Oxide	CaO	″ ″	″	1.79	.560
″ Sulfate	$CaSO_4$	″ ″	″	.735	1.36
Magnesium	Mg	″ ″	″	4.12	.243
″ Bicarbonate	$Mg(HCO_3)_2$	″ ″	″	.684	1.46
″ Carbonate	$MgCO_3$	″ ″	″	1.19	.843
″ Chloride	$MgCl_2$	″ ″	″	1.05	.952
″ Hydroxide	$Mg(OH)_2$	″ ″	″	1.72	.583
″ Nitrate	$Mg(NO_3)_2$	″ ″	″	.674	1.48
″ Oxide	MgO	″ ″	″	2.48	.403
″ Sulfate	$MgSO_4$	″ ″	″	.831	.120
Alkalinity expressed as bicarbonate ion	HCO_3	″ ″	″	.820	1.22
Sodium	Na	″ ″	″	2.17	.460
″ Bicarbonate	$NaHCO_3$	″ ″	″	.596	1.68
″ Carbonate	Na_2CO_3	″ ″	″	.944	1.06
″ Chloride	NaCl	″ ″	″	.856	1.17
″ Hydroxide	NaOH	″ ″	″	1.25	.800
″ Nitrate	$NaNO_3$	″ ″	″	.588	1.70
″ Oxide	Na_2O	″ ″	″	1.61	.62
″ Sulfate	Na_2SO_4	″ ″	″	.705	1.42
Sulfuric Acid	H_2SO_4	″ ″	″	1.02	.980
Sulfate Ion	SO_4	″ ″	″	1.04	.960
Sulfur Trioxide	SO_3	″ ″	″	1.25	.800
Hydrochloric Acid	HCl	″ ″	″	1.37	.729
Chlorine	Cl	″ ″	″	1.41	.709

Calcium	Ca	Calcium Bicarbonate	$Ca(HCO_3)_2$	4.05	.247
〃	〃	〃 Carbonate	$CaCO_3$	2.50	.400
〃	〃	〃 Chloride	$CaCl_2$	2.77	.361
〃	〃	〃 Hydroxide	$Ca(OH)_2$	1.85	.541
〃	〃	〃 Nitrate	$Ca(NO_3)_2$	4.10	.244
〃	〃	〃 Oxide	CaO	1.40	.715
〃	〃	〃 Sulfate	$CaSO_4$	3.40	.294
Magnesium	Mg	Magnesium Bicarbonate	$Mg(HCO_3)_2$	6.02	.166
〃	〃	〃 Carbonate	$MgCO_3$	3.47	.288
〃	〃	〃 Chloride	$MgCl_2$	3.92	.255
〃	〃	〃 Hydroxide	$Mg(OH)_2$	2.40	.417
〃	〃	〃 Nitrate	$Mg(NO_3)_2$	6.10	.164
〃	〃	〃 Oxide	MgO	1.66	.603
〃	〃	〃 Sulfate	$MgSO_4$	4.95	.202
Sodium	Na	Sodium Bicarbonate	$NaHCO_3$	3.65	.274
〃	〃	〃 Carbonate	Na_2CO_3	2.30	.434
〃	〃	〃 Chloride	$NaCl$	2.54	.393
〃	〃	〃 Hydroxide	$NaOH$	1.74	.575
〃	〃	〃 Nitrate	$NaNO_3$	3.70	.271
〃	〃	〃 Oxide	Na_2O	1.35	.742
〃	〃	〃 Sulfate	Na_2SO_4	3.09	.324

TABLE IX. — (CON'T)

A		B		TO CONVERT A TO B MULTIPLY BY	TO CONVERT B TO A MULTIPLY BY
NAME	FORMULA	NAME	FORMULA		
Sulfur Trioxide	SO_3	Calcium Sulfate	$CaSO_4$	1.70	.588
″ ″	″	Magnesium ″	$MgSO_4$	1.50	.665
″ ″	″	Sodium ″	Na_2SO_4	1.77	.564
″ ″	″	Calcium Carbonate	$CaCO_3$	1.25	.800
″ ″	″	Magnesium ″	$MgCO_3$	1.05	.949
″ ″	″	Sodium ″	Na_2CO_3	1.32	.755
″ ″	″	Sulfuric Acid	H_2SO_4	1.23	.816
″ ″	″	Sulfate Ion	SO_4	1.20	.833
Chlorine Ion	Cl	Calcium Chloride	$CaCl_2$	1.57	.639
″ ″	″	Magnesium ″	$MgCl_2$	1.34	.745
″ ″	″	Sodium ″	NaCl	1.65	.607
Iron	Fe	Ferrous Bicarbonate	$Fe(HCO_3)_2$	3.19	.314
″	″	″ Hydroxide	$Fe(OH)_2$	1.61	.621
″	″	″ Oxide	FeO	1.29	.777
″	″	″ Sulfate (Anh.)	$FeSO_4$	2.72	.368
″	″	″ ″ (Cryst)	$FeSO_4 . 7H_2O$	4.98	.201
″	″	Ferric Chloride (Anh.)	$FeCl_3$	2.91	.344
″	″	″ Hydroxide	$Fe(OH)_3$	1.91	.522
″	″	″ Oxide	Fe_2O_3	1.43	.699
″	″	″ Sulfate (Anh.)	$Fe_2(SO_4)_3$	3.58	.279
Calcium	Ca	Sodium	Na	1.15	.871
″ Bicarbonate	$Ca(HCO_3)_2$	″ Bicarbonate	$NaHCO_3$	1.04	.965
″ Carbonate	$CaCO_3$	″ Carbonate	Na_2CO_3	1.06	.944
″ Chloride	$CaCl_2$	″ Chloride	NaCl	1.05	.949
″ Hydroxide	$Ca(OH)_2$	″ Hydroxide	NaOH	1.08	.926
″ Nitrate	$Ca(NO_3)_2$	″ Nitrate	$NaNO_3$	1.04	.965
″ Oxide	CaO	″ Oxide	Na_2O	1.11	.905
″ Sulfate	$CaSO_4$	″ Sulfate	Na_2SO_4	1.04	.958

Magnesium	Mg	Sodium	Na	1.89	.529
″ Bicarbonate	$Mg(HCO_3)_2$	″ Bicarbonate	$NaHCO_3$	1.15	.871
″ Carbonate	$MgCO_3$	″ Carbonate	Na_2CO_3	1.26	.795
″ Chloride	$MgCl_2$	″ Chloride	NaCl	1.23	.815
″ Hydroxide	$Mg(OH)_2$	″ Hydroxide	NaOH	1.37	.729
″ Nitrate	$Mg(NO_3)_2$	″ Nitrate	$Na(NO_3)_2$	1.15	.873
″ Oxide	MgO	″ Oxide	Na_2O	1.54	.650
″ Sulfate	$MgSO_4$	″ Sulfate	Na_2SO_4	1.18	.847
Sulfuric Acid	H_2SO_4	Calcium Sulfate	$CaSO_4$	1.39	.721
″ ″	″	Magnesium ″	$MgSO_4$	1.23	.815
″ ″	″	Sodium ″	Na_2SO_4	1.45	.691
″ ″	″	Calcium Carbonate	$CaCO_3$	1.02	.980
″ ″	″	Magnesium ″	$MgCO_3$	.860	1.16
″ ″	″	Sodium ″	Na_2CO_3	1.08	.925
″ ″	″	Sulfate Ion	SO_4	.979	1.02
″ ″	″	Sulfur Trioxide	SO_3	.816	1.23
Sulfate Ion	SO_4	Calcium Sulfate	$CaSO_4$	1.42	.706
″ ″	″	Magnesium ″	$MgSO_4$	1.25	.798
″ ″	″	Sodium ″	Na_2SO_4	1.48	.676
″ ″	″	Calcium Carbonate	$CaCO_3$	1.04	.960
″ ″	″	Magnesium ″	$MgCO_3$	.878	1.14
″ ″	″	Sodium ″	Na_2CO_3	1.10	.906
″ ″	″	Sulfuric Acid	H_2SO_4	1.02	.979
″ ″	″	Sulfuric Trioxide	SO_3	.833	1.20

TABLE X. — EQUIVALENTS

PARTS PER MILLION to GRAINS PER U. S. GALLON
(1 PPM. = .05834 Grs./U. S. Gal.)

TENS

HUNDREDS	0	10	20	30	40	50	60	70	80	90
0	.0	.6	1.2	1.8	2.3	2.9	3.5	4.1	4.7	5.3
100	5.8	6.4	7.0	7.6	8.2	8.8	9.3	9.9	10.5	11.1
200	11.7	12.3	12.8	13.4	14.0	14.6	15.2	15.8	16.3	16.9
300	17.5	18.1	18.7	19.3	19.8	20.4	21.0	21.6	22.2	22.8
400	23.3	23.9	24.5	25.1	25.7	26.3	26.8	27.4	28.0	28.6
500	29.2	29.8	30.3	30.9	31.5	32.1	32.7	33.3	33.8	34.4
600	35.0	35.6	36.2	36.8	37.3	37.9	38.5	39.1	39.7	40.3
700	40.8	41.4	42.0	42.6	43.2	43.8	44.3	44.9	45.5	46.1
800	46.7	47.3	47.8	48.4	49.0	49.6	50.2	50.8	51.3	51.9
900	52.5	53.1	53.7	54.3	54.8	55.4	56.0	56.6	57.2	57.8
1000	58.3	58.9	59.5	60.1	60.7	61.3	61.8	62.4	63.0	63.6
1100	64.2	64.8	65.3	65.9	66.5	67.1	67.7	68.3	68.8	69.4
1200	70.0	70.6	71.2	71.8	72.3	72.9	73.5	74.1	74.7	75.3
1300	75.8	76.4	77.0	78.6	78.2	78.8	79.3	79.9	80.5	81.1
1400	81.7	82.3	82.9	83.4	84.0	84.6	85.2	85.8	86.4	86.9
1500	87.5	88.1	88.7	89.3	89.8	90.4	91.0	91.6	92.2	92.8
1600	93.3	93.9	94.5	95.1	95.7	96.3	96.8	97.4	98.0	98.6
1700	99.2	99.8	100.4	100.9	101.5	102.1	102.7	103.3	103.9	104.4
1800	105.0	105.6	106.2	106.8	107.3	107.9	108.5	109.1	109.7	110.3
1900	110.9	111.4	112.0	112.6	113.2	113.8	114.4	114.9	115.5	116.1
2000	116.7	117.3	117.9	118.4	119.0	119.6	120.2	120.8	121.4	121.9
2100	122.5	123.1	123.7	124.3	124.8	125.4	126.0	126.6	127.2	127.8
2200	128.4	128.9	129.5	130.1	130.7	131.3	131.9	132.4	133.0	133.6
2300	134.2	134.8	135.4	135.9	136.5	137.1	137.7	138.3	138.9	139.4
2400	140.0	140.6	141.2	141.8	142.4	142.9	143.5	144.1	144.7	145.3
2500	145.9	146.4	147.0	147.6	148.2	148.8	149.4	149.9	150.5	151.1

UNITS

1	.1
2	.1
3	.2
4	.2
6	.4
5	.3
6	.4
7	.4
8	.5
9	.5

GRAINS PER U. S. GALLON to PARTS PER MILLION

(1 Gr./U. S. Gal. = 17.14 PPm.)

TENS	UNITS 0	1	2	3	4	5	6	7	8	9
0	0	17	34	51	69	86	103	120	137	154
10	171	189	206	223	240	257	274	291	309	326
20	343	360	377	394	411	429	446	463	480	497
30	514	531	549	566	583	600	617	634	651	669
40	686	703	720	737	754	771	788	806	823	840
50	857	874	891	908	926	943	960	977	995	1011
60	1028	1046	1063	1080	1097	1114	1131	1148	1166	1183
70	1200	1217	1234	1251	1268	1286	1303	1320	1337	1354
80	1371	1388	1406	1423	1440	1457	1474	1491	1508	1526
90	1543	1560	1577	1594	1611	1628	1645	1663	1680	1697
100	1714	1731	1748	1765	1783	1800	1817	1834	1851	1868
100	1714	1731	1748	1765	1783	1800	1817	1834	1851	1868
110	1885	1902	1920	1937	1954	1971	1988	2005	2023	2040
120	2057	2074	2091	2108	2125	2143	2160	2177	2194	2211
130	2228	2245	2263	2280	2297	2314	2331	2348	2365	2383
140	2400	2417	2434	2451	2468	2485	2502	2520	2537	2554

TENTHS	
.1	2
.2	3
.3	5
.4	7
.5	9
.6	10
.7	12
.8	14
.9	15

TABLE XI. — HARDNESS: FOREIGN SYSTEMS OF EXPRESSING

One English Degree (° Clark) = 1 Grain $CaCO_3$ per British Imperial Gallon
One French Degree = 1 Part $CaCO_3$ per 10 ,000.
One German Degree = 1 Part CaO per 100,000.

	Parts $CaCO_3$ per Million (P. P. M.)	Grs. $CaCO_3$ per U. S. Gallon	English Degrees (° Clark)	French Degrees	German Degrees
1 P. P. M.	1.	.058	.07	.1	.056
1 Grain/U. S. Gal.	17.1	1.	1.2	1.71	.958
1 English or Clark Degree	14.3	.829	1.	1.43	.8
1 French Degree	10.	.583	.7	1.	.56
1 German Degree	17.9	1.044	1.24	1.78	1.

Appendix II

USEFUL CHEMICAL DATA RELATING TO WATER

1. TABLE XII. — COMMON CHEMICAL REACTIONS IN WATER TREATMENT

$Ca(HCO_3)_2 + \text{heat} = CaCO_3 + H_2O + CO_2$
$Mg(HCO_3)_2 + \text{heat} = MgCO_3 + H_2O + CO_2$
$MgCO_3 + H_2O + \text{heat} = Mg(OH)_2 + CO_2$
$2NaHCO_3 + \text{heat} = Na_2CO_3 + H_2O + CO_2$
$Na_2CO_3 + H_2O + \text{heat} = 2NaOH + CO_2$ (Steaming boiler under pressure)

$Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$
$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$
$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$
$Mg(HCO_3)_2 + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$
$MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$

$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$
$Mg(NO_3)_2 + Ca(OH)_2 = Mg(OH)_2 + Ca(NO_3)_2$
$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$
$H_2SO_4 + Ca(OH)_2 = CaSO_4$ (See 6) $+ 2H_2O$
$Ca(HCO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O$

$Mg(HCO_3)_2 + 4NaOH = Mg(OH)_2 + 2Na_2CO_3 + 2H_2O$
$MgSO_4 + 2NaOH = Mg(OH)_2 + Na_2SO_4$
$MgCl_2 + 2NaOH = Mg(OH)_2 + 2NaCl$
$Mg(NO_3)_2 + 2NaOH = Mg(OH)_2 + 2NaNO_3$
$FeSO_4 + 2NaOH = Fe(OH)_2 + Na_2SO_4$

$H_2SO_4 + 2NaOH = Na_2SO_4 + 2H_2O$
$3CaCO_3 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 3Na_2CO_3$
$3Ca(HCO_3)_2 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 6NaHCO_3$
$3CaSO_4 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 3Na_2SO_4$
$3CaCl_2 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 6NaCl$

$3Ca(NO_3)_2 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 6NaNO_3$
$3MgCO_3 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 3Na_2CO_3$
$3Mg(HCO_3)_2 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 6NaHCO_3$
$3MgSO_4 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 3Na_2SO_4$
$3MgCl_2 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 6NaCl$

$3Mg(NO_3)_2 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 6NaNO_3$
$Na_2CO_3 + 2Na_2HPO_4 = 2Na_3PO_4 + H_2O + CO_2$
$Na_2CO_3 + NaH_2PO_4 = Na_3PO_4 + H_2O + CO_2$
$NaH_2PO_4 + \text{heat} = NaPO_3 + H_2O$
$P_2O_5 + 3H_2O = 2H_3PO_4$

$3Na_2CO_3 + 2H_3PO_4 = 2Na_3PO_4 + 3H_2O + 3CO_2$
$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 6CO_2$
$Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O = 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2$
$Al_2(SO_4)_3 + 6NaOH = 2Al(OH)_3 + 3Na_2SO_4$
$Al_2(SO_4)_3 \bullet (NH_4)_2SO_4 + 3Ca(HCO_3)_2 = 2Al(OH)_3 + (NH_4)_2SO_4 + 3CaSO_4 + 6CO_2$

$Al_2(SO_4)_3 \bullet K_2SO_4 + 3Ca(HCO_3)_2 = 2Al(OH)_3 + K_2SO_4 + 3CaSO_4 + 6CO_2$
$Na_2Al_2O_4 + Ca(HCO_3)_2 + 2H_2O = 2Al(OH)_3 + CaCO_3 + Na_2CO_3$
$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$
$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$
$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 3CaSO_4 + 6CO_2$

$Cl_2 + 2NaOH = NaClO + NaCl + H_2O$
$2Cl_2 + 2Ca(OH)_2 = Ca(ClO)_2 + CaCl_2 + 2H_2O$
$2H_2S + O_2 = 2H_2O + 2S$
$NaClO + 2KI + 2HCl = NaCl + 2KCl + I_2 + H_2O$
$NaClO + H_2S = NaCl + S + H_2O$
$4NaClO + H_2S + 2NaOH = 4NaCl + Na_2SO_4 + 2H_2O$
$2NaClO + C = 2NaCl + CO_2$
$4FeSO_4 + 4Ca(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3 + 4CaSO_4$
$4Fe(HCO_3)_2 + O_2 + 2H_2O = 4Fe(OH)_3 + 8CO_2$
$2Na_2SO_3 + O_2 = 2Na_2SO_4$
$2Na_2S_2O_3 + I_2 = 2NaI + Na_2S_4O_6$
$2NaNO_2 + O_2 = 2NaNO_3$

TABLE XII. — (CON'T)

$Ca(HCO_3)_2+Na_2Z$ . . . . $= CaZ+2NaHCO_3$
$CaSO_4+Na_2Z$ . . . . $= CaZ+Na_2SO_4$
$CaCl_2+Na_2Z$ . . . . $= CaZ+2NaCl$
$Ca(NO_3)_2+Na_2Z$ . . . . $= CaZ+2NaNO_3$
$Mg(HCO_3)_2+Na_2Z$ . . . . $= MgZ+2NaHCO_3$
$MgSO_4+Na_2Z$ . . . . $= MgZ+Na_2SO_4$
$MgCl_2+Na_2Z$ . . . . $= MgZ+2NaCl$
$Mg(NO_3)_2+Na_2Z$ . . . . $= MgZ+2NaNO_3$

$$\left.\begin{matrix}Ca\\Mg\end{matrix}\right\} Z+2NaCl \ldots\ldots = Na_2Z+\left.\begin{matrix}Ca\\Mg\end{matrix}\right\} Cl_2$$

$$\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} (HCO_3)_2+H_2Z \ldots\ldots = \left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z+2H_2O+2CO_2$$

$$\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} SO_4+H_2Z \ldots\ldots = \left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z+H_2SO_4$$

$$\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Cl_2+H_2Z \ldots\ldots = \left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z+2HCl$$

$$\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z+H_2SO_4 \ldots\ldots = H_2Z+\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} SO_4$$

2. Calculation of Lime and Soda Ash Required for Softening.—

$$\text{Hydrated Lime } (Ca(OH)_2) \text{ in lb. per 1000 gal.} = \frac{A + Mg + 2.3\ CO_2}{160}$$

$$\text{Soda Ash } (Na_2CO_3) \quad \text{'' '' '' '' ''} = \frac{H - A}{113}$$

When CO_2 = Free CO_2 in parts per million in terms of CO_2

A = Methyl orange alkalinity in parts per million in terms of CaCO.

Mg = Magnesium hardness in parts per million in terms of CaCO.

H = Hardness in parts per million in terms of CaCO.

The above are the theoretical charges of pure chemicals required with no allowances for impurities in the commercial chemicals used and with no allowances for excesses of chemicals. Corrections for impurities in the chemicals amount to between 5 to 10% for hydrated lime and 1 to 2% for the soda ash. Some excess of chemicals, usually 2/7 lb per thousand gallons for soda ash and 1/7 lb per thousand gallons for lime, is required for the best results. Each grain excess of chemicals equals 1/7 of a pound per 1000 gallons. For hot lime soda eliminate CO_2 from the calculation of the amount of lime required.

3. CALCULATIONS OF FERROUS SULPHATE OR SODIUM SULPHITE CHARGES FOR THE REMOVAL OF DISSOLVED OXYGEN

1 cc/liter Oxygen = 1.43 ppm
1 ppm Oxygen = .698 cc/liter

The Ferrous Sulphate charges are based on the use of Crystallized Ferrous Sulphate ($FeSO_4.7H_2O$). The reaction involved is:—

$$4\,FeSO_4.7H_2O + 4\,Na_2CO_3 + O_2 = 4\,Fe(OH)_3 + 4\,Na_2SO_4 + 22H_2O + 4\,CO_2$$

Ferrous Sulphate + Sodium Carbonate + Oxygen = Ferric Hydroxide + Sodium Sulphate + Water + Carbon Dioxide

1 cc/liter oxygen requires 50 ppm $FeSO_4.7H_2O$
1 ppm oxygen requires 35 ppm $FeSO_4.7H_2O$

The Sodium Sulphite charges are based on the use of Sodium Sulphite (Na_2SO_3) plus the customary 33% excess to insure the complete removal of oxygen. The figures given in the table include this excess. The reaction involved is:—

$$2\,Na_2SO_3 + O_2 = 2\,Na_2SO_4$$

Sodium Sulphite + Oxygen = Sodium Sulphate

1 cc/liter oxygen requires 11.3 ppm + 33% excess = 15 ppm Na_2SO_3
1 ppm oxygen requires 7.9 ppm + 33% excess = 10.5 ppm Na_2SO_3

TABLE XIII. — AMOUNTS OF FERROUS SULPHATE OR SODIUM SULPHITE REQUIRED FOR WATER CONTAINING VARYING AMOUNTS OF OXYGEN

Dissolved Oxygen		Ferrous Sulphate		Sodium Sulphite	
cc per liter	parts per million	parts per million	lbs. per 1000 gallons	parts per million	lbs. per 1000 gallons
.01	.014	.5	.004	.15	.0013
.02	.029	1.0	.008	.30	.0025
.03	.043	1.5	.013	.45	.0038
.04	.057	2.0	.017	.60	.0050
.05	.072	2.5	.021	.75	.0063
.06	.086	3.0	.025	.90	.0075
.07	.10	3.5	.029	1.1	.092
.08	.11	4.0	.033	1.2	.010
.09	.13	4.5	.038	1.4	.012
.1	.14	5.0	.042	1.5	.013
.2	.29	10.	.083	3.0	.025
.3	.43	15.	.13	4.5	.038

4. TABLE XIV. — CHARACTERISTICS OF CHEMICALS USED IN WATER TREATMENT

						$CaCO_3$ Equivalent to one lb. acid	
Name		Formula	Sp. Gr. 60°/60°F	Conc'n.	Grams/Liter	lb.	Grains
Sulfuric Acid	60°Be.	H_2SO_4	1.7059	77.67%	1325	.7926	5548
" "	66°Be.	"	1.8354	93.19%	1710	.9509	6657
Hydrochloric Acid	18°Be.	HCl	1.417	27.92%	319	.3831	2682
			Sp. Gr. 15°/15°C				
28% Acetic Acid	5.4°Be.	$CH_3.CO_2H$	1.0388	28%	291	.2334	1634
56% " "	9.0°Be.	"	1.0660	56%	597	.4667	3267

NOTE: For textiles and laundry work to kill alkalinity for dyeing, bluing, etc:—use ⅓rd. lb 28% acetic acid per 100 gallons of bath for 100 ppm. of Alkalinity—A.

1 P.P.M. NAME	1 P.P.M. FORMULA	P.P.M. Alk. A Reduc'n	P.P.M. SO_3 Increase	P.P.M. Na_2SO_4 Increase	P.P.M. CO_2 Increase	P.P.M. T. Solids Increase
Sulfuric Acid (On 100% H_2SO_4 Basis)	H_2SO_4	1.02	.82	1.45	.90	.37
Sodium Bisulfite (Sodium Acid Sulfite)	$NaHSO_3$	.48	.77	1.37	.42	.86
Nitre Cake (Sodium Bisulfate)	$NaHSO_4$	.30	.64	1.13	.27	.81
Filter Alum (Aluminum Sulfate)	$Al_2(SO_4)_3.18H_2O$	.45	.36	.64	.40	.16
Copperas (Ferrous Sulfate)	$FeSO_4.7H_2O$	.36	.29	.51	.31	.13
Salt Cake (Sodium Sulfate)	Na_2SO_4-95%	....	.53	.95	...	1.00
Chlorinated Copperas	$FeSO_4.7H_2O+(\frac{1}{2}Cl_2)$	.54	.29	.51	.48	.18

1 P.P.M. NAME	1 P.P.M. FORMULA	P.P.M. Alk—A Increase	P.P.M. Free CO_2 Reduction	P.P.M. T.H. as $CaCO_3$ Increase
Sodium Bicarbonate	$NaHCO_3$	.596	.....	....
Soda Ash (Sodium Carbonate)	Na_2CO-	.944	.415	....
Caustic Soda (Sodium Hydroxide)	NaOH	1.25	1.10	....
Burnt Lime (Calcium Oxide)	CaO	1.79	1.57	1.79
Hydrate of Lime (Calcium Hydroxide)	$Ca(OH)_2$	1.35	1.19	1.35

TABLE XV.—FORMULAE, MOLECULAR AND EQUIVALENT WEIGHTS AND CONVERSION FACTORS TO $CaCo_3$ OF SUBSTANCES FREQUENTLY APPEARING IN THE CHEMISTRY OF WATER SOFTENING

				Multiplying Factor	
				Considering molecular wt. of $CaCO_3$ as 100.	
Substance	**Formula**	**Molecular weight**	**Equivalent weight**	**Substance to $CaCO_3$ equivalent**	**$CaCO_3$ equivalent to substance**
Aluminum	Al	27.0	9.0	5.56	0.18
Aluminum Sulfate	$Al_2(SO_4)_3 \bullet 18H_2O$	666.4	111.1	0.45	2.22
Aluminum Sulfate	$Al_2(SO_4)_3$ (anhydrous)	342.1	57.0	0.88	1.14
Ammonium Alum	$Al_2(SO_4)_3(NH_4)_2SO_4 \bullet 24H_2O$	906.6	151.1	0.33	3.02
Potassium Alum	$Al_2(SO_4)_3\ K_2SO_4 \bullet 24H_2O$	948.8	156.1	0.32	3.12
Aluminum Hydrate	$Al(OH)_3$	78.0	26.0	1.92	0.52
Alumina	Al_2O_3	101.9	17.0	2.94	0.34
Sodium Aluminate	$Na_2Al_2O_4$	163.9	27.3	1.83	0.55
Barium	Ba	137.4	68.7	0.73	1.37
Barium Carbonate	$BaCO_3$	197.4	98.7	0.51	1.97
Barium Chloride	$BaCl_2 \bullet 2H_2O$	244.3	122.2	0.41	2.44
Barium Sulfate	$BaSO_4$	233.4	116.7	0.43	2.33
Calcium	Ca	40.1	20.0	2.50	0.40
Calcium Bicarbonate	$Ca(HCO_3)_2$	162.1	81.1	0.62	1.62
Calcium Carbonate	$CaCO_3$	100.08	50.1	1.00	1.00
Calcium Chloride	$CaCl_2$	111.0	55.5	0.90	1.11
Calcium Hydrate	$Ca(OH)_2$	74.1	37.1	1.35	0.74
Calcium Hypochlorite	$Ca(ClO)_2$	143.1	35.8	oxidation	
Calcium Oxide	CaO	56.1	28.0	1.79	0.56
Calcium Sulfate	$CaSO_4$ (anhydrous)	136.1	68.1	0.74	1.36
Calcium Sulfate	$CaSO_4 \bullet 2H_2O$ (gypsum)	172.2	86.1	0.58	1.72
Calcium Nitrate	$Ca(NO_3)_2$	164.1	82.1	0.61	1.64
Calcium Phosphate	$Ca_3(PO_4)_2$	310.3	51.7	0.97	1.03
Iron (Ferrous)	Fe''	55.8	27.9	1.79	0.56

TABLE XV. — (CON'T)

Substance	Formula	Molecular weight	Equivalent weight	Multiplying Factor Considering molecular wt. of $CaCO_3$ as 100. Substance to $CaCO_3$ equivalent	$CaCO_3$ equivalent to substance
Iron (Ferric)	Fe'''	55.8	18.6	2.69	0.37
Ferrous Sulfate	$FeSO_4$ (anhydrous)	151.9	76.0	0.66	1.52
Ferrous Sulfate	$FeSO_4 \bullet 7H_2O$	278.0	139.0	0.36	2.78
Ferric Sulfate	$Fe_2(SO_4)_3$	399.9	66.7	0.75	1.33
Ferrisul	$Fe_2(SO_4)_3$	399.9	66.7	0.75	1.33
Ferrous or Ferric	Fe'' or Fe'''	55.8	55.8	oxidation	
Magnesium	Mg	24.3	12.2	4.10	0.24
Magnesium Oxide	MgO	40.3	20.2	2.48	0.40
Magnesium Bicarbonate	$Mg(HCO_3)_2$	146.3	73.2	0.68	1.46
Magnesium Carbonate	$MgCO_3$	84.3	42.2	1.19	0.84
Magnesium Chloride	$MgCl_2$	95.2	47.6	1.05	0.95
Magnesium Hydrate	$Mg(OH)_2$	58.3	29.2	1.71	0.58
Magnesium Nitrate	$Mg(NO_3)_2$	148.3	74.2	0.67	1.48
Magnesium Phosphate	$Mg_3(PO_4)_2$	262.9	43.8	1.14	0.88
Magnesium Sulfate	$MgSO_4$	120.4	60.2	0.83	1.20
Manganese Chloride	$Mn\ Cl_2$	125.8	62.9	0.80	1.26
Manganese Hydrate	$Mn\ (OH)_2$	89.0	44.4	1.13	0.89
Potassium	K	39.1	39.1	1.28	0.78
Potassium Iodide	KI	166.0	166.0	0.30	3.32
Silver Chloride	$AgCl$	143.3	143.3	0.35	2.87
Silver Nitrate	$AgNO_3$	169.9	169.9	0.29	3.40
Silica	SiO_2	60.1	30.0	1.67	0.60
Sodium	Na	23.0	23.0	2.18	0.46
Sodium Bicarbonate	$NaHCO_3$	84.0	84.0	0.60	1.68
Sodium Carbonate	Na_2CO_3	106.0	53.0	0.94	1.06
Sodium Chloride	$NaCl$	58.5	58.5	0.85	1.17

TABLE XV. — (CON'T)

Substance	Formula	Molecular weight	Equivalent weight	Multiplying Factor Considering molecular wt. of $CaCO_3$ as 100. Substance to $CaCO_3$ equivalent	$CaCO_3$ equivalent to substance
Sodium Hypochlorite	$NaClO$	74.5	37.3	oxidation	
Sodium Hydrate	$NaOH$	40.0	40.0	1.25	0.80
Sodium Nitrate	$NaNO_3$	85.0	85.0	0.59	1.70
Sodium Nitrate	$NaNO_2$	69.0	34.5	oxidation	
Tri-sodium Phosphate	$Na_3PO_4 \bullet 12H_2O(18.7\% \ P_2O_5)$	380.2	126.7	0.40	2.53
Tri-sodium Phos. (anhydrous)	$Na_3PO_4(43.2\% \bullet P_2O_5)$	164.0	54.7	0.91	1.09
Di-sodium Phosphate	$Na_2HPO_4 \bullet 12H_2O \ (19.8\% \ P_2O_5)$	358.2	119.4	0.42	2.39
Di-sodium Phosphate (anhydrous)	$Na_2HPO_4 \ (50\% \ P_2O_5)$	142.0	47.3	1.06	0.95
Mono-sodium Phosphate	$NaH_2PO_4 \bullet H_2O(51.4\% \ P_2C_5)$	138.1	46.0	1.09	0.92
Mono-sodium phosphate (anhydrous)	$NaH_2PO_4(59.1\% P_2O_5)$	120.0	40.0	1.25	0.80
Meta-phosphate (Hagan)	$NaPO_3 \ (69\% P_2O_5)$	102.0	34.0	1.47	0.68
Sodium Sulfate	$Na_2SO_4 \bullet 10H_2O$	322.1	161.1	0.31	3.22
Sodium Sulfate	Na_2SO_4	142.1	71.0	0.70	1.42
Sodium Thiosulfate	$Na_2S_2O_3$	158.1	158.1	oxidation	
Sodium Tetrathionate	$Na_2S_4O_6$	270.2	135.1	oxidation	
Sodium Sulfite	Na_2SO_3	126.1	83.0	oxidation	

TABLE XV. — (CON'T)

Substance	Formula	Molecular weight	Equivalent weight	Multiplying Factor: Considering molecular wt. of $CaCO_3$ as 100. Substance to $CaCO_3$ equivalent	Multiplying Factor: Considering molecular wt. of $CaCO_3$ as 100. $CaCO_3$ equivalent to substance
ACID RADICALS					
Bicarbonate	HCO_3	61.0	61.0	0.82	1.22
Carbonate	CO_3	60.0	30.0	1.67	.60
Carbon Dioxide	CO_2	44.0	22.0	2.27	.44
Chloride	Cl	35.5	35.5	1.41	.71
Iodide	I	126.9	126.9	0.40	2.54
Nitrate	NO_3	62.0	62.0	0.81	1.24
Hydrate	OH	17.0	17.0	2.94	0.34
Phosphate	PO_4	95.0	31.7	1.58	0.63
Phosphorous Oxide	P_2O_5	142.0	23.7	2.11	0.47
Sulfide	S	32.1	16.0	3.11	0.32
Sulfate	SO_4	96.1	48.0	1.04	0.96
Sulfur trioxide	SO_3	80.1	40.0	1.25	0.80
ACIDS					
Hydrogen	H	1.0	1.0	50.00	0.02
Acetic Acid	$HC_2H_3O_2$	60.1	60.1	0.83	1.20
Carbonic Acid	H_2CO_3	62.0	31.0	1.61	0.62
Hydrochloric Acid	HCl	36.5	36.5	1.37	0.73
Phosphoric Acid	H_3PO_4	98.0	32.7	1.53	0.65
Sulfurous Acid	H_2SO_3	82.1	41.1	1.22	0.82
Sulfuric Acid	H_2SO_4	98.1	49.0	1.02	0.98
Hydrogen Sulfide	H_2S	—	—	—	—
Manganous Acid	H_2MnO_3	104.9	52.5	0.95	1.05

Appendix III

WATER RECONNAISSANCE

Appendix III

WATER RECONNAISSANCE REPORT

Organization ____________________
Place ____________________
Date ____________________

1. Location of water source: Map______________; Map coordinates ____________________; local name ____________________

2. Date and hour inspected ____________________

3. Well, spring, stream, lake, pond (line out terms not applicable.)

4. Rate of flow ____________________gallons per day.

5. Character of water: Clearness ____________; taste ____________; odor ____________

6. Temperature of water ____________F

7. Result of tests (if tests impossible at time of inspection, take sample of water as prescribed below. Latest report of local Board of Health, if available).

____

____

8. Location of possible sources of pollution ____________________

____

9. Possibility of chemical contamination (chemical warfare agents, poisoning, etc.) ____________________

____

10. Accessibility to railroad, highway, or trail ____________________

____

11. Well:

a. Type (dug, driven, drilled, or bored. For definitions, see paragraph 213 FM 5-10)
b. Diameter: top ______________ feet; bottom ______________ feet.
c. Depth of well ____________ feet.
d. Depth of water ____________ feet.
e. Distance from surface of ground to water surface ____________feet.
f. Type, condition, and depth of casing or lining ____________________

____

g. Present method of recovering water ____________________
h. Protection provided against entrance of surface water (coping, watertight basin, ditching, etc) ____________________

12. Spring:

a. Protection provided against entrance of surface water (coping, watertight basin, ditching, etc) ------------------------------------

b. Present method of delivering water --------------------------

13. Stream or pond:

a. Sketch of cross section (show width, maximum depth, and height of banks above water surface. Reference to photograph, if one is made.)

b. Surface velocity ------------ feet per second.

c. Nature of bed --

d. Nature of banks --

14. Existing installations:

a. Purification facilities (sedimentation tanks, chlorinating apparatus, filter, etc.) --

b. Pumps:

Type	Size (HP)	Speed (rpm)	Intake connection (Size & Type)	Discharge connection (Size & Type)	Capacity (gal per day)
------	----------	------	------------	------------	--------------
------	----------	------	------------	------------	--------------
------	----------	------	------------	------------	--------------

c. Engines:

Type	Size (HP)	Speed (rpm)
------------------------------------	------------	------------
------------------------------------	------------	------------
------------------------------------	------------	------------

d. Electrical equipment --

e. Storage facilities:

Type	Elevation (feet)	Capacity (gal)
---------------------------------	--------------	------------
---------------------------------	--------------	------------
---------------------------------	--------------	------------

f. Pipe line layout (draw sketch showing arrangement, kind, lengths, and sizes of pipe, elevations, and heads of water);

g. Condition of existing installations --------------------------

15. Proposed development:

a. Description ____

____

____

b. Material available ______________________________________

____

____

c. Material required _______________________________________

____

____

d. Man-hours required _____________________________________

____
(Signature)

____
(Grade & Organization)

INSTRUCTIONS FOR TAKING SAMPLES OF WATER

If sample is to be used for chemical examination only:

1. Use a clean glass bottle, holding from 2 quarts to a gallon, with a well fitting stopper or a clean unbroken cork.
2. Rinse out the bottle two or three times with the water to be sampled.
3. In sampling a well, support the bottle in a string or wire cradle, weighted at the bottom. Lower the bottle until the neck is 2 or 3 inches below the surface. It is advantageous to attach the stopper to a separate string, so the bottle can be opened below the surface of the water. In sampling a stream or pond, hold the bottle so the neck is well below the surface. Allow the bottle to fill.
4. Insert stopper or cork, stretch a clean cloth over it, and tie down the cloth below the flange of the neck.
5. Label the sample.

If the sample is to be used for bacteriological examination:

1. Use a sterilized bottle and stopper. Never use corks.
2. Avoid touching the neck of the bottle or the stopper with the fingers.
3. Before removing the stopper and after filling, the neck of the bottle should be held in a clean flame (alcohol torch) and heated to just over the boiling point of water (212° F).

Precautions—Never let the water entering the sample bottle flow over the hand. Before taking a sample from the spout of a pump or from a tap, allow water to waste for a time.

Appendix IV

ENGINEER WATER SUPPLY CHESTS

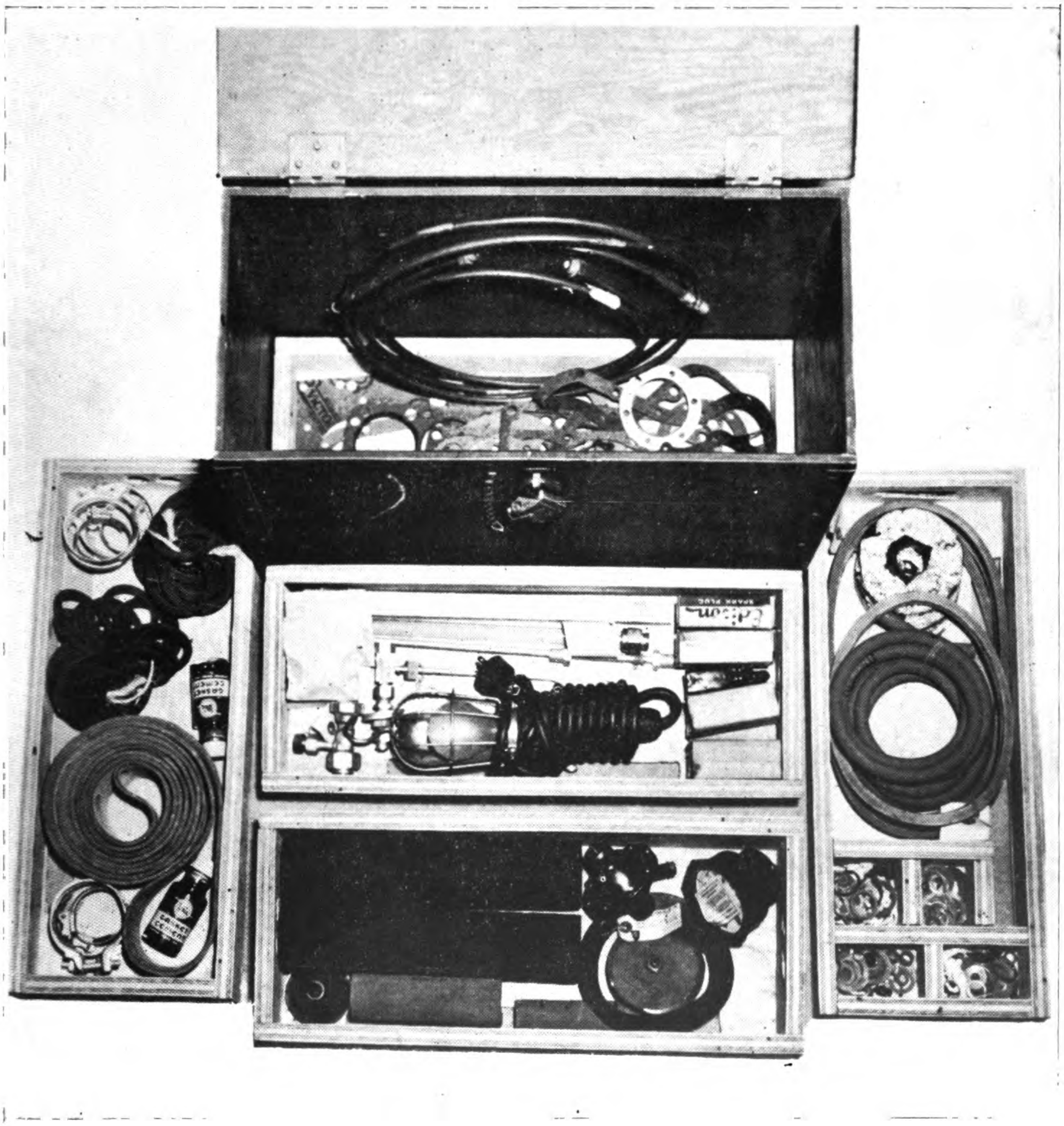


Figure 1. Spare Parts Chest for Mobile Water Purification Unit

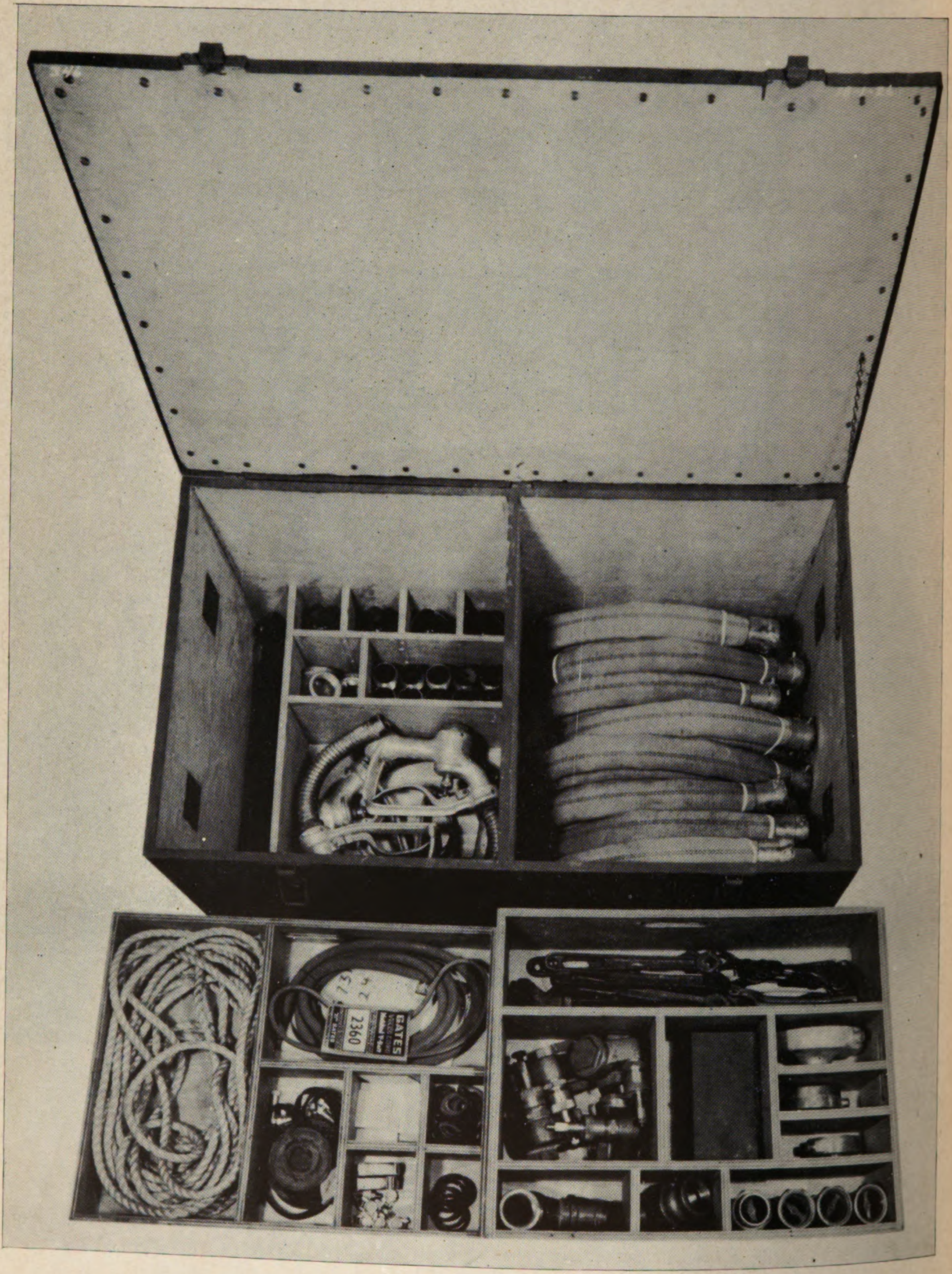


Figure 2. Engineer Water Supply Set Chest

TABLE XVI. — FRICTION OF WATER IN PIPES

Friction head loss in pipes from William & Hazen for coefficient of 100 corresponding to 10 year old steel or 18 year old C. I. pipe.

1. **Friction of Water in Pipes.**— The following table is to be used for adjusting friction head from pipe conditions in table to various other pipe conditions. For example: To find the friction head for 5″ *iron pipe with very rough inside surface,* passing 300 G. P. M., find 31.4 feet per 1000 feet of pipe in table, and multiply by 2.58. Answer: 81 feet friction head per 1000 feet of *iron pipe with very rough inside surface.*

KIND OF PIPE	FACTOR	KIND OF PIPE	FACTOR
New cast iron (straight)	.540	Wood (smooth)	.715
New lead or brass	.540	New rivet steel	.840
New concrete or masonry (very smooth)	.540	Vitrified sewer	.840
New cast iron (not straight)	.615	Cast iron (30 years old)	1.51
Smooth concrete or masonry	.615	Old wrought iron	1.51
New wrought iron (smooth)	.715	Small wrought iron (over 15 years old)	1.51
Cast iron (5 years old)	.715	Iron with very rough inside surface	2.58

Gallons per Minute	Gallons per 24 Hours	Velocity Feet per Second	Velocity Head in Feet	Friction in Ft. per 1000 Ft. of Pipe
⅛″ PIPE (0.27″ INSIDE DIA.)				
0.2	288	1.12	0.02	62.
0.4	576	2.24	0.08	220.
0.6	864	3.36	0.18	470.
0.8	1152	4.48	0.32	800.
1.0	1440	5.60	0.50	1210.
¼″ PIPE (0.364″ INSIDE DIA.)				
0.5	720	1.54	0.04	78.
1.0	1440	3.08	0.15	280.
1.5	2160	4.62	0.33	600.
2.0	2880	6.16	0.57	1030.
2.5	3600	7.70	0.93	1530.
⅜″ PIPE (0.494″ INSIDE DIA.)				
1	1440	1.67	0.04	64.
2	2880	3.35	0.18	233.
3	4320	5.02	0.40	490.
4	5760	6.70	0.70	840.
5	7200	8.37	1.09	1260.
½″ PIPE (0.623″ INSIDE DIA.)				
1	1440	1.05	0.02	21.
2	2880	2.10	0.07	74.
3	4320	3.16	0.16	158.
4	5760	4.21	0.28	270.
5	7200	5.26	0.43	410.
6	8640	6.31	0.61	570.
7	10080	7.37	0.84	760.
8	11520	8.42	1.10	980.
9	12960	9.47	1.40	1210.
10	14400	10.52	1.70	1470.
¾″ PIPE (0.824″ INSIDE DIA.)				
2	2880	1.20	0.02	19.
3	4320	1.80	0.05	41.
4	5760	2.41	0.09	70.
5	7200	3.01	0.15	105.
6	8640	3.61	0.20	147.
¾″ PIPE (0.824″ INSIDE DIA.) (CONT'D				
8	11520	4.81	0.37	250.
10	14400	6.02	0.56	380.
12	17280	7.22	0.80	530.
15	21600	9.02	1.26	800.
20	28800	12.03	2.24	1360.
1″ PIPE (1.048″ INSIDE DIA.)				
3	4320	1.12	0.02	12.6
4	5760	1.49	0.03	21.4
5	7200	1.86	0.05	32.5
6	8640	2.23	0.07	45.5
8	11520	2.98	0.14	78.
10	14400	3.72	0.22	117.
12	17280	4.46	0.30	164.
14	20160	5.20	0.45	220.
16	23040	5.95	0.55	280.
18	25920	6.69	0.70	350.
20	28800	7.44	0.87	420.
25	36000	9.30	1.34	640.
30	43200	11.15	1.93	890.
35	50400	13.02	2.65	1190.
40	57600	14.88	3.42	1520.
1¼″ PIPE (1.380″ INSIDE DIA.)				
4	5760	0.86	0.01	5.7
6	8640	1.29	0.03	12.0
8	11520	1.72	0.05	20.3
10	14400	2.14	0.06	30.5
12	17280	2.57	0.10	43.0
14	20160	3.00	0.14	57.
16	23040	3.43	0.18	73.
20	28800	4.29	0.28	111.
25	36000	5.36	0.44	166.
30	43200	6.43	0.64	235.

TABLE XVI. — (CON'T)

Gallons per Minute	Millions of Gallons per 24 Hrs.	Velocity Feet per Second	Velocity Head in Feet	Friction in Feet per 1000′ of Pipe
1¼″ PIPE (1.380″ INSIDE DIA.) (CONT'D)				
35	50400	7.51	0.90	312.
40	57600	8.58	1.14	400.
50	72000	10.72	1.77	600.
60	86400	12.87	2.57	850.
70	100800	15.01	3.50	1130.
80	115200	17.16	4.60	1450.
90	129600	19.30	5.65	1800.
1½″ PIPE (1.61″ INSIDE DIA.)				
4	5760	0.63	0.01	2.6
6	8640	0.94	0.01	5.6
8	11520	1.26	0.02	9.5
10	14400	1.57	0.04	14.3
12	17280	1.89	0.05	20.1
14	20160	2.20	0.06	26.8
16	23040	2.52	0.10	34.1
20	28800	3.15	0.15	52.0
25	36000	3.96	0.24	78.0
30	43200	4.72	0.38	110.0
35	50400	5.51	0.47	147.
40	57600	6.30	0.61	188.
45	64800	7.08	0.77	232.
50	72000	7.87	0.97	284.
60	86400	9.44	1.38	396.
70	100800	11.02	1.87	530.
80	115200	12.59	2.48	680.
90	129600	14.17	3.12	840.
100	144000	15.74	3.84	1020.
120	172800	18.89	5.51	1430.
140	201600	22.04	7.60	1900.
2″ PIPE (2.00″ INSIDE DIA.)				
6	8640	0.61	0.01	2.
10	14400	1.02	0.02	5.
15	21600	1.54	0.04	10.8
20	28800	2.04	0.06	18.2
25	36000	2.55	0.10	27.3
30	43200	3.06	0.15	38.4
35	50400	3.57	0.20	51.0
40	57600	4.08	0.26	66.0
50	72000	5.11	0.40	99.
60	86400	6.13	0.58	139.
70	100800	7.15	0.79	184.
80	115200	8.17	1.04	237.
90	129600	9.19	1.31	294.
100	144000	10.21	1.62	358.
120	172800	12.25	2.33	500.
140	201600	14.30	3.17	670.
160	230400	16.34	4.14	860.

Gallons per Minute	Millions of Gallons per 24 Hrs.	Velocity Feet per Second	Velocity Head in Feet	Friction in Feet per 1000′ of Pipe
2″ PIPE (CONT'D)				
180	.259	18.38	5.23	1070.
200	.288	20.42	6.46	1290.
220	.316	22.47	7.82	1540.
240	.345	24.51	9.31	1820.
260	.374	26.55	10.90	2110.
2½″ PIPE				
8	.01125	.52	0.00	1.1
10	.01440	.65	0.01	1.7
14	.02016	.92	0.01	3.2
20	.02880	1.31	0.03	6.1
30	.04320	1.96	0.06	12.9
40	.05760	2.61	0.11	22.
50	.07200	3.27	0.17	33.2
60	.08640	3.92	0.24	46.5
70	.10080	4.58	0.33	62.
80	.11520	5.23	0.43	79.
90	.12960	5.88	0.54	98.
100	.14400	6.54	0.66	120.
120	.17280	7.84	0.95	168.
140	.20160	9.15	1.30	223.
160	.23040	10.46	1.70	290.
180	.25920	11.76	2.15	357.
200	.28800	13.07	2.66	431.
220	.31680	14.38	3.22	520.
240	.34560	15.69	3.82	610.
260	.37440	16.99	4.48	700.
280	.40320	18.30	5.20	810.
300	.43200	19.61	5.98	920.
340	.48960	22.22	7.68	1160.
380	.54720	24.84	9.60	1420.
420	.60480	27.45	11.70	1710.
460	.66240	30.07	14.00	2050.
3″ PIPE				
10	.01440	.45	0.00	0.7
15	.02160	.68	0.01	1.5
20	.02880	.91	0.01	2.5
30	.04320	1.36	0.03	5.4
40	.05760	1.82	0.05	9.1
50	.07200	2.27	0.08	13.8
60	.08640	2.72	0.12	19.2
70	.10080	3.18	0.16	25.7
80	.11520	3.63	0.20	32.8
90	.12960	4.09	0.26	40.8
100	.14400	4.54	0.32	49.6
120	.17280	5.45	0.46	70.
140	.20160	6.35	0.63	92.
160	.23040	7.26	0.82	118.
180	.25920	8.17	1.04	148.

TABLE XVI. — (CON'T)

Gallons per Minute	Millions of Gallons per 24 Hrs.	Velocity Feet per Second	Velocity Head in Feet	Friction in Feet per 1000′ of Pipe
3″ PIPE (CONT'D)				
200	.28800	9.08	1.28	178.
220	.31680	9.99	1.55	213.
240	.34560	10.89	1.84	251.
260	.37440	11.80	2.16	291.
280	.40320	12.71	2.51	334.
300	.43200	13.62	2.88	380.
320	.46080	14.52	3.28	428.
340	.48960	15.43	3.71	479.
360	.51840	16.34	4.15	530.
380	.54720	17.25	4.62	590.
400	.57600	18.16	5.11	650.
420	.60480	19.06	5.64	710.
440	.63360	19.97	6.20	770.
460	.66240	20.88	6.78	840.
480	.69120	21.79	7.38	910.
500	.72000	22.70	8.00	980.
550	.79200	24.96	9.70	1170.
600	.86400	27.23	11.50	1370.
4″ PIPE				
20	.02880	0.51	0.00	.62
30	.04320	0.77	0.01	1.32
40	.05760	1.02	0.02	2.23
50	.07200	1.28	0.03	3.39
60	.08640	1.53	0.04	4.72
70	.10080	1.79	0.05	6.3
80	.11520	2.04	0.06	8.1
100	.14400	2.55	0.10	12.2
120	.17280	3.06	0.15	17.1
140	.20160	3.57	0.20	22.8
160	.23040	4.08	0.26	29.1
180	.25920	4.60	0.33	36.1
200	.28800	5.11	0.41	44.
220	.31680	5.62	0.49	52.
240	.34560	6.13	0.58	62.
260	.37440	6.64	0.69	72.
280	.40320	7.15	0.79	82.
300	.43300	7.66	0.91	93.
320	.46080	8.17	1.04	105.
340	.48960	8.68	1.17	117.
360	.51840	9.19	1.31	131.
400	.57600	10.21	1.62	160.
450	.64800	11.49	2.05	198.
500	.72000	12.77	2.53	240.
600	.86400	15.32	3.65	337.
700	1.00800	17.87	4.96	449.
800	1.15200	20.42	6.48	570.
900	1.29600	22.98	8.20	710.
5″ PIPE				
30	.04320	0.49	0.00	.44
40	.05760	0.65	0.01	.75
50	.07200	0.82	0.01	1.13
60	.08640	0.98	0.02	1.59
80	.11520	1.31	0.03	2.71
100	.14400	1.63	0.04	4.11
120	.17280	1.96	0.06	5.8
140	.20160	2.29	0.08	7.6
160	.23040	2.61	0.11	9.8
180	.25920	2.94	0.13	12.2
200	.28800	3.27	0.17	14.8
220	.31680	3.59	0.20	17.7
240	.34560	3.92	0.24	20.8
260	.37440	4.25	0.28	24.1
280	.40320	4.58	0.33	27.7
300	.43200	4.90	0.37	31.4
320	.46080	5.23	0.42	35.4
350	.504	5.72	0.51	41.9
400	.576	6.54	0.66	54.
450	.648	7.35	0.84	67.
500	.720	8.17	1.04	81.
550	.792	8.99	1.26	96.
600	.864	9.80	1.49	113.
650	.936	10.62	1.75	132.
700	1.008	11.44	2.03	151.
750	1.080	12.26	2.34	172.
800	1.152	13.07	2.66	194.
850	1.224	13.89	2.99	217.
900	1.296	14.71	3.36	240.
1000	1.440	16.34	4.15	292.
1100	1.584	17.97	5.00	349.
1200	1.728	19.61	5.96	409.
6″ PIPE				
35	.050	0.39	0.00	.25
50	.072	0.57	0.00	.47
100	.144	1.14	0.02	1.4
150	.216	1.71	0.05	3.2
200	.288	2.28	0.08	6.2
250	.360	2.80	0.12	9.2
300	.432	3.40	0.18	12.9
350	.504	3.98	0.24	17.5
400	.576	4.54	0.32	22.1
450	.648	5.12	0.41	26.5
500	.720	5.60	0.49	33.
550	.792	6.16	0.59	39.3
600	.864	6.72	0.70	47.
650	.936	7.28	0.82	54.
700	1.008	7.84	.96	62.

TABLE XVI. — (CON'T)

Gallons per Minute	Millions of Gallons per 24 Hrs.	Velocity Feet per Second	Velocity Head in Feet	Friction in Feet per 1000′ of Pipe
6″ PIPE (CONT'D)				
750	1.080	8.50	1.13	70.
800	1.152	9.08	1.28	80.
850	1.224	9.58	1.42	89.5
900	1.296	10.30	1.64	101.1
1000	1.440	11.32	1.99	120.4
1100	1.584	12.50	2.44	143.1
1200	1.728	13.52	2.86	166.9
1300	1.872	14.7	3.4	202.
1400	2.016	16.0	3.97	225.
1500	2.160	17.0	4.54	259.
8″ PIPE				
150	.216	.96	.01	.9
200	.288	1.28	.02	1.5
250	.360	1.60	.04	2.2
300	.432	1.90	.06	3.2
400	.576	2.60	.10	5.4
500	.720	3.20	.16	8.2
600	.864	3.84	.23	11.4
700	1.008	4.46	.31	15.4
800	1.152	5.12	.41	19.7
900	1.296	5.75	.52	24.6
1000	1.440	6.40	.64	30.2
1100	1.584	7.03	.77	35.1
1200	1.728	7.67	.92	41.5
1300	1.872	8.32	1.07	47.2
1400	2.016	8.95	1.24	55.
1500	2.160	9.60	1.43	62.7
1600	2.304	10.25	1.64	71.5
1800	2.592	11.50	2.05	88.
2000	2.880	12.70	2.5	107.1
2100	3.024	13.32	2.79	118.
2200	3.168	13.98	3.07	128.
2300	3.312	14.60	3.35	139.
2400	3.456	15.22	3.61	151.
2500	3.600	15.88	3.93	164.
10″ PIPE				
200	.288	.82	.01	.51
300	.432	1.23	.02	1.1
400	.576	1.64	.04	1.8
500	.720	2.04	.06	2.82
600	.864	2.46	.09	3.9
10″ PIPE (CONT'D)				
700	1.008	2.86	.13	5.2
800	1.152	3.28	.17	6.7
900	1.296	3.68	.21	8.3
1000	1.440	4.08	.26	10.1
1100	1.584	4.50	.31	12.0
1200	1.728	4.91	.38	14.6
1400	2.016	5.74	.51	18.7
1600	2.304	6.56	.67	23.5
1800	2.592	7.33	.84	29.6
2000	2.880	8.10	1.02	36.5
2200	3.168	8.92	1.26	43.0
2400	3.456	9.73	1.5	50.4
2600	3.744	10.55	1.74	58.3
2800	4.032	11.35	2.02	67.
3000	4.320	12.10	2.27	78.
3200	4.608	12.90	2.59	87.0
3400	4.896	13.72	2.93	97.8
3600	5.184	14.55	3.30	110.0
12″ PIPE				
300	.433	.85	.01	.45
400	.576	1.14	.02	.75
500	.720	1.42	.03	1.1
600	.864	1.71	.05	1.5
700	1.008	2.00	.06	2.2
800	1.152	2.27	.08	2.7
900	1.296	2.56	.10	3.4
1000	1.440	2.84	.12	4.1
1100	1.584	3.13	.15	4.9
1200	1.728	3.41	.18	5.7
1400	2.016	3.98	.24	7.7
1600	2.304	4.55	.32	9.9
1800	2.592	5.12	.40	12.2
2000	2.880	5.60	.48	14.3
2200	3.168	6.25	.60	17.8
2500	3.600	7.00	.77	22.8
3000	4.320	8.40	1.10	31.5
3250	4.680	9.24	1.32	36.4
3500	5.040	9.80	1.49	41.

TABLE XVII RESISTANCE OF VALVES AND FITTINGS

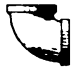
SIZE OF PIPE (SMALL DIA)	STANDARD ELBOW	MEDIUM RADIUS ELBOW	LONG RADIUS ELBOW	45° ELBOW	TEE	RETURN BEND	GATE VALVE OPEN	GLOBE VALVE OPEN	ANGLE VALVE OPEN
									
	LENGTH OF STRAIGHT PIPE GIVING EQUIVALENT RESISTANCE TO FLOW								
½"	1.5	1.4	1.1	.77	3.4	3.8	.35	16	8.4
3/4"	2.2	1.3	1.4	1.0	4.5	5.0	.47	22	12.
1"	2.7	2.3	1.7	1.3	5.8	6.1	.6	27	15.
1¼"	3.7	3.0	2.4	1.6	7.8	8.5	.8	37	18.
1½"	4.3	3.6	2.8	2.0	9.0	10.	.95	44	22.
2"	5.5	4.6	3.5	2.5	11	13.	1.2	57	28.
2½"	6.5	5.4	4.2	3.0	14	15.	1.4	66	33.
3"	8.1	6.8	5.1	3.8	17	18.	1.7	85	42.
3½"	9.5	8.0	6.0	4.4	19	21.	2.	99	50.
4"	11.	9.1	7.0	5.0	22	24.	2.3	110	58.
4½"	12.	10.	7.9	5.6	24	27.	2.6	130	61.
5"	14.	12.	8.9	6.1	27	31.	2.9	140	70.
6"	16.	14.	11.	7.7	33	37.	3.5	160	83.
8"	21.	18.	14.	10.	43	49.	4.5	220	110.
10"	26.	22.	17.	13.	56	61.	5.7	290	140.
12"	32.	26.	20.	15.	66	73.	6.7	340	170.
14"	36.	31.	23.	17.	76	85.	8.	390	190.
16"	42.	35.	27.	19.	87	100.	9.	430	220.
18"	46.	40.	30.	21.	100	110.	10.2	500	250.
20"	52.	43.	34.	23.	110	120.	12.	560	280.
22"	58.	50.	37.	25.	130	140.	13.	610	310.
24"	63.	53.	40.	28.	140	150.	14.	680	340.
30"	79.	68.	50.	35.	165	190.	17.	860	420.
36"	94.	79.	60.	43.	200	220.	20.	1000	400.
42"	120.	95.	72.	50.	240	260.	23.	1200	600.
48"	135.	110.	82.	58.	275	300.	26.	1400	680.

TABLE XVIII ENLARGEMENT AND CONTRACTION LOSSES

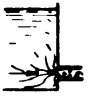
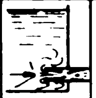
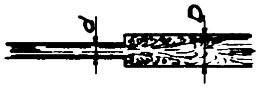
SIZE OF PIPE "d"	ORDINARY ENTRANCE	BORDA ENTRANCE	SUDDEN ENLARGEMENT			SUDDEN CONTRACTION		
			$\frac{d}{D}=\frac{1}{4}$	$\frac{d}{D}=\frac{1}{2}$	$\frac{d}{D}=\frac{3}{4}$	$\frac{d}{D}=\frac{1}{4}$	$\frac{d}{D}=\frac{1}{2}$	$\frac{d}{D}=\frac{3}{4}$
								
	LENGTH OF STRAIGHT PIPE GIVING EQUIVALENT RESISTANCE TO FLOW							
½"	.9	1.5	1.5	1.1	1.0	.77	.59	.35
3/4"	1.2	2.	2.2	1.4	1.3	1.0	.79	.47
1"	1.5	2.5	2.7	1.7	1.6	1.3	.99	.6
1¼"	2.	3.5	3.7	2.4	2.2	1.6	1.3	.8
1½"	2.4	4.0	4.3	2.8	2.6	2.0	1.5	.95
2"	3.	5.	5.5	3.5	3.2	2.5	1.9	1.2
2½"	3.6	6.	6.5	4.2	3.9	3.0	2.3	1.4
3"	4.5	7.6	8.1	5.1	4.9	3.8	2.8	1.7
3½"	5.1	9.	9.5	6.0	5.6	4.4	3.3	2.
4"	6.	10.	11.	7.0	6.5	5.0	3.8	2.3
4½"	6.6	12.	12.	7.9	7.1	5.5	4.3	2.6
5"	7.5	13.	14.	8.9	8.1	6.1	4.8	2.9
6"	9.	15.	16.	11.	10.	7.7	5.7	3.5
8"	12.	20.	21.	14.	13.	10.	7.6	4.5
10"	15.	25.	26.	17.	16.	13.	9.7	5.7
12"	18.	30.	32.	20.	19.	15.	11.	6.7
14"	20.	35.	36.	23.	22.	17.	13.	8.
16"	23.	40.	42.	27.	25.	19.	15.	9.
18"	25.	45.	46.	30.	28.	21.	17.	10.2
20"	28.	50.	52.	34.	31.	23.	18.	12.
22"	32.	55.	58.	37.	35.	25.	20.	13.
24"	35.	60.	63.	40.	38.	28.	22.	14.
30"	43.	75.	79.	50.	46.	35.	27.	17.
36"	51.	90.	94.	60.	56.	43.	33.	20.
42"	60.	110.	120.	72.	67.	50.	39.	23.
48"	69.	120.	135.	82.	75.	58.	43.	26.

TABLE XIX. — DISCHARGE OF PIPES IN G. P. M.

(Free discharge from horizontal pipes against no backpressure.)

Lbs./ Sq.In.	SIZE	LENGTH IN FEET 25	50	100	200	400	1000	SIZE	LENGTH IN FEET 25	50	100	200	400	1000
10	¾″	16	11	8	5	4		1″	31	21	14	10	7	
20		23	16	11	8	5			44	31	21	14	10	
40		34	24	16	11	8			65	44	31	21	14	
60		43	29	20	14	10			81	55	38	26	18	
80		50	34	24	16	11			94	65	44	31	21	
100		57	39	28	18	13			107	73	50	35	24	
10	1¼″	84	58	39	27	19		1½″	94	65	44	31	21	
20		121	84	58	39	27			137	94	65	45	31	
40		177	121	84	58	39			200	137	94	65	45	
60		220	151	104	72	50			250	170	117	81	56	
80		257	177	121	84	58			290	200	137	94	65	
100		292	200	137	95	65			330	225	155	106	73	
10	2″	183	126	86	59	41		2½″	290	200	137	95	65	
20		265	183	126	86	59			420	290	200	137	95	
40		385	265	183	126	86			620	420	290	200	137	
60		480	330	227	156	108			770	525	360	250	172	
80		560	385	265	183	126			890	620	420	290	200	
100		640	435	300	205	142			1160	695	480	330	225	
10	3″	575	395	270	185	130		3½″	755	520	355	245	170	
20		835	575	395	270	185			1100	755	520	355	245	
40		1215	835	575	395	270			1600	1100	755	520	355	
60		1515	1040	715	490	340			1990	1370	940	650	445	
80		1765	1215	835	575	395			2320	1600	1100	755	520	
100		2010	1370	945	650	445			2640	1790	1240	850	530	

10	4″	1070	725	495	340	235	144	4½″	1415	975	670	460	315	190
20		1535	1070	725	495	340	208		2060	1415	975	670	460	275
40		2225	1535	1070	725	495	305		3000	2060	1415	975	670	410
60		2780	1910	1315	900	625	380		3750	2560	1760	1210	840	510
80		3250	2225	1535	1070	725	445		4350	3000	2060	1415	975	595
100		3680	2520	1735	1190	820	500		4950	3380	2325	1600	1100	670
10	5″	1915	1315	900	620	425	260	6″	3100	2125	1450	1000	690	425
20		2780	1915	1315	900	620	370		4480	3100	2125	1450	1000	600
40		4040	2780	1915	1315	900	550		6520	4480	3100	2125	1450	890
60		5040	3460	2380	1635	1135	685		8140	5580	3850	2640	1630	1110
80		5880	4040	2780	1915	1315	800		9500	6520	4480	3100	2125	1300
100		6680	4560	3140	2150	1490	910		10800	7360	5075	3480	2410	1460

NOTE: For friction losses in pipes up to 48″ dia., valves and pipe fittings, see Tables M & N.

TABLE XX. — DRAIN PIPES: CARRYING CAPACITIES IN G. P. M.

SIZE	SLOPE							
	1′ in 100′	1′ in 75′	1′ in 50′	1′ in 40′	1′ in 30′	1′ in 20′	1′ in 10′	1′ in 6′
3″ Cast Iron	31	36	44	49	56	70	99	146
4″ Tile	71	81	101	114	128	158	224	289
6″ ″	225	260	315	360	405	495	720	950
8″ ″	495	585	675	765	900	1125	1575	2050
10″ ″	900	1080	1350	1465	1680	2050	2900	3800
12″ ″	1575	1800	2200	2450	2850	3475	4850	6300
14″ ″	2350	2700	3400	3800	4250	5300	7400	
15″ ″	3050	3250	4050	4500	5175	6300		
16″ ″	3470	3800	4750	5400	6250			
18″ ″	4600	5300	6550					

2. TABLE XXI. — EQUIVALENT PIPE CAPACITIES

EQUATION OF PIPES

It is frequently desired to know what number of pipes of a given size are equal in carrying capacity to one pipe of a larger size. At the same velocity of flow the volume delivered by two pipes of different sizes is proportional to the squares of their diameters; thus one 4-inch pipe will deliver the same volume as four 2-inch pipes. With the same head however, the velocity is less in the smaller pipe, and the volume delivered varies about as the square root of the fifth power. This table is calculated on this basis. The figures opposite the intersection of any two sizes is the number of the smaller-sized pipes required to equal one of the larger; thus one 4-inch equals 5.7 two-inch.

TABLE No. 79

Dia. in.	1	2	3	4	5	6	7	8	10	12	14	16	18	20	24	30	36
2	5.7	1.	.....	.....	.....	.....	.....	.....	.....	.....	....	....	....	....	....	....	....
3	15.6	2.8	1.	.....	.....	.....	.....	.....	.....	.....	....	....	....	....	....	....	....
4	32.	5.7	2.1	1.	.....	.....	.....	.....	.....	.....	....	....	....	....	....	....	....
5	55.9	9.9	3.6	1.7	1.	.....	.....	.....	.....	.....	....	....	....	....	....	....	....
6	88.2	15.6	5.7	2.8	1.6	1.	.....	.....	.....	.....	....	....	....	....	....	....	....
7	130.	22.9	8.3	4.1	2.3	1.5	1.	.....	.....	.....	....	....	....	....	....	....	....
8	181.	32.	11.7	5.7	3.2	2.1	1.4	1.	.....	.....	....	....	....	....	....	....	....
10	316.	55.9	20.3	9.9	5.7	3.6	2.4	1.7	1.	.....	....	....	....	....	....	....	....
11	401.	70.9	25.	12.5	7.2	4.6	3.1	2.2	1.3	.....	....	....	....	....	....	....	....
12	499.	88.2	32.	15.6	8.9	5.7	3.8	2.8	1.6	1.	.....	....	....	....	....	....	....
13	609.	108.	39.1	19.	10.9	7.1	4.7	3.4	1.9	1.2	....	....	....	....	....	....	....
14	733.	130.	47.	22.9	13.1	8.3	5.7	4.1	2.3	1.5	1.	....	....	....	....	....	....
15	787.	154.	55.9	27.2	15.6	9.9	6.7	4.8	2.8	1.7	1.2	....	....	....	....	....	....
16	.....	181.	65.7	32.	18.3	11.7	7.9	5.7	3.2	2.1	1.4	1.	....	....	....	....	....
17	.....	211.	76.4	37.2	21.3	13.5	9.2	6.6	3.8	2.4	1.6	1.2	....	....	....	....	....
18	.....	243.	88.2	43.	24.6	15.6	10.6	7.6	4.3	2.8	1.9	1.3	1.	....	....	....	....
19	.....	278.	101.	49.1	28.1	17.8	12.1	8.7	4.8	3.2	2.1	1.5	1.1	....	....	....	....
20	.....	316.	115.	55.9	32.	20.3	13.8	9.9	5.7	3.6	2.4	1.7	1.3	1.	....	....	....
22	.....	401.	146.	70.9	40.6	25.7	17.5	12.5	7.2	4.6	3.1	2.2	1.7	1.3	....	....	....
24	.....	499.	181.	88.2	50.5	32.	21.8	15.6	8.9	5.7	3.8	2.8	2.1	1.6	1.	....	....
30	.....	.....	.....	.....	.....	.....	.....	27.2	15.6	10.0	6.7	4.8	3.6	2.8	1.75	1.0	....
36	.....	.....	.....	.....	.....	.....	.....	.....	24.6	15.6	10.6	7.6	5.7	4.3	2.76	1.6	1.0

3. CONVERSION OF THE TERMS FOR EXPRESSION OF PRESSURE AND VOLUME

TABLE XXII. — FOR CONVERSION OF HEAD OF WATER IN VERTICAL FEET TO PRESSURE IN LBS. PER SQ. IN.

Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.
1	.43	52	22.5	204	88.4
2	.86	54	23.4	208	90.1
3	1.30	56	24.3	212	91.8
4	1.73	58	25.1	216	93.6
5	2.16	60	26.0	220	95.3
6	2.59	62	26.9	224	97.0
7	3.03	64	27.7	228	98.8
8	3.46	66	28.6	232	100.
9	3.89	68	29.5	236	102.
10	4.33	70	30.3	240	104.
11	4.76	72	31.2	244	106.
12	5.20	74	32.1	248	107.
13	5.63	76	32.9	252	109.
14	6.06	78	33.8	256	111.
15	6.49	80	34.7	260	113.
16	6.93	82	35.5	264	114.
17	7.36	84	36.4	268	116.
18	7.79	86	37.3	272	118.
19	8.22	88	38.1	276	120.
20	8.66	90	39.0	280	121.
21	9.09	92	39.9	284	123.
22	9.53	94	40.7	288	125.
23	10.0	96	41.6	292	126.
24	10.4	98	42.5	296	128.
25	10.8	100	43.3	300	130.

TABLE XXIII. — FOR CONVERSION OF PRESSURE IN LBS. PER SQ. IN. TO HEAD OF WATER IN VERTICAL FEET

Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet
		41	94.7	91	210
0.1	.23	42	97.0	92	213
0.2	.46	43	99.3	93	215
0.3	.69	44	102.	94	217
0.4	.92	45	104.	95	219
0.5	1.16	46	106.	96	222
0.6	1.39	47	109.	97	224
0.7	1.62	48	111.	98	226
0.8	1.85	49	113.	99	229
0.9	2.08	50	116.	100	231
1.	2.31	51	118.	102	236
2.	4.62	52	120.	104	240
3.	6.93	53	122.	106	245
4.	9.23	54	125.	108	249
5.	11.6	55	127.	110	254
6.	13.9	56	129.	112	259
7.	16.2	57	132.	114	263
8.	18.5	58	134.	116	268
9.	20.8	59	136.	118	273
10.	23.1	60	139.	120	277
11.	25.4	61	141.	122	282
12.	27.7	62	143.	124	286
13.	30.0	63	146.	126	291
14.	32.3	64	148.	128	296
15.	34.7	65	150.	130	300

TABLE XXII. — (CON'T)

Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.
26	11.3	104	45.1	310	134.
27	11.7	108	46.8	320	139.
28	12.1	112	48.5	330	143.
29	12.6	116	50.2	340	147.
30	13.0	120	52.0	350	152.
31	13.4	124	53.7	360	156.
32	13.9	128	55.4	370	160.
33	14.3	132	57.2	380	165.
34	14.7	136	58.9	390	169.
35	15.2	140	60.6	400	173.
36	15.6	144	62.4	420	182.
37	16.0	148	64.1	440	191.
38	16.5	152	65.8	460	199.
39	16.9	156	67.6	480	208.
40	17.3	160	69.3	500	217.
41	17.8	164	71.0	520	225.
42	18.2	168	72.8	540	234.
43	18.6	172	74.5	560	242.
44	19.1	176	76.2	580	251.
45	19.5	180	78.0	600	260.
46	19.9	184	79.7	650	282.
47	20.4	188	81.4	700	303.
48	20.8	192	83.2	800	347.
49	21.2	196	84.9	900	390.
50	21.7	200	86.6	1000	433.

TABLE XXIII. — (CON'T)

Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet	Pressure in Lbs./Sq. In.	Head in Feet
16.	37.0	66	153.	132	305
17.	39.3	67	155.	134	310
18.	41.6	68	157.	136	314
19.	43.9	69	159.	138	319
20.	46.2	70	162.	140	323
21.	48.5	71	164.	142	328
22.	50.8	72	166.	144	333
23.	53.1	73	169.	146	337
24.	55.4	74	171.	148	342
25.	57.8	75	173.	150	347
26.	60.1	76	176.	155	358
27.	62.4	77	178.	160	370
28.	64.9	78	180.	165	381
29.	67.0	79	183.	170	393
30.	69.3	80	185.	175	404
31.	71.6	81	187.	180	416
32.	73.9	82	189.	185	427
33.	76.2	83	192.	190	439
34.	78.5	84	194.	195	450
35.	80.9	85	196.	200	462
36.	83.2	86	199.	220	508
37.	85.5	87	201.	240	554
38.	87.8	88	203.	260	601
39.	90.1	89	206.	280	647
40.	92.4	90	208.	300	693

4. **Miscellaneous Data.—**

Railroad Tender Capacity — Normal 5000 gal. — Maximum 20,000 gal.

Track Storage Tanks — 25000 to 50000 gal.

Railroad Water Supply Points — Spacing — 10 to 15 miles

Tank Car Capacity — Standard Commercial — 8000 to 10000 gal.

Military — 5000 gal.

Tank Truck Capacity — Military — 1500 gal. (semi-trailer)

750 gal. (truck)

5. **Boiler Evaporation.—** Boiler Evaporation is generally stated in Lbs. per Hour. Divide by 8⅓ to convert to U. S. Gallons per Hour. If stated in Horsepower Hours, each H. P. Hour x 4 = No. of U. S. Gallons evaporated per Hour at 100% rating. Multiply this by percentage rating, divided by 100. Thus, at 300% rating, multiply x 300/100 or 3, etc.

PUMP POWER REQUIREMENTS

1 Foot Vertical Head of Water = 0.433 lbs. Pressure per Square Inch

1 Pound Pressure Per Square Inch = 2.31 Feet Vertical Head of Water

$$\text{Theoretical Horsepower} = \frac{\text{U. S. Gals. per Minute x Head in Feet}}{3960}$$

$$\text{Brake Horsepower} = \frac{\text{U. S. Gals. per Minute x Head in Feet}}{\text{3960 x Efficiency of Pump}}$$

1 Horsepower = 0.746 Kilowatt Hour

1 Kilowatt Hour = 1.341 Horsepower Hour

Consumption of Electrical Energy per 1000 U. S. Gallons of Water Pumped

$$\text{in Kilowatt Hours} = \frac{\text{Head in Feet x 0.00315}}{\text{Pump Efficiency x Motor Efficiency}}$$

CONVERSION SCALE—CUBIC FEET TO GALLONS

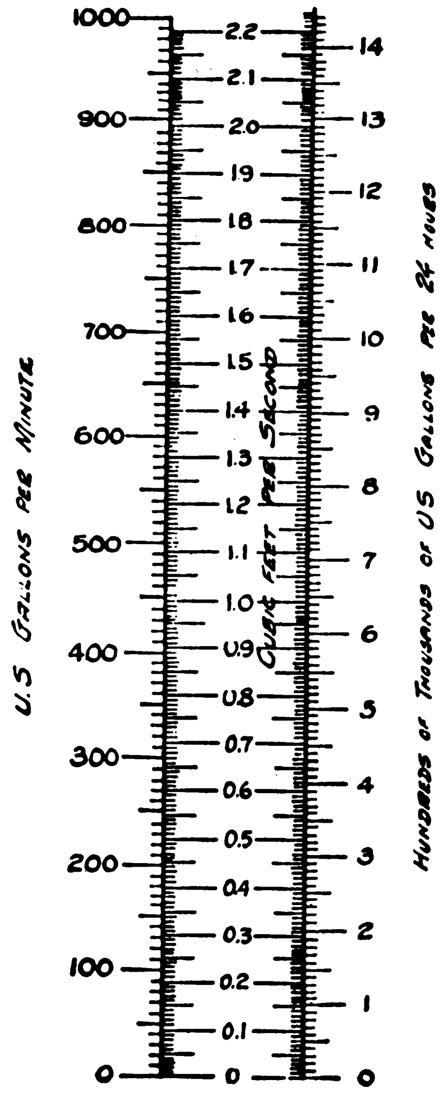


TABLE XXIV. — DAILY WATER CONSUMPTION IN GALLONS

NOTE:— These estimates must be modified according to circumstances, especially in hot climates. The requirements of the maximum month may exceed those of the average month by from 14 to 40 percent.

Unit consumer	Conditions of use	Gallons per unit per day	Remarks
Man (per capita consumption).	In combat:		
	Minimum	⅛ to ½	For periods not exceeding 3 days.
	Normal	1	
	In bivouac:		
	Minimum	1	Drinking and cooking only, for periods not exceeding 3 days.
	Normal	2	
	Temporary camp:		
	Minimum	5	Drinking, cooking, and washing.
	Normal	15	Includes also bathing.
	Field hospital	25	
	Semipermanent camp	50	Includes also water for baths, toilets, etc.
	Permanent camp	75	
	Permanent hospital	200	
Horse or mule, large domestic animals (consumption per animal).	Minimum	3 to 5	For periods not exceeding 3 days.
	Normal	10	
	Camps and cantonments	30 to 50	
Motors (consumption per vehicle).	Level and rolling country.	⅛ to ½	Depends on size of vehicle.
	Mountainous country	¼ to 1	Depends on size of vehicle.
	Permanent camps	30 to 50	Includes washing.
Locomotives (consumption per locomotive)	Standard military	33,000	150 gallons per train mile.
	Commercial	50,000	200 gallons per train mile.
Shower bath	Semipermanent buildings (consumption per fixture)	300	Depends on number of using personnel and frequency of use.
Water closet	do	40	
Lavatory, basin or sink	do	20	
Urinal	do	40	

8. DISCHARGE OVER WEIRS AND FROM ARTESIAN WELLS.—

TABLE XXV. — DISCHARGE OVER A RECTANGULAR WEIR 12 INCHES WIDE.

Depth in inches	Gallons per minute	Depth in inches	Gallons per minute	Depth in inches	Gallons per minute
1	36	4¾	375	8½	900
1¼	50	5	405	8¾	939
1½	66	5¼	436	9	978
1¾	84	5½	468	9¼	1,020
2	102	5¾	500	9½	1,062
2¼	122	6	533	9¾	1,104
2½	143	6¼	567	10	1,147
2¾	165	6½	601	10¼	1,190
3	188	6¾	636	10½	1,234
3¼	212	7	672	10¾	1,279
3½	237	7¼	708	11	1,323
3¾	263	7½	745	11¼	1,369
4	290	7¾	783	11½	1,414
4¼	317	8	821	11¾	1,461
4½	346	8¼	860	12	1,508

TABLE XXVI. — FLOW OF ARTESIAN WELLS IN GALLONS PER MINUTE

Height of jet (inches)	Diameter of pipe (inches)			Height of jet (inches)	Diameter of pipe (inches)		
	1	2	3		1	2	3
½	3.96	15.6	35.6	15	22.0	87.8	198
1	5.60	22.4	50.4	20	25.4	102	228
2	7.99	32.0	71.9	30	30.9	123	278
4	11.3	45.3	102	60	43.8	175	394
6	13.9	55.5	125	108	58.9	236	531
8	16.0	64.0	144	144	68.0	272	612
10	17.9	71.6	161				

9. TABLE XXVII. — TANK CAPACITIES

AREAS AND CAPACITIES PER ONE FOOT OF DEPTH FOR VERTICAL CYLINDRICAL TANKS 1 FT. TO 100 FT. IN DIAMETER

Diameter	Area in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth	Diameter	Area in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth	Diameter	Area in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth
1′	0.785	5.87	6′	28.27	211.5	28′	615.8	4606.
1′ 1″	0.922	6.89	6′ 3″	30.68	229.5	28′ 6″	637.9	4772.
1′ 2″	1.069	8.00	6′ 6″	33.18	248.2	29′	660.5	4941.
1′ 3″	1.227	9.18	6′ 9″	35.78	267.7	29′ 6″	683.5	5113.
1′ 4″	1.396	10.44	7′	38.48	287.9	30′	706.9	5288.
1′ 5″	1.576	11.79	7′ 3″	41.28	308.8	31′	754.8	5646.
1′ 6″	1.767	13.22	7′ 6″	44.18	330.5	32′	804.3	6016.
1′ 7″	1.969	14.73	7′ 9″	47.17	352.9	33′	855.3	6398.
1′ 8″	2.182	16.32	8′	50.27	376.0	34′	907.9	6792.
1′ 9″	2.405	17.99	8′ 3″	53.46	399.9	35′	962.1	7197.
1′ 10″	2.640	19.75	8′ 6″	56.75	424.5	36′	1018.	7616.
1′ 11″	2.885	21.58	8′ 9″	60.13	449.8	37′	1075.	8043.
2′	3.142	23.50	9′	63.62	475.9	38′	1134.	8483.
2′ 1″	3.409	25.50	9′ 3″	67.20	502.7	39′	1195.	8940.
2′ 2″	3.687	27.58	9′ 6″	70.88	530.2	40′	1257.	9404.
2′ 3″	3.976	29.74	9′ 9″	74.66	558.5	41′	1320.	9876.
2′ 4″	4.276	31.99	10′	78.54	587.5	42′	1385.	10360.
2′ 5″	4.587	34.31	10′ 6″	86.59	647.7	43′	1452.	10860.
2′ 6″	4.909	36.72	11′	95.03	710.9	44′	1521.	11370.
2′ 7″	5.241	39.21	11′ 6″	103.9	777.0	45′	1590.	11900.
2′ 8″	5.585	41.78	12′	113.1	846.0	46′	1662.	12430.
2′ 9″	5.940	44.43	12′ 6″	122.7	918.0	47′	1735.	12980.
2′ 10″	6.305	47.16	13′	132.7	992.9	48′	1810.	13540.
2′ 11″	6.681	49.98	13′ 6″	143.1	1071.	49′	1886.	14110.
3′	7.069	52.88	14′	153.9	1152.	50′	1964.	14690.
3′ 1″	7.467	55.86	14′ 6″	165.1	1235.	52′	2124.	15890.
3′ 2″	7.876	58.92	15′	176.7	1322.	54′	2290.	17130.
3′ 3″	8.296	62.06	15′ 6″	188.7	1412.	56′	2463.	18420.

TABLE XXVII. — (CON'T)

Diameter	Area in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth	Diameter	Area,in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth	Diameter	Area in Sq. Ft. Cu. Ft. per 1′ of depth	U. S. Gallons per 1′ of depth
3′ 4″	8.727	65.28	16′	201.1	1504.	58′	2642.	19760.
3′ 5″	9.168	68.58	16′ 6″	213.8	1600.	60′	2827.	21150.
3′ 6″	9.621	71.97	17′	227.0	1698.	62′	3019.	22580.
3′ 7″	10.08	75.44	17′ 6″	240.5	1799.	64′	3217.	24060.
3′ 8″	10.56	78.99	18′	254.5	1904.	66′	3421.	25590.
3′ 9″	11.04	82.62	18′ 6″	268.8	2011.	68′	3632.	27170.
3′ 10″	11.54	86.33	19′	283.5	2121.	70′	3488.	28790.
3′ 11″	12.05	90.13	19′ 6″	298.6	2234.	72′	4072.	30450.
4′	12.57	94.00	20′	314.2	2350.	74′	4301.	32170.
4′ 1″	13.10	97.96	20′ 6″	330.1	2469.	76′	4536.	33930.
4′ 2″	13.64	102.0	21′	346.4	2591.	78′	4778.	35740.
4′ 3″	14.19	106.1	21′ 6″	363.1	2716.	80′	5027.	37600.
4′ 4″	14.75	110.3	22′	380.1	2844.	82′	5281.	39500.
4′ 5″	15.32	114.6	22′ 6″	397.6	2974.	84′	5542.	41450.
4′ 6″	15.90	119.0	23′	415.5	3108.	86′	5809.	43450.
4′ 7″	16.50	123.4	23′ 6″	433.7	3245.	88′	6082.	45490.
4′ 8″	17.10	128.0	24′	452.4	3384.	90′	6362.	47590.
4′ 9″	17.72	132.6	24′ 6″	471.4	3527.	92′	6648.	49720.
4′ 10″	18.35	137.3	25′	490.9	3672.	94′	6940.	51920.
4′ 11″	18.99	142.0	25′ 6″	510.7	3820.	96′	7238.	54140.
5′	19.63	146.9	26′	530.9	3972.	98′	7543.	56420.
5′ 3″	21.65	161.9	26′ 6″	551.5	4126.	100′	7854.	58750.
5′ 6″	23.76	177.7	27′	572.6	4283.			
5′ 9″	25.97	194.3	27′ 6″	594.0	4443.			

10. TABLE XXVIII. — UNITS OF MEASUREMENT

One G.P.M. per Sq. Foot = 1.6″ Vertical Rise per Minute
1″ Vertical Rise per minute = .6234 G.P.M. per Sq. Foot.

INCHES	FEET	YARDS	CENTIMETERS	METERS
1.	.0833	.0278	2.54	.0254
12.	1.	.333	30.5	.305
36.	3.	1.	91.5	.915
.394	.0328	.01094	1.	.01
39.4	3.28	1.094	100.	1.

SQ. INCHES	SQ. FEET	SQ. YARDS	SQ. CENTIMETERS	SQ. METERS
1.	.00694	.000772	6.45	.000645
144.	1.	.1111	929.	.0929
1296.	9.	1.	8361.	.836
.1550	.001076	.0001196	1.	.0001
1550.	10.76	1.196	10000.	1.

U.S. GALLONS	BRIT. IMP. GALS.	CUBIC INCHES	CUBIC FEET	CUBIC METERS	LITERS
1.	.8327	231.	.1337	.003785	3.785
1.201	1.	277.	.1605	.004545	4.545
.004329	.003604	1.	.0005787	.00001639	.01639
7.481	6.229	1728.	1.	.02832	28.32
264.2	220.	61023.	35.31	1.	1000.
.2642	.2200	61.023	.03531	.001	1.

TABLE XXVIII. — (CON'T)

AVOIR. OUNCES	AVOIR. POUNDS	SHORT TONS	LONG TONS	KILOGRAMS	METRIC TONS
1.	.0625	.00003125	.00002790	.02835	.00002835
16.	1.	.0005	.0004464	.4536	.0004536
32000.	2000.	1.	.8929	907.2	.9072
35840.	2240.	1.12	1.	1016.	1.016
35.27	2.205	.001102	.0009842	1.	.001
35274.	2205.	1.102	.9842	1000.	1.

One Acre Inch	=	27152.	U.S. Gallons		
One Acre Foot	=	325851.	U.S. Gallons		
One Second Foot	=	1.	Cu. Ft. per Second	=	60. Cu. Ft. per min.
" " "	=	7.48	U. S. Gals. per "	=	448.8 U. S. gpm.
One Miners Inch	=	1.2 to 1.76	Cu. Ft. per Min. (Varies in different States)		

TABLE XXIX. — SHOWING HEAD ON SUCTION REQUIRED FOR BOTH RECIPROCATING AND CENTRIFUGAL PUMPS WHEN HANDLING HOT WATER AT HIGH ALTITUDES

Minimum Allowable Head in Feet on Suction	**Temperatures of Water in Degrees F.**									
	120	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**
At sea level..................					0	+ 3	+ 5	+ 7	+10	+12
At 2000 alt..................				+1	+ 3	+ 5	+ 7	+10	+12	+15
At 4000 alt..................		0	+1	+3	+ 5	+ 7	+10	+12	+14	
At 6000 alt..................	0	+1	+3	+5	+ 7	+10	+12	+14	+16	
At 8000 alt..................	0	+3	+5	+7	+ 9	+12	+14	+16		
At 10000 alt..................	+2	+4	+7	+9	+11	+14	+16	+18		

Appendix VI

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Appendix VI

BIBLIOGRAPHY

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(A. G. 062.11 (5-15-42).)

By order of the Secretary of War:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
Major General,
The Adjutant General.

1264 FORT BELVOIR, VA. 6-2-42 [illegible]