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SURFACE MACHINERY AND METHODS FOR OIL-WELL PUMPING

BY

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SURFACE MACHINERY AND METHODS FOR OIL-WELL PUMPING.

By H. C. George.

INTRODUCTION.

GENERAL SCOPE.

This bulletin deals with prime movers, power-transmitting machinery, and the surface equipment and methods used to pump oil wells. It does not discuss geological problems nor the methods and equipment used in drilling or at flowing oil wells. Much of the presentation is by photographs and drawings which are described in the text. Underground equipment and methods for pumping oil wells will be discussed in a later publication of the Bureau of Mines.

IMPORTANCE OF THE SUBJECT.

Geological knowledge is a valuable aid in the discovery of new oil fields. In the early days of the industry, wells were sunk at random; now the geological formations and structures are studied before a new field is drilled. Drilling methods, also, have been broadened and modified to meet conditions in new oil fields. In California, Texas, Louisiana, and other places where the formations are soft and loose, rotary drilling rigs have replaced standard tools. Casing, cementing, and mudding problems have been carefully studied, and many improvements made in solving them.

The surface equipment, machinery, and methods used for pumping wells, however, have not been correspondingly developed. Many of them are practically the same as those used 25 years ago. The average production for a well in the oil fields of the United States is less than 5 barrels a day. To maintain production of the individual well is as important as to discover new wells, and this can only be done by the use of modern machinery and of improved equipment and methods.

Many oil wells if pumped individually would show a loss, but operated as members of a group they show a profit. As modern industry becomes more and more dependent on petroleum products, more consideration must be given to the individual well in relation to other wells. The future life of the well should be considered rather than maximum production during the first day, month, or year. In fact, operating a well at full capacity during its early life may result in a decreased ultimate production from that well. In the interests of conservation, national welfare, and ultimate personal profit, oil operators should stress the greatest ultimate production from the group. The older oil fields of Pennsylvania, Ohio, West Virginia, and Illinois exemplify efficiency in group operation. In Pennsylvania the 59,000 operating oil wells show an average of less than a quarter of a barrel production per well per day, yet are being operated at a profit by the group method.

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CHOICE OF SURFACE EQUIPMENT AND METHODS.

The choice of machinery and surface equipment and the method of production used for the individual well or for a group of wells depend upon the following factors: (1) Conditions at the individual well; (2) conditions in the given area; and (3) qualifications of owners and operators.

CONDITIONS AT THE WELL AS A FACTOR.

In the early days of the oil industry, all nonflowing wells were pumped individually "on the beam" by steam engines. This system wasted both labor and power, as each well required a man and a steam power plant. At present a group of 15 to 30 similar wells is pumped with a central "power" or "jack" plant with practically the same labor and the same engine capacity as was then used at each well.

Whether a well is allowed to flow, pumped individually on the beam, pumped as one of a group by a central power or jack plant, or operated by the air-lift system or by some other method depends on a number of factors; among these are the location of the well, the quantity of oil, the gas pressure, the fluid level in the well, the gravity of the oil, the amount of sand, water, paraffin, and emulsion, and the depth of the well. Most of these factors must be considered at each well. However, one or two of them will probably determine the method of production.

Of course, if the well is isolated, whether flowing or pumping, it must be operated individually until further drilling develops other wells. If the well does not flow it is usually pumped on the beam; but if it is drilled with a traction drilling machine a unit pumping power is generally installed.

If a pumping well that produces oil continuously is one of a group, it can be pumped on the beam individually or from a central power as one of a power group. Individual pumping is generally best for wells that produce much sand, water, or emulsion with the oil, or for wells that produce from deep sands, as these conditions will often necessitate more care and attention.

During the first two or three years of the life of many wells in the Kern River oil field, California, much sand is produced with the oil, requiring frequent pulling of rods and tubing. As long as these wells produce excessive amounts of sand they are pumped individually. Later they are pumped as one of a group by a power or jack plant. Wells that produce excessive amounts of water must be pumped individually, otherwise the pumping stroke would not be long or rapid enough to remove the water produced.

In oil fields producing both from shallow and deep sands many of the shallow wells are pumped from power or jack plants and the deep wells are pumped individually, as in the Eldorado field, Kansas, and Big Muddy field, Wyoming.

If the fluid level in a well is high and the daily production available is greater than can be handled by ordinary pumping methods, conditions may warrant blowing the well with air lift to obtain the maximum production. However, this is costly and requires the installation of an air compressor.

Heavy surface equipment is usually required if the oil has high viscosity or high specific gravity, if it comes from deep sands with a low fluid level, or if the amount of emulsion or the amount of water or sand in suspension is great.

Development and operation in most of the older oil fields tended to standardize pumping methods and to diversify pumping equipment. The present tendency is toward standardization of equipment used for similar purposes, and diversity of pumping methods to meet the conditions existing at individual wells. This difference is well illustrated at the Salt Creek oil field, Wyoming, where most of the wells have been flowing up to the present time. Now the operators are giving serious consideration to the methods of pumping that will be used and the types of power plant to be installed for power needs when the production can no longer be obtained by flowing. In that field different wells produce from different sands.

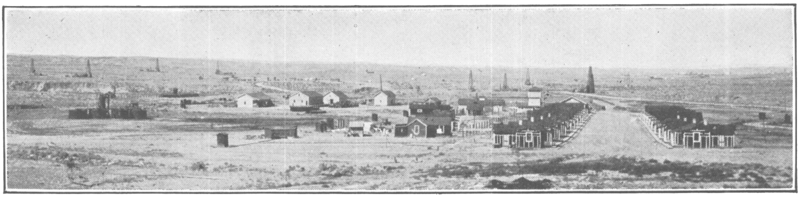
CONDITIONS IN THE GIVEN AREA AS A FACTOR.

If much natural gas occurs with the oil, enough fuel will be available on the operating property to supply a power plant. If, however, the natural-gas supply has become so depleted that it does not meet the needs, then the use of crude oil or fuel oil is considered. In oil fields of low economic limit, such as those of Pennsylvania which have available coal or wood supply, after the natural-gas supply has become exhausted wood or coal is often cheaper than the high-grade crude oil produced.

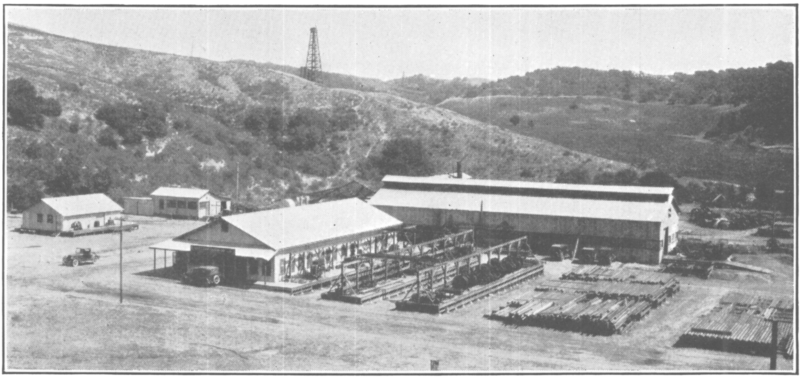
With poor living conditions,[1] especially when climatic conditions are not of the best, it is difficult to obtain and retain high-class labor and to introduce and run modern machinery. Poor living conditions usually accompany poor methods of operation. However, under the most adverse conditions many oil companies provide good quarters for their men, and modern equipment.

Plate I, *A*, illustrates an oil-field camp, which though in an arid region has good living conditions. Plate I, *B*, shows an oil-field ma-

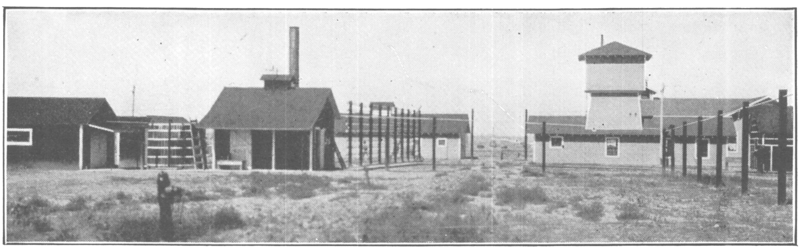
[1] Bowie, C. P., Oil-camp sanitation: Tech. Paper 261, Bureau of Mines, 1921, 32 pp.



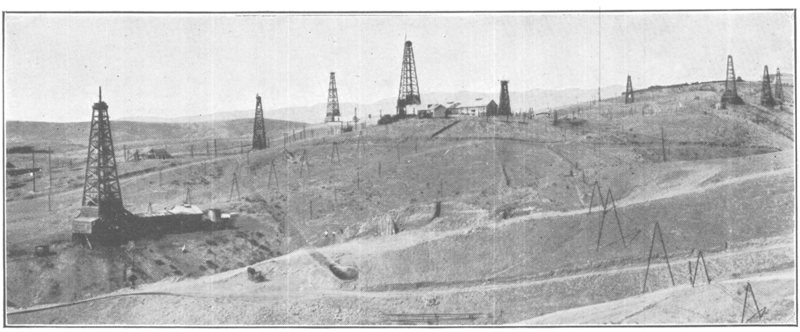
A. CAMP OF OHIO CO., SALT CREEK FIELD, WYOMING



B. MACHINE SHOP, WAREHOUSE, AND YARDS OF WESTERN UNION OIL CO., SANTA MARIA FIELD, CALIFORNIA

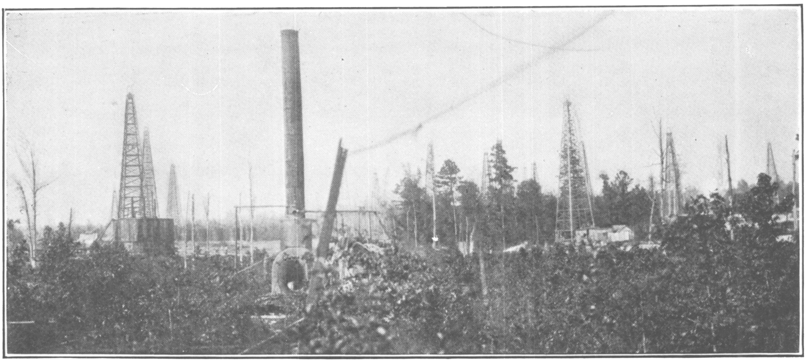


C. WATER-DISTILLING PLANT, SALT CREEK FIELD, WYOMING

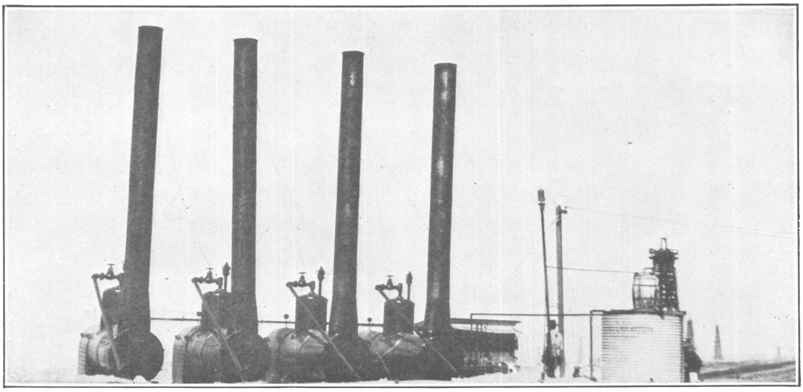


D. WELLS PUMPED BY POWER OR JACK PLANTS, COALINGA FIELD, CALIFORNIA

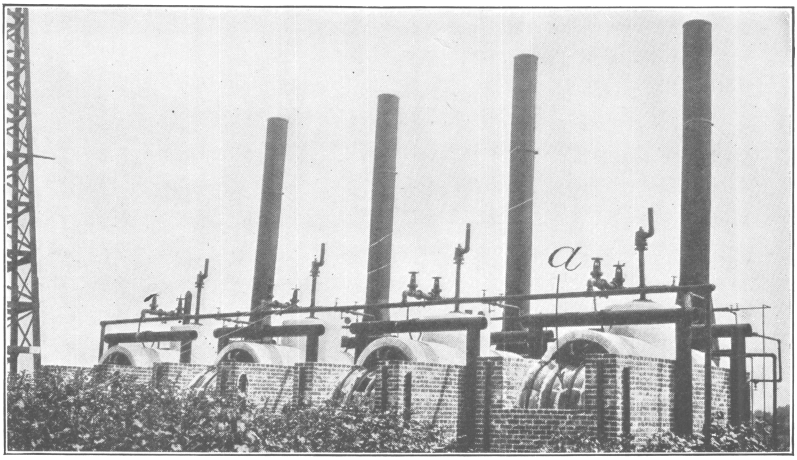
PART OF A LARGE WELL-DEVELOPED OIL FIELD, ELDORADO, KANS.



A. NEWLY DEVELOPED OIL FIELD, EL DORADO, ARK.



B. LOCOMOTIVE-TYPE BOILER IN OIL FIELDS



C. BATTERY OF RETURN TUBULAR BOILERS IN THE OIL FIELDS EQUIPPED WITH HINGED BACK ARCHES, *a*

chine shop, warehouse, and yards, where good operating methods are found in an isolated oil field.

The presence of much brush, undergrowth, and timber may determine the method used in pumping oil wells. One central power or jack plant usually operates fewer wells in such areas than in those free from brush, undergrowth, and timber.

Many oil fields lack good water for camp and power needs. Poor boiler water or a scarcity of water makes desirable the use of electric power and the use of central power plants, where provision can be made for the installation of suitable equipment for treating the poor water available and for conserving the supply if scarce. Plate I, *C*, shows a water-distilling plant in the Salt Creek oil field, Wyoming.

Oil fields in hilly or mountainous country often require certain equipment and methods of operation because of the topography. In some of the oil fields of West Virginia the hills are so steep and the valleys so narrow that wells must be pumped individually by steam or gas engines; if the topography were not so rough the wells could be pumped better by a power or jack plant. However, in the Coalinga field, California, some powers are being used in very rough and mountainous country under conditions that required large expense for installation; see Plate I, *D*.

To justify building a large central power plant in a field, or running high-tension lines from a distance to meet power needs, enough wells must be producing. Plate II shows part of a large well-developed oil field—the Eldorado, Kansas—where most of the wells are pumped by electric power.

The kind of surface equipment and method of production used in an oil field often depend upon its probable life and stage of development. If the field has been producing for years and has nearly reached its economic limit, few changes are warranted. If it is a new oil field promising extensive development and large production, changes are often beneficial. Plate III, *A*, shows a newly developed oil field.

Often the introduction of new and improved methods and equipment in an oil field is difficult. Labor may be slow to accept changes that may have proved effective at other places under the same or similar operating conditions.

When an oil field has nearly reached the stage of depletion, old equipment on hand is often used, even if it may not be the best, as the probable future life of the property does not warrant costly changes. Many of the older oil fields of Pennsylvania and Ohio have reached their low economic limit chiefly because nearly all renewals are from "second-hand" equipment from abandoned oil-well properties.

QUALIFICATIONS OF THE OWNERS AND OPERATORS AS A FACTOR.

Companies that lack capital and good financial standing often fail because of the lack of funds with which to improve operating methods and equipment. This is as true in the production of oil as in any other industry.

Among the most important of the operating factors are the authority and ability of the manager. Lack of vested authority and lack of executive ability on the part of the manager have wrecked many prosperous companies. On the other hand, the manager may be so capable that he can make operations pay even though handicapped by an incompetent group of directors and lack of capital. The older and larger oil companies generally have strong organizations as a result of years of development, but many of the smaller and newer companies operating in the gusher fields have suffered greatly from lack of management and organization.

PRIME MOVERS AND POWER-PLANT MACHINERY.

Prime movers used to supply power for oil wells are classified as to use, as follows: 1, Those at the well for individual drive; 2, those at or near a group of wells for group drive; and, 3, those in the general area to be served that can supply power to pump all of the wells of a number of properties, either individually or in groups.

Type 3 refers to the common type of electric power plant. The power generated is carried on high-tension lines to the distributing station, often on the property to be served, where it is stepped down through the transformers and is used either to drive the motor of a central jack pumping plant or is carried on low-tension lines to the motors of the wells pumped "on the beam."

Prime movers and power-plant machinery for pumping oil wells, and for use as auxiliary power at pumping oil-well properties, are classified as to type and discussed as follows: 1, Steam boilers, steam plant equipment, and fuels; 2, steam engines; 3, gas engines; 4, oil engines; 5, compressors; 6, pumps; 7, electric generating equipment; and 8, horses used for bailing and pulling oil wells.

STEAM BOILERS, STEAM-PLANT EQUIPMENT, AND FUELS.

The capacity of a boiler is usually expressed in boiler-horsepower. The standard at present is that recommended by the American Society of Mechanical Engineers. The committee on boiler tests of this society defines the boiler-horsepower as the equivalent evaporation of 34.5 pounds of water from and at 212° F. an hour. This is equivalent to 33,479 B. t. u. an hour.

Boilers are of two general classes: Fire tube, in which the gases pass through tubes expanded into headers forming part of the shell; and water tube, in which the water is in the tubes, the gases passing around them. The locomotive and California types of boilers, common in oil field use, belong to the former class.

FIRE-TUBE BOILERS.

Fire-tube boilers are either internally or externally fired; the locomotive type, shown in Plate III, *B*, is an example of the former, and the horizontal return tubular type shown in Plate III, *C*, of the latter. Both types are sold by the oil-well supply companies. They are generally installed first for drilling service and later used for pumping.

LOCOMOTIVE TYPE OF BOILER.

The locomotive type of boiler was used almost exclusively in the older oil fields and is still the more common, except in California. It is made in sizes from 20 to 60 horsepower, and is built for a working steam pressure of 100 to 125 pounds. This type of boiler is good for small or temporary plants, as it is self-contained, easily portable, and requires no external furnaces or setting and but little space. To make them readily portable some types are being built with permanent mountings, consisting of steel wheels and axles; for those with detachable mountings, the wheels, axles, and saddles are temporarily attached by means of chains or steel rods with turnbuckles and U bolts. A 40-horsepower boiler of this type weighs about 10,000 pounds without the mountings. This type of boiler is cleaned and repaired with greater difficulty than the return tubular or water-tube type.

With this type of boiler there is danger of defective circulation; leaks often start from unequal expansion of boiler shell, tubes, and fire box; and unsuspected corrosion may go on in parts that can not be readily inspected. Often the operator through ignorance or indifference permits scale and mud to collect on the crown sheet or in the water legs, or the water level to become too low; then overheating and blistering or bagging result. An examination of the repair work being done in the average field boiler shop will generally show that the locomotive type of boiler has received more abuse in operation than any other form of mechanical equipment used in the oil fields.

HORIZONTAL RETURN TUBULAR BOILER.

Horizontal return tubular boilers are becoming more widely used for drilling as well as for permanent pumping plants in many oil fields where moderate steam pressure and capacities of less than 200 horsepower are desired. This type of boiler occupies little space, gives large heating surface at less cost than the locomotive type, and is simply built. However, the flues are liable to leak and the hotter gases have a tendency to pass mostly through the upper tubes. A common type of return tubular boiler sold by oil-well supply companies has a dome, is of 40 to 70 horsepower, and is known as the California type, from its wide use in the California fields. The return tubular boiler, without the brick and fittings, weighs about 25 per cent less than a locomotive boiler of the same horsepower rating.

WATER-TUBE BOILERS.

Water-tube boilers include all types of boilers in which the water is inside the tubes and the flames and gases from the fire are outside. These boilers are much better suited than the locomotive or return tubular types for central power-plant requirements. Although the initial cost of water-tube boilers is comparatively high, the high over-all efficiencies obtained warrant use at large power plants. With the increased use of electric power for pumping oil wells, more steam power plants generating from 200 to 1,200 horsepower are being installed in some oil fields. Many such plants are in use in the Gulf Coast oil fields of Texas and Louisiana.

If power units not greater than 250 horsepower are preferable at these central power plants, return tubular boilers are used; if units of higher capacity are desired, water-tube boilers are used. Such plants generally run at uniform load 24 hours a day; they may have periods of peak load during certain hours, but seldom or never have periods of no load. Under these conditions, with the larger incidental power requirements, the chief considerations are fuel and labor costs, thermal efficiency, and safety and durability of plant. Operations are large enough to warrant the introduction of the usual boiler-plant auxiliaries that are essential to efficiency. Small or temporary boiler installations, however, may be run only a few hours a day, using gas fuel, which if not used in the boiler would be wasted, and employing men who are not regular steam engineers. Under such conditions small boilers of the locomotive or return tubular type are used.

BOILER PARTS, FITTINGS, AND AUXILIARY EQUIPMENT.

For general information on boiler domes, steam drums, water gages, steam or pressure gages, fusible or soft plugs, safety valves, blow-offs, steam taps, condensers, feed-water heaters, and other auxiliary equipment, the reader is referred to standard literature on these subjects.[2]

[2] Am. Soc. Mech. Eng. Boiler Code; Kent's Mechanical engineer's pockjet book; Marks's Mechanical engineer's handbook; or Peele's Mining engineer's handbook.

SETTINGS FOR HORIZONTAL RETURN TUBULAR BOILERS.

The quality of brick to be used for boiler settings depends upon the permanency of the installation and the temperature to be resisted. Sound, hard-burned red brick can be used for facing, and at other places where they are protected from the heat. The best quality of fire brick should be used for linings if high overloads or other extreme conditions of service are likely. Second-grade fire brick can be used for the better type of fire-box settings where normal conditions prevail. If the boiler is not often subjected to overload most of the setting can be made of third-grade fire brick, except at the most exposed places.

Formerly in the California oil fields, when a battery of boilers was installed, they were bricked up together. Recently, however, many of the oil companies have bricked up the boilers separately and often find this method more satisfactory. A 40-horsepower California-type return tubular boiler, bricked up separately with a 21-inch wall, requires about 10,000 red brick, 2,000 fire brick, 800 pounds of fire clay, and 8 barrels of lime.

In the California fields, temporary settings are made of common red brick and adobe by using about 3,500 brick for side and end walls. As such settings are inefficient and waste fuel, they are going out of use.

BACK ARCHES FOR HORIZONTAL RETURN TUBULAR BOILERS.

The back arch should be so built that the flue gases do not come in contact with and overheat that part of the boiler shell above the water level. The common back-arch construction seen in oil fields, with the back wall built above the level of the top flues and bricked over horizontally with fire brick or common brick resting on the arch bars, often causes trouble if the boiler is overloaded; the supporting arch bars burn out and the back arch falls Furthermore, every time that work has to be done on the flues the back arch and end wall have to be torn out. The hinged-back arch, shown in Plate III, *C*, at *a*, consists of special fire brick set in casings hinged at the lower and outer end. It is being installed with good results in many of the return tubular boilers in oil-field plants. Those oil companies using this type of back arch claim that it is durable, gives ready access to the flues, and eliminates the delay, labor, and expense incident to the tearing down and rebuilding of the old type of back arch.

BOILER INSULATION.

Many tests have shown that a boiler without insulation will radiate heat to the surrounding atmosphere at the approximate rate of 3

B. t. u. per square foot of exposed surface per hour per degree of difference in temperature between the contained steam and the external air. If a sufficient thickness of the better types of insulating material is used this radiation may be reduced to less than 1 B. t. u. Covering the drums of return tubular boilers with one row of brick on edge and a thin layer of cement on top is a common practice; it helps to save heat, but probably does not reduce the loss to less than 2 B. t. u. per square foot.

A better practice has been to cover the drum with a thin layer of magnesia and then a layer of cement. However, the expansion and contraction of the large metal surface of the boiler crack the cement. A good modern practice is to cover drumheads with magnesia block or plastic magnesia held in place with netting and covered with painted canvas. Asbestos and magnesia insulating cements are well suited to cover irregular boiler surfaces and fittings where either insulating blocks or sectional covering can not be placed.

In most of the locomotive-type boilers seen in oil fields no provision is made for preventing the loss of heat by radiation from the boiler surface. On cold windy days many boilers that ordinarily give the desired steam pressure and capacity are unable to supply the necessary steam. It is surprising how much fuel can be saved by a well-closed boiler house when the weather is cold or windy.

STACKS.

Most of the locomotive and return tubular boilers used in oil fields have individual sheet-iron smokestacks, 15 to 30 feet long, which are held in place by guy wires. The height of stack necessary depends on local conditions and whether or not mechanical draft is used.

A central power plant generally has one common chimney of masonry, reinforced concrete, or brick-lined steel anchored to a foundation, or else a steel stack carried on a foundation or structural support and held in place by guy wires.

As a rule, steel stacks are not so long lived as masonry; they rust out under hard service and require more care. However, they are much cheaper and can be readily moved from place to place. A steel stack radiates more heat than a brick or concrete chimney. This loss of heat means loss of draft and less boiler efficiency. Too high a stack or too strong a draft without proper regulation of the air supply will greatly reduce the efficiency of the plant, especially when the load varies.

An oil or gas burner in itself tends to increase draft, which is the reason for the good draft conditions in oil-field boilers with sheet-iron smokestacks.

STEAM PIPING.

Under normal conditions steam piping should be of such size that the maximum velocity of the steam passing through is about 6,000 feet a minute. However, at some installations using superheated steam the pipe velocities approach 10,000 feet a minute. To use steam velocity alone in determining the diameters of steam lines is not always satisfactory, as the length of pipe and the loss of pressure through friction should be taken into consideration. Too large a pipe increases the initial cost and the heat losses; too small a pipe increases the pressure drop due to friction. Steam lines should be so installed as to avoid excessive strains from expansion and contraction, for these cause leaks at the couplings. Usually certain parts of the line are firmly anchored, and the expansion is taken care of at other points by floor stands or wall brackets along which the pipe can slide, or by flexible hangers, or by long radius bends in the pipe itself.

Sleeve expansion-joints may be used for large pipes where lack of space prevents long bends. Valves in steam lines over 6 or 8 inches in diameter should have a small by-pass around them to permit the line to be warmed gradually. Large valves are often hard to open unless the pressure on both sides is equal. Many large valves include a by-pass.

To provide for the expansion and contraction of a line delivering steam from a nest of boilers, each boiler should have a swing-arm connection.

MOISTURE IN STEAM.

Moisture at the end of a long steam line is often attributed to the priming of the boiler, when it is really the direct result of condensation. The condensed steam gradually collects in low points of the steam line and is carried along at intervals, acting like entrained water. In the older oil fields in the hilly regions of Pennsylvania and West Virginia, where because of the topography the boiler is often at a distance from the engine, this condition is worst during winter. At such plants the amount of condensation in winter often amounts to 10 or 15 per cent of the steam passing through the pipe, as boiler tests made by oil companies have shown.

Figure 1 is a heat-loss chart for bare steam pipes.

INSULATION OF STEAM PIPES.

Various makeshift devices have been used in the oil fields to decrease condensation losses in steam lines. Many steam lines are inclosed in old steel casing, or board or plank boxes. Frequently these devices are not only worthless but increase heat losses, for if they are not tight and properly closed at the ends they form a channel for moving air currents, and thus aid condensation.

In some arid regions, where the ground is dry and affords good insulation most of the time, satisfactory results are often obtained by burying the line; but where there is much rainfall or snow, or the ground is wet and retains moisture, the ditch carrying the steam line may become a channel for surface water; then the heat losses will be increased. For steam lines more or less permanently installed, a common standard covering is made of 85 per cent magnesium carbonate and 15 per cent asbestos. This covering usually is 1 inch to 2½ inches thick, its thickness depending on the size of the steam line and the steam pressure used. Insulation properly installed and kept

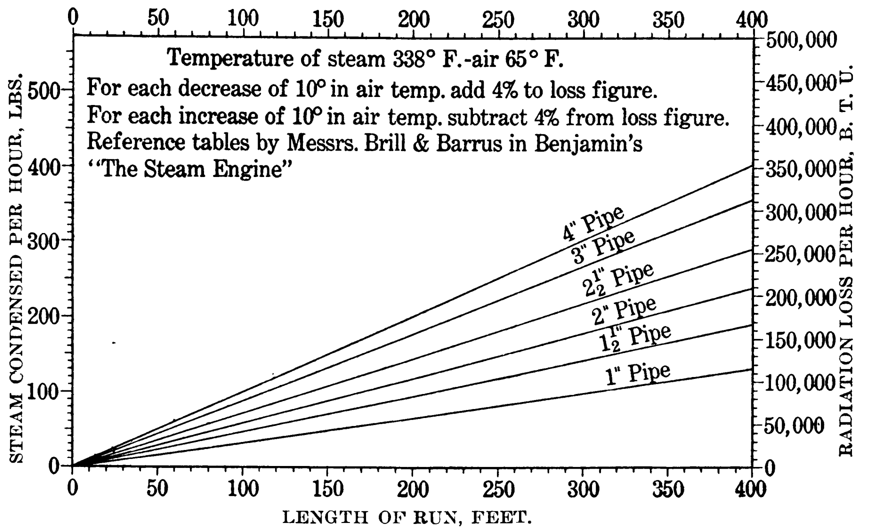


FIGURE 1.—Heat-loss chart for bare steam pipes.

in good repair saves 65 to 85 per cent of the condensation losses incident to uncovered steam lines.

Improper installation and maintenance are responsible for most of the complaints about modern steam-pipe covering. Loose sections of covering which admit air currents around the pipe, open joints caused by shrinkage, lack of insulation of irregular parts of a steam line, such as flanges and couplings, and failure to protect from moisture all decrease the efficiency of the covering. The sections of covering should be bound to the pipe with galvanized wire or netting over which is wrapped a coat of rosin paper, followed by 8-ounce canvas securely sewed on. At flanges the covering should be tapered back so that the bolts may be removed. Flanges or couplings should be insulated with asbestos or magnesia cement. Steam lines for all permanent power plants should be insulated.

LOCATION OF FEED-WATER PIPE AND CHECK VALVE.

The feed water should enter the boiler at the coldest part or at that part where the sediment will do the least harm, as mud or scale is most likely to be deposited where the feed water first reaches the temperature of the boiler. If the boiler has a mud drum, the feed water can enter there.

The feed for portable locomotive-type boilers should be through the shell and as far from the fire box and crown sheet as is convenient. Should the feed-water pipe be extended some distance into the boiler, as sometimes occurs, care must be taken to keep it clean, since with some feed waters the pipe will become filled with scale.

A straight-way valve or angle-globe valve should be placed in the feed-water pipe between the boiler and the check valve to permit repairs if the check valve gets out of order. Both valves should be as near the boiler as possible so that in winter the water lines may drain and not freeze when the boiler is shut down for the night.

METHODS FOR INTRODUCING FEED WATER TO THE BOILER.

Water may be forced into the boiler by a pump, or an injector, or fed in by gravity. Any pump, plunger or centrifugal, that can force water into the boiler can be used as a feed-water pump. Steam, electric, or air-driven pumps are used, some geared and others belt-driven. Belt-driven pumps are more economical of power than steam pumps. The cost of fuel and the size and type of plant influence the choice.

In many plants an injector would not be economical because the water fed by it must be cold, which would make impossible the use of a feed-water heater. If, however, the feed water is cold enough an injector is more economical than a pump because an injector returns to the boiler almost all of the heat in the steam used. An injector is cheaper than a steam pump of the same capacity, is durable and easy to repair, and it delivers to the boiler water that is hot when it enters, which increases efficiency and reduces the expansion and contraction stresses of the boiler.

When the source of water supply is higher than the top of the boiler, gravity feed can be readily used. The simplest device for gravity feed is a closed vessel, usually a steel tank, the bottom about 6 feet above the water line of the boiler, which at the top is connected to the boiler by the steam pipe and at the bottom by the feed pipe. A pipe connects the top of the closed vessel to the source of water supply. The vessel is nearly filled with water by gravity. Steam from the boiler is then admitted at the top, after the valve in the water supply pipe has been closed and the valve regulating the feed water has been opened. The water is subjected to the full boiler pressure and quickly flows into the boiler because of its hydrostatic head. Contact with the live steam will heat the water considerably. When the vessel has been drained, the valves in the steam and feed-water lines are closed, and that in the water-supply pipe is reopened. Automatic regulation of gravity feed is often used and works satisfactorily. Gravity feed is common in oil fields in the hilly parts of Pennsylvania and West Virginia.

Some small power plants use a boiler feed pump of simple design, attached to the steam engine and worked directly from the engine crosshead. This pump circulates water through a coil placed in the steam-engine exhaust pipe, and heats it before forcing it into the boiler.

BOILER FEED WATER AND ITS TREATMENT.

In many of the oil fields of California, Wyoming, Kansas, Oklahoma, Texas, and Illinois suitable boiler feed water is hard to obtain. Rain water is often collected in ponds and used instead of well water. A condensing system helps to conserve the supply of good boiler feed water. Certain waters should never be used for boiler feed, because no treatment can make them suitable. All of the scale-forming salts in the water forced into the boilers will ultimately be deposited, regardless of the rate at which steam is generated. However, a badly scaled boiler that would blister if operated at high rates might be safe at a lower rate, although its efficiency would be low.

Poor feed water may cause scale, foaming, priming, and corrosion. A Bureau of Mines publication[3] discusses boiler-water treatment and covers the nature and origin of scale-forming ingredients in boiler water, the effect of scale and methods of removing scale formers from water, and gives some examples of economies effected by softening boiler waters.

FUELS AND COMBUSTION.

EFFICIENCY OF DIFFERENT FUELS.

An average bituminous coal yields 13,500 B. t. u. to the pound, or 27,000,000 B. t. u. to the ton; 27,000,000 divided by 33.479 equals 806.5 b. hp. With a boiler efficiency of 65 per cent this would be 524.2 effective b. hp.

An average petroleum or fuel oil yields 19,500 B. t. u. to the pound. An oil of 16° B. weighs approximately 8 pounds to the gallon, or 336 pounds to the barrel of 42 gallons, and 1 barrel of this oil would produce 336 times 19,500 or 6,552,000 B. t. u.; 6,552,000

[3] United States Fuel Administration, Boiler water treatment: Tech. Paper 218, Bureau of Mines, 1919, 8 pp.

divided by 33.479 equals 195.6 b. hp. With a boiler efficiency of 65 per cent this would be 127.14 effective b. hp.

An average natural gas yields 22,200 B. t. u. to the pound. About 22.2 cubic feet of natural gas weighs 1 pound, and 1,000 cubic feet weighs about 45 pounds; therefore 1,000 cubic feet of natural gas will produce 45 times 22,200 or 999,000 B. t. u.; 999,000 divided by 33.479 equals 29.8 b. hp. With a boiler efficiency of 65 per cent this would be 19.4 effective b. hp.

From the data given above, 1 ton of average coal is evidently equivalent to 4.1 barrels of fuel oil or 27,000 feet of natural gas, and 1 barrel of fuel oil is equivalent to about 6,450 feet of natural gas. From the same data, coal fed into the boiler at $5 a ton, including all labor, is equivalent to oil delivered to the boiler at $1.22 a barrel, and gas delivered to the boiler at 18.5 cents a thousand feet.

Such comparisons, based solely upon the relative calorific values of coal, oil, and natural gas, do not consider the greater efficiency of oil as compared with coal, and of natural gas as compared with oil. When the fuel value of barrels of fuel oil is compared with that of tons of coal and feet of natural gas, the gravity of the oil should always be considered. Fuel oils produce practically the same B. t. u. per pound, irrespective of their gravities; but the weight per barrel varies with the gravity. For instance, a barrel of oil of 26° B. weighs 21.4 pounds less than one of 16° B.

One pound of average coal requires 11.6 pounds or 143 cubic feet of air for combustion; 1 pound of fuel oil requires 14.9 pounds or 185 cubic feet; 1 pound of natural gas requires 17 pounds or 211 cubic feet; and 1 cubic foot of natural gas requires 9.4 cubic feet.

CAUSES AND EFFECTS OF HEAT LOSSES.

Boiler efficiency is the ratio of the heat in the steam delivered by the boiler to the heat in the fuel. Furnace efficiency is the ratio of the heat delivered to the boiler to the heat in the fuel.

With all types of fuel heat is lost and furnace efficiency reduced by the burning of the carbon in the fuel to monoxide instead of dioxide, the escape of unburned hydrocarbons up the stack because of insufficient air supply or combustion space, and the admission of too much air which absorbs heat that would otherwise be absorbed by the water or steam in the boiler.

Heat losses due to inefficiency of boiler heating surface include those caused by boiler scale, which insulates the boiler tubes and plates, retards heat absorption by the water and steam, and thus makes the temperature of the flue gases too high; and losses due to radiation from the boiler shell. Oil-field boiler efficiency has been discussed by Bureau of Mines engineers.[4]

As the temperature of the furnace gases can not be reduced below the steam temperature of the boiler, much initial heat is unavoidably lost. Tests of different sizes and types of boilers with different kinds of fuel indicate a combined (or over-all) furnace and boiler efficiency ranging from 30 to 80 per cent, but averaging for larger power plants above 70 per cent. Tests[5] have shown that in oil-field practice the boiler efficiency of many locomotive and return tubular boilers with oil or gas fuel does not exceed 50 per cent; but with improved setting, properly regulated burners, and proper care of plant, these same boilers show an efficiency of 70 per cent.

Losses characteristic of the fuel itself are, with coal, due to unburned pieces dropping into the ashpit, and the slacking of coal in storage bins; with fuel oil, tank leakage; and with gas, leakage in gas lines.

Suitable burners are important for the efficient use of oil and gas as a fuel, as are the size and shape of the fire box. When coal is the fuel most of it burns slowly on the grates, and efficient combustion depends largely upon adequate grate area. When oil or gas is the fuel it burns quickly as a vapor or as a gas, and efficient combustion depends on adequate combustion space.

In respect to fuel economy, the boiler is the most important part of the power plant, and is responsible for the largest part of the operating expenses.

COAL AND WOOD AS FUELS.

Coal is not much used in the oil fields, except at some central power plants where it is cheaper than fuel oil or natural gas. Wood has been used for years in some of the older, heavily timbered, Pennsylvania oil fields, where the gas supply is depleted and wood can be obtained near by at the cost of cutting.

The grates for burning wood or coal in locomotive and return tubular boilers in the oil fields have cast-iron bars side by side in the fire box or furnace; the thickness of the lugs cast on the bars determines the width of the air spaces. For larger boiler plants, shaking grates have been designed to permit cleaning the fire without opening the door.

For central power stations burning coal, mechanical or automatic stokers have come into general use. In one of the common types the grate is a horizontal endless chain of short iron bars that moves over sprockets at each end. The coal is fed from a hopper in front of the

[4] Brewer, G. S., Youker, M. P., and Beecher, C. E., The use of low-pressure gas burners in oil-field boilers: The Mid-Continent Year Book, 1921, pp 77–121.

[5] Tourtellotte, W. B., Tests on oil field boilers. Union Oil Co., 1919, 40 pp.

boiler and travels into the furnace as the endless chain is moved by the sprockets. The clinkers and ash fall into the ash pit, through which the grate returns.

Combustion of coal and furnace design have been discussed in other publications of the Bureau of Mines[6] and will not be given further consideration here.

OIL AS FUEL.

Oil as boiler fuel is most used in gas-depleted oil fields producing heavy crude oil, or in gas-depleted oil fields near refineries that produce fuel oil as a by-product.

The evaporative effect per pound of most crude oils and fuel oils is about the same. Fuel oils generally range in gravity from 14° B. to 29° B., and their flash points are not less than 150° F. A fuel oil should be free from water and solid matter in suspension. The proper combustion of fuel oil depends on the characteristics of the oil, the type of burner used, the design of the furnace or fire box, and proper care.

COMBUSTION OF FUEL OIL.

Fuel oil is not burned as a vapor but as a heavy mist. Generally the type of burner that gives the greatest degree of atomization is the most efficient. In some burners the oil is atomized by forcing it through a small aperture under pressure; in others it is atomized by a stream of air or steam. Steam atomizers usually take about 3 per cent of the steam generated, and high-pressure steam usually is more satisfactory than low-pressure. With oil the amount of pressure differs with different types of burners from a few pounds to 60 or 70 pounds to the square inch. Low-pressure systems are generally used under standpipe pressure.

For proper combustion the air supply must be carefully regulated. Smoke, often caused by insufficient air or improper mixing, is prevented by admitting additional air through the bridge wall.

Dutch ovens are sometimes built in front of boiler furnaces, when fuel oil is used, to increase the volume of the combustion chamber and to preheat the air used for the combustion mixture. A company in the Casmalia field, California, claims a fuel saving of more than 20 per cent after the installation of Dutch ovens at the stills of their topping plant there.

[6] Flagg, S. B., Cook, G. C., and Woodman, F. E., Experiments with furnaces for a hand-fired return tubular boiler: Tech. Paper 34, Bureau of Mines, 1916, 32 pp. Clement, J. K., Frazer, J. C. W., and Augustine, C. E., Factors governing the combustion of coal in boiler furnaces, a preliminary report: Tech. Paper 63, Bureau of Mines, 1914, 46 pp. Kreisinger, Henry, Hand firing soft coal under power-plant boilers: Tech. Paper 80, Bureau of Mines, 1915, 83 pp. Saving coal in boiler plants: Tech. Paper 205, Bureau of Mines, 1918, 24 pp.

Some operators recommend preheating the fuel oil so that it will be atomized more readily.

The system for oil delivery to the burners should be properly installed and cared for. Leaks should be repaired at the first opportunity and oil should be kept from running on the floor by the use of trays under pumps and strainers. The furnace should be so constructed that the fuel is completely burned before it reaches the tubes.

OIL-FIRING INDICATOR.

The oil-firing indicator shown in Figure 2 has been developed as a reliable guide for the fireman in determining the proper amount of air required for the boiler furnace. It has been observed that there is a definite relation between the flue-gas analysis and the intensity of reflected light which is transmitted through the flue gas.

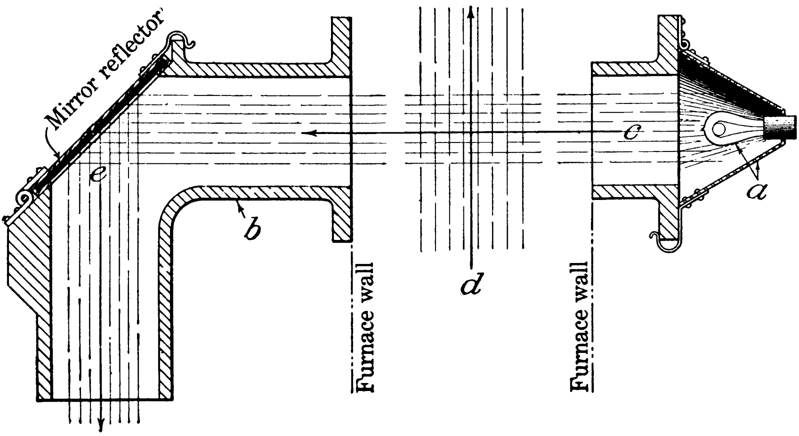


FIGURE 2.—Oil-firing indicator for determining the proper amount of air for combustion. For description, see text.

If the proper flue-gas analysis and the corresponding intensity of light reflected through it are known, the furnace efficiency can be maintained by keeping the light intensity at this point.

The device consists of an electric light and casing, *a*, and a mirror reflector and casing, *b*, each set directly opposite the other with a nipple extending through the side wall of the furnace at a point far enough from the fire box to be out of the path of the flame but in line with the path of the flue gas leaving the furnace. The course of the reflected light *c* intersects the course of the flue gas *d*. The light reflected from the mirror is indicated by *e*. The intensity of the reflected light is observed at the front of the boiler where regulation of draft to the desired intensity of light gives the proper mixture of air with the burning oil.

Many operators prefer this device to the CO_2 recorder or indicator, as any change in furnace conditions shows on this indicator instantly and can be corrected to proper adjustment by any fireman. When two or more boilers are operated on the same stack and the stack is seen to smoke, then, by observing the indicator of each boiler, the trouble is traced to its source.

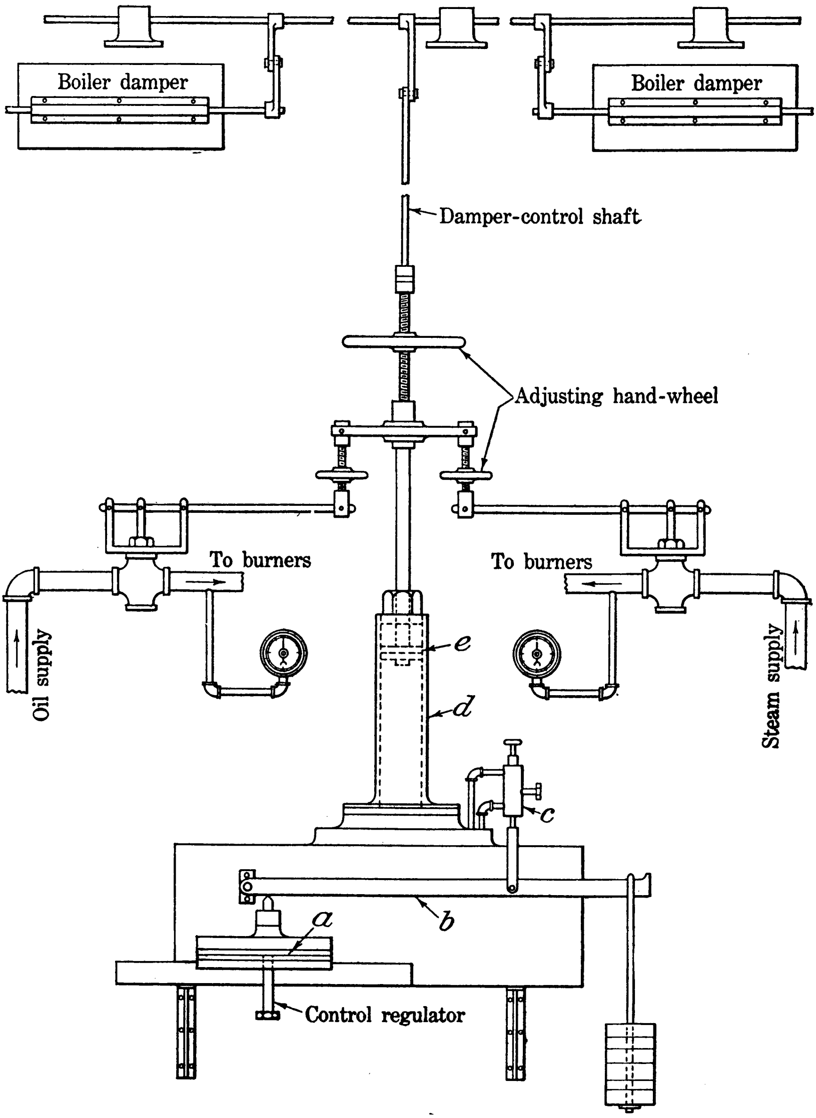


FIGURE 3.—Automatic oil-firing regulator and damper control. For description, see text.

AUTOMATIC OIL-FIRING REGULATOR AND DAMPER CONTROL.

The automatic oil-firing regulator and damper control shown in Figure 3 is an adaptation to local conditions of standard equipment for this particular service.

The regulator gives a positive relative movement to the oil and steam valves controlling the supply to the oil burners, and also controls the dampers or air supply. This device or similar devices are used at power plants in a number of oil fields where oil or gas is used as a fuel.

The steam pressure actuates the diaphragm *a*, which moves the weighted lever arm *b*, which transmits this movement to the pilot valve *c* which in turn admits water under pressure to the cylinder *d*. The admission of the water moves the plunger *e*, to which are attached the main oil valve, the main steam valve, and the boiler damper. In this way the movement of the plunger *e* controls the steam and oil supply to the burner, also the air draft. Any change in the steam pressure operates the regulator enough to supply the fuel and air needed to make the steam needed by the boiler.

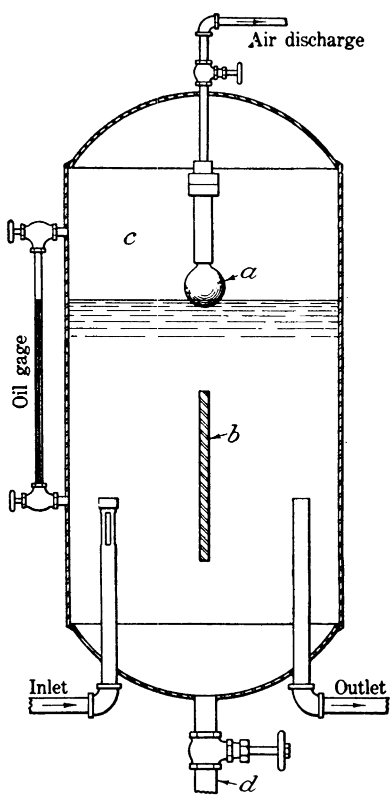


FIGURE 4.—Combined separator and compression chamber for fuel-oil burning system. For description, see text.

SEPARATOR AND COMPRESSION CHAMBER.

A combined separator and compression chamber for fuel-oil burning systems is shown in Figure 4. The chamber consists of a closed steel tank with inlet and outlet pipes; an automatic float valve, *a*, a baffle plate, *b*, air and gas space, *c*, and water and sediment blow-off, *d*. The purpose of this device is to aid in delivering oil free from gas, sediment, and water to the burners at a constant pressure.

Accumulated air and gas pressure in air space *c* for down the surface of the oil lowering the float valve *a*, opening the air-discharge pipe, releasing the pressure, and permitting the oil to return to its former level.

Various devices similar to this are used to feed oil engines.

NATURAL GAS AS FUEL.

Natural gas is an ideal fuel for boilers, as it has all of the advantages and none of the disadvantages of coal and oil. In practically all oil pools developed natural gas in varying amounts has been present. At first the fuel value of natural gas was not appreciated or understood. Coal or wood was hauled for fuel at many wells and the gas was allowed to waste. Even after gas came into general use as a fuel, no effort was made to conserve it for the future, probably because there was more than enough for all power needs, even with very wasteful use. This waste of natural gas continues in oil fields. Only rapid depletion has forced the operators to study conservation and economical use. In 1922 one of the larger oil companies of California found some of its 40-horsepower boilers consuming enough natural gas to produce 240 horsepower if burned with enough air in boilers of suitable size.

In many fields natural gas as associated with petroleum has never been marketed, but has been allowed to waste when the supply has been greater than that needed in the field. The supply has therefore been depleted. Among the chief operating problems to-day are the conservation of gas to meet field needs and the study of oil-field conditions to determine the best use of gas under steam boilers or in gas engines.

The efficient combustion of natural gas at boilers depends on the size of the fire box, which must be large enough to supply the volume needed for complete combustion of the mixture of air and gas, and to regulate the mixture of air and gas in the proper ratio to produce complete combustion without excess of air.

Some of the oil companies have built a brick subfurnace under the fire box in locomotive-type boilers to increase the space for the burning gases, and have regulated the air supply by closing all openings to the fire box except at the point of regulation. In most locomotive-type boilers the mud ring extends well into the fire box so that the subfurnace can not be of greater sectional area than the mud-ring opening.

Plate IV shows a type of subfurnace of a company in the Kansas and Oklahoma oil fields.

GAS BURNERS.

Gas burners are usually classified as high-pressure and low-pressure burners. The latter type has been investigated and described by engineers[7] of the Bureau of Mines. Burners with a pressure below 6 pounds to the square inch are classed as low-pressure burners. Steam or compressed air is often used to force the proper mixture of the air with the gas when some deficiency of plant construction, equipment, or operation causes insufficient draft, boiler, or burner capacity, or gas supply.

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[7] Brewer, G. S., Youker, M. P., and Beecher, C. E., The use of low-pressure gas burners in oil-field boilers. The Mid-Continent Year Book, 1921, pp. 77–121.

With enough gas and proper plant design, the failure of natural-gas burners can usually be traced to leaks, pipes too small and with too many bends, gas pipes clogged by dirt or corrosion, burner improperly installed or operated, burner too small for the work required, and burner poorly designed or unsuitable for the pressure used. The most common defect is deficient mixing of the air and gas; that is, not enough air to complete combustion, or excess air that passes through the boiler without combustion.

Many engineers claim higher efficiencies with combustion of high pressure gas than with low pressure gas. The use of high-pressure gas burners has been discussed by J. S. S. Brame.[8]

STEAM ENGINES.

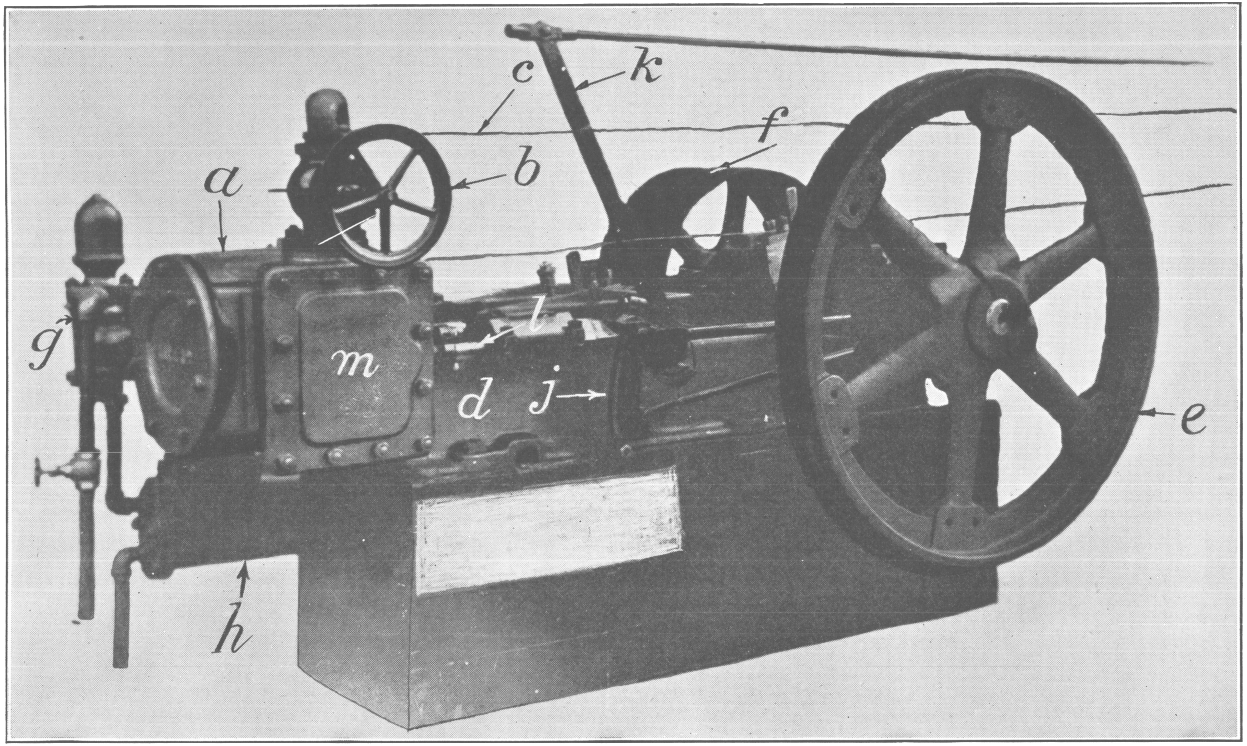
Steam engines and boilers were the only source of mechanical power in oil fields for many years. The horizontal single-cylinder slide-valve steam engine is still the chief source of power for drilling oil wells. For this purpose it is made in sizes from a cylinder with a 9-inch diameter and a 12-inch stroke and a rating of 15 horsepower to a 16 by 16 inch cylinder with a rating of 70 horsepower. It is noncondensing, of simple design, and strongly built for the severe service of the oil fields. Formerly the steam engine used in drilling on the "block" was also used to pump the completed well. Many such engines are found in the oil fields, frequently at some well where they are used for "pulling" or cleaning long after another method of pumping has been adopted.

Vertical slide-valve engines are often seen in the oil fields mounted as part of a portable steam drilling-machine. Several of the oil-well supply companies manufacture double-cylinder slide-valve engines for the European oil fields.

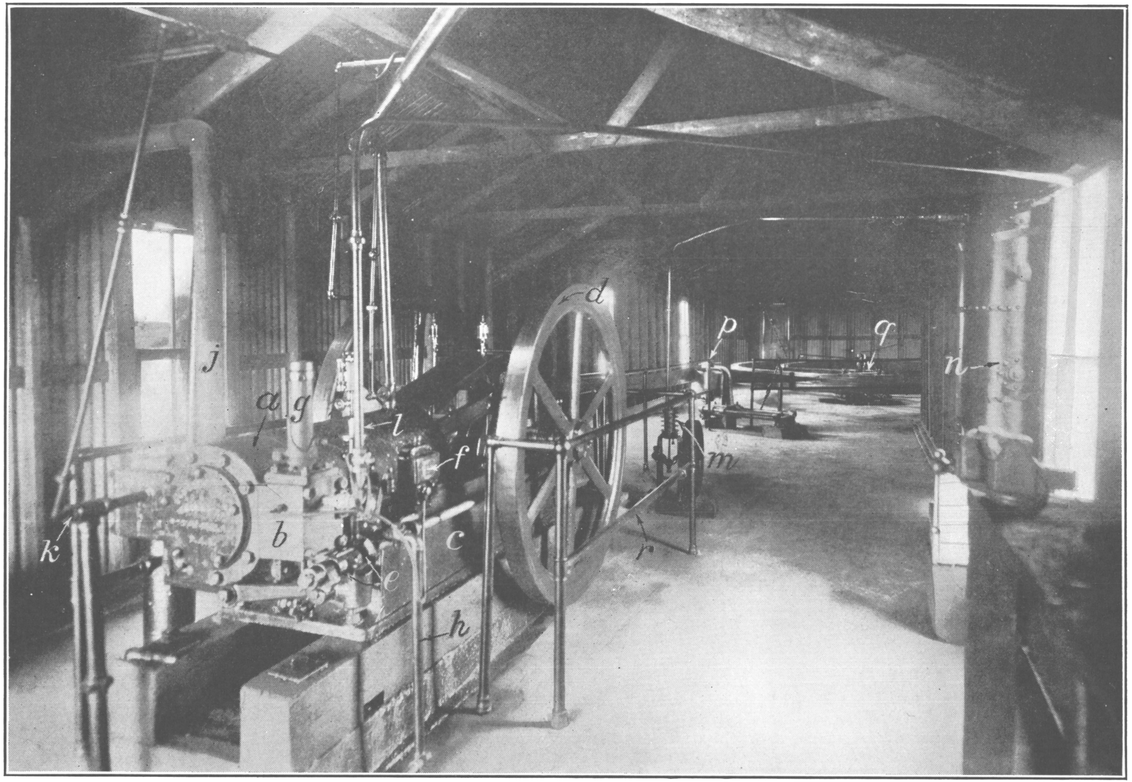
Steam engines are also classified as single expansion and multiple expansion. In the former the steam expands and does all of its work in one cylinder as in the oil-field drilling engine. The multiple-cylinder type is classified as a compound engine when there is both a high-pressure and a low-pressure cylinder, the engine doing part of its work by a partial expansion of the steam in the smaller high-pressure cylinder and completing the expansion and work in the larger low-pressure cylinder.

Steam engines are further classified as slide valve, Corliss valve, piston valve, and poppet valve. The slide valve is the simplest type of valve and uses the most steam with the lowest efficiency. It is generally suited for small or medium size engines for high speeds. The Corliss valve has long been used in large steam engines, such as those at central power plants, but it is not well suited to small, high-

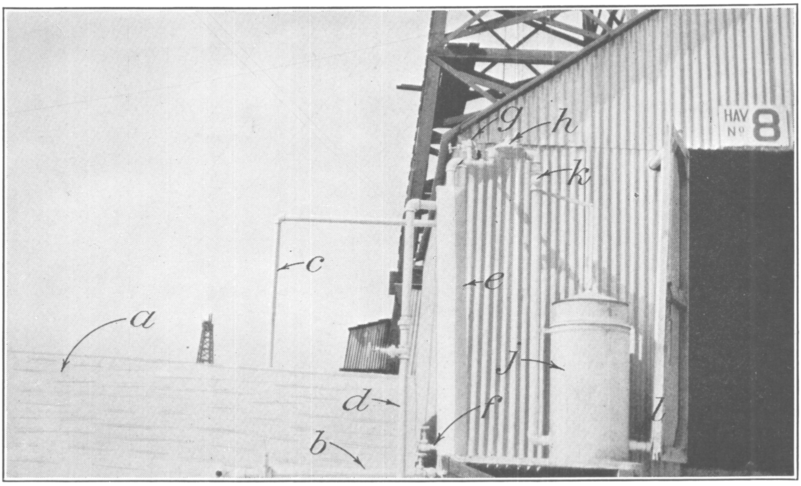
[8] Brame, J. S. S., Fuel, solid, liquid, and gaseous. London, 1917, 372 pp.



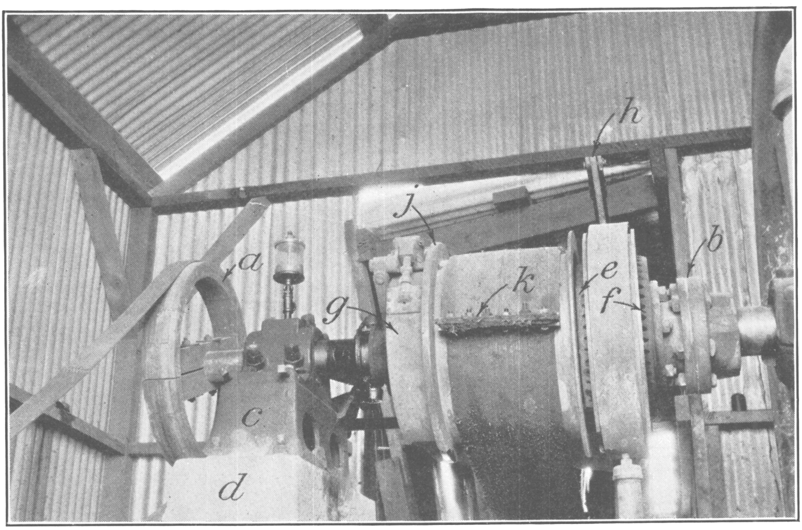
TYPICAL SLIDE-VALVE STEAM ENGINE USED FOR DRILLING, PULLING, AND PUMPING OIL WELLS. FOR EXPLANATION OF LETTERING, SEE TEXT



TYPICAL OIL-FIELD GAS ENGINE DRIVING A BAND-WHEEL POWER. FOR EXPLANATION OF LETTERING, SEE TEXT



A. WATER-CIRCULATING TANK AND GAS REGULATOR FOR GAS ENGINE: *a*, CONCRETE WATER-CIRCULATING TANK; *b*, INTAKE PIPE TO WATER JACKET; *c*, DISCHARGE PIPE FROM WATER JACKET; *d*, FEEDER FROM GAS MAIN; *e*, VERTICAL SECTION OF CASING; *f*, DRAIN COCK; *g*, PIPE AND VALVE; *h*, DRYOMETER; *j*, FLUID-SEALED GASOMETER; *k*, CONNECTION TO THROTTLE; *l*, GAS PIPE LEADING TO ENGINE



B. REVERSING GEAR FOR GAS ENGINE AT WELL PUMPING ON THE BEAM: *a*, PULLEY; *b*, EXTENSION OF ENGINE SHAFT; *c*, OUTBOARD BEARING; *d*, CONCRETE PIER; *e* AND *f*, GEARS; *g*, CLUTCH; *h*, OPERATING LEVER; *j*, FLANGE; *k*, CLAMP

speed engines. The piston valve and the poppet, or drop, valve are suitable for engines with high pressure and superheated steam. However, the piston valve is not so economical of steam as is the Corliss valve.

The slide-valve engine is now made only for drilling. It is used for pumping only in emergencies.

Although the electric motor has replaced the steam engine in some oil fields for drilling, steam is generally more common, because of flexibility of speed and efficiency under overloads.

For pumping, however, and for general power service, the gas engine, the oil engine, or the electric motor have largely replaced the steam engine.

Plate V shows a typical slide-valve steam engine, as used in the oil fields for drilling and pumping: *a*, Steam cylinder; *b*, throttle valve operated by wire cord, *c*, from derrick, when drilling or pulling rods or tubing; *d*, engine bed; *e*, split-hub flywheel; *f*, pulley; *g*, water pump for supplying water to boilers; *h*, boiler-water heater; *j*, engine link; *k*, reverse lever; *l*, valve rod and slide; and *m*, steam chest.

GAS ENGINES.

About 25 years ago, the gas supply became so depleted in the eastern United States that a gas engine cylinder was made to replace the steam cylinder on the oil-field drilling and pumping engine. One manufacturer, B. D. Tillinghast, of McDonald, Pa., developed a convertible gas and steam cylinder. An engine equipped with this cylinder is used as a gas engine for pumping oil wells, and as a steam engine for pulling rods and tubing and cleaning out wells.

Manufacturers used oil-field steam engine dimensions in designing these gas engine and convertible gas and steam cylinders, so they can supply a gas cylinder or convertible steam and gas cylinder with the necessary instructions for installation on the steam engine bed for any size and make of steam engine. Many of these old steam engines, converted to gas engines or engines which can use either gas or steam, have been in use for years in the older oil fields of the eastern United States.

From this beginning the single-cylinder, horizontal gas engine, in sizes from 10 to 60 horsepower, has become the universal prime mover for pumping oil wells. The 20-horsepower to 35-horsepower sizes are the most common.

Most of the gas engines of more than 60 to 75 horsepower are multiple cylinder and many are vertical; they are used at central power stations and at casing-head gasoline plants.

Engines, either horizontal or vertical, of less than 10-horsepower rating are used to drive small pumps and to pump shallow wells. Some vertical types are air cooled and are particularly suited for small wells, where power is needed only a few hours a day. As they are air cooled and the cylinder need not be drained in cold weather, they need little attention.

Gas engines are of two general classes, the two cycle and the four cycle. In the former, every revolution of the crank shaft pushes the piston; in the latter, every two revolutions push the piston. Both types are widely used, but the latter is the more common.

TWO CYCLE.

The two-cycle engine has fewer moving parts such as valves and valve control mechanism, a lighter fly wheel, a more uniform rate of revolution, a smaller cylinder, and lighter engine to the unit or power than the four-cycle engine, and simplicity and compactness of design.

FOUR CYCLE.

The four-cycle engine has higher efficiency, can be regulated easier under conditions of varying load, and compression does not depend upon tightness of any parts except valves and piston rings. The four-cycle engine is generally provided with a heavier flywheel in order to bridge the gap between explosions and afford smooth running.

Plate VI shows a typical oil-field gas-engine installation used for driving a pumping power. The principal engine parts clearly shown are: *a*, Engine cylinder; *b*, inlet chamber; *c*, engine bed; *d*, flywheel; *e*, valve and governor mechanism; *f*, Wico magneto; *g*, hot tube igniter; *h*, gas-supply pipe; *j*, engine-exhaust pipe; *k*, circulating water pipe; *l*, compressed-air pipe. Other accessories shown as a part of the installation are: *m*, Compressor used to start engine; *n*, air received; *p*, idler; *q*, power wheel with eccentrics to pump wells; and *r*, guard rail at engine. Plate VI shows the engine bolted to timbers which in turn are bolted to the concrete foundation.

GOVERNING ENGINE SPEED.

The common horizontal gas engine for pumping wells is generally designed for speeds of 180 to 250 r. p. m. Racing or cutting out the governor with a by-pass controlled from the derrick gives much higher speeds for swabbing the well, where this is done. Two general types of governors are used, the hit-and-miss and the throttling control types.

The former holds the speed of the engine constant by the missing of certain explosions on the power stroke when running on light load. As the load increases the number of explosions increases until the engine fires regularly. As the load decreases the engine tends to increase in speed, and the governor prevents one or more explosions by holding the exhaust valve open and the inlet valve closed. This is done by means of cams or eccentrics which are geared to the crank shaft and in turn control the inlet and exhaust valves by rod connections.

The throttle-control governor is designed to give an impulse to the piston regularly, that is, regular firing on every cycle or two cycles, the speed being held constant by regulating the quantity of explosive mixture admitted to the cylinder or by varying the richness of the mixture. This type of governor acts directly on the throttle valve. The governor proper is actuated by the centrifugal force of a flywheel or flyball, and at no time is the connecting mechanism disengaged from the driving cam. (See Plate VI at *e*.)

Two-cycle engines always have throttle-control governors because the design usually precludes control of the ports as in the hit-and-miss system.

METHODS OF IGNITION.

A minute part of the mixture of gas and air in the engine cylinder must be raised to the ignition temperature in order to produce an explosion and work the piston. The higher the initial temperature of this air and gas mixture, the less heat is required from the ignition system. The initial temperature will be largely determined by the heat of the cylinder and the degree of compression. The charge of air and gas in the cylinder is ignited by hot-tube ignition or electrical ignition.

HOT-TUBE IGNITION.

Hot-tube ignition is based upon the principle that a combustible gas mixed with the proper amount of air may be ignited by bringing it in contact with a surface heated above the ignition point. The hot tube consists of a small metal tube closed at one end and attached to the cylinder by the open end so as to communicate with the charge in the cylinder. An asbestos-lined chimney is placed around the tube. A gas burner in the space between the tube and the chimney keeps the upper part of the tube at a temperature above the ignition point.

Each compression forces the mixture of air and gas further and further into the tube until at the highest point of compression it reaches the part of the tube heated to the ignition temperature, and explosion results. The length of the tube required varies with different conditions. The point of maximum heat in the tube should be so located that the explosion takes place at the highest compression. Lowering the point of maximum heat advances the ignition.

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Hot-tube ignition is not advisable in oil fields producing large quantities of natural gas, as disastrous explosions may result.

ELECTRIC IGNITION.

Ignition by electric spark is most satisfactory, as it makes prompt starting and accurate timing possible. The low tension, or "make and break," and the high tension, or jump spark, are the two types of electrical ignition. As a source of current the magneto is generally used; however, the primary battery and the storage battery are other sources.

In the make-and-break system spark is made by the intermittent separation of the terminals of a circuit through which a low-voltage current is flowing. To increase the spark intensity, an induction coil is usually placed in the circuit. The terminals or contact points are extended into the clearance space of the engine cylinder. In a common type, one of the terminals is mounted on a movable shaft to the outer end of which is attached a coil spring and arm. This arm at regular intervals engages with a push rod actuated by a cam that connects with the engine shaft. Where the arm slips off the edge of the push rod, the coil spring instantly separates the terminals, thus producing a spark in the cylinder.

In the jump-spark system the voltage of the current is increased enough to break down the resistance of the spark gap and to jump from one terminal to the other. The ordinary spark plug supplies the terminals.

Of the many types of high-tension magnetos the Wico high-tension igniter is most generally used with gas engines in the oil fields. It differs from others in that the intensity of the spark is independent of the engine speed and the motion is reciprocating instead of rotary. The design is simple, requiring no adjustment; it is without condensers, contact points, or primary windings. The current is generated by the reciprocating movement of the two soft-iron armatures that in their movement pass through the center of the electric fields. The upward movement of the armatures is produced by the movement of the engine, but the downward movement which produces the spark is caused by the action of a spring. Plate VI at *f* shows a Wico magneto.

The installation of the jump-spark system costs more than the make-and-break system, which in turn costs more than the hot tube.

LUBRICATING SYSTEMS.

The three principal systems of lubrication are: Sight, splash, and force feed.

The sight-feed system makes use of drip oil cups. Oil cups should be cleaned frequently with gasoline or kerosene to remove gum or lint which might interfere with proper lubrication. Winter temperatures affect the feed of oil cups. If the engine room is not warmed in cold weather, lighter lubricating oils should be used, or about 10 per cent of kerosene added to the heavier oil used for lubrication.

The splash-feed system lubricates the bearings, piston, and cylinder by means of the oil spray caused by the end of the connecting rod splashing through an oil puddle in the bottom of the closed crank case. By this system constant and uniform lubrication is maintained as the oil in the crank case is kept up to the overflow point. A low-pressure circulating pump forces the oil into the bottom of the closed crank case. By means of the overflow opening the oil returns to the pump. Usually a wire-gauze strainer in the suction pipe of the circulating pump keeps out dirt and carbon which would otherwise interfere. This gauze should be removed frequently and cleaned. Dirt, chips, and grit accumulating in the crank case increase the wear on the bearings. All of the oil should be removed from time to time and clean oil substituted.

One objection to the splash-feed system is the leakage of oil through the crank case. Clogging of the overflow pipe will cause an excess of oil in the crank case and light colored smoke at the exhaust.

The force-feed system is the most reliable. A small pump driven from the engine by a belt draws oil from a reservoir and forces it through copper tubes or leads to the various bearings. In many types of this system, each of the leads is provided with a regulating valve and sight feed, by which the amount of oil delivered by each is known and regulated. With this system the gauze oil-strainer must be kept clean, so that the pump can always supply the necessary oil. The oil piping should be cleaned at least once a year with gasoline and a piece of wire to remove sediment which may have accumulated. The driving belt for the oil pump should be kept tight and in good repair so that oil circulation is always assured.

In oil-field practice the greatest need for proper lubrication is found in the inner clutch bearing and the three crank-shaft bearings. The inner bearing of the clutch should first be filled with hard oil when the engine is first set up and should thereafter be filled from time to time. Bearings equipped with soft oil cups show a greater waste of oil than with hard oil cups, as with the former the thin oil runs out between the shaft and the bearings.

Hot bearings often indicate lack of lubricating oil. This trouble should be located and remedied at once.

Oil leaks, stoppage of oil pump, obstructions or holes in oil leads, or too high viscosity of oil are common causes of hot bearings. An engine should not be run for any length of time with a hot bearing as the bearing may seize tight on the shaft and wreck the engine.

COOLING SYSTEMS.

The object of a cooling system on internal-combustion engines is to keep the cylinder walls cool enough to prevent vaporization of the lubricating oil and thus insure good lubrication of the cylinder and piston. Vaporization of the oil through overheating of the cylinder will cause rapid wear of the piston rings and cylinder.

Gas engine cylinders are either air cooled or water cooled. The common type of small gas engine, which is air cooled, has a small fan mounted on one side of the cylinder and driven by a belt from the flywheel. The fan keeps the engine cool, provided that the belt used for driving the fan is kept tight and in good repair. By this system there is little danger of decreasing the efficiency of the engine by keeping the cylinder too cool, as sometimes happens when the cylinder is cooled with cold water.

Some small gas engines are water cooled, without the use of water-circulating tanks, by means of a hopper extension of the water jacket which is open to the air. The evaporation of the circulating water keeps the engine cool. As the hopper is open to the air, the temperature of the cylinder can not exceed 212° F., the boiling point of water, provided the hopper is kept filled with water.

The standard practice with most types of gas engines is to inclose the cylinder within a covered water jacket through which water is kept circulating. Rapid circulation of cold water greatly reduces efficiency of the gas engine by the chilling of the expanding gases in the cylinder. To insure the best results, from 4 to 6 gallons per horsepower should pass through the jacket each hour. The water leaving the jacket should not have a temperature in excess of 160° F., for if it contains an appreciable amount of mineral matter, which frequently happens, higher temperatures cause rapid deposition of mineral within the water jacket.

In oil fields with ample water supply and suitable topography, the water is frequently piped by gravity from reservoirs or springs to the water jacket, without any provision made for return. The objection to this system is chilling of the cylinder, due to the too rapid circulation of the water, if the water is cold. To flow water from a tank through the water jacket by means of connecting pipes is standard practice. The water enters the water jacket by means of a pipe connecting the bottom of the tank with the bottom of the water jacket. The water is returned to the tank by means of a pipe connecting the top of the water jacket with the surface of the water in the tank. The water-circulating pipes should be as free from bends as possible, and the top or return water pipe should be larger than the bottom or inlet pipe.

WATER CIRCULATION.

The methods of water circulation are the thermosiphon system, the gas or air pressure system, and the pump circulating system.

The thermosiphon system is based upon the fact that as the water in the jacket becomes heated it expands and rises and starts to flow through the discharge pipe to the tank, being replaced by the colder water from the bottom of the tank. With this system, to obtain the best results the tank should be installed so that its bottom is a little above the bottom of the water jacket, and the lower or intake pipe, carrying water from the tank to the water jacket of the engine, should slope toward the water jacket. The discharge pipe from the water jacket should also slope toward the water jacket, and should enter and discharge in the water tank several inches below the surface of the water.

Water circulation is maintained by introducing gas or compressed air into the discharge pipe from the water jacket, so that an impulse is given to the water in the direction of the tank.

The pump circulating system is usually driven by means of a small centrifugal pump from a pulley on the engine shaft. Plate VII, *A* and *B* (p. 22), shows an installation of this type. Plate VII, *A*, shows concrete water-circulating tank at *a*, intake pipe to water jacket *b*, and discharge pipe from water jacket at *c*. Plate VII, *B*, at *a* shows the pulley used to drive the centrifugal pump to circulate the water.

In many oil fields where water conditions are bad, concrete water-circulating tanks have replaced wooden and steel tanks. Bad water rusts the hoops on the wooden tanks rapidly, and steel tanks soon leak and must be replaced after a year or two of service.

Some operators using wooden tanks have replaced the ordinary steel hoop by sucker rods with turnbuckles, which usually prevents hoop trouble.

A standard type of concrete water-circulating tank, used by some companies in the California oil fields, is 9 feet square and 3 feet deep, with reinforced walls and bottom 3 to 4 inches thick.

TROUBLES WITH WATER-COOLING SYSTEMS.

The deposition of scale or lime on the walls of the water jacket causes heating of the engine cylinder, because it insulates the cylinder and prevents the circulating water from absorbing heat. This deposit of scale also obstructs the pipes and water passages and prevents proper circulation. If the water circulation is partly or entirely obstructed, the engine should be stopped and the scale removed from the jacket.

The scale can be softened by draining about half the water out of the jacket, and pouring in a gallon of kerosene oil. The inlet and outlet pipes are then plugged and the engine is started and run for 15 or 20 minutes with the mixture of oil and water in the cylinder. The engine is then stopped and allowed to cool. The scale becomes soft like mud and can readily be removed. A mixture of 1 part of sulphuric acid and 10 parts of water allowed to stand in the engine jacket for 10 or 12 hours will give the same result.

Some oil-field operators have an ingenious system for stopping the gas engine when water circulation is deficient, if the magneto is used for ignition and a pump is used for water circulation. A pail with a hole in the bottom is suspended under the end of the water discharge pipe at the water tank. The rope supporting the pail passes over a small pulley attached above the tank, into the engine house, and over another pulley fastened directly above the spark plug of the engine, terminating in a steel counterweight connected by a wire to the engine piping. When enough water circulates, the discharge water running into the suspended pail at the circulating-water tank holds the counterweight away from the spark plug. But when the circulation becomes deficient or ceases, the water runs out of the pail and the counterweight drops on the spark plug, shorts the ignition, and stops the engine. This arrangement is especially convenient when the man in charge must spend much of his time at other wells.

Other troubles in the water-circulating system are caused by the swelling of packing at unions in the water pipe, which obstructs the flow of water; breaking of the belt driving the centrifugal pump; stripping or wearing of the impeller blades in the pump; and cracking of the water jacket in winter because of failure to drain the jacket when the engine is shut down. All of these troubles can be eliminated by proper care and attention.

ENGINE CLUTCH.

If the gas engine is used for pulling rods and tubing, a reversible clutch is needed; otherwise an ordinary clutch suffices. The reversing clutch enables the operator to reverse the motion of the belt without stopping the engine. Plate VII, *B*, shows a common type of reversing gear.

The clutch is mounted on an extension of the engine shaft at *b* by means of a flange coupling, the outer end being supported and held in alignment by an adjustable outboard bearing, *c*, firmly mounted upon a concrete pier, *d*. The reversing mechanism consists of a system of gears partly shown at *e* and *f*, a contracting band clutch, *g*, controlled by an operating lever, *h*, manipulated from the derrick floor. This lever has three positions, neutral or stationary in the middle, rotating with the engine in the forward position, and rotating counter to the engine with the rear position. When rotating with the engine all parts are locked together and the action is the same as with the ordinary clutch. When rotating counter to the engine the gears come into play. A deep flange, *j*, on the clutch side of the pulley prevents the belt from coming in contact with the clutch.

The oiling system must be kept at the highest efficiency to obtain the best results with the reversing gear, as lack of oil will soon cut out the gears.

GAS SUPPLY SYSTEM.

Gas must be delivered to a gas engine at constant pressure, therefore the gas lines should be free from leaks and the pressure should be regulated at the engine. Most of the leaks in gas lines are due to lack of care during installation. Pressure is regulated at the engine either by a cast-iron dryometer or regulator, or by a fluid-sealed gasometer. Some installations with high line pressure use both at each engine.

Plate VII, *A*, shows such an installation in the Elk Hills oil fields, California. As shown in this plate, *d* is the feeder from the gas main, *e* is a vertical section of casing with a drain cock, *f*, used as a chamber for drawing off water that may be entrained in the gas, *g* is a pipe and valve used for supplying line gas pressure to the engine in starting, *h* is a dryometer or regulator, *j* is a fluid-sealed gasometer which by means of a connection to the throttle at *k* controls the gas supply, and *l* is the gas pipe leading to the engine.

The dryometer *h* is used to reduce line pressure so that the fluid-sealed gasometer *j* can be worked. For ordinary gas pressures either a dryometer or a fluid-sealed gasometer can be used to insure a uniform gas pressure at the engine. Some manufacturers of gas engines use the dryometer entirely for gas regulation; others specify no special regulator.

INSTALLATION AND OPERATION OF GAS ENGINES.

The gas engine is often installed by one department, operated by another, and repaired chiefly by still another, so that the blame for engine trouble is often difficult to place. The installation should be standard, it should be regularly inspected, and all parts repaired or renewed should be fitted in the shop before assembling. The engine should be firmly mounted on a concrete block and properly aligned with the band wheel or countershaft pulley. Improper alignment will always cause belt trouble. Poor alignment of the crank shaft and clutch is indirectly responsible for much bearing trouble. There must be no leaks in the water and gas lines. Suitable gaskets should be properly placed in the engine, and any compression leaks corrected. Knocks in the crank shaft or piston should be corrected as they prevent good lubrication and vibrations from them will eventually cause a breakdown. The caps must be kept down on the shaft bearings, or the bearings will pound out before they wear out. The flywheel should be firmly keyed or bolted to the shaft to prevent play. As a matter of safety to the workmen the key should never extend beyond the end of the shaft. The gas-supply pipe should be large enough to meet the needs of the engine. The proper size can be determined as follows: Multiply the horsepower rating by 0.03 and add 0.75; this gives the minimum diameter in inches. The exhaust pipe should be as straight and free from bends as possible, and its diameter should be between one-third and one-quarter of the cylinder diameter.

One of the largest operating companies supplied the following data on gas engine operation and maintenance, based upon the use of a 30-horsepower engine.

We estimate that the life of an oil-well engine is 15 years and its gas consumption 10,000 to 12,000 cubic feet per 24 hours.

Our gas-engine crew consists of one foreman and two helpers. They take care of 37 engines operating continuously at wells pumping "on the beam," repair engines operating central powers or jack plants when necessary to work on these wells, look after the countershafts at motor installations, and make practically all belt repairs and replacements.

The average annual maintenance cost of the gas engines operated by this oil company, exclusive of interest, taxes, and depreciation, is shown in Table 1.

TABLE 1.—*Engine maintenance exclusive of interest, taxes, and depreciation.*

(Cost per year, engine operating continuously.)

Materials:	
1 set clutch bushings, renewed once a year	$60.30
1 exhaust valve	2.25
1 exhaust clutch, renewed every 5 years at $42.30	8.46
1 set clutch shoe blocks a year	13.68
Reboring cylinder, every 5 years at $20	4.00
Water pump, 32 feet 3 inches, 3-ply rubber belt at $0.20	6.40
1 set magneto tension springs a year	.50
Miscellaneous bearing metal, wiring, spark plugs, etc	10.00
	105.59

Labor:

Yearly cleaning and overhauling, 9 men days at $7.30, average	$65.70
Repairing and overhauling clutch (yearly), 2 men days at $7.30	14.60
Overhauling water pump, magneto and lubrication, cleaning and adjusting, 2-men days at $7.30	14.60
Reboring, 5-year interval, 4-men days at $9, first machine at $36	7.20
	102.10

Lubricating Oil:

96 gallons Zerolene per year at $0.40	38.40
60 gallons Red. Eng. per year at $0.24	14.40
	52.80

Figure 5 is a form of report used by the foreman of the gas engine repair crew of one of the Mid-Continent oil companies. He fills it out after repairs are made at each of the gas engines used for pumping oil wells. The gas engines are inspected at regular intervals as well as when a breakdown gives trouble. The reports, filed in the office, are a reliable record of the operation of each engine as well as of the relative merits of different methods of water circulation, ignition, and lubrication.

ENGINE______ COMPANY NO.______ DATE____________ DISTRICT____________
LEASE______________ WELL______________ SEC______________
KIND OF UNIT____________________________
COUNTERBALANCE____
GASOMETER AND REGULATOR__________ GAS LEAKS________________________
WATER CIRCULATION____
ENGINE HOUSE______________________ FOUNDATIONS_____________________
ALIGNMENT:
FLY WHEEL ____
CRANKSHAFT AND CLUTCH____
KNOCKS:
PISTON__________________________ CROSSHEAD_______________________
CRANKSHAFT____
CLUTCH____
BEARINGS:
CLUTCH BEARING AND STAND_______________________________________
INNER BEARING ____
OUTER BEARING ____
LUBRICATION:
OIL CUPS________________________ HARD-OIL CUPS___________________
LUBRICATORS, SIZE AND KIND_____________________________________
IGNITION:
MAGNETO____
WICO ____
HOT TUBE____
CARBURETION:
AIR REGULATOR ____
GOVERNOR: MECHANISM____
VALVE GEAR ____
GAS LEAKS ____
WASTED OIL____
REMARKS____

FIGURE 5.—Form of report of foreman of gas engine repair crew.

OIL ENGINES.

Oil engines are used widely in fields whose gas supply has failed and where cheap electric power is not available. As prime movers for pumping they are generally of the horizontal one-cylinder, two-cycle explosive type, 10 to 60 horsepower, and use crude oil. Sand and water in suspension in the oil are removed as completely as possible by heating and filtering before the oil enters the engine. Even after treatment, some crude oil contains enough sand to cut out the cylinder. One company in southern Illinois rebores the cylinders of oil engines about every six months. This same difficulty from sand in the crude oil has been encountered in some of the Kansas oil fields. However, at other places the crude oil used seems to give no trouble in oil engines, as in some of the Texas and Oklahoma oil fields.

The oil engine is fully described in a Bureau of Mines bulletin.[9] An abstract of that part of the first 18 pages, with particular reference to the explosive two-stroke cycle type, which is most commonly seen in use in the oil fields, is quoted herewith:

GENERAL CHARACTERISTICS AND TYPES OF OIL ENGINES.

The term oil engine, as generally used at the present time, is applied to internal-combustion engines that burn directly in the cylinder heavy liquid fuels of high boiling points, the fuel being injected into the compressed air shortly before or at the completion of the compression stroke. The distinguishing features of oil engines are that the fuel vapor is not absorbed by air before it is admitted to the cylinder, and that no inflammable mixture of vapor and air is compressed preceding its ignition. Oil engines compress air alone, and the heat of compression is used to ignite the fuel, which burns by consuming the oxygen of the air in the cylinder, the engine transforming the heat energy into work.

To facilitate and accelerate the burning of a liquid fuel it must either be vaporized, atomized, or intimately mixed with air immediately preceding its ignition.

Light, highly volatile liquid fuels, such as benzols, gasolines, alcohol, and distillates, offer no particular difficulties to vaporization; the air in its passage to the engine cylinder readily absorbs the fuel vapors and forms a combustible mixture, which is ignited electrically in the cylinder.

The process of charging the air with fuel vapors is called carburetion. The more volatile fuels, like gasoline, can be carbureted at ordinary atmospheric temperatures—that is, without previous heating of the air or the fuel. Liquid fuels with higher boiling points may require heating of the air or the fuel, or both, to bring about their evaporation and absorption by the air preceding combustion. In the heavy-oil engine the vaporizing of the fuel takes place inside of the engine. As a fuel with a high boiling point can not be evaporated at moderate temperatures, thorough mechanical division preceding ignition and combustion is necessary.

[9] Haas, Herbert, The Diesel engine; its fuels and its uses: Bull. 156, Bureau of Mines, 1918, 133 pp.

THREE GENERAL TYPES OF LIQUID-FUEL ENGINES.

According to the means used for atomizing the liquid fuels and igniting them, there are two mechanically and thermodynamically distinct types of engines. In one type the entire fuel charge is sprayed against a highly heated surface in a chamber connected with the working cylinder. Contact with this highly heated surface gasifies the fuel, which is ignited and burns with explosion-like rapidity. Engines of this type are properly termed "explosion oil engines," or engines in which the fuel is burned at constant volume.

In engines of the other type the fuel to be converted is finely subdivided by air, and in this act of atomization is injected directly into the engine cylinder, where it is ignited automatically by the highly heated air in the cylinder. The combustion is not explosion like, but is prolonged as constant pressure for the entire period during which the fuel is injected into the cylinder. This type of engine is universally known as the Diesel engine, being named after the late Rudolph Diesel, of Munich, Germany, its inventor. It is also termed a "constant-pressure oil engine."

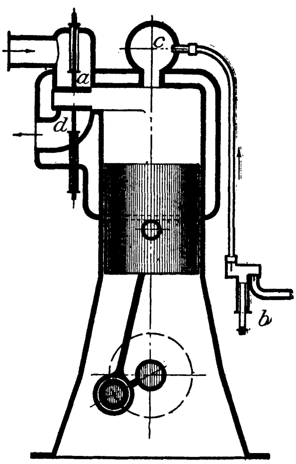


FIGURE 6.—Explosion oil engine, four-stroke cycle.

There is a third general type of engine, combining features of the two types mentioned, in which the fuel is burned at both constant volume and constant pressure. Engines of this type are known as Sabathé engines.

According to whether an engine receives a working impulse every other revolution of each revolution, it is said to have a four-stroke cycle or a two-stroke cycle. Either type of engine may be a single acting or double acting, such constructions being wholly mechanical and influencing in no manner the thermodynamic cycle of an engine. All the three general types of oil engines enumerated may be built to work either on the four-stroke cycle or the two-stroke cycle and may be either single or double acting.

EXPLOSION OIL ENGINES.

ENGINES WITH FOUR-STROKE CYCLE.

Figure 6 shows the elements of an explosion oil engine having a four-stroke cycle. During the first stroke of the piston downward, which creates a partial vacuum in the cylinder, atmospheric air is admitted through the air-admission valve *a* into the cylinder. On the return stroke of the piston, valve *a* is closed, and the air in the cylinder is compressed. Before the piston is at the inner (upper) dead center, the fuel charge is sprayed by the fuel pump *b* into the chamber *c*, known as a hot bulb or hot ball, which is kept at a dull, cherry-red heat. As the piston reaches its inner (upper) center, the fuel is burned with explosion-like rapidity, the temperature and pressure in the cylinder increase, and the piston receives a power impulse, the gaseous mixture expanding during the second downward stroke of the piston. On its return stroke the exhaust valve *d* is opened and the piston sweeps the gaseous products before it and through the valve *d*. The working cycle of four strokes is then repeated.

Before the engine is started the chamber or bulb *c* must be heated with a torch to a dark-red color, after which the successive explosions of the fuel oil will keep it hot. Inserted into this chamber in some engines is a thin-walled copper pipe against which the oil is sprayed. This small pipe can be heated quickly and readily absorbs heat from the chamber. It therefore tends to reduce the time required for starting the engine, which can thus start before the entire bulb is heated, and it also reduces missed ignitions after the engine is operating. Heating of the bulb sufficiently to permit starting the engine requires 10 to 20 minutes. Compressed air, usually furnished by a small independent air compressor operated by a gasoline engine, is used to start the engine.

ENGINES WITH TWO-STROKE CYCLE.

Figure 7 illustrates the working of an explosion oil engine having a two-stroke cycle. Engines of this type have a closed crank case, provided on one side with large disk valves opening inwardly to the crank case and serving as air intakes. A large conduit connects the crank case with the cylinder, the conduit ports being so placed in the lower part of the cylinder that they are closed by the piston during the greater part of its travel; they are uncovered only a few degrees before it reaches its lower dead center.

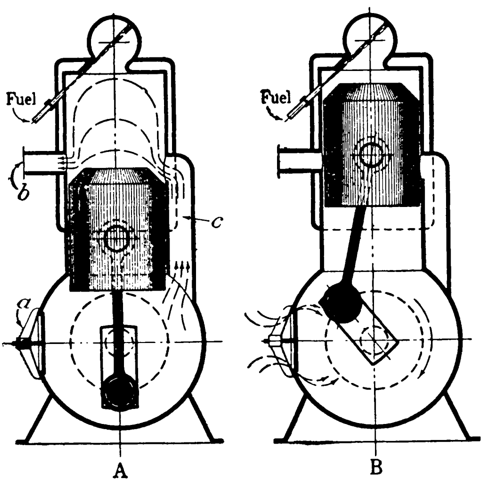


FIGURE 7.—Explosion oil engine, two-stroke cycle.

Figure 7, A, shows the engine with a crank case full of air compressed by the previous downward travel of the piston, this internal pressure having closed the disk valve *a* leading to the atmosphere. The piston has traveled to its outer (lower) dead center and uncovered the exhaust port *b* and the air port *c*. The pressure in the cylinder is higher than that of the atmosphere, so that the burned gases are swept out of the exhaust-gas port. The air port *c* admits fresh compressed air into the cylinder, sweeping it free of the products of combustion and refilling it with air needed for burning the next fuel charge. On its upward travel the piston covers the exhaust and air ports, compressing the air thus imprisoned in the cylinder. The air still in the crank case expands and its pressure falls below that of the atmosphere. Consequently the disk valve opens automatically and lets in a fresh supply of air (Fig. 7, B). Just before the piston reaches its inner (upper) dead point a fuel charge is sprayed against the heated surface of the hot ball; the vaporized fuel is ignited and burned with a great increase of temperature and pressure by the time the piston has passed its inner dead point. The resulting impulse drives the piston downward, the 2-stroke cycle being then repeated.

In explosion oil engines, the air is compressed in the cylinder to a pressure of 145 to 220 pounds per square inch and in the crank case to a pressure of 1 to 7 pounds per square inch. The explosion pressure varies from 270 to 470 pounds per square inch. The cylinder and the cylinder head are water-cooled, with the exception of the hot ball, which is kept at a dull-red heat. The construction described is the one generally accepted and is to be preferred on account of its greater simplicity. Engines of this type are built both horizontally and vertically, the latter construction being preferred in multicylinder units.

The air for scavenging could also be furnished by constructing the working piston as a differential piston, traveling with the enlarged part in an air cylinder, or by an independent air pump. This design would result in a more complicated and expensive engine, hardly justified by its limitations.

COMPARATIVE ADVANTAGES OF FOUR-STROKE AND TWO-STROKE CYCLES.

As regards the relative theoretical advantages of the four-stroke and the two-stroke engines, the two-stroke engine appears to be superior. For a given cylinder size and speed, the specific duty of an engine having a two-stroke cycle is double that of an engine having a four-stroke cycle, for it receives a power impulse for every revolution as against one for every two revolutions of the engine having a four-stroke cycle. Its mechanical efficiency also would appear to be greater, as the engine with a four-stroke cycle has to make two strokes for expelling the products of combustion and for filling the cylinder with a fresh supply of air for burning the next fuel charge. The power for this work has to be drawn from the flywheel, in which it has to be stored again during the power stroke. As in addition the cyclic regularity of an engine with a four-stroke cycle but having the same power and speed is greatly less, a much heavier flywheel is required. The four-stroke engine is also much heavier per horsepower than the two-stroke engine.

In practice, however, these advantages are not so apparent. Engines having a two-stroke cycle require an auxiliary air pump for performing the work of scavenging and of refilling the working cylinder with fresh air, work that in the engine having a four-stroke cycle is performed by the engine directly in the working cylinder. The air pump, proportioned to the engine it has to supply, is a large and heavy piece of machinery, requiring considerable power for its operation. To insure thorough scavenging of the working cylinder, a volume of fresh air greater than the volume of the cylinder must be supplied by the air pump. The pump is usually proportioned to supply one and three-tenths times the working cylinder volume of air. Even then sweeping of the working cylinder clean of the remants of the products of combustion is difficult, and any gases remaining in the cylinder displace a proportionate amount of oxygen needed to maintain combustion, thus lowering the possible power output of the engine.

The heat exchange in an engine having a two-stroke cycle being more rapid than in one having a four-stroke cycle, the material of the former is more severely taxed, and it is not advisable to use as high mean effective pressures nor piston speeds as in engines having a four-stroke cycle. High mean effective pressure results in high terminal pressure at the time of exhausting, with a consequent loss in power. As the exhaust ports of two-stroke engines are uncovered by the piston, and as exhausting of the gases must be rapid, the piston has to uncover these ports several degrees before it reaches its lower dead center. High mean effective pressure will, therefore, cause proportionately greater losses in an engine having a two-stroke cycle than in one having a four-stroke cycle. These features combine to diminish the theoretical advantages that engines having a two-stroke cycle appear to possess over engines with the simpler four-stroke cycle.

To avoid any misconception it is well to emphasize that the difficulties and the considerable fuel losses during exhausting experienced with the usual two-stroke gas engine, chiefly on account of the successive scavenging and loading of the engine cylinder, are absent in the two-stroke Diesel engine. In this engine the same air pump does the scavenging and the charging, whereas in the two-stroke gas engine separate pumps are used for scavenging and for charging the cylinder with the gas-and-air mixture. These pumps consume considerable power, and it is difficult to prevent a part of the fresh gas-air charge from being expelled with the products of combustion during exhausting. Having to deal with inert air (air not mixed with any combustible gas) and a liquid fuel, the working process of the two-stroke-cycle Diesel engine is much simpler than that of the gas engine having a two-stroke cycle.

Engines with a four-stroke cycle, in sizes from 50 to 800 horsepower, have been developed to a high degree of perfection, and are so simple in operation that little justification for the adoption of two-stroke engines in these sizes exists at present. The field of two-stroke types lies chiefly in engines of very small and very large powers, the latter from 1,000 horsepower upward.

ESSENTIAL QUALITIES OF ENGINES OF SMALL POWER.

Engines of small power should combine lightness with the greatest simplicity in design, to assure low manufacturing costs and ease of operation in inexperienced hands. In low-powered engines fuel economy and refinements in design are sacrificed to low first cost of engine. Nor is fuel economy of so much moment in small engines, as the total fuel consumption is a relatively small source of expense. Explosion engines having a two-stroke cycle best meet these requirements. Engines of this type have merely self-acting disk valves for admitting air to the crank case of the engine, and a fuel pump delivering a measured amount of fuel to the fuel-injection nozzle. This construction insures simplicity, but also results in low volumetric and mechanical efficiency and low fuel economy. Diesel engines, to insure high fuel economy, demand mechanically operated valves, and a high-pressure air compressor, which, together with the high compression and resulting high temperatures used, demand the highest grade materials anl workmanship, involving a high cost per horsepower.

Although in European countries Diesel engines are manufactured in sizes as small as 15 horsepower there is little demand for this size in America, where fuel prices generally range lower, and where Diesel engines of 75 horsepower indicate the probable commercial limit in size. For large powers, from 1,000 horsepower upward, engines having a two-stroke cycle are preferred, as in these sizes limitations are put on the size of cylinder practical for engines having a four-stroke cycle by the high temperatures and pressures produced in such engines. An increased use of material to withstand the greater total pressure in large cylinders merely accentuates the difficulty of cooling the cylinder, the cylinder head, and the piston, and of carrying off the heat fast enough through thick cylinder and cylinder-head walls. Stresses due to unequal expansion and contraction may easily lead to ruptures of vital engine parts, such as cylinder heads, pistons, and cylinders. Successful building of large Diesel engines must, therefore, be fortified by a great amount of practical experience, particularly in the rational design and selection of casting mixtures with correct chemical and physical properties.

Twenty-four inches in cylinder diameter represents the probable upper limit with air-cooled pistons and 30 inches with water-cooled pistons for Diesel engines having a four-stroke cycle.

COMPARATIVE ECONOMIES OF DIESEL AND OF EXPLOSION OIL ENGINES.

The use of explosion oil engines should be dictated entirely by their overall economy. Although they are materially cheaper in first cost, they consume considerably more fuel and lubricating oil than Diesel engines, and their fuel consumption at fractional loads increases at a greater rate than does that of Diesel engines.

The difference in economy between explosion oil engines and Diesel engines is due not so much to a difference in thermodynamic cycles as in constructional differences, which decidedly favor the Diesel engines.

The higher the initial temperature and the lower the terminal temperature the more perfect will be the heat utilization. High initial temperature is a function of pressure. If the compression were carried as high in the explosion engine as in the Diesel, the explosion oil engine theoretically would show a slightly higher thermodynamic efficiency than the Diesel engine. The final pressure, when the fuel is burned at constant volume, would, however, be greatly increased above the compression pressure, or to about 60 atmospheres, with an accompanying rise in temperature far beyond that practicable with the materials of construction available. These limitations impose a lower compression pressure on explosion oil engines than on Diesel engines, so as to keep the maximum pressure and temperature within safe limits of permissible engine construction.

Thus with a compression pressure of 150 to 250 pounds per square inch the explosion pressure becomes 270 to 500 pounds per square inch; and with the instant ignition and burning of the previously vaporized oil common to explosion oil engines, a temperature of 2,300° to 3,150° F. is reached.

The Diesel engine has a higher but more gradually increasing compression pressure (450 to 500 pounds per square inch), which does not subject the engine to sudden shocks, with a resulting increase in temperature from atmospheric to about 1,000° F. The fuel is gradually injected as the piston moves from its top center (inner dead center) downward, the pressure remaining practically constant during the time of fuel admission. With a decrease in load, the time of fuel admission is also shortened; that is, the fuel supply is shut off sooner. Therefore, the increase in temperature due to the burning of the fuel at constant pressure does not exceed that reached in an explosion engine, notwithstanding the higher compression pressure used in the Diesel engine, and the higher initial temperature caused by this compression. Thus, the temperature in a Diesel engine seldom exceeds 2,600° F. and reaches 3,000° F. only when the engine is overloaded.

If, then, the working cycles of the two types of engines are compared on the basis of compression pressures used, the Diesel engine is found to have a greater thermal efficiency, because it can work successfully with the higher compression pressure. This superiority is confirmed by comparative entropy diagrams.

Whereas in explosion oil engines the efficiency is influenced by the compression ratio alone, in the Diesel engine the efficiency is influenced by the compression and the cut-off ratios, the efficiency increasing with a decrease in the length of the cut-off or constant-pressure line. Thus, at fractional loads, the indicated thermal efficiency of Diesel engines increases, which partly offsets the loss in mechanical efficiency; that is, the increased fuel consumption for performing the internal work of the engine. This accounts for the very "flat" fuel-consumption curve of Diesel engines, which maintain an almost constant fuel economy over a fairly wide range in load. Thus at three-fourths load the increase in fuel consumption per brake horsepower-hour is only 2 to 5 per cent, and at one-half load 10 to 15 per cent greater than at full load in high-grade engines, which is in marked contrast with fuel increases in other prime movers. The ability to create higher initial temperatures, aside from increased thermal efficiency, enables the Diesel engine to burn a greater variety of fuels. In addition to the fuel being thoroughly atomized by highly compressed air, the heated oxygen has an augmented power of combining with the carbon and hydrogen in the fuel, so that the velocity of the chemical reaction at the high temperature in a Diesel engine is greatly increased. As a result the range of fuels suitable for the Diesel engine comprises such heavy liquid fuels as petroleum residues, coal-tar oils, and coal tars.

A serious fuel loss in explosion engines is frequently caused by the decomposition of the fuel oil sprayed into the hot ball. Various hydrocarbons are formed with a separation of carbon and oil soot; part of this coats the hot ball and the cylinder, and a larger part is expelled with the gaseous products of combustion. From time to time accumulated soot in the exhaust piping catches fire and burns, necessitating precautions against fire from this source.

Comparative economies of Diesel and of explosion oil engines are shown in Table 2 following. On a basis of oil costing $1 a barrel, the minimum yearly fuel cost in dollars corresponds to a number of barrels of oil consumed yearly. Oil usually costs more than $1 a barrel, especially gas oils, which are the only oils suitable for use in explosion oil engines. On the other hand, residues and heavy fuel oils can be burned in the Diesel engine. Lubricating expense is also materially higher in explosion than in Diesel engines. With a fairly good load factor it will not take long to make up the difference in first cost by greater economy, particularly when the fuel cost is increased by long hauls.

TABLE 2.—*Comparative economies of Diesel and of explosion oil engines*

(Cost of fuel oil taken as at $1 a barrel of 320 pounds; cost of lubricating oil taken as at 35 cents a gallon.)

Item.	Diesel engine, American make.[1]					Explosion oil engine, American make.[2]				
	Load.	Fuel per horsepower-hour.	Per cent fuel per horsepower	Barrels per year.	Fuel cost per horsepower-year (8,760 horsepower hours).	Load.	Fuel per horsepower-hour.	Per cent fuel per horsepower.	Barrels per year.	Fuel cost per horsepower-year (8,760 horsepower hours).
		Pounds.					*Pounds.*			
Fuel consumption or cost at different loads.	4/4	0.48	100	986	$13.15	4/4	0.75	100	1,540	$20.53
	3/4	.50	104.2	770	13.68	3/4	.83	110.7	1,280	22.76
	2/4	.58	120.8	610	16.27	2/4	.95	126.7	975	26.00
Oil consumed for lubrication, gallons per year.	360 to 550					1,100 to 1,460.				
Cost of lubrication	$128 to $193 per year, or $1.70 to $2.60 per horsepower year.					$380 to $510 per year or $5.10 to $6.80 per horsepower year.				
Cost of installation including building.	$90 per horsepower					$60 per horsepower.				

[1] 75-horsepower, one-cylinder, single-acting engine having a four-stroke cycle.
[2] 75-horsepower, two-cylinder, single-acting engine having a two-stroke cycle.

The engineers of the Bureau of Mines believe that the oil engine has proved its usefulness as a prime mover in oil fields whose gas supply is too low to run gas engines. The oil engine is economical of fuel, reliable, and requires no more attention than a gas engine. However, care should be taken to have the fuel oil free from sand and dirt.

To decrease the water content and solid matter in suspension, many oil companies using crude oil as fuel heat and settle it before using it. Some oil companies feed their oil to the engine through a heat exchanger; the oil passes to the engine through a 1-inch pipe within a 3-inch pipe, through which the cooling water leaves the engine jacket. This arrangement tends to keep the oil at a uniform temperature, decreases its viscosity, and generally increases the efficiency of the operation of the engine.

One of the manufacturers of oil engines recommends that the fuel oil used have the following specifications:

SPECIFICATIONS FOR FUEL OIL.

Flash—below 275° F. (Open-cup test.)
Baumé gravity—not below 26°.
Sulphur content—less than ½ per cent.
Water content—less than ½ per cent.
Coke—not over 3 per cent.
Fraction which will distill below 360° C.—at least 60 per cent.

COMPRESSORS.

Compressors are used in oil fields to compress natural gas to extract the gasoline content,[10] to produce petroleum by the Smith-Dunn or Marietta compressed-air process,[11] to compress air for the air-lift system of production,[12] and to start oil or gas engines. Compressors are also used to supply compressed air intermittently for small pumps, for steam engines that pull rods and tubing, and for machinery at the machine and repair shops.

Compressors are either driven by a belt from a steam, gas, or oil engine or electric motor, or are direct connected to a gas or steam engine, the engine or compressor forming one unit on a single bed plate. The latter type eliminates belts and saves much in floor space and often on first cost and maintenance.

TYPES OF COMPRESSORS.

Compressors are classified as single stage and multiple stage. Most compressors are double acting; that is, they compress the air

[10] Burrell, George A., Seibert, Frank M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, pp. 51. Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration: Bull. 151, Bureau of Mines, 1918, p. 80.

[11] Lewis, J. O., Methods for increasing the recovery from oil sands: Bull. 148, Bureau of Mines, 1917, pp. 39 and 41.

[12] Arnold, Ralph and Garfias, V. R., Methods of oil recovery in California: Tech. Paper 70, Bureau of Mines, 1914, p. 44.

on both strokes of the piston. For air compression to less than 100 pounds to the square inch, single-stage compressors are satisfactory and are most common; for pressures up to 500 pounds to the square inch, two-stage compressors are used. For oil-field practice single and two stage compressors meet requirements.

Two-stage compressors have two cylinders of different sizes that compress the air by stages. The free air enters the larger cylinder, is partly compressed, and passes through a cooling device called an intercooler to the smaller cylinder where compression is completed.

Because of the high temperatures caused by compression in a single stage to pressures above 100 pounds to the square inch, lubrication of the cylinder and valves is difficult. The oil used tends to deposit a coke-like substance in the ports and pipes, decreasing the air discharge area and adding to the compressor load. A two-stage compressor eliminates the overheating of cylinders and the resultant operating troubles, as compression is distributed between the two cylinders.

COMPRESSOR EFFICIENCY.

Even the most efficient compressor loses much power. The ratio of the power available in the compressed air to the power required to compress the air seldom exceeds 70 per cent, and is often much less.

Due to the expansion of air by heat, a less weight of air is compressed at each stroke when intake temperatures are higher. The lower the initial temperature the lower will be the final temperature, the greater the final weight of compressed air, and the greater the efficiency of compression.

COOLING DEVICES.

Use of an intercooler between the high and low pressure cylinders is the most important factor in two-stage compression. The intercooler is a closed cylindrical steel tank containing a water coil; circulating water and air ports lead to the two cylinders. The location of the intercooler differs with the size of the compressor. It is generally placed crosswise—in the smaller compressors beneath the air cylinders and in the larger compressors above the cylinders. By cooling the partly compressed air entering the high-pressure cylinder, the intercooler greatly increases compressor efficiency.

The cylinder barrels and heads are water-jacketed to keep the cylinder walls cool enough for good lubrication and to prevent cumulative heating.

AIR RECEIVERS.

An air receiver is a closed steel tank that receives and stores air from the compressor. It is especially valuable for intermittent air consumption, as pressures can be built up in the receiver, and much of the pulsation from the compressor eliminated before the air is discharged from the receiver into the air line. Receivers also act as separators for any water condensed from the air in the process of compression and thus give drier air.

TRANSMISSION OF COMPRESSED AIR.

Compressed air is delivered on the lease through pipe lines from the compressor plant to the point of consumption. Losses in pressure are due to lower temperature of the air at the compressor, leaks in the pipe line, and the friction of the air passing through the pipe line.

Losses due to friction vary directly as the length of the pipe, directly as the square of the velocity, and inversely as the diameter of the pipe. Tees, elbows, and scale or dirt in the pipe increase friction losses. The losses from leaky joints or open seams frequently exceed all other losses. In cold weather water often freezes in and clogs unprotected air lines.

CHOICE OF COMPRESSOR.

Like steam, oil, or gas engines, the size of a compressor is indicated by the cylinder diameter and the length of stroke.

The theoretical capacity of free air a minute in cubic feet is the product of the cylinder area in cubic feet by the piston travel a minute in feet. If the amount of air of a given pressure required a minute is known the size of a compressor can be estimated; however, the pipe-line losses and the altitude above sea level must be considered.

Any compressed-air handbook gives tables showing compressor capacities, conversion of compressed air into free air, horsepower requirements, and losses of pressure in transmission.

PUMPS.

TYPES IN USE.

All standard makes of reciprocating pumps are used in oil fields to handle water and oil. Centrifugal pumps are used for water, but are not suited to the high pressures used in pumping oil through pipe lines. They are used as boiler feed-water pumps, and water-line pumps, but very little for the pumping of oil. Rotary pumps are much used around refineries for pumping blended gasoline and refined products, but are not adapted to high suction lifts. Single and duplex reciprocating pumps, also known as vacuum pumps, are also used for pumping gas from wells, thereby decreasing the gas pressure.[13]

[13] Lewis, J. O., Methods of increasing the recovery from oil sands: Bull. 148, Bureau of Mines, 1917, pp. 32–35.

Triplex plunger-pumps, power pumps, and centrifugal pumps are driven by belt or gear transmission by means of steam, gas, or oil engines, electric motors, or combinations of these systems. Choice of pump depends on whether high or low pressure is to be met and whether direct, geared, or belt transmission is preferable.

Some of the common types of reciprocating pumps are single and duplex steam-pumps, single and double acting triplex plunger-pumps, and geared and belt-driven power pumps. All of these vary in design to meet different requirements. Steam pumps probably have the broader range of service; they are used as boiler feed pumps, water pumps, pipe-line gathering-system pumps, main line pumps on oil pipe lines, terminal and large loading station pumps, and for forcing mud into wells being drilled with rotary tools.

Centrifugal pumps are single and multiple stage, according to the head or pressure under which the pump is worked.

A detailed discussion of the plunger pump or of other types used in oil or water wells does not fall within the scope of this paper.

Pumps for handling oil at the well are used to pump oil from the well, or from sumps, to the production or collecting tanks, and from there to the receiving or central shipping tanks. In hilly or rugged country, pumps are often unnecessary, as the oil will flow by gravity from the well to the collecting tank and from there to the shipping tank. In some fields of the eastern United States the oil flows by gravity from the shipping tank of the producer to the storage tank of the purchasing company. In flat or level country, or for heavy or viscous oil, pumps must be used.

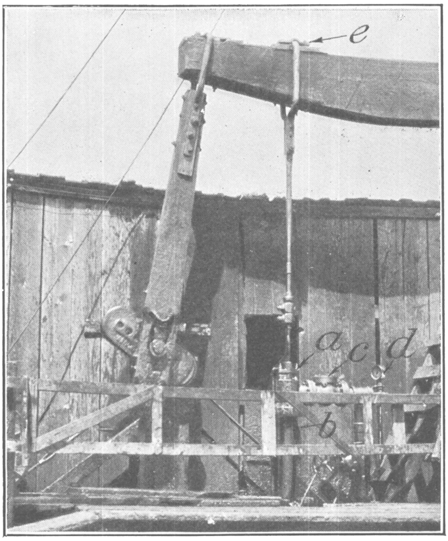
The oil lines from the various production or collecting tanks may lead to a central point from which a pump forces all of the oil to the storage or shipping tanks. Steam pumps or power pumps belted or geared and driven by steam, gas engine, or electric motor are generally used.

Plate VIII, *B*, shows a duplex steam-pump used for pumping oil from the production tanks to the storage tanks. The steam cylinders are shown at *a*, the steam chest at *b*, the oil cylinders at *c*, the steam line at *d*, the oil intake pipe at *e*, the oil discharge pipe at *f*, and the lubricator at *g*. The boiler that supplies steam for the pump is also used to steam the oil in the production tanks before its delivery to the pipe line leading to the storage tanks.

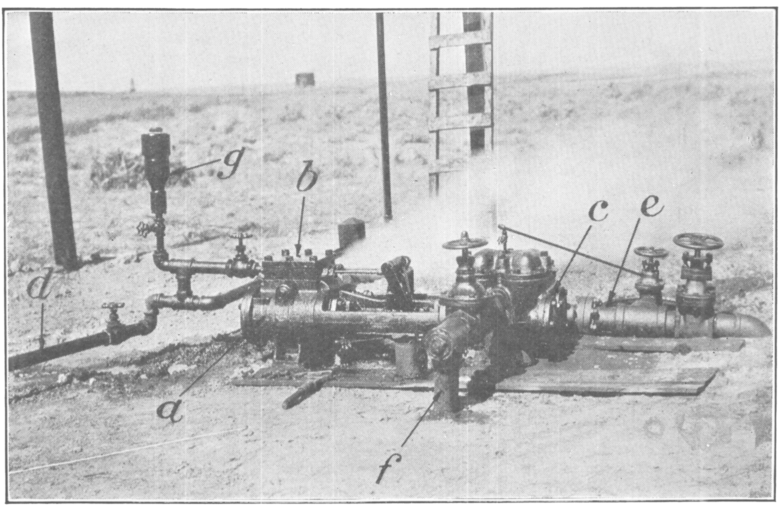
TAIL PUMPS.

The " tail pump " is commonly used to avoid small installations for moving oil from the well to the collecting or production tank, and from there to the storage or shipping tank.

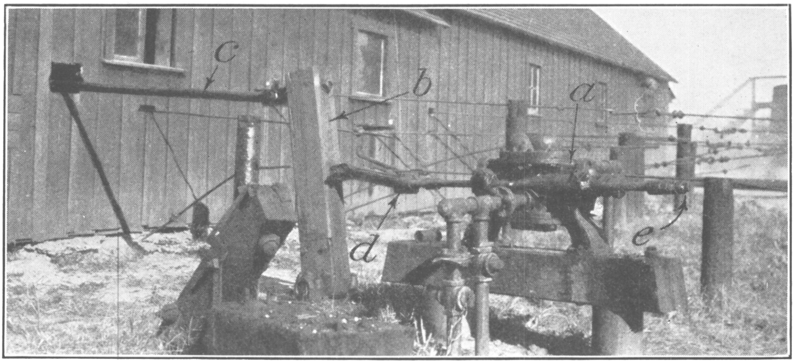
The tail pump consists of a 2-inch to 6-inch pump cylinder and plunger operated from the beam of a well pumping on the beam, as



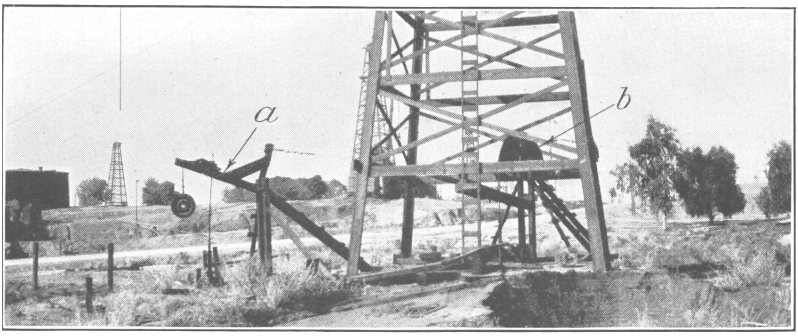
A. TAIL PUMP ATTACHED TO POWER ARM OF BEAM. FOR EXPLANATION OF LETTERING, SEE TEXT



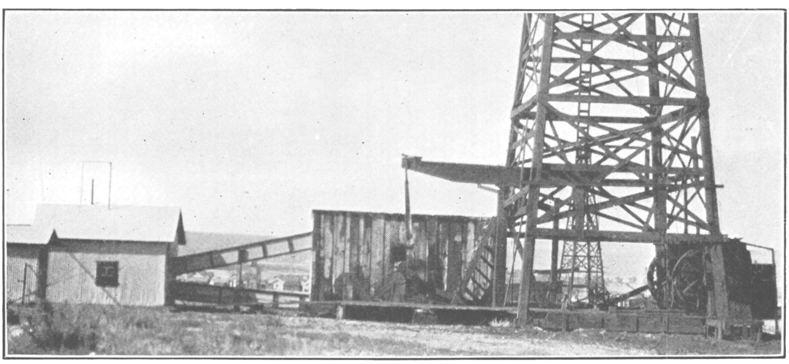
B. DUPLEX STEAM PUMP USED FOR PUMPING OIL FROM PRODUCTION TANKS TO STORAGE TANKS. FOR EXPLANATION OF LETTERING, SEE TEXT



A. TAIL PUMP CONNECTED TO A CENTRAL POWER. FOR EXPLANATION OF LETTERING, SEE TEXT



B. TAIL PUMP WORKED BY PUMPING JACK, *a*, DRIVEN FROM CENTRAL POWER, *b*



C. SHEET-IRON BOXING FOR WELL PUMPING ON THE BEAM shown in Plate VIII, *A*, at *a*, or attached by a steel rod to the eccentric disk of a central pumping power, as shown in Plate IX, *A*, at *a*, or attached to a jack operated by a central pumping power, as shown in Plate IX, *B*, at *a*. There are many ingenious variations of type, but those shown are typical. Tail pumps are designed to use existing power installations.

The pump shown in Plate VIII, *A*, at *a* is moving oil from the production tank to the storage tank. The well to which this tail pump is attached is situated near the production tank, and the connecting pipe line to the storage tank is placed so that the power available at the beam of the well can be used.

The tail pump shown in Plate VIII, *A*, is single acting. It pumps the oil on the upstroke of the plunger. The pump cylinder is shown at *b*, a check valve at *c*, and an oil-pressure gage at *d*. The plunger of the pump is attached by a steel rod to the power arm of the walking beam at *e*. As the pump does its work on the upstroke, it acts as a counterbalance to the well being pumped. Some manufactured types of tail pumps work as shown in Plate VIII, *A*.

Some types of tail pumps attached to the beam, as shown in Plate VIII, *A*, are double acting, pumping oil with both strokes by use of a piston instead of a plunger with a valve. This type has pipe connections to the intake and discharge lines at both the top and the bottom of the pump cylinder. In each of these pipe connections is a check valve so placed that with the upstroke of the piston the check valve is open at the lower intake, closed at the lower discharge, open at the upper discharge, and closed at the upper intake. With the downstroke the valves formerly open are closed, and the valves formerly closed are open.

With this type of tail pump the downstroke of the piston adds to the load at the well, and usually necessitates a counterbalance. Some tail pumps instead of being attached to the beam, as shown in Plate VIII, *A*, are attached to a timber extension of the power arm of the beam, similar to some types of counterbalance.

At times when the tail pump is not being used to pump oil it should be detached from the beam, not only to save in wear on the pump, but also to prevent the risk of fire. Disastrous fires have resulted from operating the tail pump dry. Tail pumps are operated under maximum pressures of 200 pounds to the square inch.

Plate IX, *A*, shows a tail pump connected to a central power. The piston of the pump, *a*, is attached to a rocker arm, *b*, which in turn is made to oscillate by a rod connection, *c*, to the eccentric disk of the power. The tail pump can not always be placed near the pumping power, but the type shown in Plate IX, *A*, can be erected at any convenient point and operated by means of a shackle-line connection from the power, attached to the pump at *d*, and provided with a shackle-line attachment at *e*, leading to a counterweight like that sometimes used at a well pumping "on the beam," as shown in Plate XI, *B*, at *a* (p. 60), which provides for the return stroke of the pump.

Plate IX, *B*, at *a* shows a tail pump worked by a pumping jack driven from a central power. The work arm of the jack has a scrap-iron weight to provide for the return or down stroke of the pump. Much heavier installations of this type are used in the Kern River oil fields, California, to pump oil from sumps to flumes or to production tanks.

GAS OR VACUUM PUMPS.

At many pumping wells on which vacuum is maintained the vacuum pumps are often run by the equipment used to pump oil. At wells pumping on the beam, the gas pump is often placed and worked like the tail pump shown in Plate VIII, *A*. The pump consists of a gas cylinder and piston with rod connection to the walking beam. Most types are double acting, and are provided with intake and discharge gas ports and valves at each end of the cylinder. Where a central power is used, a gas cylinder is generally direct connected to the steam or gas engine used for the power. When electric power is used, a gas pump of suitable size is generally belt-driven from a motor; however, some types are gear-driven from the motor.

In some oil fields a large central gas compression and pumping plant is built which controls the vacuum on all the wells of a number of properties, maintaining practically the same vacuum on all wells, and extracting the gasoline from the gas before returning it for field use.

For use at these gasoline extraction plants, some manufacturers recommend their compressors as vacuum pumps, while other manufacturers, rather than design the low-pressure cylinder of the compressor for this work, make a gas or vacuum pump for bringing the gas from the wells to the compressors. If a vacuum is not desired at the wells supplying gas to the gasoline plant, a back-pressure regulator, set to work at any desired pressure, is installed and is generally found satisfactory.

ELECTRIC GENERATING EQUIPMENT.

Up to the present time the extensive use of electric power for pumping oil wells has been chiefly at fields so located that the power can be purchased from the public service corporations. In California, of the 10,000 producing oil wells, about one-third are pumped with electric power usually obtained from the large power companies that supply cheap hydroelectric generated power. In Kansas, Oklahoma, and Texas most of the electric power used by the oil companies is similarly procured. However, in some of the Mid-Continent and Appalachian fields, some of the companies have built their own electric power plants.

If a hydroelectric plant is impracticable, local conditions will determine which type of prime mover will be used to generate the electric power. For large power-plant installations, a steam-turbine plant is generally much cheaper than a gas engine installation.

If natural gas is available a gas engine plant is usually the cheapest to install and operate for requirements of less than 500 horsepower. Both vertical and horizontal gas engines in units up to 200 horsepower are used. If one unit of 200 horsepower does not furnish enough power, several units can be used in parallel.

If the supply of natural gas is too low, oil engines will give high economy, although their installation costs are higher than for gas engines. Like gas engines, their size is limited but they can be operated in parallel. Steam boilers and engines may also be used and if much power is needed the steam turbine used as a prime mover is the most desirable because of its low first cost and upkeep and its simplicity of operation. Two or three turbine units are generally advisable instead of one larger one, to reduce the chances of all the power being "off" at one time.

A steam, gas, or oil engine for driving the electric generator can use either belt or shaft drive; the former is, however, the cheaper to install.

The writer recently visited a modern electric power plant built by one of the larger producing oil companies in one of the Gulf Coast oil fields. This plant was built to eliminate the scattered smaller power units of various types formerly used, which had proved costly and inefficient. The plant was completed in 1920 at a cost of about $465,000; since then it has run continuously and has shown a saving of more than $1,000 a day over former operating costs. This plant is well housed in a steel building with concrete floors. It has three power units, each consisting of a 300-horsepower boiler, a steam turbine driving a generator of 625 kw. capacity at 900 r. p. m., and producing electric current at 2,400 volts, 450 amperes, 3 phase and 60 cycle.

Two units of the plant are kept running continuously, and the third is run during periods of peak load. The boilers are cleaned once a month. Water purifiers and heaters are used. Boiler feed pumps are used for forcing water into the boilers, and a centrifugal pump driven by a 5-horsepower motor brings water to the pump at the boilers.

Oil is used as fuel for the boilers, and 135 barrels are used daily to produce the 1,600 to 1,800 kilowatts of electric power generated. The cost of the power, including depreciation of plant, maintenance, and operating costs, is about 2½ cents a kilowatt. The electric power generated is distributed to 16 different pumping properties, where it is stepped down to 440 or 220 volts. The wells are all pumped on the beam. They range in depth from 2,000 to 3,000 feet, and are equipped with 2½ or 3 inch tubing.

The electric power is used for all field purposes, including drilling and pumping of wells and running pumps and compressors; it is changed to direct current for the treatment of emulsion, which is high in the oil produced.

The distribution of the electric power is shown in Table 3.

TABLE 3.—*Monthly distribution of power.*

	Kilowatts.
Circuit No. 5 water-circulating pump and cooling pump	48, 600
Treating plant (direct current)	13, 800
Drilling rig	4, 500
Field water-supply	39, 005
Blowing oil wells, two or more wells on synchronous motor	201, 240
Miscellaneous: Lighting, etc	6, 333
Portable well washer	1, 260
Motors, B. S. pumps	4, 567
Pipe-line oil	199
Miscellaneous pumps	770
Mud pumps	120
Power used for pumping 56 wells on the beam (counter balanced)	185, 106
Total power (actual output)	505, 000

Average of 16,833 kw. per day.

The maintenance of this plant for the first 13 months was $1,647.19 a month, the operating cost $4,458.12 a month, and the depreciation $3,486.47 a month.

PURCHASED ELECTRIC POWER.

The following information, given to the writer by the San Joaquin Light and Power Corporation of California, shows the basis upon which electric power is supplied to the oil companies by public service corporations:

Oil-field service is covered by Schedule P-4, which is the general oil-field service rate, and also Schedule P-5, which is the wholesale power service rate. Under this latter rate service is sold to some of the large companies whose requirements are such as to bring them under this classification.

You will note that under Schedule P-4 that this rate is applicable to service supplied equipment for pumping of oil wells, operating and gathering pumps, leased line pumps and dehydrating plants, in connection with the actual production of oil. This is not applicable to service to tank farms or booster stations on oil pipe-lines, as that service is considered as coming under the industrial or commercial rate. This, however, represents a very small part of such service and is not considered in the light of production.

Under Schedule P-5 it is contemplated that the rate provided shall be applicable to large leases where their power demand would be equal to or in excess of 200 kw. per month. Such service is rendered at the primary voltage of our available distributing mains and is metered on the primary side of the transformer, and on this basis the consumer owns and maintains the necessary step-down transformers and all secondary or distributing mains.

The extension rule that is the basis upon which power is furnished is quoted below:

a. Where estimated annual revenue equals or exceeds 33⅓ per cent of the cost of the extension:

Such extension will be made at the entire expense of the company.

b. Where estimated annual revenue exceeds 20 per cent but is less than 33⅓ per cent of the cost of the extension:

Such extensions will be made provided applicant for service advances the difference between the cost and an amount equal to three times the estimated annual revenue. The amount thus advanced will be refunded quarterly on the basis of 20 per cent of the monthly bills of applicant for service received. No refund, however, will be made after the tenth year of service. If the revenue from applicant during any continuous period of one, two, or three years within the first ten years of service exceeds the amount invested by the company, such excess will be refunded, it being provided, however that the total amount refunded shall not exceed the amount advanced by applicant.

For the purpose of determining refunds, the applicant's revenue during the tenth year shall not be considered as more than the average revenue of the three next preceding years.

Extensions under this class will be made requiring no advance provided applicant guarantees during a three-year period a revenue equal to the total cost of the extension. Such guarantee shall be paid in three equal annual payments, dating from the time service is first rendered. It is provided, however, that in the event payments for service rendered during the first and second year exceed the annual guarantee requirements, such excess shall accrue toward the fulfillment of the normal third year guarantee. Furthermore, should the payments for service rendered during the first year or during the first and second year combined equal the cost of the extension, then the three-year guarantee shall be considered as having been fulfilled.

c. Where the estimated annual revenue is less than 20 per cent of the cost of the extension:

Such extensions will be made provided applicant for service advances the entire cost of the extension, in which case the advance will not be subject to refund. Extensions under this class, however, may be made under rule 2, *b*, above, provided applicant guarantees an annual revenue equal to 20 per cent of the cost of the extension.

d. Extensions to speculative business such as wildcat drilling, where the estimated revenue exceeds 20 per cent of the total cost of the extension, such extension will be made provided the applicant for service advances the total cost of the extension, the amount advanced will be refunded on the basis of 20 per cent of the monthly bills for service received.

SCHEDULE P-4—OIL-FIELD SERVICE.

Applicable to all power service supplied to equipment used for pumping oil wells, operating and gathering pumps, leased line pumps and dehydrating plants, in connection with the production of oil.

TERRITORY.

Entire territory served.

RATE.

One-fourth cent per kilowatt hour.

MINIMUM CHARGE.

One dollar and twenty-five cents per horsepower of connected load per month, but not less than $12.50 per month.

When dehydrators are used the minimum charge for this load together with any other load will be at the rate of $1 per kilowatt of maximum demand, but not less than $1 per kilowatt of necessary transformer capacity required.

SPECIAL CONDITIONS.

a. Service under this schedule to be supplied at 110, 220, or 440 volts at the option of the consumer. All necessary transformers to obtain such voltage will be supplied, owned, and maintained by the company.

SCHEDULE P-5—WHOLESALE POWER SERVICE.

Applicable to general power and resale service delivered at a standard voltage of 2,200 volts or more.

TERRITORY.

Entire territory served.

RATE.

Service at standard distribution voltage of 2,200 volts or more—

DEMAND CHARGE.

(Kilowatts of maximum demand per month.)

First 200 kilowatts or less per month	$230 per month.
Next 300 kilowatts per month	$1 per kilowatt.
All over 500 kilowatts per month	$0.90 per kilowatt.

ENERGY CHARGE.

(Kilowatt-hour per kilowatt of maximum demand per month.)

	Oil field service (per kw. h)	Resale and other service (per kw. h.)
First 300 kilowatt-hours, per kilowatt	$0.85	$0.75
All over 300 kilowatt-hours, per kilowatt	.70	.60

MINIMUM CHARGE.

Service from transmission lines at standard transmission voltage:

The rate is the same as set forth under Rate (A) above, less 10 per cent.

SPECIAL CONDITIONS.

a. The total charge is the sum of the demand and energy charges given above.

b. Service under Schedule *a* will be supplied by the company at a standard distribution voltage of 2,200 volts or more depending upon the distribution voltage obtainable. Service under Rate B will be supplied by the company from its main transmission line at the transmission line voltage.

c. The maximum demand in any month will be the average kilowatt delivery of the 15-minute interval in which the consumption of electric energy is greater than in any other 15-minute interval in the month. The maximum demand on which the demand charge will be based will not be less than 60 per cent of the demand occurring during the 11 preceding months.

d. Any demand occurring between the hours of 11 p. m. and 6 a. m. of the following day will not be considered in determining the above demand charge.

HORSES USED FOR POWER.

In some of the older fields of northern Pennsylvania, the horse whim was common until recently, chiefly at wells where much sand was in suspension. With modifications as to detail this is now a common method of handling production in Rumania.

The horse whim, as formerly built in the shallow oil fields of Pennsylvania, consisted of a wooden shaft about the length and thickness of a bull-wheel shaft, with the gudgeons attached. The shaft was placed vertically with the gudgeons resting in timber bearings, the bottom one being flush with the surface of the ground and the upper one being held in position by braces to the derrick. At the upper end of the shaft, a flanged drum 10 to 12 feet in diameter, with a 12 to 15 inch face was built. This drum was used for winding the three-quarter inch manila rope used in bailing. Through a mortise at the bottom of the shaft, one end of a pole about 10 feet long was inserted. A horse was hitched to the outer end of this pole and driven around in a circular track with the vertical shaft of the whim as a center. In this way the rope was wound on the drum and the oil raised from the well in the bailer. When the bailer reached the surface, the oil was dumped into a barrel or small tank, placed on the floor of the derrick, and the bailer was returned to the bottom of the well by its own weight unwinding the rope on the drum, the horse having been unhitched.

CHOICE OF POWER.

The choice of power depends chiefly upon the cost and availability of fuel and equipment as well as on the conditions under which the power is to be used. Steam, gas, or oil engines built in large units serve as prime movers in centrally located electrical power plants. Built in smaller units they serve as prime movers in the smaller power plants at groups of wells. In still smaller units they as well as electric motors are used at single wells to pump, clean, swab, and bail.

In some oil fields it may be cheaper to install electric motors, power lines, and transformers using electric power purchased from a power company than to install and operate steam, gas, or oil engines.

Often the operators in an oil field could get cheaper power by erecting a central electrical power plant, large enough to meet all of their power requirements. This would save duplication of expense in running many smaller power units and would mean a smaller investment cost per horsepower generated and a broader range of distribution for maintenance charges and depreciation. It would ultimately mean less cost per horsepower generated. However, before such a plant is built, those contemplating its construction should be satisfied that the economies gained will provide for depreciation of plant and the interest and dividends on the capital invested.

STEAM ENGINES.

The ordinary type of slide-valve engine used for this service has a low thermal efficiency as is shown in the following comparison of gas consumed per horsepower-hour by it and other types of engines.[14]

Type of engine.	Cubic feet gas per horsepower-hour.
Large natural-gas engine, highest type	9
Ordinary natural-gas engine	13
Triple-expansion condensing steam engine	16
Double-expansion condensing steam engine	20
Single cylinder and cut-off steam engine	40
Ordinary high pressure, without cut-off, steam engine	80
Ordinary oil-well pumping steam engine	130

A steam engine should have a boiler station close by in order to minimize the steam loss due to exposed steam lines. However, the steam engine is highly flexible and can be operated at 30 to 130 per cent of the rated load at efficiencies close to the maximum efficiency of the engine.

The writer recently saw a set of four 70-horsepower boilers, built to furnish steam to the engines of 10 or 12 wells pumping on the beam. Some of the 2½-inch steam lines leading to the individual wells were 1,600 or 1,800 feet long, but all were well insulated.

When asked for the reason for using steam engines instead of gas engines in this oil field of ample gas supply, the general superintendent gave the following information:

> The wells in this particular field flow with great violence and as a result enormous quantities of heavy wet gas settle in the canyons and behind the small hills in dead air spaces. This necessitates locating a central power plant at a point on a hill less likely to be within this gas zone.

[14] Westcott, Henry P., Handbook of natural gas. 1913, p. 596.

We have had considerable experience with electric motors and gas engines and as a result of that experience we knew it would be inadvisable to place either a gas engine, an electric motor, or an oil engine in close proximity to any of these active wells as danger of fire was too great. In this field it is necessary to take every precaution to eliminate the fire risk. Even so, we have had several disastrous fires. For that reason we use only steam for power.

GAS ENGINES.

The gas engine is widely used to pump oil wells, especially in oil fields with low gas supply. It has high thermal efficiency, and at many wells it burns natural gas that would otherwise be wasted. By the use of the reversible gear the gas engine gives good service for bailing, pulling, or swabbing. It is more flexible than the oil engine, is lighter and cheaper, and is more readily started and restarted, but it is not so adaptable as the steam engine.

Table 4 shows comparative costs of gas engines and electric motors for oil-field pumping and cleaning for one of the larger oil companies.

Another oil company operating in one of the Mid-Continent oil fields has given the following comparison of gas engine and electric motor maintenance for a year. There were 367 wells pumped by gas engine and 241 wells by electric motor, all on the beam and from about the same depth.

367 wells pumped by gas engine.

	Average cost per well per month.
Repairs—	
Labor	$5.33
Material	18.81
Total	24.14

241 wells pumped by electric motor.

	Average cost per well per month.
Repairs—	
Labor	$1.66
Material	2.98
Total	4.64

TABLE 4.—*Comparative costs of gas engine and electric motor for pumping and cleaning.*

Generating electrical energy	1.04 cents per kw. h.
Purchasing electrical energy	1.1 cents per kw. h.
Cost of installing 15/30-hp., 6 to 12-pole, 440-volt, 50 to 60-cycle motor	$3,175.00
Cost of installing 35-hp. gas engine, including reverse gear	3,155.00
Yearly cost of operating gas engine	1,255.62
Yearly cost of operating 15 to 30 hp. motor	798.94
Saving by motor over engine operation	456.68

Electric plant investment (transmission line excluded)	$36,000.00
Fixed charges—15 years life.	
Sinking fund at 7 per cent a year	1,432.44
Taxes and insurance 2 per cent a year	720.00
	2,152.44
Operating cost (plant):	
Fuel, 240 hp. at 12 cubic feet per b. hp. h., at 6 cents per 1,000 cubic feet	1,513.73
Water, 20 barrels daily, at 1/2 cent per barrel	36.50
Lubricating oil, 1,575 gallons a year, at 40 cents per gallon	630.00
Labor, two oilers per day, at $190 per month each	4,560.00
Maintenance for material complete for year, including labor	2,150.00
Complete cost of plant yearly	11,042.67

Plant output:
135 kw. at switchboard 10 per cent loss between board and load—net load, 121.5 kw.
121.5 kw. × 3,760 hrs. a year = 1,064,340 kw. h.
Unit power cost at switchboard $11,042.67, developing 1,064,340 kw. h. = 1.038 cts. per kw. h.

Installation cost (pumping engine):	
Gas engine, 35-hp., with reverse gear, f. o. b. field	1,950.00
Foundation and floor, 16 yards, at $35, includes excavation, forms, and floor	560.00
Connecting and erecting	200.00
Water tank set up, including grading	165.00
Gas line and water line, 800 feet, at 35 cents, laid	280.00
Total cost	3,155.00
Installation cost (electric motor):	
Motor and necessary control equipment f. o. b. field	1,350.00
Foundation and floor (cement) 8 yards, at $35	280.00
Transformers, switches, etc., in place, wired	275.00
Electric lines	120.00
Connecting and erecting material and labor	100.00
Turbo gear, 5 to 1 ratio, f. o. b. job	775.00
Flex couplings, f. o. b. job	175.00
Shaft pulley and bearings, f. o. b. job	100.00
Total cost	3,175.00
Gas engine cost a year, operates 356 days a year:	
Fuel, 4,000 cubic feet a day, at 6 cents per M	85.14
Water, 3 barrels a day, at ½ cent	5.34
Oil, 2 quarts a day, at 40 cents per gallon	71.20
Maintenance	175.00
Fixed charges, sinking fund, 15 years life	125.54
Taxes, insurance, 2 per cent	63.10
Cost of gas engine accidents, estimated	10.00
Loss of 9 day's production, average 40 barrels, at $2 per barrel	720.00
Total cost	1,255.62

Motor cost a year:

Electricity, 5 kw. required at 1.04¢ per kw. h	$453.00
Oil, 10 gallons a year, at 40 cents per gallon	4.00
Fixed charges, sinking fund, 20-year life, taxes and insurance, at 2 per cent	63.50
Cost of motor accidents	1.00
Loss of 2 days' production, 40 barrels, at $2 per barrel	160.00
Total cost	798.94

OIL ENGINE.

The oil engine has high thermal efficiency. It generally consumes less than one-fifth of the oil that would be required to produce the same amount of power with an oil-field steam boiler and engine using the oil as a fuel. Like the gas engine, it needs only enough water for cooling.

ELECTRIC MOTORS.

The development of the two-speed, two-power electric motor for use at oil wells has given a source of power well suited to pumping, pulling, bailing, or swabbing. This development, like that of the oil engine, has been largely the result of the failure of the natural gas supply.

With the electric motor, advantage can be taken of the higher thermal and general efficiency of the central power plant, as compared with smaller and scattered power installations.

POWER-TRANSMITTING MACHINERY.

EQUIPMENT FOR PUMPING INDIVIDUAL WELLS.

PUMPING ON THE BEAM.

In the early days of the petroleum industry, all wells were pumped on the beam. Later, in order to decrease costs, methods for operating a number of wells from one power unit were developed, such as pumping by "jerk line," and by a central "jack plant" or "power." The adaptability of any method of production, other than pumping on the beam, depends on the depth of the well, the frequency of pulling jobs, and the distance between wells. Many operators claim that wells in which the fluid has to be raised more than 2,500 feet can not be successfully pumped by jack plants or powers. However, wells 3,500 feet deep are being successfully operated by this method in the Humble field, Texas.

In the Mid-Continent and California fields, at many of the deep wells drilled by rotary tools, standard equipment is installed after the well is completed or before drilling into the sand, and the well is then pumped on the beam. At wells drilled by standard tools, that part of the drilling equipment which is essential to beam pumping, the pulling of rods and tubing, and the cleaning of the well is left in place and used as long as serviceable.

Wells that produce a great amount of water, and hence require large tubing, and long and frequent pump strokes to produce the maximum amount of fluid, are pumped on the beam. The author recently saw an oil well at Augusta, Kans., pumping on the beam and producing 1,400 barrels of water and 30 barrels of oil a day; it used a 64-inch stroke and 3-inch tubing.

In the Kern River field, California, the general practice is to pump a well on the beam during the first two or three years of its life, because of the large amount of sand and the frequency of pulling. Also, if there is much water, the well is left on the beam indefinitely, as 35 to 40 two-foot strokes per minute are often necessary to handle the production properly. Jack plants or powers can not be satisfactorily used under such conditions. Further, different wells require widely different lengths and frequency of stroke, and these requirements can not be met by any system of group drive.

The deep wells in the Coyote Hills field, California, are pumped on the beam after they cease flowing. One company, having 66 wells there, has 10 flowing wells and 56 that are pumped on the beam from depths ranging from 3,500 to 4,500 feet.

EQUIPMENT.

The standard type of equipment for pumping on the beam consists of the walking beam, Samson post, pitman, and band wheel which are used in drilling and are left in place to pump the well. A steam, gas, or oil engine direct-connected by belt to the band wheel, or an electric motor belt-connected through a counter shaft to give the proper speed, is used for power.

The band-wheel house and the engine house are made either of lumber with boards nailed on two by fours and two by sixes, or of corrugated sheet iron on lumber framing. Plate IX, *C*, page 45, shows a corrugated sheet-iron engine house and sheet-iron boxing for the belt. The boxing replaces that part of the band-wheel house used to house the belt connecting the engine with the band wheel. This construction is used by the Ohio Oil Co. at Big Muddy, Wyo., chiefly as a means of preventing fire. Some fires originate in the engine house and, if not discovered at once, rapidly spread to the band-wheel house and derrick if the band-wheel house is of lumber. It is good practice to cover the band-wheel house with corrugated sheet iron, which is durable and fireproof. Often the destruction by fire of the engine house, band-wheel house, derrick, and machinery at a well will mean a loss of $10,000, besides the loss from suspended production during rebuilding.

One of the companies in the Coalinga field, California, has adopted the policy of using, in all wells producing from depths greater than 2,500 feet, concrete posts for derricks and concrete piers under the main sill instead of redwood posts and mud sills. Concrete foundations of this sort cost about $280, whereas redwood timber cost $240; but concrete will last for the life of the well and does not permit as much vibration of moving parts as timber does.

Plates X and XI give details of the type of machinery and construction used by many oil companies for pumping on the beam by electric power. This type of installation requires a countershaft to insure the proper speed at the band wheel; consequently the motor house must be larger than the engine house used with steam, gas, or oil engine power.

At some recent installations the use of a countershaft has been eliminated by coupling the electric motor used for power to a turbo-gear, which in turn is coupled direct to the pulley driving the band wheel. This turbo-gear reduces the speed of the pulley to one-fifth that of the motor. (See Pl. XXVIII, *A*, p. 110.)

Table 5 lists the machinery and material used in this type of plant.

TABLE 5.—*List of machinery and material for electrical installation for beam pumping.*

Reference No.	Amount	Machinery and material	Classification	Plate No.
1	10	Cubic yards sand and gravel	Foundations and floor.	X, A.
2	45	Sacks cement	do	Do.
3	4	7/8 by 36-inch anchor bolts, hexagonal nuts, 2½ inches of threads and loop for 2-inch pipe.	do	Do.
4	4	7/8 by 48-inch anchor bolts, hexagonal nuts, 2½ inches of threads and loop for 2-inch pipe.	do	Do.
5	4	¾ by 12-inch machine bolts, hexagonal nuts	do	Do.
6	7	5/8 by 5-inch machine bolts, hexagonal nuts	do	Do.
7	8	1½ inches by 15 inches old pipe	do	Do.
8	4	2 inches by 2 feet 6 inches old pipe	do	X, F.
9	1	Knockdown adjustable foundation form	do	
10	2	4 by 4 inches by 12 feet, Oregon pine, rough, for end sills.	8-foot motor house	X, B.
11	2	4 by 4 inches by 16 feet, Oregon pine, rough, for corner posts.	do	Do.
12	2	4 by 4 inches by 24 feet, Oregon pine, rough, for side sills.	do	Do.
13	16	2 by 4 inches by 12 feet, Oregon pine, rough, for cupola, gables, joists, plates, side girts, and studs.	do	Do.
14	4	2 by 4 inches by 14 feet, Oregon pine, rough, for purlins.	do	Do.
15	20	2 by 4 inches by 16 feet, Oregon pine, rough, for cupola, rafters, end girts, studs, and doors.	do	Do.

List of machinery and material, etc.—Continued.

Reference No.	Amount	Machinery and material	Classification	Plate No.
16	12	2 by 4 inches by 20 feet, Oregon pine, rough, for purlins and braces.	8-foot motor house	X, B.
17	2	2 by 4 inches by 24 feet, Oregon pine, rough, for plates.	do	Do.
18	2	2 by 4 inches by 12 feet, Oregon pine, surfaced one side, for girts at windows.	do	Do.
19	7	1 by 6 inches by 16 feet, Oregon pine, surfaced four sides, for facings, casings, louver, etc.	do	
20	1	2 by 3 inches by 6 feet, Oregon pine, surfaced four sides, for windows.	do	
21	6	1 by 4 inches by 16 feet, Oregon pine, surfaced four sides, for window trim.	do	
22	2	2 feet 6 inches by 2 feet 6 inches, plain mill windows, 6-light.	do	
23	25	Pounds 2-inch galvanized roofing nails	do	
24	15	Pounds 20-d. common wire nails	do	
25	10	Pounds 10-d. common wire nails	do	
26	3	Pounds 8-d. common wire nails	do	
27	1	Pound 4-d. common wire nails	do	
28	1	Pound 6-d. finishing nails	do	
29	2	Pair 8-inch strap hinges with 1½-inch screws	do	
30	34	26 by 96 inches, No. 26 gage, corrugated galvanized iron.	do	X, B.
31	26	do	do	Do.
32	3	26 by 84 inches, No. 26 gage, corrugated galvanized iron.	do	Do.
33	4	26 by 72 inches, No. 26 gage, corrugated galvanized iron.	do	Do.
34	3	Pieces, No. 26 gage, galvanized roll ridge-cap, 10 feet long.	do	Do.
35	1	Location sign	do	X, C.
36	1	Precaution sign	do	Do.
		Nine-foot motor house, used for wells with 10-foot band wheel, has identical material with those for 8-foot motor house, used for wells with a 9-foot band wheel, except items 11, 15 and 30 which are to be as follows:		
11	2	4 by 4 inches by 18 feet, Oregon pine, rough	9-foot motor house	X, B.
15	11	2 by 4 inches by 16 feet, Oregon pine, rough	do	Do.
	9	2 by 4 inches by 18 feet, Oregon pine, rough	do	Do.
30	34	26 by 108 inches, No. 26 gage, corrugated galvanized iron.	do	Do.
37	1	Countershaft	Power equipment—mechanical.	X, E.
38	2	Grease cup	do	X, F.
39	2	½-inch and 3-inch nipples	do	Do.
40	2	½-inch coupling	do	
41	1	10 inches by 36 feet 6 inches, 4-ply endless rubber belt.	do	X, E.
42	1	20-inch countershaft pulley, cast iron	do	Do.
43	1	40-inch, 48-inch or 60-inch countershaft pulley to give speed required. When old engine pulley is used in lieu of 20-inch pulley, the large pulley must be selected to meet conditions.	do	Do.
44	1	Motor, oil well, 30/15-hp., 3-phase, 60-cycle, 440-volt, two-speed variable, complete, with 12-inch diameter by 10½-inch paper pulley and pole changing switch with cover.	Power equipment—electrical.	Do.

List of machinery and material, etc.—Continued.

Reference No.	Amount	Machinery and material	Classification	Plate No.
45	1	Type 52-P controller with rope wheels	Power equipment—electrical.	X, E.
46	1	Type F, Form K-20, oil circuit-breaker	do	Do.
47	6	Type SG rheostat frames and grids	do	Do.
48	1	Type LM-5, 100-ampere, 500-volt, a. c., triple-pole switch.	do	Do
49	1	Metal junction-box, back of controller	do	XI, A.
50	1	Metal housing for pole changing switch to motor	do	X, E, and XI, D.
51	1	Grid and switch support	do	XI, C.
52	1	1¼-inch, type F, condulet, with 3-hole porcelain cover.	do	X, B.
53	2	2-inch, type A, condulets, with 5-hole porcelain cover.	do	X, E.
54	4	Feet 1¼-inch Greenfield flexible steel conduit	do	Do.
55	9	Feet 1½-inch Greenfield flexible steel conduit	do	Do.
56	2	1½-inch combination couplings	do	
57	2	1¼-inch panel box connections	do	
58	4	1½-inch panel box connections	do	
59	1	2-inch conduit unit	do	X, E, and XI, E.
60	1	1½-inch conduit unit	do	Do.
61	20	Feet 1¼-inch black conduit	do	X, E.
62	2	1¼-inch conduit bends	do	
63	1	U-bolt clamp 1¼-inch conduit	do	X, E, and XI, F.
64	1	1¼-inch steel lock nut	do	
65	1	1¼-inch lock bushing	do	
66	6	Ground clamps, adjustable, ½ inch to 3 inches	do	
67	250	Feet No. 4. R. C. stranded copper wire	do	
68	80	Feet No. 4 flame-proof copper wire	do	
69	28	⅜-inch by 1¼-inch machine bolts, for grids	do	
70	1	½-inch by 8-inch machine bolt, for cross arm	do	
71	16	⅜-inch by 1-inch machine bolts	do	
72	1	4-inch by 6-inch by 22-foot round redwood service pole.	do	X, E.
73	1	4-inch by 4-inch by 40-inch 3-pin redwood cross-arm	do	
74	3	1½-inch by 9-inch locust pins	do	
75	3	Insulators, Thomas	do	
76	2	½-inch by 2-inch nipples, no thread, for controller	do	
77	4	1¼-inch pipe straps	do	
78	1	Type M transformer, air-cooled, 60-cycle, 250-watt, 440/110-volt, with ¾-inch conduit end bells.	do	X E.
79	1	½-30 ampere, 500-volt, a. c., double-pole, fused safety first switch.	do	Do.
80	9	Branch spragulets	do	Do.
81	9	C-1 flat closed covers	do	
82	2	¾-inch spragulet couplings	do	
83	22	½-inch spragulet couplings	do	
84	2	1-ampere, 600-volt, inclosed fuses	do	
85	2	½-inch steel lock nuts	do	
86	2	½-inch lock bushings	do	
87	4	½-inch, type V, condulets with porcelains, receptacles, globes, and guards.	do	X, E.
88	1	½-inch, type VC, condulets with porcelains, receptacles, globes, and guards.	do	Do.
89	1	½-inch, type H-15, condulet	do	Do.
90	1	Snap switch metal cover	do	Do.
91	5	60-watt Mazda lamps	do	
92	60	Feet, ½-inch galvanized conduit	do	Do.
93	16	½-inch pipe straps	do	

List of machinery and material, etc.—Continued.

Reference No.	Amount	Machinery and material	Classification	Plate No.
94	160	Feet, No. 14, R. C. solid copper wire	Power equipment—electrical.	X, E.
95	2	4 inches by 4 inches by 12 feet, Oregon pine, surfaced four sides.	Guard rail	
96	2	2 inches by 4 inches by 12 feet, Oregon pine, surfaced four sides.	do	
97	3	1 inch by 4 inches by 18 feet, Oregon pine, surfaced four sides.	do	
98	7	Guard-rail shoes	do	X, A, and XI, F.
99	64	2-inch flat-head wood screws	do	
100	6	3/16 inch by 4 inch stove bolts	do	
101	1	9-inch Star coil spring	do	
102	1	Pair 6-inch Stanley tee hinges	do	
103	1	13/16 inch by 2 inches by 12 feet, Oregon pine, clear, surfaced four sides.	Safety mat	XI, F.
104	1	13/16 inch by 12 inches by 16 feet, Oregon pine, clear, surfaced four sides.	do	Do.
105	5	3/8-inch by 36-inch dowel pin stock	do	Do.
106	1/4	Pound furniture glue	do	
107	1	8 by 12 inches by 18 feet, Oregon pine, rough	Counter balance	XI, B.
108	1	1½ inches by 8 inches by 20 inch stirrup	do	Do.
109	3	3/4 inch by variable machine bolts	do	Do
110	1	1 inch by variable hook rod, from old sucker rod	do	Do.
111	1	1¼ inch by 2 foot 3 inch eyebolt	do	Do.
112	2	3 inch by 12 foot jointed tubing or pipe	do	Do.
113	2	4 inch by 2 foot tubing or pipe (no thread)	do	Do.
114	6	Sacks standard cement	do	
115	1	Cubic yard sand and gravel	do	
116	12	Pieces 7/8 inch by 1 foot 10 inches, old sucker rod, for reinforcement.	do	XI, B.
117	40	Board feet of scrap lumber	do	Do.

COUNTERBALANCE FOR BEAM PUMPING.

With the introduction of electric power for pumping oil wells, balanced load has received more attention and marked saving of power has resulted. By meter readings it is possible to determine exactly the amount of power needed to operate each well pumping on the beam. The counterbalance, however, has been used for years in the oil fields of the East, not to save power but to insure a balanced load and thus obtain a smoother stroke at the polish rod. With steam engine or gas engine drive there is sometimes a tendency, if the load is unbalanced, to pick up the rods with a jerk. A counterbalance eliminates much of this trouble. With motor drive and unbalanced load the motor is liable to heat. At several wells[14] pumping oil of 26° B. by electricity from depths of about 3,600 feet (fluid levels of 2,800 feet) motors of 20 to 50 horsepower run without counterbalance heated to temperatures of 180° to 190° F. With counterbal-

[14] W. L. Boles of the Coalinga Mohawk Oil Co.

ances the maximum temperature was about 160° F. and the decrease in power consumption was noticeable. The author has seen the record of a deep well in another California oil field where by using a counterbalance $40 a month in cost of electric power was saved. A company in the Eldorado oil field, Kansas, which is pumping a number of wells on the beam by gas-engine drive, has cut the consumption of gas by the gas engine more than 15 per cent by the use of counterbalance.

The saving in power consumption by a counterbalance is usually between 10 and 20 per cent; it varies with conditions at each well and with the kind of power equipment used for pumping.

TYPES OF COUNTERBALANCE.

Plate XI, B (p. 60), shows the concrete-block type of counterbalance which is coming into general use for permanent beam-pumping plants. The concrete block is suspended by an iron rod from the end of a timber bolted to the power end of the walking beam. When the block is poured two pieces of 4-inch pipe are placed vertically in it to serve as sleeves for two pieces of 3-inch pipe which are placed vertically and concreted into the pier. Thus the two pieces of 3-inch pipe serve as guides to the counterbalance as it rises and falls with the reciprocating motion of the walking beam. Some guides have at the top of the concrete pier a threaded coupling to facilitate the installation of the counterbalance, but generally this is poor practice because the pipe works loose from the couplings, destroys the threads, and causes trouble.

Some counterbalances are made with four guides and sleeves instead of two. Others are made in slabs so that the number can be increased or decreased to balance the load. Plate IX, *C* (p. 45), shows a well being pumped on the beam without the use of a counterbalance. Plate XII, *A* and *B*, show two common types of counterbalances for beam pumping, each box filled with stone or old iron. In the type shown in Plate XII, *A*, at *a*, the box rests on a bearing on the ground and the upper part of the frame is attached to the wrist pin of the band-wheel crank arm by a steel cable that passes under a pulley anchored below the wrist pin. Plate XII, *B*, shows a counterbalance consisting of a box suspended from the end of the power arm of the walking beam by a steel cable or steel rod at a point between the pitman and the Samson post. Another type is suspended from a timber extension of the power arm of the walking beam by a steel cable or steel rod, and is at a point between the pitman and the engine house.

The type shown in Plate XII, *B*, is held in a vertical plane by means of an arm and support extending from the box container to a bearing or hinge. This arrangement is not as good as suspension from a timber extension of the power arm of the walking beam, because a given weight of counterbalance will not be as effective and its location may interfere with the lowering of the walking beam.

Other crude but serviceable types of counterbalance are: A box of stone or old iron placed on top of the end of the power arm of the walking beam and old logs or old timbers suspended at one end by a steel cable or steel-rod attachment to the power-arm end of the walking beam. The latter type is sometimes used where timber is plentiful and stone is scarce.

When the counterbalance is hung from a timber extension of the power arm of the walking beam this extension is generally 8 by 8 inches to 12 by 12 inches in sectional area, depending upon the distance it extends beyond the end of the walking beam and the weight required for proper counterbalancing. Some oil companies use spiked or bolted planks instead of solid timber.

Close adjustment of the type of counterbalance shown in Plate XI, B (p. 60), can be made by changing the point of support on the timber extension of the walking beam.

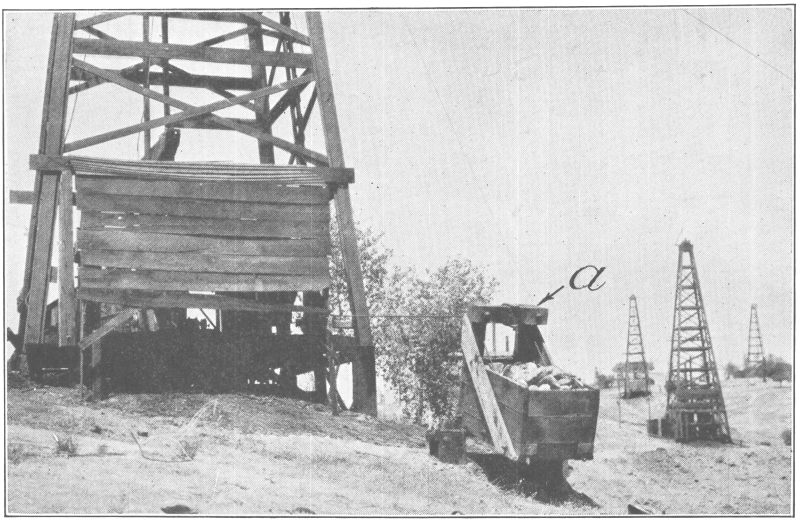
SUMAN PUMPING JACK.

The Suman pumping jack, shown in Plate XIII, *A*, is described by John R. Suman, of Houston, Tex., as follows:

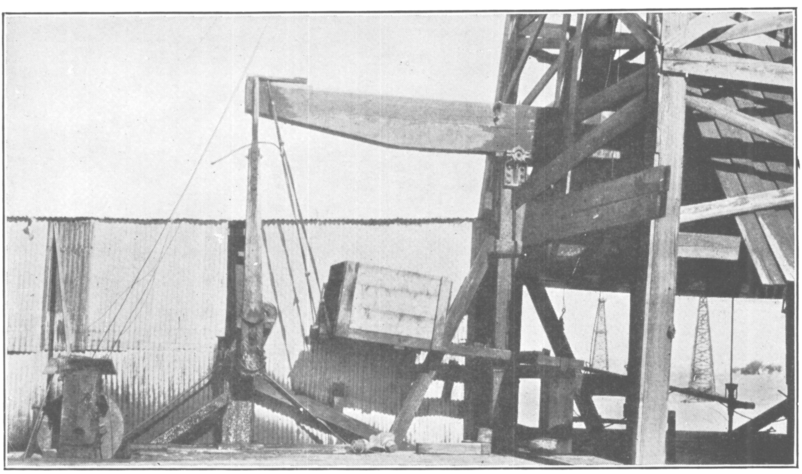
This apparatus was designed in an effort to get together a pumping jack which would do the same work as a standard rig and which at the same time would be simpler, cheaper to install, and have a lower rate of depreciation. The standard pumping rig, consisting of bull wheels, band wheel, belt house, mud sills, etc., is a very cumbersome affair, requiring about 12,000 board feet of lumber in its construction. In territory such as the Gulf Coast, southern Oklahoma, northern Louisiana, and southern Arkansas, where rotary tools are used altogether, this part of the rig is used exclusively for pumping and is not constructed until after the well has been completed.

The standard rig has a very high rate of depreciation, especially in the territory mentioned, where leaky belt-house roofs are quite common with the attendant slipping belt and lowered production. The construction of the ordinary standard rig requires five or six days' time, causing serious delay where offset wells are being brought in. The weight of the material which goes into this rig is no inconsiderable item, and quite often in regions where the roads are bad considerable trouble and delay are caused before it is all delivered to the location.

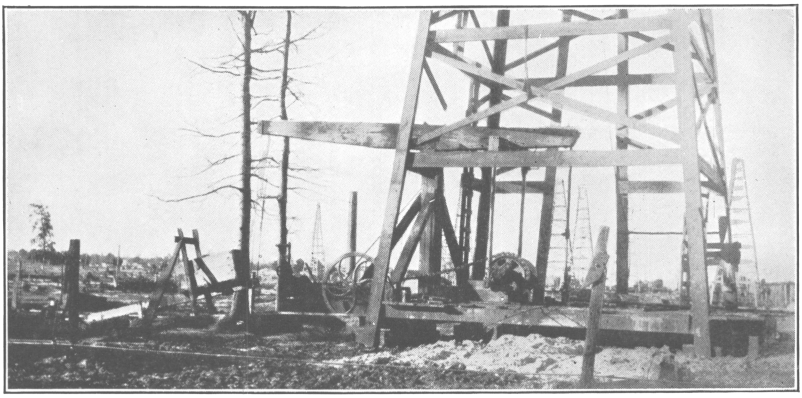
The Suman pumping jack is a very simple and light apparatus which can be hauled to the location in one load, can be set up in a few hours, and will operate in any kind of weather without a housing of any sort. It is shown in Plate XIII, *A*, as being driven by a steam engine, but it can be driven equally well with the standard oil-field motor by using a countershaft. The apparatus consists of a revolving shaft on which are mounted a sprocket, a drum, and a crank arm at either end. The sprocket is keyed to the shaft and the drum idles on the shaft, being thrown in and out of motion by means of a clutch. The shaft runs



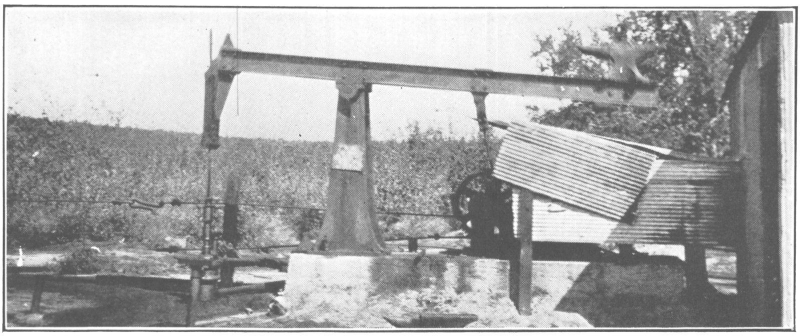
A. COUNTERBALANCE, *a*, ATTACHED TO WRIST PIN OF BAND-WHEEL CRANK ARM



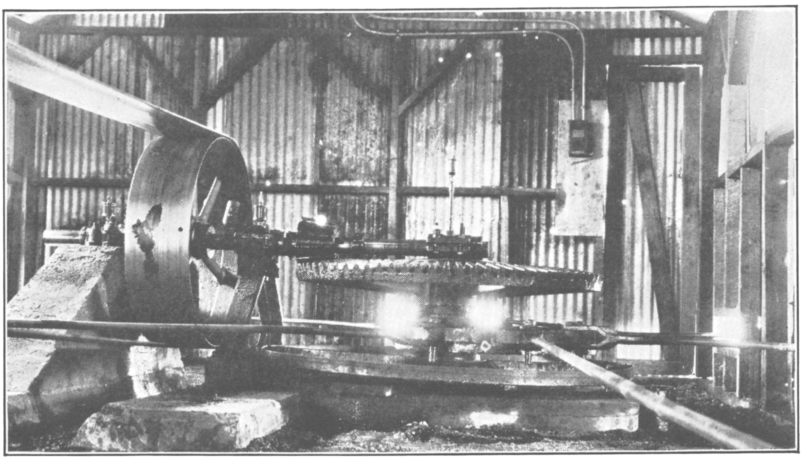
B. COUNTERBALANCE ATTACHED TO BEAM



A. SUMAN PUMPING JACK, SARATOGA, TEX.



B. UNIT PUMPING POWER, BARTLESVILLE, OKLA.



C. GEARED POWER, COALINGA OIL FIELD, CALIFORNIA in bearings, which are in turn supported by a suitable framework. The sprocket is connected to the engine by a chain drive of No. 1030 or No. 1240 chain, the same as is used in driving a rotary draw works. The engine sets on sills which are in the same position as for use in drilling a well with rotary tools. The throttle controlling the speed of the engine, the reversing lever and the clutch lever are in the same relative position on the derrick floor as they are in rotary drilling. Hence, anyone familiar with the operation of rotary drilling equipment will easily adapt himself to the operating of this equipment in pulling rods and tubing and in bailing. By means of wrist pins in the crank arms, a reciprocating motion is given to the walking beam by means of the pitmans and the cross yoke. The walking beam, Samson post, and saddle irons are identical with those in use in the ordinary standard rig, except for the notches in the lower side of the walking beam. These two notches are so cut as to make the beam suitable on a derrick having either a 22-foot or a 24-foot base. On the end of the walking beam which protrudes outside of the derrick an ordinary counterweight is attached. This is not shown in the illustration.

The lower connection from the pitman to the wrist pin is adjustable. This is the means of adjusting the length of pitman so as to make up for any irregularities in the level of the derrick floor.

The crank arms having holes as shown in the accompanying illustrations will allow for pumping strokes of 24, 32, 40, and 48 inches. In test runs at Saratoga, Tex., in a well 1,500 feet deep, it was possible to maintain a pumping speed of 30 strokes per minute of a length of 40 inches without any trouble whatever.

A standard pumping rig having a 30-inch pulley on the steam engine and a 10-foot band wheel (4 to 1 ratio) will impart a pumping speed of 30 strokes per minute when the engine is running at 120 revolutions per minute. The Suman pumping jack using an 8-tooth sprocket on the engine and a 27-tooth sprocket on the drive shaft (3.375 to 1 ratio) will impart a pumping speed of 30 strokes per minute with the engine running at only 101.25 revolutions per minute. If a 32-tooth sprocket is used on the drive shaft the power ratio becomes identical with that on the standard rig.

It is believed that the depreciation of this type of pumping jack is only about one-fourth that of the ordinary standard rig. The cost of this outfit is only about one-third the cost of the ordinary standard pumping rig using 5-inch rig irons.

The power ratios being practically the same, it is quite evident that pulling rods and tubing and bailing can be carried on with the Suman jack with the same degree of speed and power as with the standard rig. When carrying on these operations the pitmans are disconnected and the walking beam is pointed up into the derrick in the same manner as when using the ordinary standard rig. In the operation of bull wheels, however, one man is required at the brake and another one at the throttle. In the operation of the Suman jack doing identical work, one man handles both the brake and the throttle.

UNIT PUMPING POWER.

Some of the oil-well supply companies manufacture unit pumping outfits for a single well, which by using a balanced load can often be adapted for pumping a group of two or three wells. These unit powers generally consist of a small wooden or steel counterbalance beam, Samson post, and pitman mounted on a concrete, wooden, or steel main sill and driven by a small motor, or oil or gas engine, by belt, chain, or gear drive.

Portable unit pumping powers are used in some of the older and shallower oil fields for testing individual production of isolated wells or for wells that need to be pumped the full 24 hours. Such wells can not be pumped advantageously by the power unit for the other wells in the vicinity which are pumped only a few hours a day.

The Brundred Bros., oil producers of Oil City, Pa., use several of these portable pumping units, each consisting of a wagon truck on which is mounted the power equipment of 6 or 8 horsepower gas engine, gears, pitman, walking beam, and accessories.

Some of the traction drilling machines used in the oil fields are also designed for use in pulling rods and tubing, cleaning out old wells, and pumping the well until other means are provided.

Plate XIII, *B*, shows a unit pumping power at the property of the Interstate Oil & Gas Co. near Bartlesville, Okla. This small power pumps three wells, the one at the power location by means of the beam and the other two by shackle-line connection from the wrist pin of the large gear forming part of the power to a jack at each of the two wells. The three wells pumped are each about 1,300 feet deep and equipped with 2-inch tubing. A stroke of 20 inches is used at a rate of 21 strokes a minute. The wells are pumped about eight hours a day and the production from the three wells averages about 80 barrels a day. An 8-horsepower oil engine, belt-connected for driving, uses 3½ to 4 gallons of crude oil a day.

Other types of small-geared powers, run without a beam, are sometimes used for individual drive by use of counterbalance, but this type is designed chiefly to operate from two to five shallow wells by means of shackle lines and jacks.

EQUIPMENT FOR PUMPING GROUPS OF WELLS.

Groups of wells are pumped either by modifications of the beam pumping system used for individual wells, or by means of jack plants or powers. In either system shackle lines and jacks are used to transmit power.

SYSTEMS BASED ON MODIFICATION OF BEAM PUMPING.

Sometimes the power for pumping is transmitted from the beam at one well to the beam at another well by means of two jacks connected by a shackle line; each jack is connected to the walking beam by means of a pitman attachment, one beam delivering the power and the other beam receiving it. Figure 8 is an example.

In a modification of this method, two additional wells are pumped by attaching a pipe or steel rod near each end of the walking beam of the first well. The lower end of each of these steel rods is attached to a piece of sprocket chain that passes under a sprocket wheel supported by bearings attached to the main sill. The lower and outer end of each of these sprocket chains is attached to the shackle line leading to a well being pumped by a jack.

This method, as used by the Texas Co. in the Homer oil field, Louisiana, has recently been described by Steen.[15]

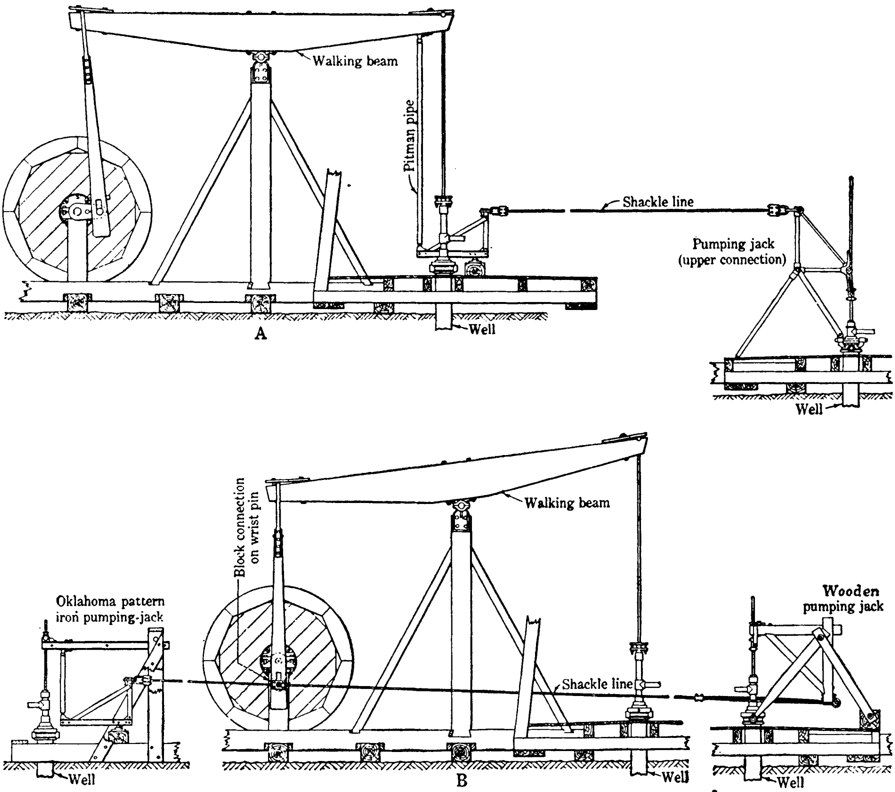


FIGURE 8.—Modification of beam pumping; use of two jacks and a shackle line.

Figure 8, B, is an example of two wells being pumped by shackle lines attached by a block to the wrist pin on the crank arm of the band wheel and delivering power to jacks, one at each of the wells. This method of pumping is known as pumping by jerk line. When the load is properly balanced, the method is often used to pump four or five wells from the wrist pin of one well pumping on the beam.

[15] Steen, A. B., Making three blades of grass grow where one grew before, The Texaco Star, Sept., 1922, pp. 9–10.

This latter method of pumping is common where a number of wells are situated at intervals along a property line, as are a number of wells of the Pacific Oil Co. of Coalinga, Calif. Under such conditions, there being no interior wells near by, this method is much more satisfactory than the use of a power or jack plant.

Plate XIII, *B*, shows a unit pumping power, previously described, being used, by a modification of the jerk-line method, to pump two additional wells.

PUMPING BY THE ENDLESS CABLE SYSTEM.

The endless cable system of pumping has been used for years to pump shallow oil wells at Volcano, W. Va.[16]

This system of pumping has also been used for about 25 years by the Burma Oil Co., at Yenangyung, Upper Burma, India, where 20 wells ranging in depth from 300 to 400 feet are pumped on the beam by one 15-horsepower engine. The wells were drilled with a light standard rig with a small band wheel, walking beam, and derrick. At the time of drilling there were not enough engines for one to pump each well and this system was developed to meet the shortage.

The entire system consists of a boiler with a 15-horsepower steam engine belted to a band wheel 18 feet in diameter, with a tug pulley attached to its side, and two small steel tug-pulleys, one opposite each edge of the band wheel and each mounted on the top of a braced post at a point just above the top of the band wheel. The endless wire rope runs over one of these small steel tug-pulleys, around the lower half of the tug pulley of the large band wheel, and then over the top of the other small tug pulley. The 8-foot band wheel at each of the wells is similarly equipped. The steel cable runs from the main band wheel to the tug wheels and band wheel of the first oil well, from there to each of the other oil wells, and finally back to the main band wheel.

Each of the carriers for the cables between wells consists of a flanged steel pulley 18 inches in diameter mounted on the top of a small wooden derrick. Suitable direction of approach for the cable at each well is insured by means of a flanged steel wheel 18 inches in diameter mounted as an idler on the top of a braced post. The cable lasts about three years and seldom breaks.

The wells are about 300 feet apart, and are equipped with 2-inch tubing and 1⅝-inch wooden sucker rods. They are pumped nine hours a day with a 14-inch stroke and 20 strokes a minute. The oil produced has a gravity of 45°.

[16] Rig and Reel Magazine, Pumping by endless cables: March, 1923, pp. 1–5.

S. C. Sampson, who was in charge of this property for a number of years, states that the installation and maintenance of this system in a tropical climate, such as that of India, have been much more expensive than the installation and operation of a central power or jack-plant system.

SYSTEMS OF JACK-PLANT OR POWER PUMPING.

The jack-plant or power system of pumping oil wells by groups was developed about 30 years ago in the oil fields of Pennsylvania to meet the need for lower operating costs, which the decline in crude oil prices and production per well necessitated.

There are three types of jack plants or powers: A, Push-and-pull powers; B, geared powers; and C, band-wheel powers. The first and last named were originally made chiefly of timber, but in recent years the tendency has been to make all types of powers of steel, although some types of band-wheel powers still have the wooden band wheel.

No attempt is made here to discuss the relative merits of these different types of powers. Both well and poorly designed powers of each type are on the market and in use. The number and depth of the wells to be pumped, their relative location, and the operating conditions to be met must all be considered in deciding the size and type of power that will give best results.

Poor results from jack plants or powers can be more often traced to equipment too light for the service required, improper foundations, or improper alignment of installation than to any defects of the type used. After the type to be used has been chosen it is well to compare the different designs available and to buy a make that is well built and has been proved by service.

PUSH-AND-PULL POWERS.

One of the first powers developed in the oil fields was the push-and-pull type shown in Figure 9. It was made mostly of timber with wooden pull wheels and 2 by 4 inch main pull lines held together with bolted steel plates. Many powers of this type were once used in the oil fields of northern Pennsylvania. The power proper was serviceable, but the use of wooden pull lines between the primary and secondary pull wheels was a constant source of trouble, as the lines often parted at the strapped couplings, especially during long dry periods in the summer. In addition, there was considerable lost motion between the pull wheels because of the difficulty of keeping the wooden pull lines in proper tension. Motion is also lost because of the working loose of the wooden keys in the power proper and in the primary and secondary pull wheels. For this kind of service it is very difficult to make timber braces rigid even when well seated, bolted, and keyed.

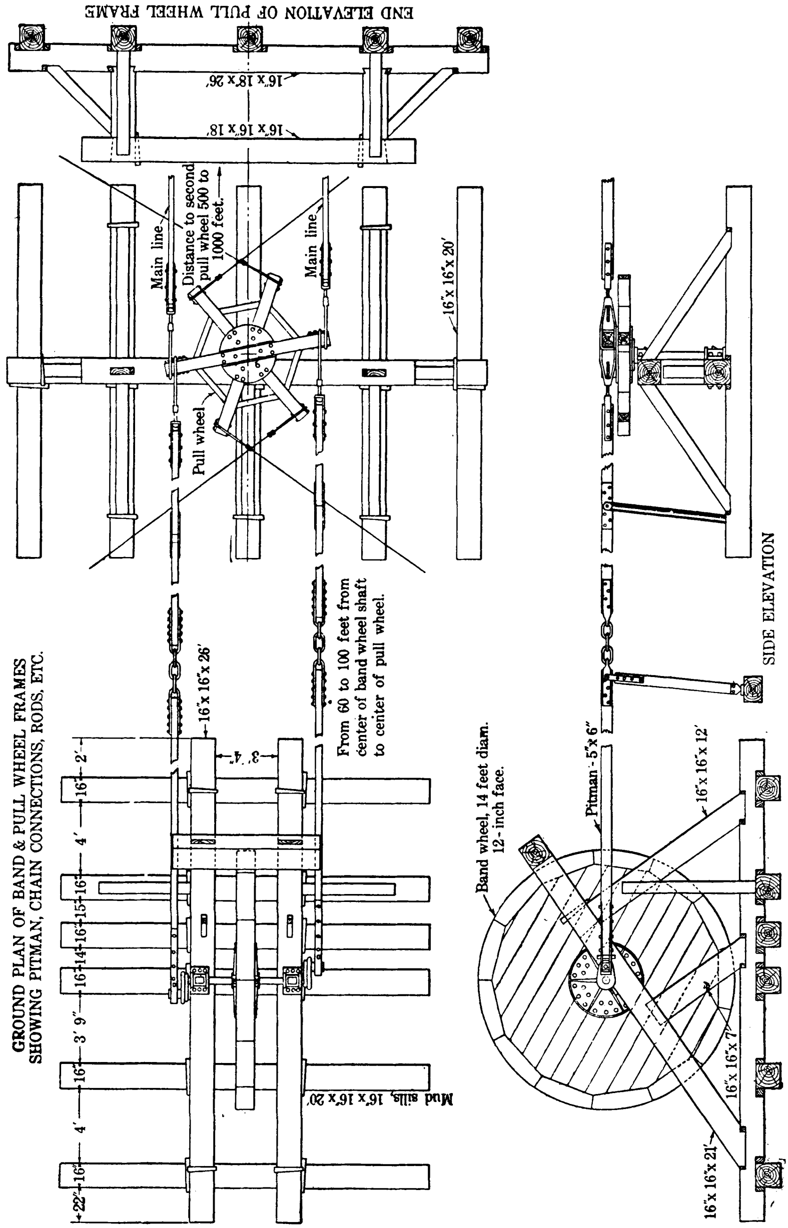


FIGURE 9.—One of the first powers developed in the oil fields; push-and-pull type, timber construction.

A modern type of push-and-pull power, using steel-rod pull lines and having well-built and properly erected pull wheels, with the same general arrangement as used in this old type, can be used satisfactorily, especially for a property about three locations wide and seven locations long with a total of 21 wells to be pumped from one power.

The modern push-and-pull power of iron is driven by an engine or motor through a belt to a pulley on a countershaft to which is attached a pinion meshing with a large gear wheel mounted on a shaft having two crank arms. A pitman connects each crank arm to a horizontal iron disk mounted on a vertical shaft and anchored to a concrete foundation. The revolution of the pulley imparts a reciprocating motion to the disks, which move in a horizontal plane, and impart reciprocating motion to the shackle lines. When the number of wells to be pumped is small often only one disk is used, and the second pitman and crank arm are not needed. Plate XIV shows the plan and section of a modern power of this type, manufactured by one of the oil-well supply companies and commonly used.

A single-disk power of this type is generally run by a 25-horsepower engine or motor and is designed to handle from twelve to fifteen 1,600-foot wells, or eight to ten 2,500-foot wells, or a proportionate number of deeper wells. A double-disk power is generally run by a 35-horsepower engine or motor and when properly balanced will handle nearly twice the load of the single-disk power.

Efficient service from this type of power requires good foundations and proper alignment, a balanced load, frequent lubrication, proper condition of babbitt in boxes, and tight nuts, bolts, and keys. The pulley on the countershaft should be of such a size that the crankshaft will make 16 to 20 revolutions a minute, which imparts the same number of strokes to the shackle lines.

GEARED POWERS.

Geared powers are of three general types: The spur gear and crank-arm type, the bevel gear and disk type, and the bevel gear and eccentric type.

SPUR GEAR AND CRANK-ARM TYPE.

The spur gear and crank-arm type consists of a horizontal countershaft with drive pulley and a pinion that meshes with a spur gear wheel mounted on a horizontal shaft having two crank arms, to each of which several wells may be attached, by adjustable wrist-pin connections, to give a range in length of stroke of 12 to 18 inches. This arrangement is similar to the corresponding part of a push-and-pull power; but it is generally built much lighter and is designed to handle four or five wells less than 1,000 feet deep. With a balanced load, a 10-horsepower engine will serve. Figure 10 shows a plan and section of this type of power; *a*, *b*, *c*, and *d* are attachments for shackle lines.

BEVEL GEAR AND DISK TYPE

Small powers of the bevel gear and disk type consist of pulley, shaft, beveled gear and pinion, wrist pin, and disk mounted on a cast-iron bed plate, with the large gear placed to revolve in a horizontal plane. Usually, three wrist-pin adjustments on the upper face of

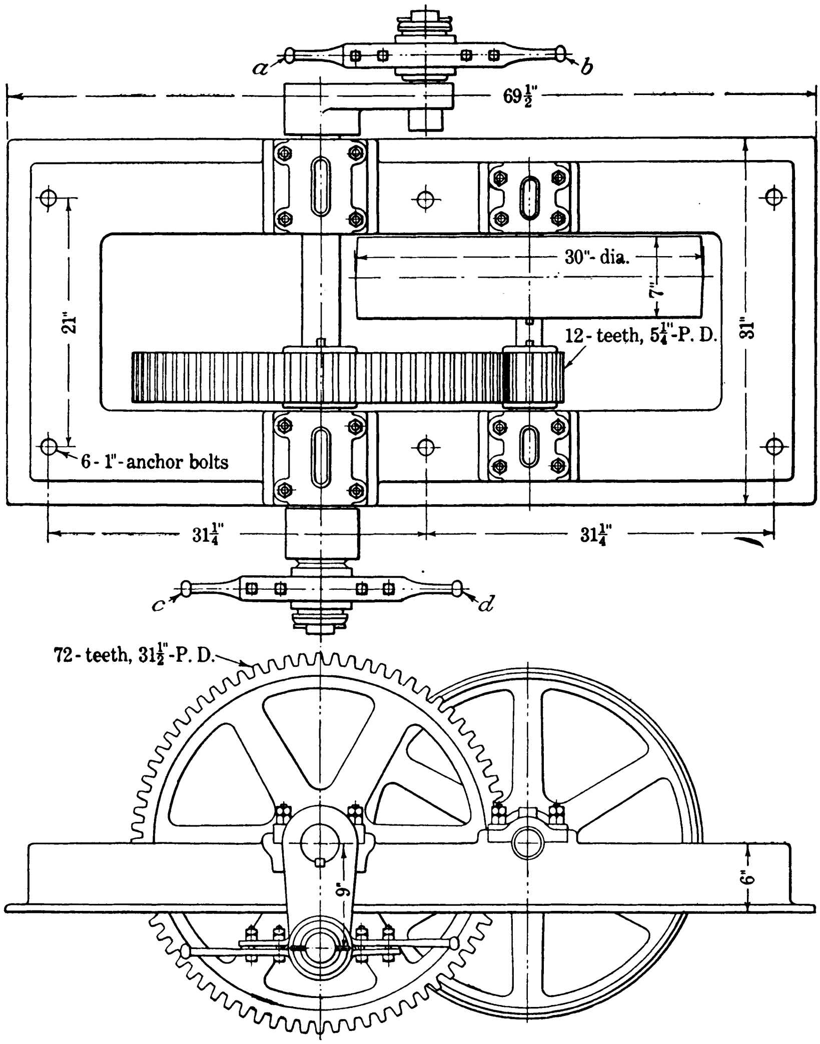
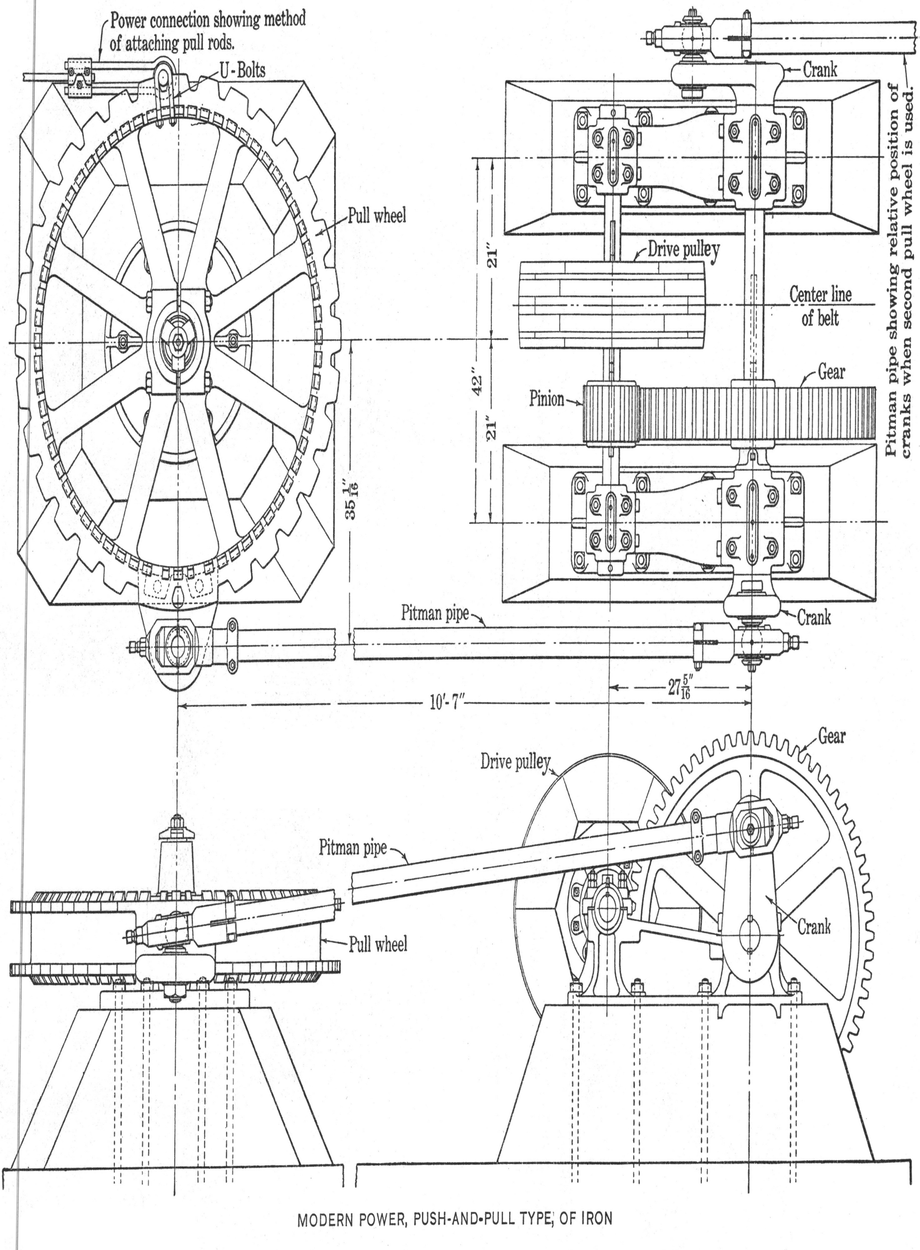


FIGURE 10.—Small spur gear and crank-arm type of power.

the gear permit three different positions of the disk with reference to the gear axis, and thus allow three different lengths of stroke. These powers are light, strong, and compact and are well suited for pumping two to six shallow wells. The disk on the wrist pin wears rapidly, however, unless enough bearing surface is insured by using



MODERN POWER, PUSH-AND-PULL TYPE, OF IRON a wrist pin of large diameter and a correspondingly large opening in the disk.

This type of power may be either small and of light construction to pump a few shallow wells, or large and of heavy construction to pump a larger number of deep wells. One of the largest, strongest, and best built powers the writer has seen in operation is of this type. Five or six years ago the Producers Oil Co., Houston, Tex., designed this power to handle deep production at some of its properties in the Texas oil fields, using the maximum stroke required without multiplying. One of the oil-well supply companies is now manufacturing this power with modifications as to length of crank-arm stroke to meet the requirements at any property. The three lengths of crank-arm stroke, 20 inches, 32 inches, and 38 inches, should ordinarily eliminate the need of multiplying to obtain increased length of stroke.

Several deep-well powers of this type are used in the Humble oil field, Texas. Each is direct connected to a 55-horsepower oil engine, to avoid the use of a belt, uses the 38-inch crank-arm stroke, and pumps 16 or 17 wells of an average depth of 3,500 feet. The chief engineer of the company using these powers says that one has worked nine months and another six months without a shutdown. The cost of this deep-well power with buildings and equipment, installed several years ago, is shown in Table 6.

TABLE 6.—*Cost of deep-well power, building, and equipment, near Houston, Tex.*

Galvanized, corrugated iron building.		Dimensions.
Original building (walls and roof)	$254.88	16 by 22 feet by 9 feet.
Concrete pit	309.00	16 by 22 feet by 3 feet 6 inches.
Addition to rear (walls and roof)	171.36	14 by 20 feet by 9 feet.
Concrete pit in addition	208.00	14 by 20 feet by 2 feet.
Addition to front of building (walls and roof)	36.36	4 by 5 feet by 9 feet.
Concrete foundation for above addition	7.40	
Addition to side of building (walls and roof)	49.14	5 by 7 feet by 9 feet.
Concrete foundation for above	9.80	
Concrete pit in above addition	32.75	4 by 5 feet by 3 feet 6 inches.
	1,078.69	
One 55-horsepower oil engine	3,227.00	
Concrete foundation under engine block	120.00	3 by 9 feet by 6 feet.
Concrete block under engine	23.33	3 by 9 feet by 14 inches.
Deep-well power with countershaft, etc	2,839.86	
Concrete foundation under power	471.20	9 by 10 feet.
Concrete foundations under cut-off coupling with above power.	44.40	3 by 5 feet by 4 feet.
Two concrete blocks under cut-off	4.00	14 by 36 by 12 inches (base). 14 by 30 by 12 inches (top).
One Goulds No. 2 rotary pump	113.25	
Two 50-barrel Donovan steel tanks	130.00	
Two platforms for tanks	101.42	
	7,074.46	
Sucker rods (250 feet) used as hook-off rods	28.55	
Miscellaneous connections	67.02	
Pipe and fittings	241.43	
	337.00	
Total	8,490.15	

Plate XV shows a plan and vertical section of this power, now operating in the Humble oil field near Houston, Tex. It consists of a base plate, *a*, bolted to a concrete foundation by eight large bolts. In the center of the base is a vertical shaft around which the table *b* revolves. Between this table and the shaft is a replaceable liner to take up wear. The table is supported on the base by a horizontal bearing surface, which has an outside and an inside oil channel running around the entire circumference. By means of a pump the surfaces are supplied with oil to insure ample lubrication. Any surplus oil runs into a sump at the base of the vertical shaft and is led off in a drain pipe. A mud band that entirely surrounds the gib over the bearing surface protects the surface from dirt and other foreign matter.

The table also carries the cranks *c* and *d* and the gear table *e*, both of which are firmly bolted to it. A steel pinion, *f*, firmly held in place by a key and a large nut and lock washer, drives the gear table. The pinion and shaft are supported at the table by a strong heavy bearing box, *g*, which is firmly bolted to the base. The cranks are of cast steel and carry two disks or crank rings, *h* and *k*, one above the other and 38 inches between centers. These rings are of cast iron, babbitted to the crank, and are cast in halves fastened together by six bolts which can be tightened to take up the wear. Each disk or ring has 16 brass bushing holes, to each of which a shackle line leading to a well can be attached. Each ring is well lubricated and has a stroke of 38 inches, but this stroke may be varied according to the size of the crank used. The gear ratio in the power is 8 to 1.

Fifty-five horsepower is needed, and a steam, gas, or oil engine may be direct connected. This "power" was especially designed to pump wells 3,500 to 4,000 feet deep. The 55-horsepower oil engine is shown at *l* connected by a coupling, *m*, to the drive shaft *n*. At *o* is a clutch that is thrown out until the engine is started. The air compressor *p* belt-connected to the pulley *m* on the drive shaft supplies air to a receiver, where it is stored to start the engine. A rotary pump, *q*, is driven by the pulley *r*.

BEVEL GEAR AND ECCENTRIC TYPE

For more than 20 years bevel gear and eccentric powers have been common in the oil fields. In construction they are similar to the bevel-geared disk type, except that eccentrics, instead of crank and disk, are used on the vertical gear shaft to impart motion to the shackle lines. Generally they are made with one, two, or three eccentrics, according to the number of wells to be pumped. Two eccentrics are generally placed 180° apart and three eccentrics 120°

apart to give a balanced load. When the eccentrics are placed on the shaft above the gear wheel, the power is termed an overpull type; when the eccentrics are placed under the gear wheel the power is termed an underpull type. In some overpull types the eccentrics are between the gear wheel and the top of the frame; in some they are on an extension of the shaft above the top of the frame; and in some one eccentric is between the gear and the top of the frame and the other is on an extension of the shaft above the top of the frame. If a third eccentric is used, in some powers it is put above and in others below the top of the frame. Still other types of both overpull and underpull bevel-gear and eccentric powers are designed without braces and frame work above the gear wheel, and depend more on the weight and stability of the foundation for rigidity. The relative merits of the different types of bevel gear and eccentric powers are not discussed here.

In a rough, hilly country, where conditions require the shackle lines to be carried some distance from the ground, the overpull power is often advantageous; in a flat country, without timber and obstructions to shackle lines, the underpull power may be proved the more satisfactory.

As a general rule, the longer the shaft carrying the gear and eccentrics, the more the reliance placed on the braces; the shorter the shaft, the more the reliance on the mass and rigidity of the foundations. Generally, with other conditions equal, the nearer the gear and eccentrics are to the ground the more satisfactory will be the service, provided the foundations are suitable, for there will be less chance for play and stresses to develop.

Plate XIII, *C* (p. 63), shows a power of the bevel gear and eccentric type but without top braces. It is rigidly held in place by a heavy concrete foundation.

BAND-WHEEL POWERS.

Band-wheel powers are similar to the bevel gear and eccentric type, except that a large belt-driven wooden or steel band wheel—16 feet, 18 feet, or 20 feet in diameter and usually with a 14-inch or 15-inch face—is used instead of a bevel gear and pinion drive. The position of the eccentrics with reference to the band wheel varies as does that of the eccentrics with reference to the gear in the bevel gear and eccentric type. If top braces are used, they have to be long, strong, and firm, because of the larger diameter of the band wheel and the consequent greater lateral thrust. If no top braces are used, a heavy, firm concrete foundation is necessary for the same reason. This latter type of band-wheel power is shown in plan and vertical section in Plate XVI, where *A* is the engine driving the power, *B* is the idler or belt tightener, and *C* is the band wheel with eccentrics.

Most operators who have used both steel and wooden band wheels prefer the former because they are lighter, smoother, give less wear on the belt, and are more rigid. A wooden wheel must be made of seasoned lumber, or it may become rim bound and warp, which will necessitate removing a section between two of the spokes, drawing up the wheel, and rebuilding the removed section. If a wooden wheel is dished 2 inches toward the center, any tendency to sag will tighten the wheel, and the oil used for lubricating the shaft will not tend to run toward the rim and get on the belt.

Plate XVII, shows a new band-wheel power before being housed, with the engine *a*, the idler *b*, the steel-rod-braced wooden band-wheel with eccentrics for shackle-line attachment *c*, take-off rail for shackle lines *d*, water-circulating tank for engine *e*, and concrete floor. Plate XVIII, *A*, shows a steel band-wheel, with eccentrics in place, ready for the belt.

DIRECT-CONNECTED ELECTRIC MOTOR-DRIVEN AND GEARED PUMPING POWER.

With the development of electric power for pumping oil wells, the type of equipment has been improved. Recently attention has been directed to the possible use of a direct-connected motor-driven and geared pumping power. One of the larger oil companies is developing a power of this type. Briefly, it consists of gears and eccentrics driven by an electric motor bolted to the top of the power frame. Although the merits of this type of power have not yet been proved by service, its use will doubtless be general in a few years.

IDLERS FOR BAND-WHEEL POWERS.

The idler should be so placed that the upper length of belt, as it leaves the engine, travels as nearly as possible directly above the lower length. The idler frame should be parallel to the lower belt length so that as the belt stretches and the idler is tightened, a side pull tending to strain the fiber will not be developed in the belt as it leaves the engine pulley. The idler should not be too near the engine pulley, for then the friction surface of the belt on the band wheel will be decreased, requiring a tighter belt, and the belt will be twisted in too short a distance to meet the face of the idler, which also will tend to strain the fiber of the belt. The idler should not be placed too near the band wheel, because then the belt is twisted in too short a space as it leaves the face of the idler to meet the face of the band wheel, which likewise tends to strain the belt fiber. The proper position and measurements for the idler are shown in Plate XVI (p. 74).

Idlers are of two general types: Those that are mounted on a frame bolted to a foundation and adjustable within the frame; and those that consist of a loose pulley on a shaft whose lower end is adjustable with reference to a floor anchor or foundation, and whose upper end is held in place by adjustable attachments to the frame work of the power building. If the power is properly aligned, the former type meets all requirements, but if alignment is poor and the features of installation abnormal, the latter type frequently proves the more adaptable.

An ingenious way of keeping constant tension on an endless belt used for driving a band-wheel power is to mount the idler pulley on a truck which is movable on a track running parallel to the belt as it leaves the engine or countershaft pulley. The idler is held at constant tension against the belt by means of a steel cable attached to the front end of the truck. This cable passes below the band wheel to a point outside of the power building, where it passes under a pulley fastened near the ground, and then over a pulley fastened in a frame at a point 8 or 10 feet above the ground and ending in a suspended weight that maintains the necessary tension.

Many oil companies have adopted the practice of utilizing old steam engines by making the crank shaft and that half of the frame to which it is attached serve as a countershaft. Sometimes a steam engine and boilers formerly used are left in place; and the steam engine is used as a countershaft; if the electric power or the oil or gas engine being used fails, the drive belt is thrown off and pumping is continued by steam power until the necessary repairs have been made.

Plate X, F, shows a countershaft made from an old steam-engine bed, as used by one of the California oil companies.

HOUSING FOR POWERS.

Plate XVIII, *B* and *C*, and XIX, *A*, show three standard types of construction for power buildings used by three different oil companies in three widely separated oil fields.

The power building shown in Plate XVIII, *B* (p. 77), is at Bridgeport, Ill. It is sectionalized, as are all the oil-field buildings of the company. Sections from the sides of the building can be readily unbolted and removed in order to take out or replace old or broken machinery. Ample light is admitted through five windows on the long side of the building, four on the off-set side and one at the back. The side walls are made of boards nailed to 2 by 4 inch sills and plates, with batten over the cracks. The sills are attached to steel angle-plates, set 6 inches in the concrete floor and with nail holes in the protruding ends. These angle plates are so placed that when the sill is attached to them its lower side will be one-quarter of an inch above the concrete floor and its outer side will be one-quarter of an inch outside of the outside edge of the concrete floor and foundation. Thus there is an air space between the floor and the sill and between the side boards and the foundation wall.

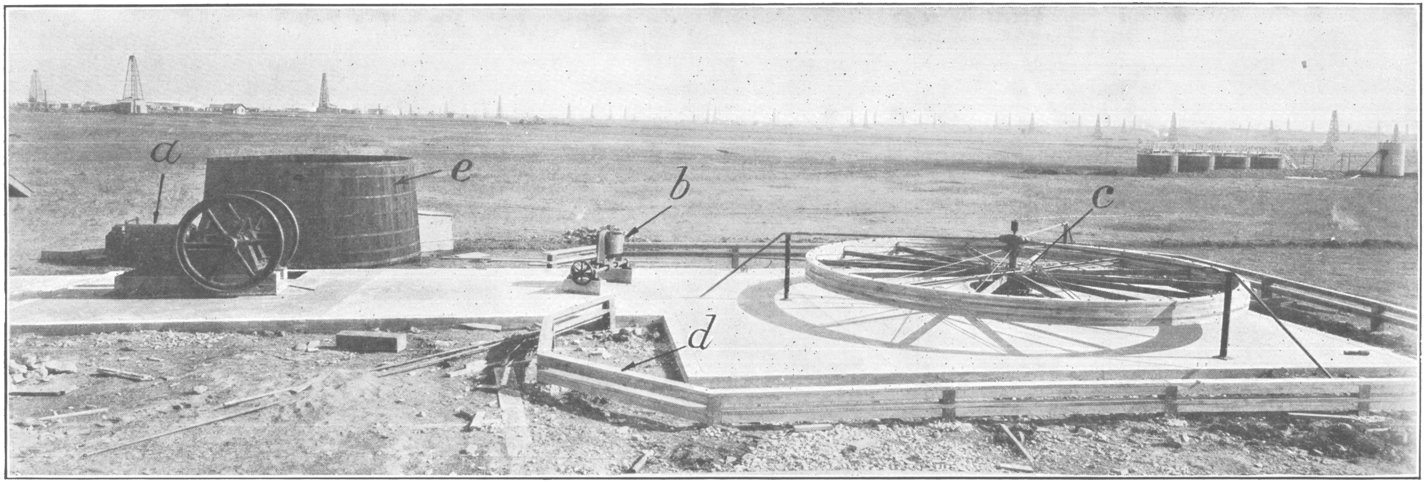
With this arrangement the floor can be washed with a hose and the sills and the lower ends of the side wall boards will not remain damp and become rotten. Moreover, the floor level is far enough above the ground for the lower ends of the wall boards to be in the dry, and the drainage of the surface water is away from the building. The roof is of shingles dipped in paint, drawn over a strip of belt to remove the excess paint and dried before being put on the roof. Shingles treated in this way last much longer than those that are simply painted on the upper and exposed side after being nailed on. A sheet-iron ridge row is used to keep the shingles from blowing off and to give a tighter roof.

The power building shown in Plate XVIII, *C* (p. 77), is at Bakersfield, Calif. The sills are 2 by 6 inch lumber laid flat; the plates are two thicknesses of 2 by 4 inch scantling. The corner posts are 4 by 4 inches, the studding is 2 by 4 inches, the rafters are 2 by 4 inches, and the sheathing is 1 inch by 6 inches. The walls and roof are covered with 26-gage galvanized corrugated sheet iron. The windows and door frames are painted and the floor is of concrete.

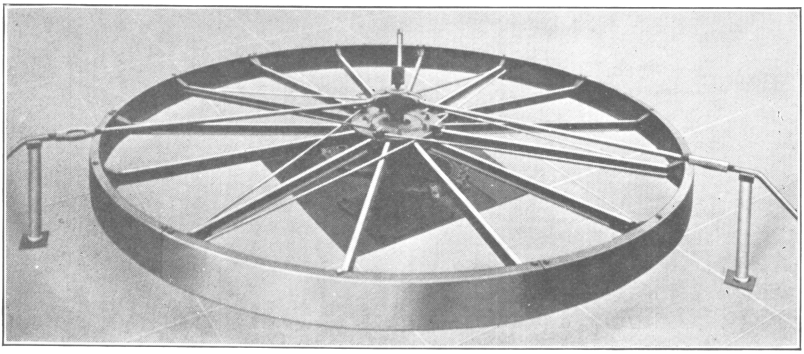
The frame building shown in Plate XIX, *A*, is at Big Muddy, Wyo. It has a concrete floor and roof and walls covered with galvanized corrugated sheet iron, like the house shown in Plate XVIII, *C*.

SHACKLE LINES.

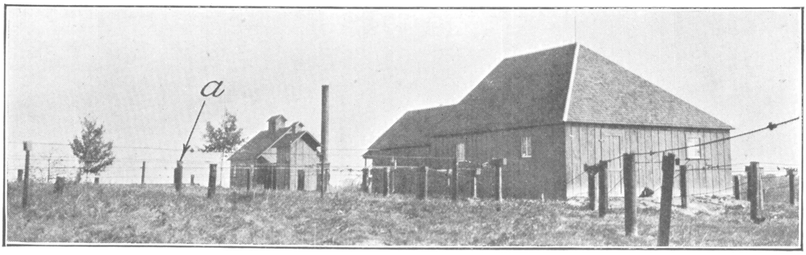
Shackle lines are used to transmit reciprocating motion from the central jack plant, or power, to the jack or wheel at the well. Some wooden shackle lines are still in use, but wire cables or steel rods are seen more often. When new material is put in, steel rods are generally used, although a galvanized, seven-strand, twisted wire rope is manufactured in suitable sizes for this purpose. Old drilling cable is often used, however, for shackle lines, and in many respects is better than new cable because most of the stretch has been taken out of it. Some oil fields have been drilled with hemp cable, and in those fields steel-cable shackle lines are seldom seen. It is difficult to compare the relative merits of old steel cable and steel rods for shackle-line service.



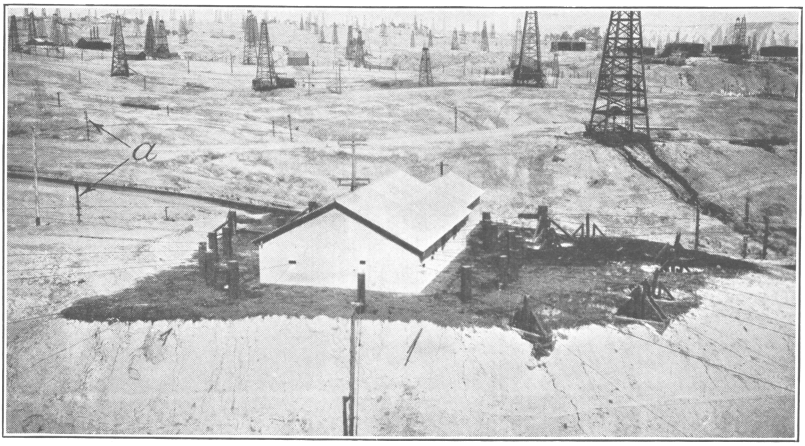
NEW WOODEN BAND-WHEEL POWER, BEFORE BEING HOUSED. FOR EXPLANATION OF LETTERING, SEE TEXT



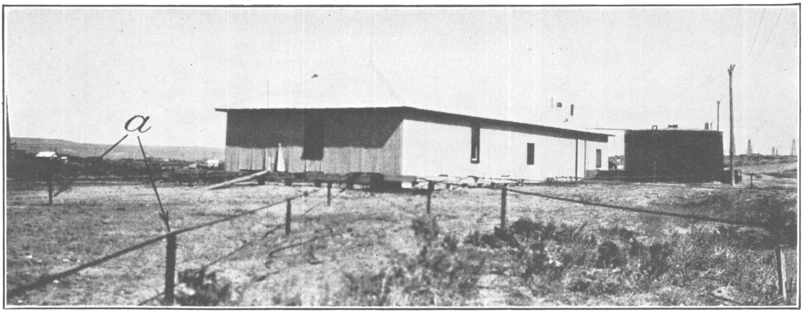
A. STEEL BAND WHEEL FOR POWER PUMPING



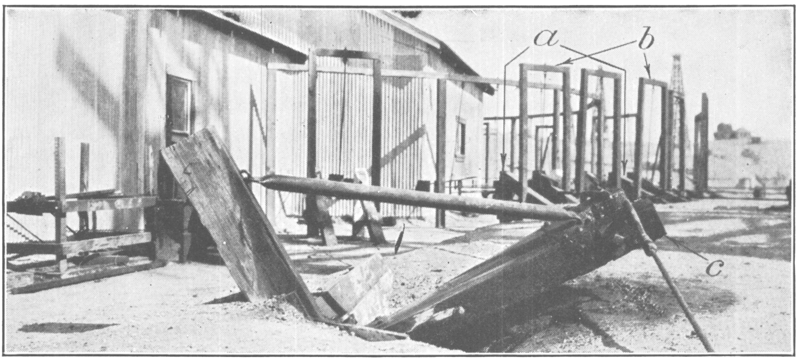
B. POWER OR JACK-PLANT HOUSE, BRIDGEPORT, ILL., WITH SUPPORT HAVING DOLL HEAD GROOVED TO RECEIVE SHACKLE LINE AT *a*



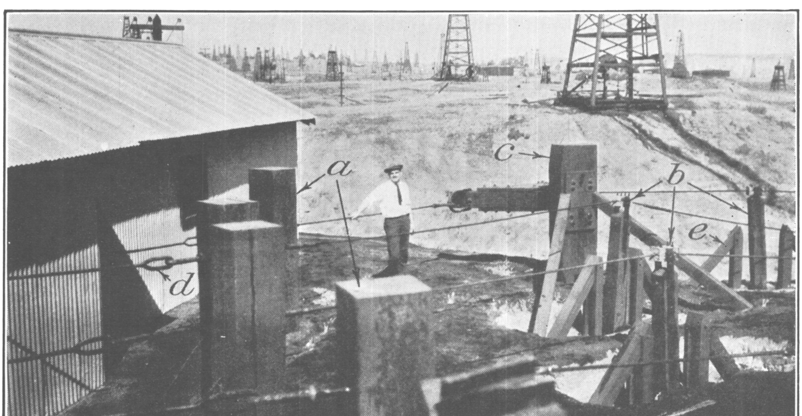
C. POWER OR JACK-PLANT HOUSE, KERN RIVER OIL FIELD, BAKERSFIELD, CALIF.



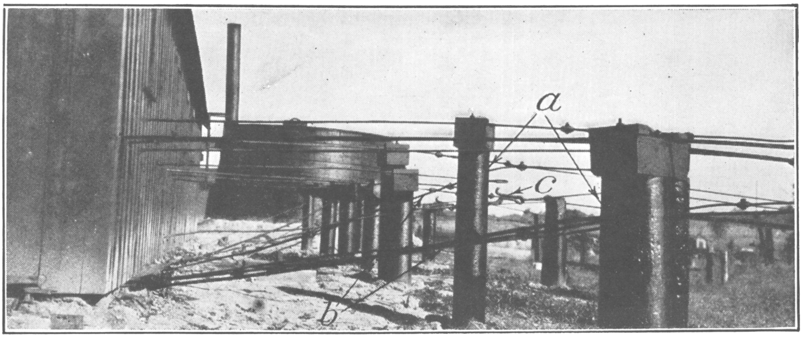
A. POWER OR JACK-PLANT HOUSE, BIG MUDDY OIL FIELD, WYOMING: *a*, SHACKLE LINE RESTING ON FRICTION-POST SUPPORTS



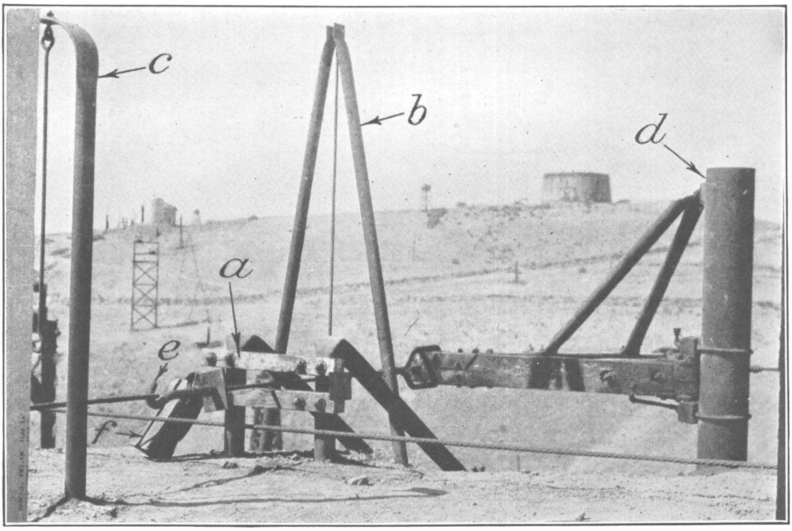
B. *a*, TAKE-OFF POST OF HEAVY BRACED TIMBER; *b*, TWO-POST PENDULUM; *c*, COMBINATION BUTTERFLY



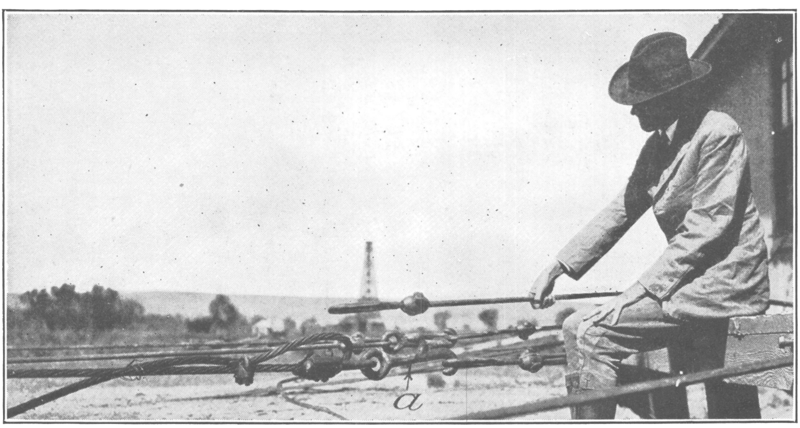
C. *a*, HEAVY TIMBERED POST CONCRETED IN PLACE WITH SHACKLE LINE RUNNING IN HOLE BORED THROUGH IT; *b*, ROCKER USED AS HOLD-UP; *c*, BUTTERFLY MADE OF TIMBER AND ATTACHED BY BEARINGS TO HEAVY TIMBER POST; *d*, ATTACHMENT FOR SHACKLE LINE; *e*, END BRACE



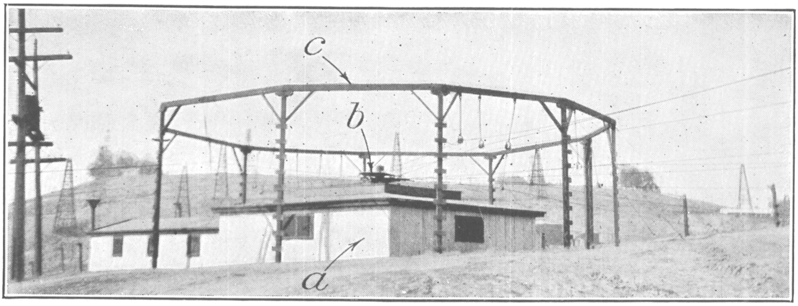
A. POWER EQUIPPED WITH TAKE-OFF POSTS, *a*, SHOWING TAKE-OFF ROD *b*, AND WELL TAKEN OFF POWER *c*



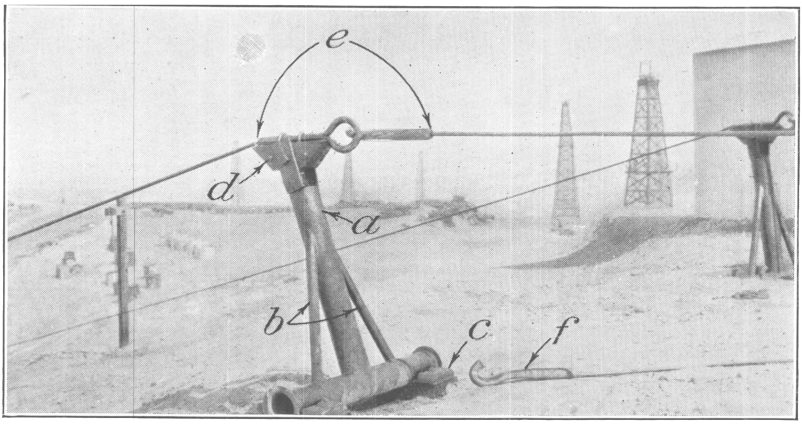
B. *a*, TAKE-OFF POST MADE OF OLD PIPE; *b*, STEEL-ROD PENDULUM; *c*, ONE-POST PENDULUM; *d*, BUTTERFLY OF TIMBER ARMS AND PIPE BRACES; *e*, POWER AND JACK ATTACHMENT FOR SHACKLE LINES



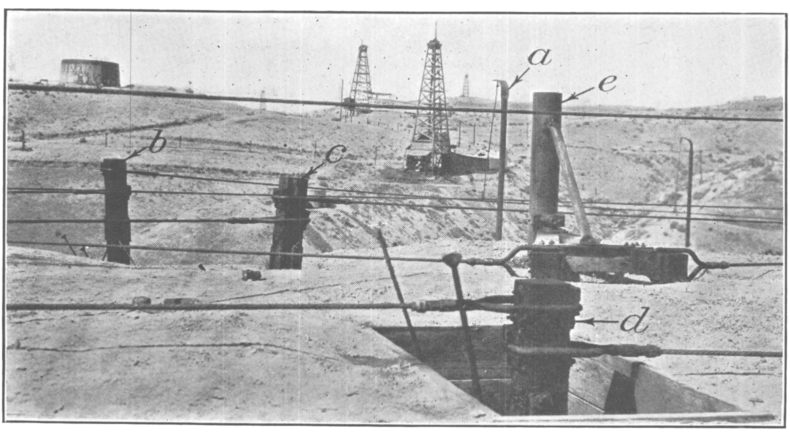
C. TAKE-OFF RODS AND RAIL IN USE; SHACKLE-LINE ATTACHMENT AT *a*



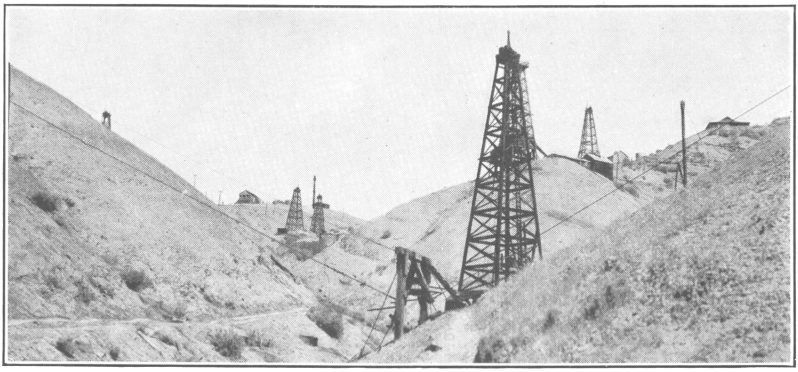
A. POWER BUILDING WITH PENDULUM-TYPE HOLD-UP STRUCTURE TO PROVIDE FOR ALL SHACKLE LINES AT THE POWER. FOR EXPLANATION OF LETTERING, SEE TEXT



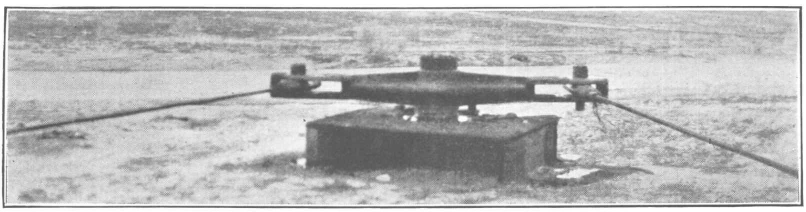
B. ROCKER TYPE OF HOLD-UP MADE FROM PIPE. FOR EXPLANATION OF LETTERING, SEE TEXT



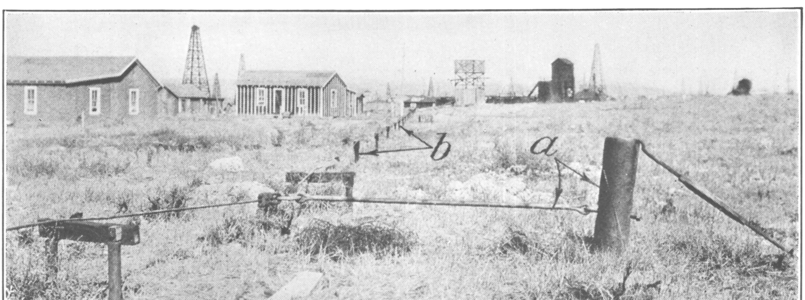
C. ***a***, ONE-POST PENDULUM; ***b***, *c*, *d*, ROCKERS; ***e***, BUTTERFLY MADE OF TIMBER ARMS AND PIPE BRACES



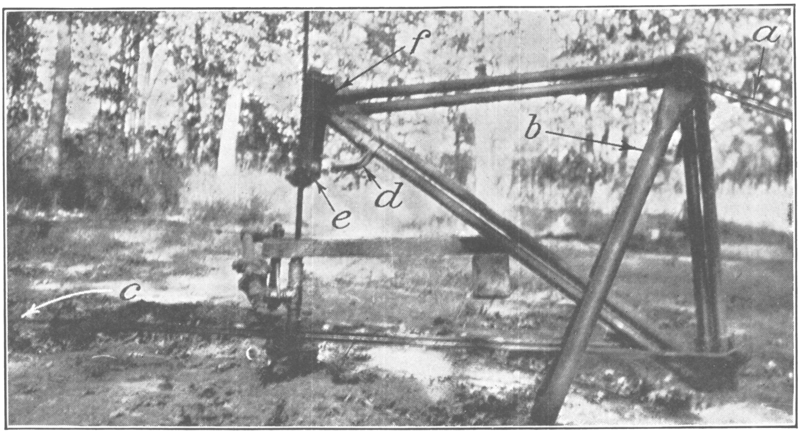
A. BUTTERFLY TYPE OF PENDULUM, USED AS A HOLD-DOWN



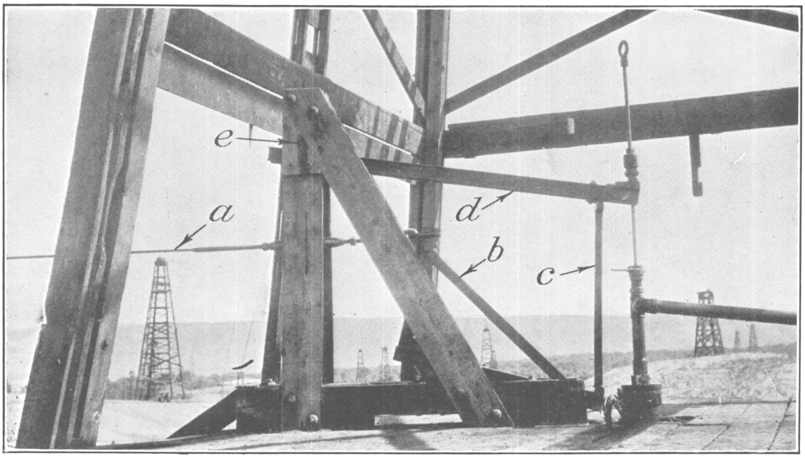
B. ONE-ARM BUTTERFLY WITH CONCRETE FOUNDATION



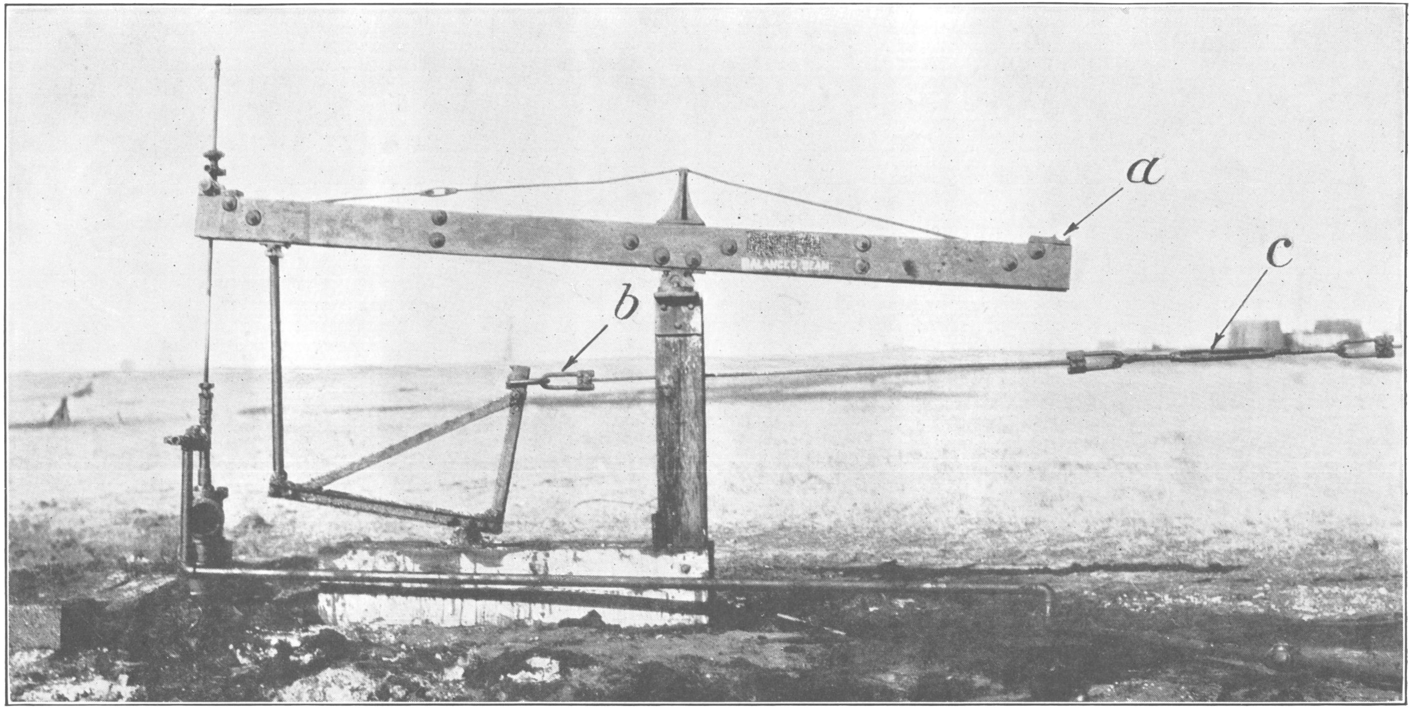
C. OLD CASING, AND STEEL ROD HOLD-OVER, *a*; FRICTION-POST SHACKLE-LINE SUPPORTS, *b*



A. LONG-STROKE PENNSYLVANIA-TYPE JACK MADE FROM PIPE, IN OPERATION: *a*, BACK SUPPORTS; *b*, SUPPORTING LEGS; *c*, SHACKLE LINE; *d*, ARM; *e*, POLISH-ROD CLAMP; *f*, WORK ARM OF JACK



B. OKLAHOMA-TYPE STEEL AND WOOD JACK IN OPERATION: *a*, SHACKLE LINE; *b*, STRUCTURAL STEEL JACK; *c*, PITMAN; *d*, STRUCTURAL STEEL BEAM; *e*, PIVOT



HEAVY BALANCED BEAM USED WITH OKLAHOMA TYPE OF JACK, SHACKLE-LINE CONNECTIONS, AND TURNBUCKLE IN SHACKLE LINE. FOR EXPLANATION OF LETTERING, SEE TEXT

The steel rods may be old bent sucker rods from wells and the condition of old drilling cables differ widely. One driller discards a drilling cable much sooner than another; one discarded drilling cable may have been subjected to much more severe service than another. Some operators using old steel cable for shackle lines claim that when each shackle line is made from about equal lengths of right lay and left lay cable babbitted together, the line has less stretch.

A section of cable is often inserted into a long rod line to take up the "pound." If many pieces of steel cable are used in one shackle line, the couplings are usually made by babbitting the ends together within a short piece of pipe. The connections at the jack and the power ends are usually similar.

The wooden sucker rods, once commonly used for shackle lines, are made of octagon hickory or ash in lengths of 16 feet to 22 feet and diameters of 1½ inches to 2 inches, with forged wrought-iron couplings riveted on the ends. After the wood has lost its life, many of these wooden rods become brittle and break, necessitating frequent repair.

Steel rods or pull rods, as used for shackle lines, are generally made of round steel in lengths of 20 feet, 25 feet, and 30 feet, in diameters ranging from ½ inch to 1 inch, with upset ends connected by a 2-piece rod clamp held together by one or more bolts. Steel sucker rods with steel box and pin connections with wrench square, or the type with pins on both ends connected by a common malleable-iron boxing, are often used for shackle lines.

Some oil companies have adopted the policy of using new sucker rods in the wells as pump rods, which they later remove for shackle-line service and replace with new rods. This practice is probably based on the theory that it is easier to repair rod breakage in the shackle lines on the surface than in the well, where breakage will probably mean a "fishing" job and perhaps pulling the tubing.

Much of the breakage of steel-rod shackle lines is due to the use of rods that do not have enough support or have been bent.

SHACKLE-LINE STRUCTURES AND EQUIPMENT.

The power or jack plant, and the machinery, shackle line, and jack are generally standard and are purchased from oil-well supply companies, but the shackle-line structures are usually designed and built by the operating oil company. This results in a multiplicity of designs and a variety of material unequaled in any other class of oil-well equipment.

Shackle-line structures may be classified as: 1, Equipment that is used to take a well off or put it on the power; 2, equipment that supports the shackle line; 3, equipment that changes the length of stroke; 4, equipment that changes the direction of the shackle line in a vertical plane; 5, equipment that changes the direction of the shackle line in a horizontal plane; 6, equipment that connects the shackle line with the power at one end and with the jack at the other end.

Some oil companies make shackle-line structures out of old pipe and casing when possible; others use bolted timber entirely. In heavily timbered regions the limbs of suitably situated trees are used as supports for shackle lines by means of rope or steel-rod pendulums. A large tree or rock may serve as an anchor for a hold-over. In most of the oil fields, every advantage is taken of natural features to cut the cost of erecting shackle-iron structures.

EQUIPMENT TO TAKE A WELL OFF OR PUT IT ON THE POWER

TAKE-OFF POSTS AND TAKE-OFF RODS AND RAILS.

Take-off posts generally do double work; they keep the shackle lines in a horizontal plane when leaving the power and they enable a well to be taken off the power by the detaching of the shackle line from its connection to the power. Many are so made that the side sweep of the rods as they leave the power is confined to that section of them between the take-off post and the attachment at the power disk or eccentric.

Plate XX, *A*, shows a power equipped with take-off posts, *a*, made of old casing concreted in the ground and having a timber block with side pieces bolted on top to keep the shackle lines in a horizontal plane as they leave the power and to limit their side sweep at the take-off post to the space between the two blocks. The take-off arrangement for this type of post consists of a take-off rod, *b*, which rests in two slots cut into opposite sides of the take-off post, with the take-off stirrup at the upper and outer end of the rod but below the take-off hook *c* on the shackle line. The lower end of the rod is anchored to the power foundation. At *c* is shown a well taken off the power; the stirrup connection to the power is directly above it.

The company using this type of post first digs a hole about 18 inches in diameter and 4 feet deep, in which the post is placed. Concrete is then poured around the post to within about 8 inches of the surface; this depth below surface is necessary to keep frost from lifting or loosening the posts. The wooden posts formerly used by this company rotted in about two years.

Some take-off posts are set poorly. The writer has seen posts placed in funnel-shaped holes into which concrete was poured. As most of the concrete was near the surface of the ground, there was nothing to hold the bottom of a post firmly in place, and the posts soon became loose.

Plate XIX, *B*, at *a* shows a take-off post of heavy braced timber. To take a well off the power a slotted block is dropped between the take-off frame and the shoulder on the end of the rod when the return stroke of the shackle line is completed.

Plate XIX, *C*, at *a* shows a heavy timber post concreted in place with the shackle line running in a hole bored through it. On the side of the post next to the power a shoulder is welded to the shackle line; this shoulder moves from the edge of the post toward the power for a distance equal to the length of stroke. To take off a well a slotted block of suitable length is dropped over the rod between the post and the shoulder when the return stroke of the shackle line is completed.

Plate XX, *B*, at *a* shows a take-off post made of old pipe placed vertically about 2 feet apart in a concrete foundation, with timber cross-arms bolted to the pipe supports. Wells are taken off by dropping a slotted wooden block, *f*, between the take-off post and the shoulder at the end of the shackle line, as in the type previously mentioned.

At many wells take-off rods and take-off rails are used instead of take-off posts, generally when the eccentrics of the power are below the band wheel or gear wheel, and when the power is in level country. Under these conditions the take-off rail will support the shackle lines at the power without hold-ups of the pendulum or rocker type, and the shackle line will not greatly tend to cut into the rail. At their inner and lower ends the take-off rods are anchored to the power foundation and their outer and upper ends extend through the side of the take-off rail to a point below the take-off hook. Plate XX, *C*, shows take-off rods and rail in use. The rod held up by the man is the connection to the power, and the take-off hook on the end of the shackle line is shown attached to the stirrup of the take-off rod; evidently the well is off the power. The man is seated on the take-off rail, which is made of plank with an outside plank facing attached to 8 by 8 inch posts for support. The top of the rail as shown is about 2 feet above the ground.

Plate XXI, *A*, shows a power building, *a;* eccentric disks, *b;* and pendulum type of hold-up frame, *c*. The hold-up frame is built of braced timber made rigid by guy wires. A steel take-off, or release ring, is attached to the framework of the power just below the eccentric disks *b*. Wells are taken off by means of a steel bar with bent ends; one end of the steel bar is fitted over a shoulder on the shackle line and, on the return stroke of the well, the other end is dropped over the release ring.

Plate XXI, *B*, shows a rocker type of hold-up made from pipe. The vertical member *a* and the horizontal member are made from casing. The plate also shows the braces *b*, made of pipe gas-welded in place, the guide blocks *c* bolted to the concrete foundation, the attachment *d* for the take-off hook, the old cable shackle line babbitted to the attachment hooks at *e*, and the take-off hook *f*.

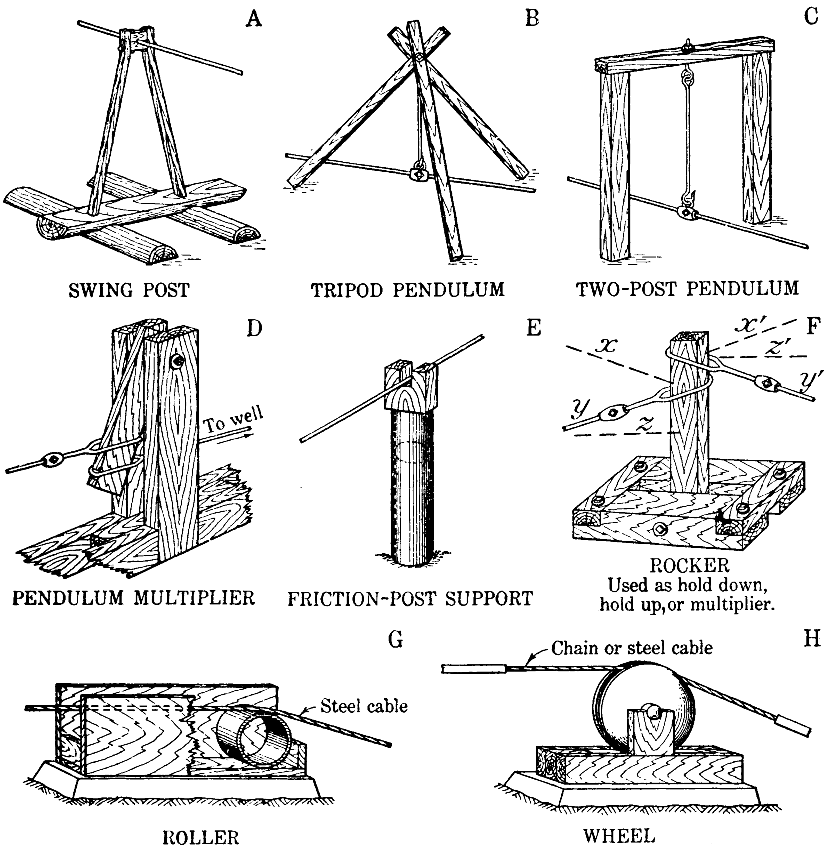


FIGURE 11.—Shackle-line structures.

EQUIPMENT FOR SUPPORTING SHACKLE LINES.

SWING POSTS.

The swing post, Figure 11, A, is commonly used in Pennsylvania where it is made of the green timber at hand. A log is split and the two pieces placed flat side down for ground sills; across these another piece of split log with the round side down fits into notches cut in the sills which serve as bearings. To the upper side of the crosspiece, two mortised or bolted arms extend up to meet the shackle line and are coupled to it by a clamp and loose bolt attachment. The two ground sills must have the same elevation and are placed parallel to the shackle line which is midway between them. This device is crude but serviceable. It is not only used for line support but often as a hold-up post near the power, where a shackle line leads to a well on lower ground. It is best suited to regions with little soil where to drive or to concrete post hangers in place would be difficult, or where timber is plentiful. However, the swing post is not well suited to heavy duty and requires frequent repair.

TRIPOD PENDULUM.

The tripod pendulum, Figure 11, B, is used under much the same conditions as the swing post. The legs of the tripod are placed so as to give best alignment and proper support to the shackle line. They are generally made of split green timber, bolted together at the top, and the shackle line is held up with a rope or steel-rod pendulum. The tripod pendulum is suited to localities where the frost line is deep or where to drive or to concrete a post hanger in place is difficult.

TWO-POST PENDULUM.

The two-post pendulum, Figure 11, C, usually consists of two posts driven or concreted in the ground about 2 feet apart with a crosspiece bolted on the top; from the middle of the crosspiece the shackle line is suspended by a steel rod with a hook and eye. Other pendulums of this type, but of heavier construction, are shown in Plate XIX, *B*, at *b*.

Still other types eliminate the crosspiece at the top by the use of two pieces of old pipe with the upper ends flattened and bolted together—the shackle line being supported by a steel-rod pendulum as shown in Plate XX, *B*, at *b*. Under favorable conditions, this type of two-post pendulum is highly satisfactory for heavy duty and permanent service.

ONE-POST PENDULUM.

A one-post pendulum for supporting a shackle line is shown in Plate XX, *B*, at *c* (p. 76), and Plate XXI, *C*, at *a* (p. 77), as made from old pipe; and in Plate XVIII, *C*, at *a*, as made of timber with a short bolted cross arm. At some places these one-post pendulums are concreted in position; in California many companies place the wooden ones in dug holes and tamp them in place with oil sand from the well sumps.

In California 4-inch by 4-inch Oregon pine, redwood, or cedar posts are commonly set 4 feet in the ground; they extend 5 to 10 feet above the ground, depending on the topography. Most of them are spaced 25 feet apart and are painted once or twice a year with crude oil.

PULL-ROD POSTS OR FRICTION-POST SUPPORTS.

Friction-post supports are made by driving wooden posts into the ground at intervals of 20 feet to 30 feet; the pull line or shackle line rests on the tops of the posts where it is held in place by a notch or groove. These supports are also made by cutting old pipe, usually 2 inch, into suitable lengths and driving these into the ground by the use of a sledge and a steel drivehead for the pipe. This drivehead slightly spreads the upper end of the pipe so that a piece of hard wood is readily inserted into the top of the pipe after it has been driven to the proper position. The piece of wood, usually oak and known as a "doll head," has its upper surface grooved to carry the pull rod and has a 2-inch shank. The latter type is shown in Figure 11, E (p. 80); Plate XVIII, *B*, at *a* (p. 77); Plate XIX, *A*, at *a* (p. 76); and Plate XXII, *C*, at *b* (p. 77). Other carriers to be inserted in the top of the pipe support have a sheave that carries the shackle line and rotates with the reciprocating motion of the shackle line. If wooden blocks are used for support, they should be kept well greased; otherwise the friction will increase the power requirements and, in long shackle lines, greatly reduce the length of stroke at the well. The superintendent of a Gulf Coast oil company stated that in his experience ungreased posts made wells pull practically twice as hard, thus greatly increasing breakage of shackle-line rods, and, on many long lines an 18-inch stroke imparted to a shackle line at the power produced only an 8-inch stroke at the end of the line. This type of support is most common in level country—as in parts of Wyoming, Kansas, Oklahoma, and Illinois.

Friction-post or pull-rod supports, made of old pipe, are generally unsatisfactory if they extend more than 4 feet above the surface of the ground, because they tend to become loose when higher. They are most satisfactory when not more than 2 feet high. They should be set about 3 feet in the ground for support, and hence can not be satisfactorily placed where there is much rock or gravel in the soil. In places where the ground freezes deep they may work loose when the ground thaws.

When the shackle line crosses gullies or low places, the pull-rod posts should be replaced and the shackle line supported by a well-braced or concreted two-post pendulum or a tripod pendulum.

EQUIPMENT TO CHANGE THE LENGTH OF STROKE.

Pendulums and rockers are sometimes used to make the length of stroke at the well differ from that imparted to the shackle line at the power. The length of stroke is increased or decreased by increasing or decreasing the distance between the fulcrum of the attachment for the shackle line leading to the well and the attachment for the shackle line leading to the power. When they increase the stroke these devices are known as multipliers, and when they decrease it they are known as reducers.

The pendulum as used for a hold-up, or hold-down, or multiplier, Figure 11, D (p. 80), is attached by suitable bearings to vertical side posts, the lower ends of which are set in the ground, or are bolted or framed to buried sills that may be set in concrete when heavy loads are to be handled.

The rocker, Figure 11, F, as used for the same purposes, is attached by suitable bearings to sills bolted or framed together and generally placed with their tops flush with the surface of the ground. When used for heavy loads the sills are often set in concrete. Plate XXI, *C*, (p. 76) shows three rockers at *b*, *c*, and *d*; the two former are used to increase the length of stroke at the well, and the last is used to decrease the stroke. The power is situated to the left of the photograph. As these rockers are near the power they also hold the shackle lines horizontal when leaving the power.

EQUIPMENT TO CHANGE DIRECTION OF SHACKLE LINE VERTICALLY.

Devices located near the power to change the direction of a shackle line in a vertical plane are known as "hold-ups" if the shackle line leads to a lower level, and as "hold-downs" if the line leads to a higher level. However, if the shackle line crosses a series of gullies and ridges, hold-ups are put on top of the ridges and hold-downs in the bottom of the gullies. If the shackle line is stretched from ridge to ridge without any intervening support, the sag in the line takes up any stroke imparted by the power and there is no appreciable reciprocating movement at the well. Plate XXII, *A* (p. 77), shows a butterfly type of pendulum used as a hold-down because of the sharp angle between the two shackle lines.

Hold-ups are generally of the pendulum, rocker, roller, and wheel types; hold-downs are generally of the pendulum and rocker types.

Figure 11, F (p. 80), shows a rocker. When the solid lines *y* and *y'* represent shackle lines, it is used as a hold-up; when the broken lines *x* and *x'* represent shackle lines, it is used as a hold-down; and when the broken lines *z* and *z'* represent shackle lines it is used as a multiplier.

Figure 11, D, shows a pendulum used as a multiplier. By variations in its position and in the attachment of shackle lines, it can be used as a hold-up or a hold-down, in the same way as a rocker. Figure 11, G, shows a roller, generally a casing coupling placed horizontally in a concrete or plank box firmly attached to a foundation, used as a hold-up. Under the reciprocating motion of the shackle line resting on it the coupling support rolls back and forth in the box guide. The sides of the box must fit closely and extend above the top of the coupling so that the shackle line will not slide off. This device is used only with steel cable as shackle line, or at least, for that part of the line passing over the coupling.

Figure 11, H, shows a crown pulley, or other flanged wheel, resting in bearings placed on a firm foundation and used as a hold-up. This device is used only where cable or chain forms the part of the shackle line that reciprocates on the pulley.

Plate XIX, *B*, at *b* (p. 76) shows a pendulum used as a hold-up. Plate XIX, *C*, at *b*, shows a rocker used as a hold-up.

Some oil companies use the rocker type of hold-down, with the rocker arm made of pipe, iron bearing for support, and iron clamp and bearing for attachment to the shackle line. The lower bearing is held in place by a concrete foundation. Equipment of this type is used in Osage County, Okla., west of Bartlesville.

Care should be taken that the pendulum or the rocker arm is so long—at least four times as long as the length of stroke used in pumping—that the arc through which the shackle line moves will not cause excessive vertical motion in the shackle line and a lateral pull on the rocker or pendulum arm.

The rocker or pendulum should be attached to the shackle line at such a point that it will bisect, at the middle of the pumping stroke, the angle between the sections of line on either side of the point of attachment.

Some rockers are provided with end braces, as shown in Plate XIX, *C*, at *e*. These braces prevent the rocker from moving through a greater arc than that between the tops of the two end braces, but this distance is greater than the length of stroke. The braces will frequently prevent breakage of the shackle line and the sucker rods if the well connection at the power breaks.

EQUIPMENT TO CHANGE DIRECTION OF SHACKLE LINE HORIZONTALLY.

The butterfly and the hold-over are devices to change the direction of a shackle line in order to pass an obstacle, or to run the shackle line away from the power in a direction other than that of the well to be pumped and thus balance the load at the power.

A butterfly, or angle, usually consists of two arms framed and bolted together at right angles and attached by bearings to a vertical post or attached to a vertical shaft resting in a firmly fixed bearing, about which they reciprocate horizontally with the movement imparted to the shackle line from the power.

Plate XIX, *C*, at *c* (p. 76) shows a butterfly made of timber and attached by bearings to a heavy timber post. Plate XX, *B*, at *d* (p. 77) and Plate XXI, *C*, at *e* (p. 76) shows a butterfly made of timber arms and pipe braces attached by bearings to a vertical piece of old casing concreted in place. Plate XXII, *B* (p. 77), shows a butterfly that has a single steel arm, with shackle-line attachments at each end, mounted and oscillating on a shaft the lower end of which is set in a concrete foundation. This type of butterfly is used for pumping a well from the side of the power, opposite the side on which the well is located, thus insuring a balanced load. A butterfly is sometimes made from timber arms bolted to flanges and shaft made of rig iron. The shaft is placed vertically and reciprocates in a bearing bolted to a conrete foundation.

The hold-over serves the same purpose as the butterfly. Most hold-overs consist of a steel rod, attached by an eye and ring to the shackle line at one end and attached by an eye to an anchored eye-bolt at the other end, which is anchored to a tree or rock, or a piece of timber or casing concreted in place. Plate XXII, *C*, at *a* shows a hold-over anchored to a piece of old casing.

Shackle lines should approach and leave the butterfly in the plane of the two arms in order to prevent "side play" in the bearings and structure. This is usually done by using either a rocker or pendulum as a hold-down or hold-up, as required. Plate XIX, *B*, at *c* (p. 76) shows a butterfly that provides a change in direction in the shackle line both in a vertical and a horizontal plane. Peculiar conditions required this installation.

When during a pulling job the shackle line of a well has been disconnected at the power, and the jack is disconnected at the well, often the end of the shackle line at the well is attached to a hook to keep the shackle line taut, so that connections to the jack can be readily made when work at the well is completed.

EQUIPMENT TO CONNECT TO JACK AND POWER.

Shackle lines are attached to the power disk, or eccentric, by means of clevises or yokes with an eye or stirrup connection to a rod extending to the point, outside of the power building, where the throw-off equipment is situated. Shackle lines are attached to the jack at the well by means of a stirrup and bolted clamp. Some of these power and jack attachments for shackle lines are shown in Plates XX, *A*, at *c* (p. 77); XIX, *C*, at *d* (p. 76); XX, *B*, at *e*; and XX, *C*, at *a*.

A turnbuckle at some convenient point in the shackle line permits the length of the line to be changed without the well being taken off. A turnbuckle so situated may also be used to pull a broken line together, and to change the position of the working valve in the well.

When shackle lines not provided with turnbuckles break, they are pulled together to their former position by means of a set of tackle blocks or a fence jack, after the broken rod has been repaired or replaced by a new one. When a shackle line breaks it is sometimes detached from the power, pulled together by hand, repaired, and then brought to its former position by repeatedly using the throw-off at the power with rods and hooks of decreasing length until the line is pulled up to its former position. This, of course, is done while the power is in motion.

POWER-TRANSMITTING EQUIPMENT AT THE WELL.

Pumping jacks and pumping wheels are used at wells to convert the horizontal reciprocating motion of the shackle line to the vertical reciprocating motion of the polish rod and its attached sucker rods and plunger pump in the well.

JACKS.

Jacks are made of timber, structural steel, pipe, or combinations of these materials. They are of two general classes; the direct pull or Pennsylvania type, and the indirect pull, or Oklahoma type. Various trade names designate different models of these two types as manufactured by oil-well supply companies, but all types, with variations of set-up and details of construction, belong to one of these two types.

Plate XXIII, *A*, shows a Pennsylvania type of jack built of pipe and castings held in alignment by back supports, *a*, made of steel rods with turnbuckles to permit necessary adjustments. When these back braces are diagonally crossed they occupy less space and alignment can be more readily made by the turnbuckles. The supporting legs *b* rest in holes cut in a buried piece of casing laid transversely to the direction of pull. These legs are inclined so that they also serve as front braces and, with tension on the shackle line *c*, hold the jack in proper position.

This jack is strongly made and is well suited to heavy duty and long stroke, the normal length of stroke being 28 inches. The polish rod is kept in a vertical position with this length of stroke by means of an arm, *d*, the end of which comes in contact with the side of the polish-rod clamp *e* when the upward stroke is about half completed and remains in contact until the downward stroke is about half completed. The polish-rod clamp and bearing *e* has two pieces of steel bolted on its sides, by means of which it is attached to the bearing on the end of the work arm of the jack at *f*. In the Illinois oil fields this type of jack is used at wells that produce much water.

For transmitting a long stroke a short-arm jack of the Pennsylvania type should have some device to keep the polish rod in a vertical plane and thus prevent the wear causing leaks at the stuffing box.

Jacks constructed of pipe and castings are common in many oil fields, and many oil companies make their own. Most of the oil-well supply companies manufacture them. Pipe jacks are strong and durable. They have the advantage over wooden jacks that they are less bulky and are not subject to rot.

Plate XXIII, *B*, shows a jack of the Oklahoma type in operation. This jack is made of structural steel, pipe, and a bolted timber frame. The shackle line *a* is attached by means of a stirrup to a box on the end of the upper arm of a structural steel jack, *b*, which is pivoted by a saddle fastened to the lower arm near its junction with the upper arm and resting on bearing plates bolted to the wooden frame. The jack is connected by a pitman, *c*, to a structural steel beam, *d*, which is pivoted at *e* in the wooden frame. This type of jack is built in many variations of design and materials. Usually it has a long beam and is well suited for a long stroke and for service at deep wells.

The Pennsylvania jack, made of timber with wooden frame and braces, was the first type used in the Appalachian oil fields. Wooden jacks usually cost less than those made of pipe or structural steel, but they rot and give trouble from lost motion unless carefully framed and tightly bolted. Many wooden jacks of the Pennsylvania type are built with long arms and work well with a long pumping stroke.

LENGTH OF STROKE.

With most types of jacks the length of the stroke at the well is varied by changing the relative lengths of the power and work arms of the jack, or by varying, with a reference to the fulcrum, the relative position of the polish rod and shackle-line attachments on the jack.

In many types of jack, the stirrup box to which the stirrup and shackle line are attached has two or more seats and the length of stroke can be regulated by changing the seat of the stirrup.

COMPARISON OF TYPES.

The Pennsylvania jack is made and used either with upper or lower connections. For upper connection, as shown in Figure 8, A (p. 65), the vertical and power arm of the jack extends up from the saddle and bearing plate to the shackle-line connection; for lower connection this arm extends downward as shown in Plate XXIII, *A*. The upper connection is not so common, but it is used at many wells in hilly country on ground lower than the power in order to give a more direct pull from the power to the jack. It is also used when there is a particular reason for having the shackle line some distance above the ground, as where low-lying obstructions would interfere with the lower connection being made.

Pennsylvania jacks cost less than those of the Oklahoma type, but are not so well suited for heavy duty. In some types the supporting legs are clamped around the casing head, in others they are bolted to the derrick floor.

The Oklahoma type of jack is easier to disconnect and lay aside during a pulling job than is the Pennsylvania type. When a well "sands up," which is generally on the up stroke, the jack automatically falls apart, because the pitman (*c*, in Pl. XXIII, *B*) drops out of the upper bearing. The stroke of the Oklahoma jack can be more easily regulated at the well than that of the Pennsylvania type. In California, where many Oklahoma

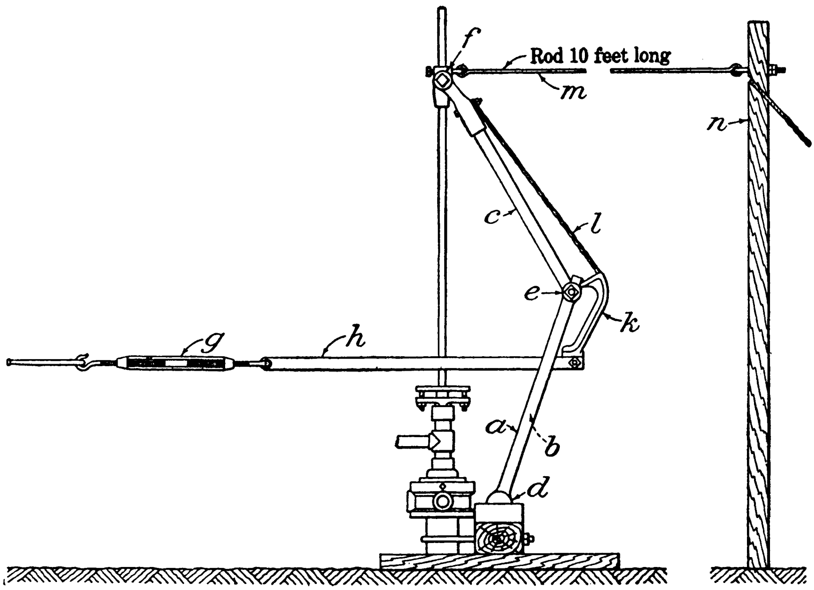


FIGURE 12.—Lightning pumping jack.

jacks are used, it is considered good practice to mount them on a rigid support of Oregon pine.

Figure 12 shows a new type of pumping jack, known as the lightning pumping jack, recently introduced into some of the Mid-Continent oil fields. The frame is made of three tubular steel members, *a*, *b*, and *c*. Pieces *a* and *b* serve as the supporting legs, and terminate at their lower ends in a bearing, *d*, which in turn is supported on a timber or concrete foundation placed directly back of the casing head. The upper ends of these supporting legs are attached by a bolted hinge joint *e* to the lower end of the member *c*. The upper end of *c* is attached by a bearing and coupling, *f*, to the polish rod. The shackle line is attached to the hinge joint *e* by a turnbuckle, *g*, and a long stirrup, *h*, bolted to the bearing iron *k*. The bearing iron *k* is held in the proper position by the steel cable *l*, which is attached at its upper end to the upper end of the upper member *c*, and after passing around a groove in the bearing iron *k* is attached to the bolt coupling at the lower end of *k*.

The polish rod is held in a vertical position by means of a steel fulcrum-rod, *m*, about 10 feet long, which is attached at one end to the polish-rod connection *f*, and at the other end, by means of a bolt and eye, to a 4 by 4 inch or 6 by 6 inch post, *n*, which is firmly cemented and braced in position. This post *n* is so placed that the fulcrum rod *m* and the shackle line are in alignment in a vertical plane. By means of the turnbuckle *g* on the shackle line the expansion and contraction of the line is adjusted, as is the length of the stroke imparted to the polish rod. The greater the interior angle between the lower members *a* and *b* and the upper member *c*, the shorter will be the vertical stroke imparted to the polish rod by a given length of stroke of the shackle line.

BALANCED BEAM.

Plate XXIV (p. 77) shows a heavy balanced beam used with the Oklahoma type of jack; it is suitable for pumping deep wells with a power or a jack plant. The balanced beam helps to decrease the load at the well. Additional weight can be suspended at *a* on the beam if the well pulls exceptionally hard. The shackle-line attachments are shown at *b* and the turnbuckle and attachments at *c*.

If the probable life of a well warrants the expenditure, concrete foundations for the jack will give more rigidity and maintain alignment better, thus decreasing wear and the need for repairs and increasing the efficiency.

PUMPING WHEEL.

In some oil fields pumping wheels are used at the wells instead of jacks to convert the horizontal motion of the shackle line to the vertical motion of the rods. Where the shackle lines are steel cables, a large wooden wheel as shown in Plate IX, *B*, at *b* (p. 45) is generally used. Where the shackle lines are steel rods a derrick crown-pulley is used for the wheel at some wells, and a section of chain is inserted in the part of the shackle line that passes over the wheel.

Some production foremen claim that wheels pull easier than jacks and that, since the pull is always from a point on the circumference of the wheel, the polish rod at the well always reciprocates in a vertical line; and, further, that a long stroke can be used in pumping when conditions warrant, without pulling the polish rod out of its vertical position. Many types of long-arm jacks, however, and some types of short-arm jacks, having an arc or double-coupling attachment for holding the polish rod, also keep the polish rod in a vertical position at all points of the stroke and are designed for long-stroke pumping.

ADAPTABILITY OF THE POWER SYSTEM OF PUMPING.

In the oil fields of the eastern United States most of the wells are pumped by group drive, which is generally of the "power" type. In most of the Mid-Continent, Wyoming, and California oil fields the shallower and older wells are pumped in this way. In general this system is suited for wells: 1, That are shallow; 2, that produce oils of lighter gravity; 3, that are free from loose sand and need few pulling and cleaning jobs; 4, that produce little water; 5, that have little gas pressure; 6, that are in groups; 7, that have a settled production; 8, that produce not more than 5 barrels of oil an hour; 9, that pump only a few hours a day or week; and 10, that have a low economic limit. As a result of the work done in the last 5 or 6 years, however, this system of pumping is being used for a greater range of service, as methods of operation are improved and heavier and better equipment is available. Some oil fields have both shallow and deep producing oil sands within the same area, with different wells drilled to handle the production from each sand. To see the deep wells, equipped with derricks, pumped on the beam, and shallow wells, without derricks, pumped by a central power is common. This is the practice at Eldorado, Kans., and at Big Muddy, Wyo. Plate XXVI, *C* (p. 110), shows an example in the latter field.

Some of the heaviest and best made central-power pumping equipment in the United States is in California, where, in a rough and rugged country, heavy gravity oil is pumped from a depth of 2,000 feet, as at Coalinga, or from shallower depths from wells producing some sand and water, as at Kern River. In some of the Gulf Coast oil fields of Texas wells as deep as 3,500 feet, producing 26° B. oil, are successfully pumped by this method.

Some of this heavy central-power pumping equipment, including all changes and additions necessary for installing this system to replace beam pumping, such as power, power building, shackle lines, shackle-line supports, jacks, foundations, and labor, several years ago under the high prices then prevalent and under difficult conditions of installation, cost as much as $2,000 per well served. At present, installations of this type ordinarily cost $700 to $1,000 per well served, the cost depending on the conditions of topography and location. For shallow wells and easy service, costs are much less, especially in some of the Mid-Continent and most of the eastern oil fields where topographic conditions are favorable or where second-hand material is available.

LOCATION OF POWER OR JACK PLANT.

The geographical center of a group of wells is usually the logical place for the power, so that the load can be balanced by a straight pull from the disk or eccentric on the power to each of the wells to be pumped, without butterflies and counterbalances. It often happens, however, that difficult topography, poor grouping of the wells to be pumped, or the probability that wells to be drilled later will have to be pumped by the power prevent the location of the power at this central location.

Some companies determine the power location by graphs. Each well is given a load factor based on the depth of the well, the size of the tubing, the gravity of the oil, and the length of stroke to be used, and the power is located with reference to these load factors.

If the choice is between high ground or low ground and other conditions are equal, high ground is generally the better site. Some oil-field operators claim that if the wells are on lower ground than the power the shackle lines will be taut at the beginning of the up stroke and thus give the full length of stroke to the well. On the other hand, if the power is on lower ground than the wells, the shackle lines sag back toward the power and part of the stroke at the well is often lost, especially if the wells are shallow.

A survey and map to scale, giving the location of all wells and showing the topography by means of 10-foot contours, will greatly aid in determining the most suitable location. Such a map is of especial value in hilly and wooded areas and will greatly facilitate the erection of shackle lines.

Plate XXV shows a plan of a number of pumping powers at Kern River, Calif., where topography has greatly influenced location.

BALANCED LOADS FOR THE POWER.

A balanced load is important because it saves power and prolongs the life of belts and machinery. If the power is centrally placed, a direct connection to the nearest point of the disk in a one-disk power may require little adjustment to give a balanced load. The use of one counterbalance may give the quickest and easiest adjustment. With a two or three disk power, the load should be balanced on each disk as nearly as possible before a general trial.

Some properties have wells that produce much water and are pumped with a long stroke all of the time; other properties have wells that are pumped only a few hours daily; still others have some wells that pump one hour, some that pump two hours, and some that pump three hours, all to be pumped by one power. Wells of like characteristics, such as pumping time, length of stroke, and size of tubing, should be balanced for best results. Some oil companies pump wells of like characteristics at the same time, then take those wells off the power and put on other wells of like characteristics. This practice is common in some of the eastern oil fields, where many wells do not pump more than a few hours a week, and where powers handle 15 to 30 wells, each pumped only two or three times a week and only several hours at a time.

When the power is driven by an electric motor, an ammeter in the circuit often helps to determine the best arrangement for shackle-line attachment. When the power is driven by a steam, gas, or oil engine, an experienced operator will usually detect the presence of unbalanced load by the action of the engine and the belt.

COUNTERBALANCE AT THE POWER.

If a balanced load at the power is not obtained by direct shackle-line connection from the wells to be pumped, or if a butterfly in one or more of the shackle lines to direct properly the approach necessary for balanced load is inadvisable, then a counterbalance is used. The counterbalance is generally of the type shown in Plate XII, *A*, at *a* (p. 62). It is so placed with relation to the power as to give a balanced load, and it is attached to the power by a shackle line. The desired amount of counterbalance is obtained by putting enough material in the weight box or by introducing a multiplier in the shackle line between the counterbalance and the power. Such adjustment is required at many powers when new wells are added to the load.

COUNTERBALANCE AT THE WELL.

Sometimes a counterbalance is used at a well to keep the load balanced when the well pumps much harder than the others on the same power.

SPEED AND LENGTH OF STROKE.

The speed and length of stroke of the power are important factors in assuring maximum production from the wells and in maintaining equipment. The pound or jerk that is so often noticed in shackle lines, and so often breaks them, is sometimes the result of too fast a motion, which causes the shackle line to begin its return stroke while the rods and plunger in the well are still on the down stroke. Sometimes the pound or jerk is due to the plunger of the pump being too low in the working barrel; then the bottom of the working valve or plunger hits the top of the stand valve and thus slacks the rods and shackle line before the up stroke begins. The former difficulty can be corrected by slowing up the power; the latter, by shortening the shackle line or by lowering the polish-rod adjuster. Most oil men seem to agree that the shortest and slowest stroke that will give the maximum production will also give the best operating conditions for the power.

In pumping with a power the frequency of stroke generally ranges from 10 to 20 a minute, and the length of stroke from 10 to 24 inches. However, some powers in the Texas oil fields have a 38-inch stroke and make 19 strokes a minute. If in pumping with a power there is a choice between a long slow stroke and a short rapid one, the former usually gives the better results both in work at the well and in maintenance of equipment.

In pumping with a power the frequency of stroke is the same at all of the wells. In some of the older eastern oil fields, wells attached to the same power differ widely in the time required to pump them off. These wells may be pumped only two or three times a week, and at each pumping there may be some that pump off in about an hour, others in about two hours and still others in three hours or more. These differences are sometimes due to different sizes of tubing being used but more frequently are due to the wells differing in yield. Under such conditions, the length of stroke can be changed at some of the wells by using a multiplier or by changing the relative length of the power and weight arms of the jack; then by proper adjustment all of the wells on the power can be pumped off in about the same length of time.

MOTIVE POWER FOR GROUP PUMPING.

Steam, gas, or oil engines or electric motors, of 15 to 50 horsepower, depending on the load to be handled, are used to drive power pumping systems. Steam engines and gas engines have been used for years; the more recent use of oil engines and electric motors has proved fully as satisfactory and under certain conditions has been much cheaper. The low maintenance and smooth running of electric motors are particularly desirable features for power pumping and for pumping " on the beam."

POWER REQUIRED PER WELL.

As a result of the use of purchased electric current for pumping, attention has been given the amount of power consumed. By use of the counterbalance and balanced load, the power needed for pumping has been materially reduced, but attempts to calculate the amount of power required to pump a well—by means of formulas having variables covering size of tubing, amount of fluid, length and freqnency of stroke, gravity of oil, amount of sand in suspension, depth of well, amount of gas, and balanced or unbalanced load—have not been at all satisfactory. Many shallow wells will require more power than deep wells. In other ways results as to power requirements will be obtained that do not agree with the conditions supposed to exist at the well.

Wells pumped on the beam seem to show the greatest variation in power requirements. Here the requirements range from less than 1 horsepower to more than 20 horsepower, depending upon the depth of the well and other conditions. In many oil fields where wells average more than 3,000 feet in depth and the oil has high viscosity, the general power requirements seem to range from 4 to 8 horsepower when the wells are pumped on the beam and a counterbalance is used.

Some oil-field operators estimate 2.5 horsepower as the average power required per well when the wells are pumped by a central power or jack plant with a well-balanced load. However, the power requirements for this method of pumping range from less than 1 to more than 5 horsepower per well.

The power required for bailing, swabbing, or pulling of rods and tubing at the well is from two to three times that required for pumping.

SYSTEMS BASED UPON THE USE OF COMPRESSED AIR.

Although compressed air as a source of power for pumping is less efficient than steam or gas engines, or electricity, sometimes its use is warranted, as when compressed air is already used extensively for some other purpose is available, and when efficiency can be sacrificed to quantity production.

The use of compressed-air pump heads and direct-displacement pumps is an example of the former, and the air-lift system is an example of the latter.

COMPRESSED-AIR PUMP HEADS.

On some properties at Bradford, Pa., compressed air is piped to each of the wells to be pumped, and there it is delivered to an air-pump head attached to the tubing above the casing head.

The piston rod of this air cylinder also acts as the polish rod of the well. The air enters the vertically placed cylinder below the piston, forcing the piston to the upper end of the cylinder. This produces the upstroke or the lifting stroke of the working valve and rods. When the upstroke is completed, the compressed air in the cylinder is released; then the valve and sucker rods drop and produce the down stroke by gravity. Air is again admitted to the lower end of the cylinder and the process is repeated.

DIRECT-DISPLACEMENT PUMPS.

Direct-displacement pumps displace the oil in the well by an equal volume of air; the air pressure used corresponds to the height of lift. This system is used extensively in connection with the

Smith-Dunn process[17] in the shallow oil fields of Marietta, Ohio, where the Watts and Dunn displacement pump is used to raise the oil. This pump and its improvements are covered by United States patents 1,187,579, 1,190,491, 1,198,881, 1,202,932, and 1,206,065.

Briefly, this pump consists of a casing, placed near the bottom of the well. A valve at the bottom of the casing chamber communicates with the fluid to be lifted. A screen below this valve prevents the entrance of dirt into the chamber. A float within the casing is attached to a steel rod that extends through a stuffing box at the upper end of the casing and is connected, through a coil spring and counterbalanced arm, to the valve at the casing head controlling the supply of compressed air to the casing chamber. The casing chamber also has an outlet pipe extending into the chamber and along its side to a point below the check valve of the inlet opening.

As the chamber fills with oil the float rises until it reaches the top of the chamber, where the air-valve connections open the valve. The air admitted to the top of the casing chamber forces the contained oil through the discharge pipe. When the air has forced all of the oil from the casing chamber, the float has dropped to the bottom of the chamber closing the air valve. This process is repeated as often as the casing chamber fills with oil.

AIR-LIFT SYSTEM.

A synopsis of the general principles of the air-lift system[18] taken from Technical Paper 70, Bureau of Mines, is as follows:

> The operation of the air lift depends on the buoyancy of aerated liquids. To obtain the desired results, air is pumped into the well through a small pipe to a convenient point below the surface of the liquid, where it is allowed to discharge into a larger pipe through which the aerated fluid rises above ground. It is important that air be admitted to the fluid in a finely divided state and in such a manner as to realize the full cross-sectional area of the discharge pipe for the passage of the liquid. The pumping of water by this method has been successfully accomplished for many years and most of the experience gained with the air lift has been obtained in pumping water. * * *
>
> The successful operation of the air lift for pumping oil and water mixtures depends upon a number of factors, most important of which are: (1) The height of the column of fluid that the aerated mixture has to overcome or the height from air inlet to the surface of liquid in the well. This is known as

[17] Lewis, J. O., Methods for increasing the recovery from oil sands: Bull. 148, Bureau of Mines, 1917, pp. 36–91.

[18] Arnold, Ralph, and Garfias, V. R., Methods of oil recovery in California: Tech. Paper 70, Bureau of Mines, 1914, pp. 44; Ambrose, A. W., Underground conditions in oil fields: Bull. 195, Bureau of Mines, 1921, pp. 237 (containing on pages 75–77 an extract from an unpublished manuscript of the Bureau of Mines, by Wagy, E. W., The use of compressed air in California for producing mixtures of oil and water).

submergence. (2) The total vertical distance from the point of admission of air to the point of discharge, the ratio between these two quantities representing the percentage of submergence. (3) The lift or distance from the surface of the liquid to the level of discharge. (4) The air pressure. (5) The pressure of gas in the well. (6) The gravity of the oil. (7) The percentage of water in the oil. (8) The quantity of sand in the oil. * * *

The quantity of air should be carefully regulated, the best results being obtained with the minimum volume of air necessary to cause the liquid to flow in a constant stream. Owing to the extra pressure needed to overcome the friction and inertia, the starting pressure is about double the working and calculated air pressure. The variations in the level of the liquid in the well are indicated by pressure gages on the compressor and air side of the valve that controls the air supply.

The gas that sometimes accompanies the oil helps the action of the air lift by diminishing the required air pressure, and in order to utilize all the available gas pressure it is customary to place a packer between the tubing and the casing, thus forcing the gas to flow through the discharge pipe. Wells of the same depth may require different pressures, and in order to obtain the best results a careful study of the special conditions will be desirable.

In most fields where the use of compressed air proves most beneficial, the oil and water occur in somewhat well-defined layers—a lower indefinite layer of water, an upper one of nearly pure oil, and an intermediate layer consisting of a mixture of oil and water. In nearly all such fields the water surface stands at a well-defined plane; below, water is obtained, above, the percentage of pure oil increases with the distance above this plane. It is possible, therefore, providing the necessary submergence is available, to pump either water or oil, or, within limits, any combination of the two, by regulating the location of the air inlet in relation to the water surface. If air is admitted to a stratum where water and oil are mixed the churning action caused by the air has a tendency to mix them more thoroughly and to form emulsions. This result is avoided sometimes by pumping the water and oil in the same well separately, using the air lift for the water and removing the oil by means of a plunger pump.

The conditions under which the use of an air-lift pump becomes advisable can be ascertained only after a careful and intelligent analysis of all factors affecting the operation of the property, and usually it will be found economical to seek the advice of a competent mechanical engineer before incurring the necessary expense for development. The high initial cost renders the selection of compressed-air machinery of special importance, and the proper choice and disposal of air lines and well tubing, the regulation of air pressures, and the proper determination of the many factors involved in power-plant economics are each problems of such importance that their solution can be best determined by a technically trained man familar with local conditions.

In general, it may be stated that air-lift pumping in the oil fields should be used as a last resort when the ordinary methods are no longer effective, and should be restricted to territory where considerable water accompanies the oil and there is ample submergence.

A number of years ago the air-lift system was much used in the Kern River oil field, California, where conditions favored its successful operation. The wells in the field average about 1,000 feet in depth and produce an oil with gravity of about 14° B.; at many wells the production is 80 to 85 per cent water. Most of the air lifts were submerged 250 to 400 feet or about 33 per cent, and the average air pressure used was about 180 pounds to the square inch. Most of the installations were intended to exhaust the water entering the wells. However, air lifts seemed to increase the water, and the system was finally replaced by pumping on the beam at those wells that produced large amounts of water with the oil.

More recently in the Blackwell district of the Dilworth oil field, Oklahoma, attempts have been made to produce large amounts of fluid by air lift, but results have been far from economical. The Duluth Oil Co. pumped its wells in this field by air lift until July, 1921, using five large compressors, but the expense was too heavy and the plant finally shut down. In the fall of 1921 the Kay-Kiowa Oil Co. in the same field was using the air-lift system at two wells that together produced about 150 barrels of oil and 3,500 barrels of water a day.

In the Goose Creek oil field, Texas, some of the wells out in the bay are pumped by air lifts using air pressures of 300 to 550 pounds. The wells producing 800 to 900 barrels a day are readily pumped on the beam, but those producing 1,500 to 2,000 barrels are best pumped by the air lift. The wells using air lifts are about 3,900 feet deep, and the fluid level is about 2,000 feet from the surface.

The air-lift system is expensive, as shown by the power costs of the company operating the wells in the Goose Creek field. Power consumption averages 201,204 kilowatts a month for three wells as compared with 185,106 kilowatts a month for 56 wells pumping on the beam in the same oil field. In other words, pumping the three wells by air lift costs more than pumping 56 wells on the beam.

BELTS.

Leather, fabric, and rope belts are each used for some purpose in oil-field practice.

LEATHER BELTS.

Leather belts are made in one thickness of leather or in two or more thicknesses, cemented together. Those of one thickness are most common. However, double-ply leather belts eliminate open laps and the unequal stretch that often develops in single-ply belts and are better suited to heavy service. For transmitting power in other industries, leather belts have been used more than other kinds and have been the standard against which all comparisons of value and efficiency have been made. They are not well suited, however, to conditions where they are exposed to the action of water, steam, oil, or heat, hence they are not generally used in the oil fields. They are most commonly seen at central power plants, where they drive generators, motors, compressors, and other prime movers. More recently, with the increase in the use of electric power for pumping oil wells, they are often used for transmitting power from the motor to the countershaft.

With better construction and housing of the plant and more care of equipment, leather belts can be successfully used to transmit power at pumping oil wells. Endless leather belts are now used successfully to transmit power to the band wheel where a group of wells are pumped by a central power or jack plant.

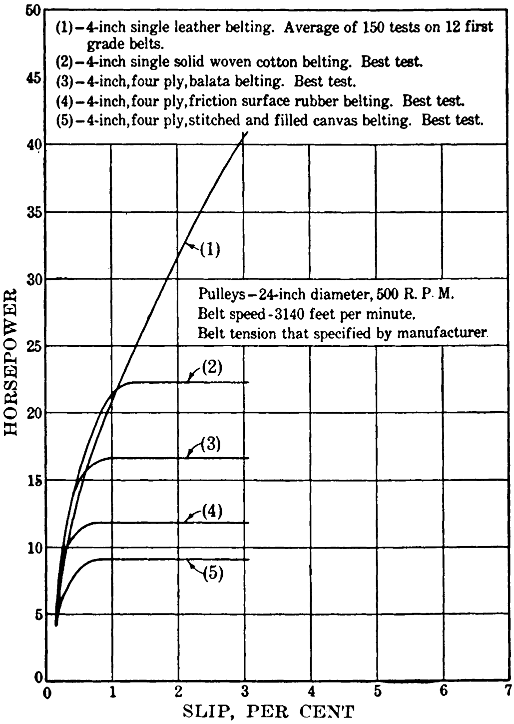


FIGURE 13.—Chart showing horsepower-slip curves for belts.

Figure 13 shows the horsepower-slip curves of leather and fabric belts. The data were obtained from tests made by the Mellon Institute of Industrial Research for the Leather Belting Exchange.

FABRIC BELTS.

Fabric belts, such as solid woven cotton, balata, rubber, and stitched canvas, are all extensively used in the oil fields, and often under the same conditions. Various weights of material, different grades of cotton or fiber, and different methods of manufacture greatly affect the strength and durability of such belts.

Solid woven belts made of cotton, camel's hair, and other fibrous materials are generally impregnated with a waterproofing compound to make them resistant to such conditions as the presence of water, steam, oil, or heat. These belts, in widths and weights proportioned to the service required, are woven in single, double, or triple thickness. They are generally pliable and have excellent wearing qualities. The makes that have a camel's hair or alpaca facing, or are made from long-fibered cotton, are exceptionally strong, pliable, and durable. They seldom crack, even when used with oil-field belt clamps. They stand high temperatures and much dirt or grit better than most other fabric belts, and are well suited for transmitting power under adverse conditions.

Balata belt consists of several plies or folds of cotton duck thoroughly impregnated with balata gum and solidified by pressure. The belt surface is finished with a thin coating of the gum. This type of belt is very good for general transmission service, especially in places where it may be exposed to moisture. It is not well suited, however, to temperatures above 110° F., as the balata gum that binds the canvas plies together softens and the plies loosen and separate. Therefore they are not suitable for steam-engine drive, or for use in climates where summer temperatures are high.

Rubber belt consists of several plies of canvas coated with rubber and vulcanized together under high pressure so that the rubber and duck are firmly united. This type of belt is usually well suited to transmission and general use. It can be used under temperatures up to 200° F. without showing ill effects. In some makes of rubber belting for oil-field service the canvas is interstitched.

Rubber belts probably vary more in quality than do any other kinds of fabric belt. The strength of a rubber belt, like that of any other belt made of canvas, lies chiefly in the canvas. Some rubber belt is made with too much filler and too little rubber; in consequence, adhesion of the canvas plies is poor and slippage results. Great care should be used in selecting a rubber belt, as a poor, cheap belt is not worth the cost of installation. Rubber belts for transmission service are usually classified as rubber covered, when a rubber cover is applied on the outside; as friction surface, when a thin coating of the "friction" is used on the outside as well as between the plies; and as stitched and rubber covered, when the plies are united with the "friction," stitched, and then covered with rubber. Rubber belts of all these kinds are in use in the oil fields. The second class, or friction-surface type, is generally the most economical for this service.

Stitched canvas belts usually consist of several plies or thicknesses of cotton duck, sewed or stitched together and treated with oil or gums. These belts tend to stretch and shrink more with changes in the weather than other fabrics. However, they are much used in the oil fields. They are generally heavier and stiffer than the others. Figure 14 shows the four different types of fabric belts commonly used.

ROPE BELTS.

Rope belts are used in the oil fields to transmit power from the band wheel to the bull wheel and to pull rods and tubing. They usually consist of a suitable length of manila cable cut from the end of a drilling cable. However, plain laid manila rope is best adapted and is recommended for this service.

At some groups of wells in the Burma oil fields of India an endless steel cable is used to transmit power from a winding drum attached to the engine—the prime mover—to the band wheels of the different wells being pumped on the beam.

BELT FASTENERS.

The oil-field clamp, shown in Plate VII, *B*, at *k* (p. 22), and in Figure 15, is more widely used at oil wells than any other type of belt fastener. It is easy to apply and holds securely. However, the belt can be injured if the clamp is shorter than the width of the belt, or if the square edge of the clamp is placed next to the belt. The latter error generally causes the belt to crack and tear at the clamp. This clamp should not be used with belts of more than six ply, as the abrupt bend produced by its use with a heavier belt causes strains and shortens the life of the belt. Some oil companies use with the clamp a rubber fillet, also shown in Figure 15, to give a smoother contact with the pulley and to prevent the jump and lash often noticed when this clamp is used.

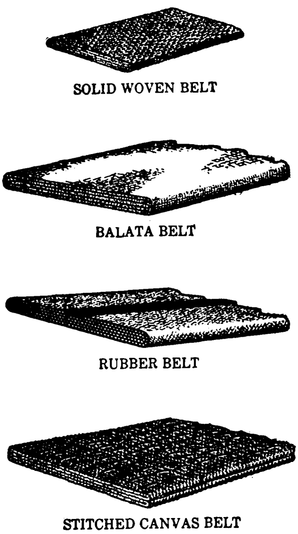


FIGURE 14.—Types of belts.

Some of the other standard methods of fastening belt ends together are shown in Figure 16: *A*, Leather-thong lacing; *B*, clipper wire lacing; *C*, crescent belt fasteners; *D*, steel-belt lacing; *E*, Jackson's belt fasteners; *F*, alligator flexible-steel belt lacing; and *G*, lap splice.

When metal belt hooks are used, the back of the hooks should have a slight curvature to conform to that of the pulleys, and for heavier service hooks having at each end two rows of teeth of suitable length to clinch properly are advisable.

Some belt manufacturers recommend for all types of belts the use of rawhide leather lace in preference to any of the different styles or makes of belt hooks or fasteners, provided the rawhide lace is properly used. They say that tearing out at the lace is usually due to a wrong method of lacing, an accident, or a defective belt, but generally to the method of lacing or to an accident.

CARE OF BELTS.

Belting should be suitably stored or it will deteriorate as rapidly in stock as in use. It should not be kept in stock more than three months, even when not subjected to extremes of temperature. Excessive heat causes belts to dry out and crack.

Mineral oils, grease, and acids destroy belt fabric and the composition cementing the plies together. Oil from the bearings of the machinery sometimes gets on the belt. This should be prevented.

Burnt belts are generally caused by slipping. In leather belts a burn shows as a hard unyielding spot; in canvas belts a burn weakens the fabric; in balata belts it melts the inner composition holding the plies together and thus loosens the plies.

Belts subjected to dust, sand, and dirt should be dusted or wiped off frequently. Lumps on belts or pulleys are often caused by the application of too much belt dressing, which mixes with dirt and dust and solidifies. These lumps strain and injure the belt. The improved service obtained by cleaning a dirty belt always repays the effort.

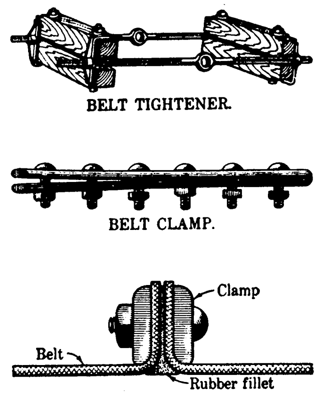


FIGURE 15.—Belt tightener and belt clamp.

Leather, cotton, or hair belts can be cleaned by washing with two parts of gasoline or naphtha and one part of turpentine. Rubber and balata belts must not be washed with this mixture, but can be washed with soap and hot water. After the belt has been washed, any adhering lumps of dirt or grease can be scraped off with a dull knife or a flat piece of steel.

The application of a good belt dressing recommended by the belt manufacturer will help to keep the belt pliable, or lessen slipping if it has stretched. A few drops of castor oil is a good dressing for rubber or stitched canvas belts. For leather belts, a melted mixture of two parts of beef tallow and one part of cod liver oil is often used with good results. Frequent and excessive use of castor oil will often make a belt crack. This oil is one of the gummiest known, and as it dries, the gum forms, hardens, cracks, and often cracks the belt fiber with it. Most manufacturers of belts do not advise the use of belt dressing.

A balanced load will materially increase the life of a belt. Most operators are agreed that a belt will last much longer with motor drive than with gas-engine drive. With the former a steady strain is applied to the belt, whereas with the latter the belt is subjected to a series of jerks corresponding to the explosions in the engine cylinder.

INSTALLATION AND CARE OF BELTS.

When belts are applied to pulleys—especially leather belts, and the standard 10-inch or 12-inch, five or six ply rubber, balata, and stitched canvas belts which are used in pumping oil wells and for general transmission service—they should not be "run on" the pulleys. They should be placed over the pulleys and drawn together with a belt tightener, one type of which is shown in Figure 15. On account of the danger to life and limb, belts should not be taken off or put on moving pulleys by hand.

The grain or hair side of leather belting, which is the more compact side and has a better friction surface, should be placed next

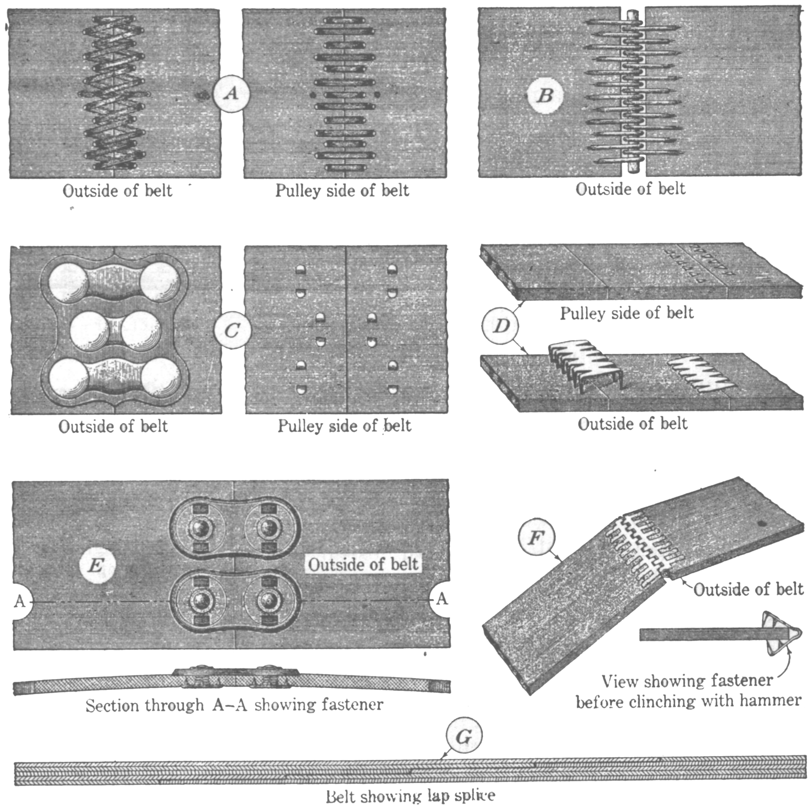


FIGURE 16.—Belt fasteners and lacing. For description, see text.

the pulley. The flesh side is coarser and stronger and will better conform to the curvature of the pulleys if on the outside.

When the ends of belts are held with clamps or lacing they should be cut square so that after the belt is applied, the strain will be equal throughout its width. Many belts are split and torn by crooked ends at the clamp or fasteners.

In cold weather a new belt should be kept in a warm room for several days before being put on the pulleys, so that it will be more pliable, will conform more readily to the curvature of the pulleys, and will be drawn more easily to the proper tension.

The seam side of a rubber belt and the trade-mark side of other fabric belts should be run away from the pulleys. It often happens that endless belts can only be installed by removing the shafting, to which the pulleys are attached, from the bearings, and then inserting the belt and replacing the shafting.

Most manufacturers recommend that an endless or spliced belt should be so placed on the pulleys that the thin edge of the splice on the inner side will be the first part to come in contact with the pulley.

Endless belts wear longer and cause less wear of the machinery and bearings. Much of the jumping and lashing of belts, especially over small pulleys, is caused by the metal fasteners, which prevent a smooth contact with the pulley face. With the high speeds and small pulleys used with motor drive, endless belts are required for good results.

Leather belts are usually made endless at the factory. Fabric belts are now commonly made endless for pumping oil wells from a central power or jack plant, especially where an electric motor with a countershaft is used for drive. Sometimes these belts are made endless in the field by using a step splice, in which the plies are cut away and overlapped as shown in Figure 16 at *G* (p. 102). The plies are first cemented, then stitched, and sometimes further reinforced with rivets.

With motor drive a belt can be run moderately slack without much slippage. With steam engine, and especially with gas engine drive, a belt must be run tighter, as the pulsations of the engine tend to make the belt lash and slip. However, belts should not be run too tight, for this increases wear on the bearings, increases the consumption of lubricating oil, and causes excessive stretch which weakens the belt until ultimately it breaks. Belts that are too tight can be easily slackened by reducing the pulley centers or by inserting a piece of belt. Belts too small for the power requirements or pulleys too small for the thickness of belt often cause trouble. If it can not carry the load, a belt will break or the lace or the fasteners will give way.

Normally, a belt should be wide enough to run slack without slipping. The slack side should be on top. Pulleys should be about the same size when possible; the smaller pulley should preferably be the driven pulley. A pulley should be at least an inch wider than the belt. The slip usually is one-half to 2 per cent, and the driving power will be decreased by this amount. Shafts and pulleys should be in perfect alignment. Belts poorly aligned often run off the pulleys or slip.

In pumping oil wells, belts are run at comparatively low speeds, but with much difference in the size of pulleys. These conditions are compensating in that the former increases effective tension and the latter, from the decreased arc of contact on the smaller pulley, which is usually the drive pulley, decreases effective tension. Introducing a jack shaft under these conditions materially increases effective tension. With motor drive the presence of such a shaft is essential unless a speed-reduction gear is used.

The following data are given by many belt-manufacturing companies as to the minimum sizes of pulleys that should be used with the various plies of belts made of regular heavy duck: For four ply, 18 inches; for five ply, 24 inches; for six ply, 30 inches; for seven ply, 36 inches; for eight ply, 48 inches; for ten ply, 60 inches. Light duck belt requires for five-ply belt, 6-inch pulleys and smaller, and for seven-ply, 6-inch pulleys and larger.

DERRICKS.

WOODEN DERRICKS.

All oil-field derricks were of lumber until recently. When the drilling derrick was removed or destroyed it was replaced with a 40 or 60 foot wooden derrick for pulling rods and tubing. This practice holds in many oil fields, especially where the wells are pumped on the beam. In other oil fields, such as those in the heavily wooded areas of Pennsylvania where forest fires often destroyed derricks, tanks, and buildings, years ago derricks were replaced by poles 40 or 50 feet long held in place by guy wires. In other fields under similar conditions, three poles bolted together at the top and with a clevis for attaching a block have been used as crude derricks to pull rods or tubing in shallow wells. In the oil fields of Ohio, Indiana, Illinois, and in some of the Mid-Continent fields, the practice for years has been to carry a mast or gin pole from well to well as a part of the pulling equipment. (Pl. XXVI, *A*.) In most of these oil fields few derricks are seen, except at new wells. The practice is most common in the shallower oil fields where the jack plant or "power" system of pumping has been used for years.

An ordinary type of wooden derrick used at wells pumping on the beam is shown in Plate XXVII, *A*. A wooden derrick, unless it is bolted, or has timber legs and girts held in place by bolted steel plates and turnbuckle braces, will not average more than 50 per cent salvage when torn down. Bolted wooden derricks are made of seasoned wood. The parts are fastened together by bolts in iron corner-pieces. No nails are used. They are easily movable and can be quickly put up or taken down.

STEEL DERRICKS.

Steel has been used as a substitute for wood in many places, and derricks may now be obtained in which the proportion of steel and wood varies to suit local conditions. Plate XXVI, *B*, shows a derrick built to conform to the orders of the California Industrial Accident Commission. This derrick is described on page 115.

More recently tubular steel derricks have gained wide use, both in the larger sizes for drilling and in shorter lengths suitable for permanent installation at pumping wells. They have these advantages over wooden derrick: They are fireproof, they offer less surface to wind pressure, they are easily erected or taken down, they have greater stability and alignment, they last longer and one derrick may be used at a number of wells, and they are lighter, decreasing transportation costs. Some types of tubular steel derricks can be erected or taken down without removing a bolt; the only tools needed are two 10-inch nut wrenches to loosen or tighten nuts.

Plate XXVI, *C*, shows a tubular steel derrick in use at a well pumping on the beam in the Big Muddy oil field, Wyoming.

Some of the older oil fields of the Mid-Continent, such as the Glenn pool in Oklahoma, have chiefly tubular steel derricks.

Most of the steel derricks in use are manufactured and sold by companies that make derricks. However, many oil companies make their own tubular derricks for pumping wells. Some companies formerly used old pipe but experience has proved that new tubing cut to the proper length at the factory is more economical. An Oklahoma oil company that builds its derricks from new pipe gave $350 as the approximate cost per derrick of its 60-foot derricks for the year 1920. The figure includes the cost of new pipe, concrete for foundations, lumber for crown blocks and floor, and the labor required.

To run or pull casing, many operators reinforce the legs of steel and tubular derricks by bolting a duplicate reinforcing leg up each corner.

USE OF GUY WIRES ON DERRICKS.

Oil derricks that must withstand severe windstorms are generally reinforced with guy wires. Plate XXVII, *A*, shows the use of guy wires on a wooden derrick in the Eldorado field, Kansas. Windstorms in the California, Texas, Oklahoma, and Kansas fields have blown down hundreds of derricks with great loss of property and of oil. Guy wires have much increased the stability of derricks. In standard practice twelve guy wires are used, three attached to each of the derrick legs.

The value of guy wires for oil derricks has been discussed[19] by F. B. Tough as follows:

On January 17, 1916, and again on the 27th of the same month, the Sunset-Midway, McKittrick, and Coalinga oil fields were visited by severe wind-

[19] Tough, F. B.. Prevention of oil-derrick failures in windstorms by improved methods of guying: Western Engineer, vol. 8, February, 1917, pp. 63–66.

storms from the southwest. Of a total of 2,000 in the Sunset-Midway field, 940 rigs or 47 per cent were blown down, and many others badly strained. I had occasion to inspect the wrecked derricks of a company that had lost 38 out of 150 or 25.3 per cent of its derricks.

In the 38 rig failures observed 94 guy wires had failed. Of this number 3 cases were not determinable, so that only the 91 determinable cases are tabulated.

The investigation of the wrecked derricks showed that the various kinds of failures may be grouped under four heads as follows:

	Number of failures	Total. per cent.
1. Deadmen were pulled out of the ground	61	67.0
2. Guy wires broken when kinked or pulled loose by slipping in a knot	26	28.6
3. Guy wires broken by straight pull where no kink or sharp bend could be observed	2	2.2
4. Deadmen so rotten that either the central part pulled out, or the wire pulled through the deadmen	2	2.2
	91	100.0

Following the storm which caused so much damage to oil derricks, improved methods of guying were used, embracing the following general features:

(1) Substantial deadmen that will neither pull out or decay during the life of the well.

(2) A rod connecting the deadman to the guy wire so that the latter will not be exposed to rust under the ground surface.

(3) Some method for tightening the guy wires that will not kink them, so that the guy wires may be kept taut at all times. A slack guy wire that will allow a derrick to sway is almost as bad as no wires at all.

(4) Absence of square knots anywhere in the wire.

(5) Three guy wires to each derrick leg.

No one of the various systems can be properly termed the best, since such devices are usually built largely, if not entirely, out of scrap from other operations, such as old drill pipe or casing for the deadmen, and worn-out sucker rods to connect the deadmen with the guy wires. Also, the shop facilities are different for different companies. Therefore, what might be the cheapest system for one company might not be the cheapest for another.

Mr. Tough shows a sketch of an improved system of guying derricks which is in common use at present. The three guy wires from each derrick leg are anchored to a concrete deadman 5 feet below the ground surface and 100 feet from the derrick corner. Each of the three guy wires is attached to the upper end of a seven-eighths-inch eyebolt by means of a three-fold eye clamp, thimble, and turnbuckle. Each eyebolt is protected from rust by a piece of $1\frac{1}{4}$-inch pipe that extends from the deadman to the threads on the upper end of the eyebolt, at a point above the surface of the ground. The space between the eyebolt and the inside of the pipe is filled with asphalt. The lower end of each of the three eyebolts is bent around the middle of a piece of 6-inch casing 6 feet long. This casing is embedded in the middle of a block of concrete 6 feet 4 inches long, 16 inches wide, and 12 inches thick. Table 7 gives the bill of material required for this guy system at each derrick.

In 1916 this system was installed by one oil company at a cost of $58 a derrick, including all labor and material. Mr. Tough says:

In attaching the guy wire to the derrick leg, the same care should be used to eliminate sharp bends and kinks as at the deadman. Also, inspection is likely to be less efficient when the derrick has to be climbed than otherwise. Since even a three-bolt clamp may work loose due to vibration, it is unsafe to rely on such a clamp entirely. A good method is to pass the wire at least three times around the derrick leg and to place a three-bolt clamp so it will be about 3 feet from the derrick leg when the guy is taut. The free end of the wire should then be fastened below the clamp by a lineman's "make-up." This make-up consists of wrapping the free end to the line itself with one or more of the galvanized wires composing the line. Such a make-up, if properly done, should carry the load even without any clamp.

No system of safety devices ever designed can be trusted without adequate inspection, and guying a derrick is no exception to this rule. Besides cautioning the men actually working on a rig to keep the guy wires taut at all times, it is advisable to have a competent man inspect all the guy wires on the property twice a year, in the spring and fall, and have him prepare a report showing the date when each guy wire was inspected and what work, if any, was done upon it at the time of inspection.

TABLE 7.—*Bill of material for guying derrick.*

Eyebolts, ⅞ inch by 9 feet long		4
Eyebolts, ⅞ inch by 9 feet 6 inches long		4
Eyebolts, ⅞ inch by 13 feet long		4
1½-inch pipe, 7 feet 4 inches long	pieces	4
1½-inch pipe, 7 feet 10 inches long	do	4
1½-inch pipe, 11 feet 4 inches long	do	4
Turnbuckles		12
½-inch thimbles		12
3-bolt guy clamps		12
Standard ⅞-inch square nuts		24
6-inch pipe, 6 feet long	pieces	4
⅜-inch guy wire	linear feet	2,000
Broken rock	cubic yard	1
Sand	do	½
Cement	sacks	5

ELECTRICAL EQUIPMENT FOR PUMPING OIL WELLS.

DEVELOPMENT IN THE USE OF ELECTRIC POWER.

The first use of electricity for the production of crude oil was in the Baku fields of Russia in 1900 where several wells were pumped by motor. The first use in the United States, so far as the writer has been able to ascertain, was by the South Penn Oil Co. at Folsom, W. Va., in 1906. Few installations were made subsequently in the United States until 1913, when the use of electricity spread in the oil fields of Texas, Kansas, and Oklahoma. During the past 6 or 7 years electrification of the oil fields has progressed rapidly, especially in the newer and larger fields. California, Texas, Louisiana, Oklahoma, and Kansas oil fields use much electrical machinery.

SOURCE AND DISTRIBUTION OF ELECTRIC POWER.

Electric power is either generated in the oil field or bought from a power company. It is generated in the field only when generation is cheaper than purchase. When power can not be bought, a private plant is generally built, if the power demand is large and permanent enough to warrant the cost, otherwise steam or gas engines are used.

The power company's charges are generally based on high-voltage current delivered to the oil company's primary distributing station, which is also the metering station for the power company. Many of the oil companies of California pay from 1.4 to 1.1 cents a kilowatt, the former rate being for a minimum daily demand of 125 kw. from one metering station.

From the primary station of the oil company the current is carried for secondary distribution to banks of transformers owned by the oil company and advantageously located with regard to the wells to be pumped. Here the power is stepped down and supplied to 6 or 10 wells within suitable radius to be pumped on the beam, or to a central "power" or jack plant pumping a group of wells, or to motors for other power needs. The more scattered the wells or groups of wells on the property the longer are the primary distributing lines required and the greater the number of banks of transformers for secondary distribution.

Plate XXVII, *B*, (p. 111), shows a bank of transformers between the primary and secondary distributing lines of an oil company that uses electricity for all power needs in the Coalinga field, California. Power is distributed from these transformers to a group of wells being pumped on the beam.

If the power requirements of the oil company are small, or if the wells to be served are compactly grouped, primary lines for distribution may not be needed, as one bank of transformers at the metering station may suffice.

The distance the power is to be transmitted determines the voltage to be used. If the generating plants are near the place of consumption 2,200 volts is usually enough. Power companies generally use much higher voltage when the transmission lines are long.

One company using electric power extensively in the Kansas oil fields buys its power at 60,000 volts and transforms it to 11,000 volts at its main distributing station, using a bank of transformers of 3,000 kv.a. capacity, which is protected on both the high and the low voltage sides by electrolytic lightning arresters and automatic switches. A metering set checks the power consumption, and an ammeter checks the load on the individual feeder from each of the four 11,000-volt feeders. Each 11,000-volt main distributing circuit is stepped down through banks of transformers of 75 kv.a. capacity to motor circuits of 440 volts. Each of these motor circuits carries six wells and the transformer capacity permits five of them to be pumped while the sixth is pulling rods and tubing.

As far as possible the motor circuits are carried on the same pole line as the main distributing system, for which 35-foot poles are high enough for clearance for two 3-phase circuits. Where motor lines can not be carried on the poles of the main distributing lines, they are carried on 30-foot poles, and on 25-foot poles at the drops to the pump houses. All of the poles are western cedar, butt treated.

For the 11,000-volt circuit the standard sizes of copper are No. 4 and No. 6 medium hard drawn. The standard sizes for the 440-volt motor circuit are No. 1 and No. 4, solid weatherproof. As no motor is more than 1,200 feet from a transformer, these sizes are satisfactory.

If the wells are in two rows, the main distribution line is run between the two. Under other conditions the lines are erected where they will probably best meet future developments.

All insulators and switches for the main distribution lines are for 13,000 volts, allowing a reasonable factor of safety. Lightning arresters and cut-outs are installed on each bank of transformers, and provision is made for choke coils.

ELECTRIC MOTORS.

With the introduction of electric power, electric motors of various types and of suitable speed and power rating have replaced steam and gas engines in the oil fields for driving pumps, compressors, unit powers, jack plants, and wells pumping on the beam, where many pulling jobs are required. Pumping of the well requires that the motor run continuously at high efficiency with low power demand, and at comparatively low speed; pulling of rods and tubing requires higher power demand, higher speed, and high torque. To meet both conditions, several of the electrical manufacturing companies have developed the two-speed, variable-speed induction motor in which the lower horsepower rating is used for pumping and the higher rating for pulling rods and tubing.

Steam engines, like electric motors, give maximum torque at zero speed and are therefore well suited for pulling rods and tubing. However, the relatively high cost of running steam engines in small units is against their use for beam pumping. Oil and gas engines exert their maximum torque at high speeds and have no torque at zero speed; hence the complicated reversing clutch is necessary for pulling rods and tubing.

Plates X and XI (pp. 58 and 60) show the machinery and equipment a California company uses at the well for an electrical installation for pumping on the beam; Table 5 gives a list of the machinery and equipment required. Reference No. 44 in Table 5 describes the motor used as 15 to 30 horsepower, 3-phase, 60-cycle, 440-volt, 2-speed variable, complete.

These 2-speed motors are made in various sizes, as: 10 to 25, 15 to 30, and 20 to 50 horsepower. The lower rating for each motor is the pumping rating, and the higher that used to pull rods and tubing.

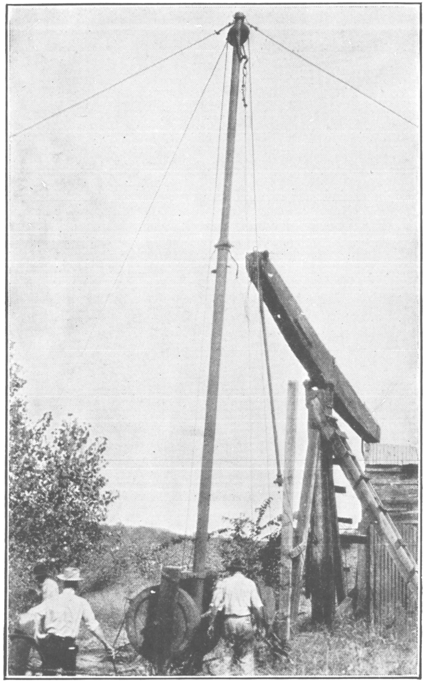
Some oil-field operators, who use electric power at wells pumping on the beam and requiring little pulling of rods and tubing, prefer to install a motor of suitable size for pumping service only, such as 5, 7½, 10, or 15 horsepower, and use a 30-horsepower motor mounted on a truck to pull rods and tubing at all of the wells. This means a decided saving, as a 15 to 30 horsepower motor installed at the well for pumping and pulling costs about $1,200, as compared with $150 for a 5-horsepower motor when the latter is large enough for pumping alone.

No special electrical features are necessary with an electric motor for driving a central power or jack plant. However, a countershaft or a reduction gear is necessary with many types of powers to secure proper speed.

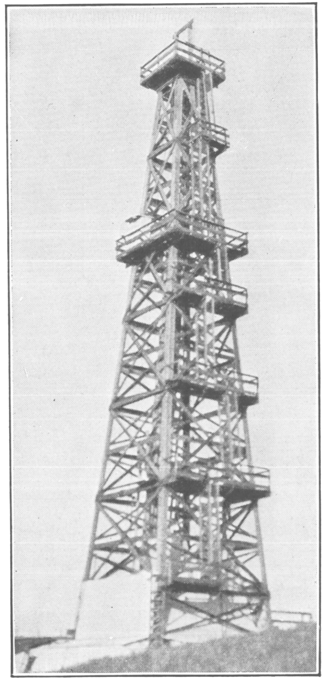
ADVANTAGES OF ELECTRIC MOTORS.

Many operators claim less breakage of shackle lines and longer life of belts because of the smoothness and regularity of motor drive.

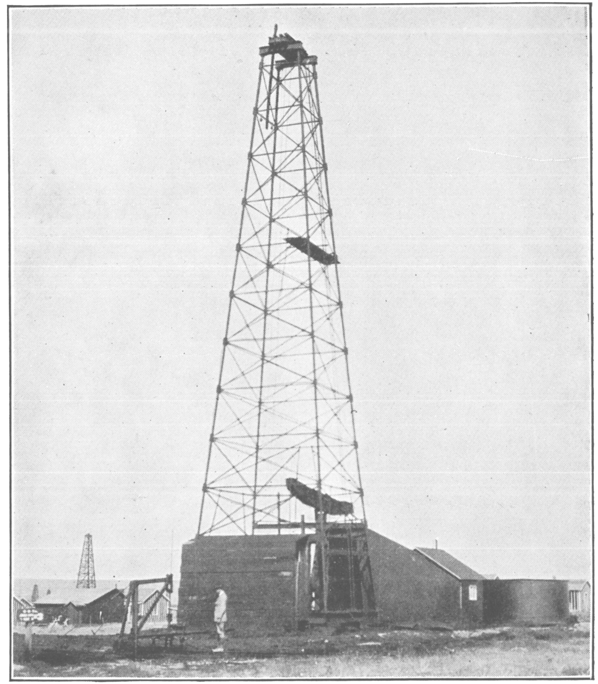
Wells pumped by a central power or jack plant have rods and tubing pulled with a portable pulling machine operated by a team of horses, or if electric power is used at the property, operated by a motor-driven pulling machine. Electric power, when available, is generally more satisfactory for unit pumping powers than steam, oil, or gas engines, as the wells so operated are generally small, and the use of motor drive usually means much saving in labor and attention. At Bartlesville, Okla., wells formerly pumped by a central power or jack plant are now pumped individually by motor-driven unit powers, because the growth of the city necessitated removal of the shackle lines which formerly crossed the streets and alleys. A number of wells on the Arkansas River bed, near Jenks, Okla., that are surrounded for several months during the year with water, were formerly pumped by a central power. The breakage of shackle lines during high water, and the difficulty of repair in the water, caused



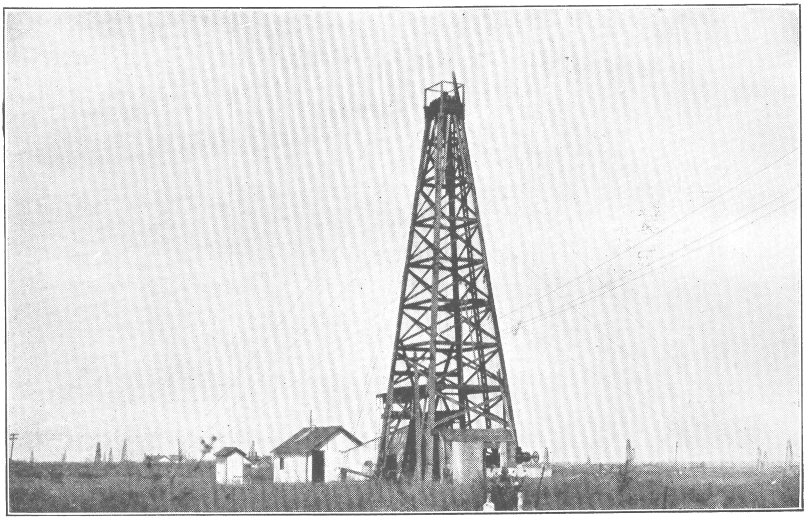
A. PIPE MAST AND DRUM FOR PULLING OIL WELLS, BARTLESVILLE, OKLA.



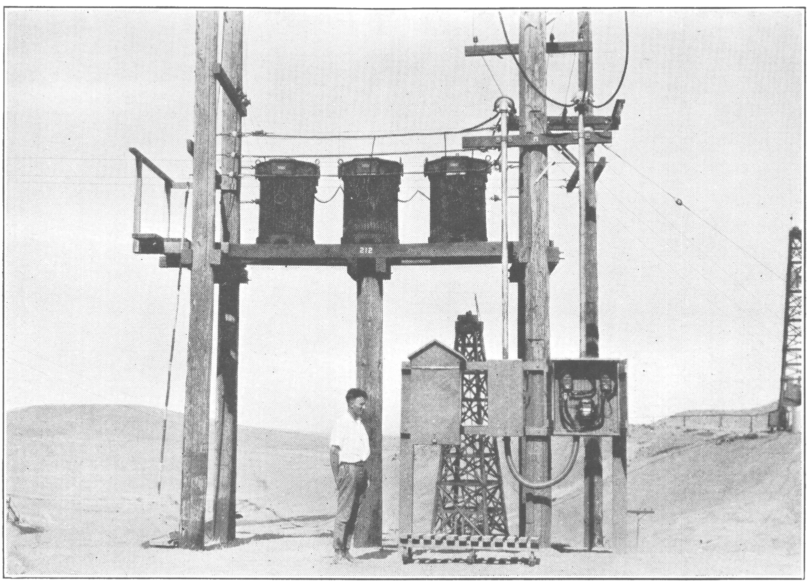
B. DERRICK BUILT TO CONFORM TO THE ORDER OF THE CALIFORNIA ACCIDENT COMMISSION



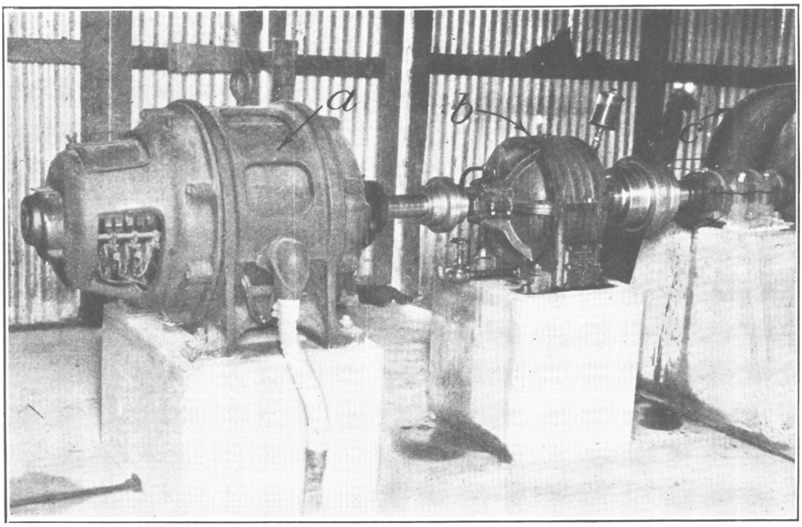
C. TUBULAR DERRICK, BIG MUDDY OIL FIELD, WYOMING



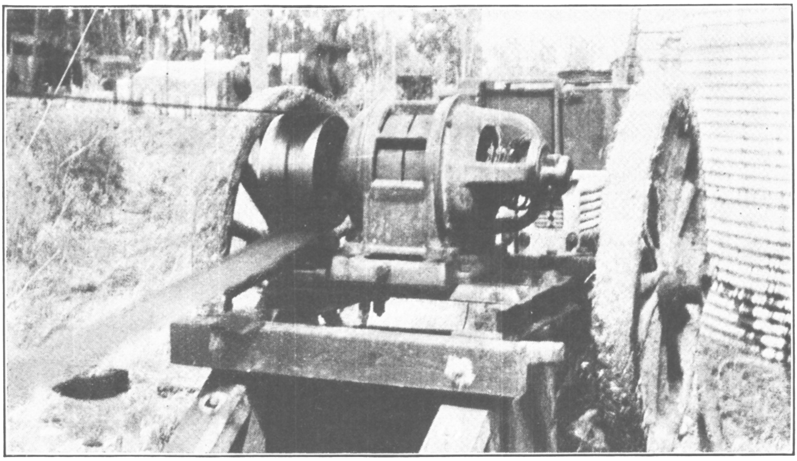
A. WOODEN DERRICK WITH GUY WIRES, ELDORADO OIL FIELD, KANSAS



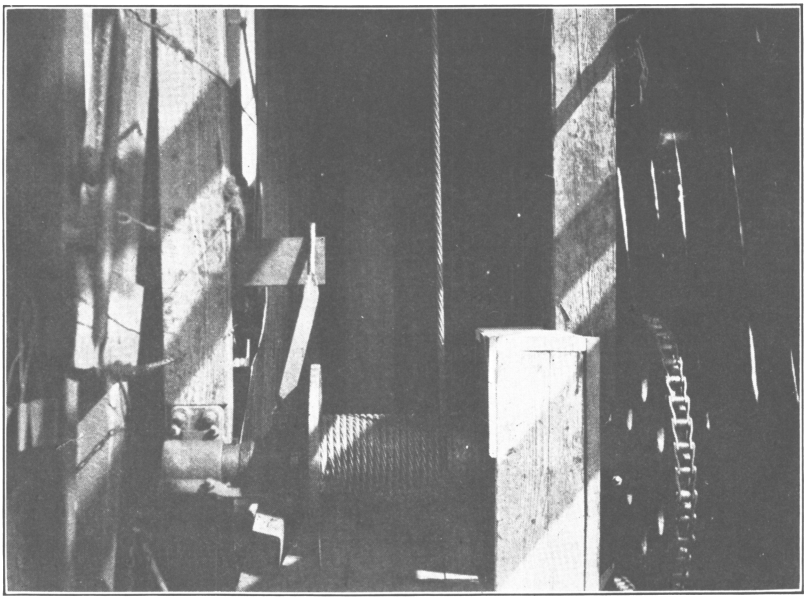
B. BANK OF TRANSFORMERS AT GROUP OF WELLS BEING PUMPED ON THE BEAM



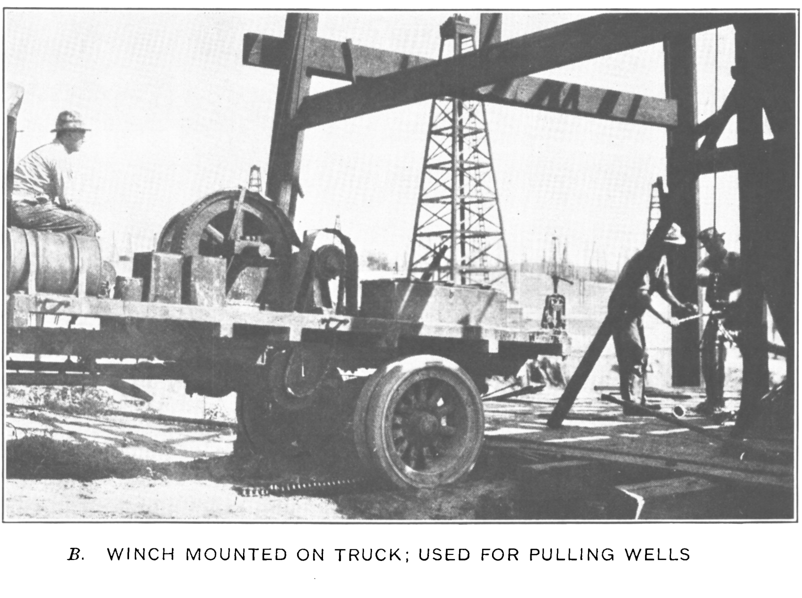
A. NEW TYPE OF 15 TO 35 HORSEPOWER OIL-WELL MOTOR, *a*, DIRECT-COUPLED TO TURBO-GEAR *b*, WHICH IN TURN IS COUPLED DIRECTLY TO THE PULLEY DRIVING THE BAND WHEEL *c*



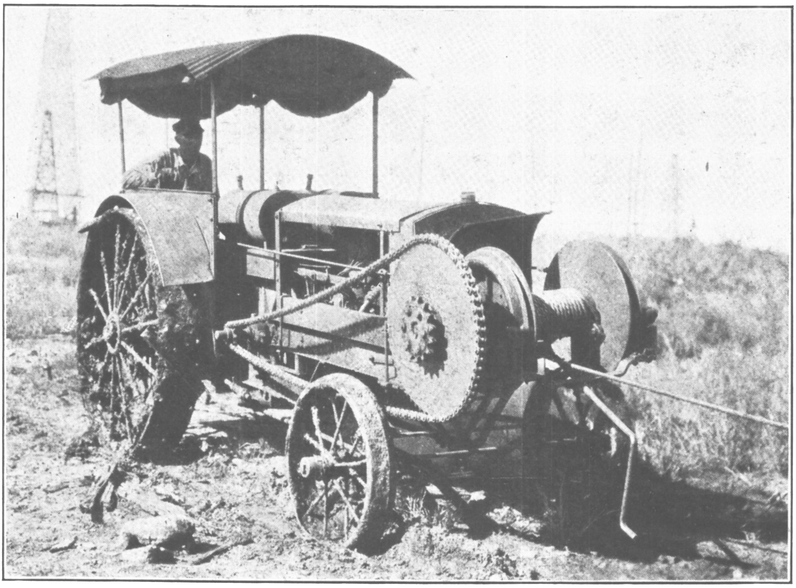
B. ELECTRIC MOTOR FOR PULLING WELLS; MOUNTED ON WAGON TRUCK



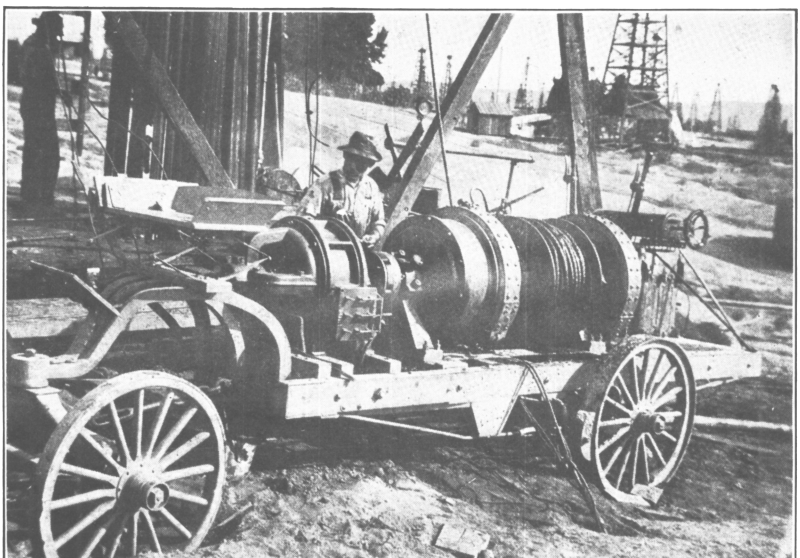
A. WINCH INSTALLED AT WELL; CHAIN DRIVE FROM BAND WHEEL



B. WINCH MOUNTED ON TRUCK; USED FOR PULLING WELLS



A. WINCH MOUNTED ON TRACTOR; USED FOR PULLING WELLS



B. ELECTRIC MOTOR AND DIRECT-CONNECTED WINCH MOUNTED ON WAGON; USED FOR PULLING WELLS

much lost production. To correct this difficulty a small electric motor driving a unit pumping power was installed at each well, and the operation of each motor controlled by a switch located on the river bank.

For driving pumps and compressors, motors have proved just as satisfactory in oil-field practice as in mining and other industries. Plate XXVIII, *A* (p. 110), shows a new type of 15 to 35 horsepower oil-well motor direct-coupled to turbo-gear, which in turn is direct-coupled to the pulley driving the band wheel at wells pumping on the beam.

WELL PULLING-MACHINES.

In the early days of the oil business, all wells were pulled with a steam engine, bull wheels, and the other drilling equipment left in place for pumping, after the well had been completed. This method is still used at many places, noticeably where the wells are pumped individually on the beam.

At other wells where the steam engine has been replaced by a gas engine for pumping, the pulling of rods and tubing is often done with the reversible clutch attachment on the gas engine, shown in Plate VII, *B* (p. 22).

At still other wells pumping on the beam where electric power has replaced the steam or gas engine, the motor used is often the 2-speed, 2-power type designed both for pumping and pulling. Sometimes, however, as previously mentioned, a motor of a rating suitable only for pumping is installed at the well, and a larger motor powerful enough to pull any of the group of wells to be served is moved to the well to be pulled, aligned outside of and in back of the motor house, the belt connecting the pumping motor to the band well is removed, and power for pulling is delivered from the motor mounted on the truck to the band wheel by means of a longer belt carried with the larger motor for this purpose. See Plate XXVIII, *B* (p. 110).

Recently one of the larger California oil companies has adopted the practice of installing a winch for pulling at each of its wells pumping on the beam. This hoist is equipped with a clutch and is chain-driven from the tug on the band wheel, as shown in Plate XXIX, *A*.

In many oil fields, since adoption of the central power or jack plant, all mechanical equipment has been removed from the individual well, the derrick alone being left in place. Pulling was formerly done by using horses and a set of tackle blocks to increase the power. More recently, mechanical devices have replaced horses, such as a winch mounted on a truck, as shown in Plate XXIX, *B*, or a winch mounted on a tractor, as shown in Plate XXX, *A*, or a winch driven by an electric motor and mounted on a wagon, as shown in Plate XXX, *B*.

In many of the older oil fields, where all pumping is done by a power or jack plant, derricks are seldom seen. For the pulling of these wells, a machine is used that consists of a pipe or timber mast 35 to 40 feet long, with an attached crown pulley, drum for winding, and guy wires for temporary support in proper position at the well. This equipment is moved from well to well on a truck, tractor, wagon, or wheel-carriage attachment. If the machine is moved by a wagon or wheel-carriage attachment, the well is usually pulled by a team of horses. If it is moved on a truck or tractor, the well is often pulled by a winch mounted on the truck or tractor, or by direct pull, using the truck or tractor like a team of horses. Plate XXVI, *A* (p. 110), shows a well being pulled by a team of horses with a mast and reel of this type.

Some of the oil-well supply companies sell a caterpillar tractor with mast and winch mountings to pull oil wells. Several makes of tractor drilling-machines run by gas engine are also designed and equipped to pull rods, tubing, and casing. Recently two men using one of these machines at a well near Bridgeport, Ill., pulled and replaced 1,960 feet of rods and tubing in one day. Formerly, two teams of horses and four men, including the teamsters, took two days to complete the same work.

A winch mounted on a truck or tractor can pull rods and tubing much more quickly than they can be pulled by horses. Recently at Oil City, Pa., a winch mounted on a tractor pulled 950 feet of rods and tubing in 1 hour and 15 minutes, as compared with 3 hours formerly required with a team.

Horses are used for pulling wells at places where a truck or even a tractor could be moved only with great difficulty.

A tractor can be moved over roads that would be impossible for a truck. A tractor can turn and get into suitable position for pulling in a much smaller space than a truck. However, with good roads, a truck can be driven much more rapidly from well to well and can carry men and the equipment needed in pulling.

In general, the choice of equipment to be used for pulling wells is largely a question of conditions at the individual property, such as frequency of pulling jobs, character of roads leading to the wells, amount and variety of service required of the motive power, and amount of capital expenditure warranted for new equipment.

Wells of the Chilkat Oil Co. at Katalla, Alaska, in a mountainous area with swamps and tundra, are pulled by means of a donkey engine and boiler mounted on a truck. This equipment is moved to the well to be pulled over a track of 12-pound steel rails which connects all of the wells with the machine shop and storehouse. The truck is moved by unwinding the cable from the engine drum and attaching the free end as a ground line to a tree ahead, and then winding the cable on the drum. This procedure is repeated until the well is reached. In many places the grades on this track are as high as 10 to 12 per cent. This system facilitates the movement of equipment to the wells, which are so situated that the construction of roads and transportation over them would be practically impossible.

MISCELLANEOUS OPERATING EQUIPMENT AND PRACTICE.

Miscellaneous operating equipment and practice at pumping oil-well properties are classified as: 1, Housing and sanitation; 2, heating, lighting, and safety; 3, tanks, ponds, and reservoirs; 4, pipe lines and flumes; 5, traps for saving gas at oil wells; 6, buildings, storerooms, and shops; 7, records and forms; 8, roads and transportation; and 9, field organization.

Many data on equipment and practice have been given in bulletins and technical papers of the Bureau of Mines. However, this bulletin would not be complete without a reference to the publication in which equipment and practice have been discussed.

HOUSING AND SANITATION.

Housing and sanitation are important considerations for oil companies operating in arid, isolated, or thinly settled regions. In most of the oil fields in the eastern United States, and in many in the Mid-Continent, the employees live in towns or villages near the fields, so that housing and sanitation are municipal problems. However, in California, Texas, Louisiana, Kansas, Wyoming, and Montana many of the new oil fields discovered have been in thinly settled regions, so that oil companies, like many coal companies, have had to give attention to the housing and care of employees and their families.

Plate I, *A* (p. 4) shows the good housing conditions at the camp of an oil company in the Salt Creek field, Wyoming. Similar camps are found at many other oil fields in the United States.

Housing and sanitation have been discussed in publications of the Bureau of Mines.[20]

HEATING, LIGHTING, AND SAFETY.

Buildings in most oil fields are heated largely by natural gas burned in stoves. Houses of employees, offices, and shops, however,

[20] Bowie, C. P., Oil-camp sanitation: Tech. Paper 261, Bureau of Mines, 1921, 32 pp.; White, Joseph H., Houses for mining towns: Bull. 87, Bureau of Mines, 1914, 64 pp.

are generally the only buildings that are heated. Many offices and shops that are convenient to boilers are heated by steam lines from the boilers.

In many oil fields the wells are pumped only during the day, so that a lighting system is not required. Oil companies that use electricity for power use it for lighting also. At many properties where other forms of power are used, a small generator belted to a steam, gas, or oil engine is used during the night. The wiring should be properly installed and insulated to prevent danger from fires. Gas lights are extensively used in some fields, but in buildings they are liable to cause fires unless the pressure is properly regulated.

To increase both safety and efficiency enough light should be supplied men working at night. Special care should be taken to have plenty of light in engine and power buildings, at stairs, and along walks.

Oil fields are subject to the general safety orders regarding the use of boilers, engines, compressed air, gears, belts, clutches, and pulleys of the industrial accident commission of the State in which they are located. Most of the oil-producing States have no special safety regulations for oil fields. Only recently have such regulations been formulated in the State of California. That part of these tentative regulations pertaining to pumping oil-well properties is given below:

FIRST AID.

The minimum assortment of first-aid materials that shall be kept in a cabinet approved by the Industrial Accident Commission at each drilling well, compressor plant, pipe-line pumping plant, and central boiler room or other places of employment where eight or less men are employed, is as follows:

First-aid manual, triangular bandages, sterile first-aid compresses, picric acid gauze, aromatic spirits of ammonia, iodine (not stronger than ¼ U. S. P.), one pair forceps, roller bandages, and adhesive tape.

REPORT OF INJURIES.

Every employer of labor, without any exceptions, and every insurance carrier, and every physician or surgeon who attends any injured employee, is hereby required to file with the commission, under such rules and regulations as the commission may from time to time make, a full and complete report of every injury to an employee arising out of or in the course of his employment and resulting in loss of life or injury to such person; provided, that such report shall not be required unless disability resulting from such injury lasts through the day of the injury or requires medical service other than ordinary first-aid treatment. Where the injury results in death, a report shall be made by the employer to the commission by telephone or telegraph forthwith.

DERRICKS.

Every derrick and every derrick floor, walk, and platform shall be substantially constructed of structurally sound material to conform to standard practice, and shall be kept in good repair.

DERRICK CROWN PLATFORMS AND RAILINGS.

On every platform hereafter constructed for drilling or equipped for redrilling, a platform at least 2 feet wide shall be provided around the edges of the derrick crown. This platform shall be equipped on its outer edges with a standard two-rail railing 3½ feet high and a toeboard 12 inches high above water table.

OUTSIDE DERRICK PLATFORMS FOR DRILLING RIGS.

A platform shall be provided completely around the derrick and level with the quadruple board or with the principal working platform.

A platform shall be provided completely across the ladder side of the derrick and level with each auxiliary platform other than the principal working platform.

The width of platforms shall be not less than 2 feet; platforms shall be provided with openings to permit the passage of men climbing derrick ladders; standard two-rail railings 3½ feet high shall be provided around the outer edges of platforms.

INSIDE DERRICK PLATFORMS.

Double (kelly) boards, triple boards, quadruple (fourble) boards and all drill pipe or tubing platforms in derricks shall completely cover the spaces from the working edges of the platforms back to the legs and girts of the derricks.

The decking planks on working sides of all platforms shall be secured to derrick girts with U bolts or I bolts.

FINGER BOARDS.

Fingers (finger boards) shall be secured to derricks by safety wires or cables attached to outer ends of fingers.

GINPOLES.

The ginpoles at the crown of every derrick hereafter constructed or reconstructed shall have two uprights and a crossbeam.

The clearance between the water table and the crossbeam shall be not less than 7 feet.

AUXILIARY MEANS OF ESCAPE.

Auxiliary means of escape from the quadruple board, or the principal working platform, and from the kelly board on every drilling and redrilling derrick shall be provided either via a derrick guy line or by means of a specially rigged life line from each of said working levels to the ground.

Unless a specially rigged life line has been provided, the guy line shall be smooth and free of obstruction, so that in case of fire or other emergency in or around a derrick, any employee whose escape has been cut off from the regular passageways can reach the ground by sliding down the guy line.

CROWN SHEAVES.

The gudgeons of crown sheaves on derricks shall be provided with boxing or metal straps on top to prevent the sheaves jumping out of bearings.

LADDERS.

Ladders shall be provided on all derricks, extending from the floors to the water tables as follows:

The stringers shall be of 2-inch by 4-inch sound lumber, or equivalent. The tops and bottoms of ladder sections shall be fastened to the derrick girts with bolts. Ladder stringers shall terminate 3½ feet above water tables.

The rungs shall be of 1-inch by 4-inch sound lumber, or equivalent, uniformly spaced not to exceed 16 inches on centers, and shall be securely fastened to the stringers. The length of the ladder rungs (width of ladder) shall be not less than 12 inches.

Rungs shall be not less than 4 inches from girts or other derrick members.

Over the ends of the rungs there shall be fastened securely strips of sound lumber, two-strand galvanized or copper twisted wire, equivalents, of ample strength and secured so that rungs can not be pulled off.

At no point shall a ladder lean back from the vertical.

CALF-WHEEL TIE RODS.

Every calf-wheel headboard shall be tied to the main sill with an iron or steel rod not less than 1 inch in diameter.

BULL-WHEEL SPREADERS.

Spreaders placed on a bull-wheel shaft shall be bound to the shaft with cable or heavy wires and secured so that the spreaders can not fly.

SAFETY BELTS AND LIFE LINES.

Safety belts and life lines shall be provided for and worn by *all* employees when working on walking beams and at every other point in a derrick above the derrick floor.

Steel cable or rod life lines shall be extended from derrick leg to derrick leg completely around the inside of derricks at all inside platform levels. These lines shall be strung not lower than 3 feet above platform levels, and in such fashion that derrick men can easily and readily attach their belt lines to main life lines at any point, around all sides of derricks.

Safety belts, life lines, cables, rods, and derrick members to which life lines are made fast shall be strong enough to hold a weight of 200 pounds falling 10 feet.

Safety belts, life lines, rods, and fittings shall be inspected and tested by drilling or production foremen, or other competent persons and shall be kept in good repair at all times.

PIPE HOOKS.

A pipe hook shall be provided for the use of every workman when handling drill pipe on a derrick floor.

If used above a derrick floor, every pipe hook shall be secured to the derrick with a rope in such a manner as to prevent the hook from falling.

BELT-HOUSE ROOF RUNWAYS AND LADDERS.

Runways shall extend from sides of derricks to points at least 2 feet beyond the stirrups at the ends of walking beams. These runways shall be at least 2 feet wide and shall be guarded on both sides by standard two-rail railings, 3½ feet high.

Ladders extending from derrick-floor levels to belt-house roof runways shall be provided.

The stringers shall be of 2-inch by 4-inch sound lumber, or equivalent.

If Samson post braces be used as ladder stringers, the other ends of rungs shall be supported by stringers.

Rungs shall be of 1-inch by 4-inch sound lumber, or equivalent, uniformly spaced not to exceed 16 inches on centers and shall be securely fastened to the stringers. The length of the ladder rungs (width of ladder) shall be not less than 12 inches in the clear between stringers.

Secure hand holes shall be provided at the tops of ladders.

WALKING-BEAM STEPS.

To provide safe and easy access to walking beams, steps and hand holes shall be provided on Samson posts above belt-house roofs.

CALF-WHEEL SPROCKETS.

Every calf-wheel sprocket shall be guarded so that a breaking chain can not fly into the derrick.

BELT HOUSE FROM ENGINE ROOM TO CALF WHEEL.

In every belt house used as a runway, the engine drive belt, the band wheel, the friction pulley, the sprockets and the sprocket chain, the clutch, the calf wheel, and all other moving mechanisms in the belt house shall be guarded by a standard two-rail railing 3½ feet high, placed not less than 15 nor more than 18 inches in the clear from said mechanisms and extending from the engine room to the calf-wheel jackpost.

A stairway or a runway shall be provided at every band wheel so that workmen can handle the bull rope in safety.

LOOSE MATERIAL IN DERRICKS.

Tools, machine parts, or material of any kind shall not be kept in a derrick above the derrick floor, unless there is occasion for their immediate use, and then adequate precaution shall be taken to prevent their falling on employees below.

TRAVELING BLOCKS AND HOOKS.

The sheaves of traveling blocks at the points of contact with cables shall be guarded with suitable housing approved by the Industrial Accident Commission.

Drill pipe, casing, tubing, and sucker-rod hooks shall be provided with latches to prevent the elevator links and other equipment becoming accidentally disengaged from the hooks.

The hooks of traveling blocks used in handling casing or drill pipe shall be equipped with suitable handles.

COUNTERBALANCES.

Counterbalances shall clear the ground or the derrick floor level by not over 5 feet and suitable provision shall be made to prevent them from falling on workmen.

ROTARY DRILLING RIGS.

On both sides of the drawworks, guards of heavy metal shall be provided for all drive sprockets and chains. These guards shall be strong enough to withstand the shocks of breaking chains, and shall be so installed that workmen can not come into contact with moving parts.

The guard for the low-gear drum-drive sprocket and chain next to the driller shall be flanged with steel plate, so that a breaking chain can not hit the driler or foul the brake lever.

On every chain-drive rotary, the drive pinion, the shaft, the coupling, and the bevel gears shall be guarded with metal shields.

The eccentrics of every two-cylinder drilling engine shall be guarded with suitable metal shields.

The pump end of every rotary hose shall be fastened to the derrick, and the other end of the hose shall be fastened to the gooseneck, or to the swivel bail with a chain or with a wire cable.

The key seat and projecting key on every cathead shall be covered with a smooth thimble.

To support the snapping line and the breaking line, a U bolt, or other suitable device, shall be set in the jackpost at a point below the cathead.

WALKING BEAMS.

At every well being drilled with a rotary rig, the walking beam shall be kept outside of the derrick, except when necessary or expedient to alternate between rotary and standard methods of drilling.

FLYWHEELS OF ONE-CYLINDER ENGINES.

The flywheels of one-cylinder rotary drilling engines shall be so guarded that employees can not be injured by a bursting wheel or rim.

No engine flywheel shall be weighted with other than the balancing rims provided for that purpose, and then never in excess of rated capacity.

STEAM-ENGINE STOP VALVES.

Every steam engine shall be equipped with a stop valve installed in the steam line directly ahead of the engine.

LOADING RACKS.

Every platform shall be not less than 3 feet wide. If constructed of metal gratings, the maximum size of the openings shall be 1 inch by 6 inches.

The outer edges and the ends of every rack, except at the stairways and on the loading sides of the rack, shall be provided with standard two-rail railings 3½ feet high.

Stairways shall be provided from the ground to the ends of every rack, and shall be equipped with handrails, the tops of which shall be 30 inches vertically above the nose of the tread. The slope of stairways shall not exceed 50 degrees (119.2 per cent).

OIL AND GAS STORAGE TANKS AND CONTAINERS.

No workman shall be required to enter any tank or other container used for the storage of crude oil, or any product thereof, or any confined space until it has been freed from injurious gas, unless he is equipped with suitable breathing apparatus and appurtenances, No workman shall be required to enter any tank or other container provided only with manholes in the top, excepting earthen and concrete lined reservoirs, until he has been supplied with a rope which shall be made fast to his body and to a substantial support on the outside of the tank or other container. The rope must be of sufficient length to reach from the outside support to any point of work in the tank or container, and shall be of sufficient strength to bear the weight of the workman.

All work in any confined space when atmospheric conditions are nauseating, or in any way cause indisposition on the part of the workmen, shall be arranged in short shifts, the men on the outside alternating to relieve those inside.

CONTROL OF STATIC ELECTRICITY.

Metallic parts of containers and conductors of inflammable liquids shall be in electrical contact and connected to ground in such manner as will prevent development of static electric sparks.

TANKS, PONDS, AND RESERVOIRS.

Tanks, reservoirs, and ponds for the storage of oil have been discussed in Bureau of Mines publications.[21]

At pumping wells the oil is run into tanks made of wood or steel, or into concrete reservoirs. In some fields dams are built across small valleys or depressions for the purpose of impounding and recovering oil that may be lost from wells, pipe lines, or tanks and escape into the drainage of the area. Much oil is often recovered in this way. In some fields oil seepage or loss into streams also must be prevented, because, as in California, the water of the streams is used for irrigation. At other oil fields the building of dams and the construction of ponds are necessary to provide storage for oil from new wells with a large production when enough tankage is not immediately available or where pipe lines have not yet been laid.

Wooden tanks are generally made with white pine, Louisiana cypress, or California redwood staves, white pine bottoms, and steel or wrought-iron hoops.

STEEL TANKS.

Steel tanks are of three general classes—steel riveted, corrugated steel, and bolted steel. The smaller sizes of steel tanks are generally bolted or corrugated. The former type is most common in the Mid-Continent and eastern oil fields, and the latter in the California fields. The bolted-steel tank is easily erected without the use of skilled labor, and is readily taken down and moved from place to place. The bolts and nuts holding the plates together are on the outside of the tank and can be readily tightened if a leak develops.

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[21] Bowie, C. P., Oil-storage tanks and reservoirs, with a brief discussion of losses of oil in storage and methods of prevention: Bull. 155, Bureau of Mines, 1917, 73 pp.; Wiggins, J. H., Evaporation losses of petroleum in the Mid-Continent field: Bull. 200, Bureau of Mines, 1922, 115 pp.

Operators using corrugated-steel tanks claim that they are more rigid than ordinary steel tanks, and hence the smaller sizes can more readily be moved from place to place without being taken apart.

Plate XXXI, *A*, shows a steel gun-barrel tank at *a* and production tanks at *b* and *c*, as used in the Kern River field, California. The oil, water, and sand from the wells is delivered through the flume *d* to the gun-barrel tank, where the sand and water is drawn off before the oil is pumped to the production tanks.

Plate XXXI, *B*, shows a steel gun-barrel tank, *a*, and four production tanks, *b*, in the Big Muddy field, Wyoming. As in the Kern River field, the water produced with the oil is drawn from the bottom of the gun-barrel tank before the oil is run to the production tanks. At *c* is the boiler used for steaming the oil before it is run.

Plate XXXII, *A*, at *a*, shows a corrugated-steel production tank in the Santa Maria field, California.

Production tanks generally range in size from 50 to 2,000 barrels, according to the production requirements of the property.

Evaporation losses from tanks are decreased by proper housing, water-sealed tops, and closed tops.[22]

CONCRETE RESERVOIRS.

Concrete reservoirs are used instead of steel or wooden tanks in some of the California and Mid-Continent fields to steam emulsified oil before it is delivered to the storage tanks. One type used by a company in the Eldorado field, Kansas, is made 11 by 26 feet in area and 5½ feet deep with walls, bottom, and baffle plates of reinforced concrete 6 inches thick.

PIPE LINES AND FLUMES.

Crude oil is led from the well to production and storage tanks through a collecting system of pipe lines. From the storage tanks the oil is run through larger pipe lines to the storage tanks of the purchasing company, and from these through 6-inch or 8-inch lines to the refinery.

The natural gas is piped from the well with the oil to the gas trap, or to the gasoline-recovery plant if the gas is wet, and then to the point of consumption.

PIPE AND JOINTS.

The pipe generally used for oil, gas, and water lines is standard steel pipe with threaded couplings. Table 8 gives the sizes and

[22] Wiggins, J. H., Evaporation losses of petroleum in the Mid-Continent field: Bull. 200, Bureau of Mines, 1922, 115 pp.

weights of standard pipe. Flanged couplings are used at convenient points where it may be necessary to break the line from time to time. In many recent large oil or gas pipe-lines, the joints have been welded by the oxy-benzol or oxy-acetylene torch instead of put together with couplings.

TABLE 8.—*Standard pipe, black and galvanized.*

(Weights given in pounds. Dimensions given in inches.)

Size.	Diameters.		Thickness.	Weight, per foot.		Threads per inch.	Couplings.		
	External.	Internal.		Plain ends.	Threads and couplings.		Diameter.	Length.	Weight.
⅛	0.405	0.269	0.068	0.244	0.245	27	0.562	⅞	0.029
¼	.540	.364	.088	.424	.425	18	.685	1	.043
⅜	.675	.493	.091	.567	.568	18	.848	1⅛	.070
½	.840	.622	.109	.850	.852	14	1.024	1⅜	.116
¾	1.050	.824	.113	1.130	1.134	14	1.281	1⅝	.209
1	1.315	1.049	.133	1.678	1.684	11½	1.576	1⅞	.343
1¼	1.660	1.380	.140	2.272	2.281	11½	1.950	2⅛	.535
1½	1.900	1.610	.145	2.717	2.731	11½	2.218	2⅜	.743
2	2.375	2.067	.154	3.652	3.678	11½	2.760	2⅝	1.208
2½	2.875	2.469	.203	5.793	5.819	8	3.276	2⅞	1.720
3	3.500	3.068	.216	7.575	7.616	8	3.948	3⅛	2.498
3½	4.000	3.548	.226	9.109	9.202	8	4.591	3⅝	4.241
4	4.500	4.026	.237	10.790	10.889	8	5.091	3⅝	4.741
4½	5.000	4.506	.247	12.538	12.642	8	5.591	3⅝	5.241
5	5.563	5.047	.258	14.617	14.810	8	6.296	4⅛	8.091
6	6.625	6.065	.280	18.974	19.185	8	7.358	4⅛	9.554
7	7.625	7.023	.301	23.544	23.769	8	8.358	4⅛	10.932
8	8.625	8.071	.277	24.696	25.000	8	9.358	4⅝	13.905
8	8.625	7.981	.322	28.554	28.809	8	9.358	4⅝	13.905
9	9.625	8.941	.342	33.907	34.188	8	10.358	5⅛	17.236
10	10.750	10.192	.279	31.201	32.000	8	11.721	6⅛	29.877
10	10.750	10.136	.307	34.240	35.000	8	11.721	6⅛	29.877
10	10.750	10.020	.365	40.483	41.132	8	11.721	6⅛	29.877
11	11.750	11.000	.375	45.557	46.247	8	12.721	6⅛	32.550
12	12.750	12.090	.330	43.773	45.000	8	13.958	6⅛	43.098
12	12.750	12.000	.375	49.562	50.706	8	13.958	6⅛	43.098
13	14.000	13.250	.375	54.568	55.824	8	15.208	6⅛	47.152
14	15.000	14.250	.375	58.573	60.375	8	16.446	6⅛	59.493
15	16.000	15.250	.375	62.579	64.500	8	17.446	6⅛	63.294

Welded joints have not been used to any extent for the smaller oil and gas gathering lines, probably because the lines are not considered permanent enough. However, the gas torch could be extensively used to weld smaller lines and avoid the use of couplings.

The gathering-line systems for oil and gas use pipe ranging in size from 1¼ to 6 inches at the well to 2 to 8 inches in the main lines. The size of the oil pipe-lines depends on the quantity and gravity of the oil and the amount of sand and water produced with the oil; for gas lines, the size and weight of the pipe used depend upon the volume and pressure of the gas as it comes from the well.

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PIPING HEAVY OIL.

At some of the wells in the Casmalia field, California, the oil is very viscous, and has a gravity of 8° to 10° B. This oil can not be transported through pipe lines unless it is heated. A 4-inch lead line is used at the well, inside of which steam is introduced through a 1-inch line. This 1-inch steam line extends the entire length of the lead line and heats the oil to about 200° F., when its viscosity is decreased so that it will run through the line. The handling of these heavy oils is discussed in a publication of the California State Mining Bureau.[23]

FREEZING OF PIPES.

In most of the oil fields of the United States, gathering lines for oil and gas are laid on top of the ground. In many of the California fields and in some of the Wyoming and the Mid-Continent fields the gathering lines are buried. Before large pipe lines are buried the usual practice is to paint the pipe and sometimes cover it with tar paper. Gathering lines are, however, seldom painted and covered with paper, although in relatively permanent installations this would often be good practice.

Where winters are hard, if the lines are buried, they should be placed below the frost line, or water may freeze in them and cause trouble. When this happens, it often means that the lines must be abandoned until the frost leaves the ground, unless they can be thawed out with live steam.

Where it is usual to bury lines, less trouble develops from coupling leaks caused by expansion and contraction with changes of weather. The lines are also out of the way and do not interfere with surface operations.

GRAVITY DRAINAGE.

In some fields the oil-gathering lines often freeze in the winter, especially if much water is produced with the oil, and if the lines do not drain properly. To correct this difficulty, some operators introduce a short length of casing in the line and place a gas burner underneath it. This heats the oil and water and prevents freezing. In oil fields where the gathering lines are liable to freeze during winter it is always advisable to take full advantage of the topography in order that the lines may drain by gravity.

Several years ago a Kansas oil company greatly improved its system of handling oil from wells by making a topographic survey and map of the oil-well property, after which location of the tanks and gathering lines was changed to give a gravity system. The cost of this change was well warranted as shown by the recovery of

[23] Starke, E. A., A process for reducing the viscosity of heavy oil: Third annual report of the State Oil and Gas Supervisor of California, 1918, p. 107.

equipment that was a part of the formerly used gathering system and the reduction of operating costs.

PREVENTION OF CORROSION.

In some of the oil fields of the eastern United States, where much salt water is produced with the oil, the pipe used in the gathering systems soon corrodes and leaks. These leaks are generally along the lower side of the pipe, if the gravity system is used. Under such conditions the life of many pipes has been greatly prolonged by giving them a quarter turn once a year or oftener so that the effects of corrosion will be distributed over the interior surface of the pipe.

FLUMES.

In those parts of the Sunset-Midway and Kern River oil fields, California, where much sand is pumped with the oil, flumes are used instead of pipe lines to transport oil from the wells to the production tanks. Flumes are used because the sand with the oil may plug a pipe. In the flume system, the oil, water, and sand from a well are pumped through a short pipe line into the flume, where the oil floats on top of the water and the sand settles to the bottom.

Plate XXXI, *A* (p. 120), shows a flume system in the Kern River field, California. The oil, water, and sand are delivered from the flume *d* into the gun-barrel tank *a*, where the water and sand are drawn off before the oil goes to the production tanks *b* and *c*.

At some properties where flumes are used the mixture of oil, water, and sand from the well is first pumped into a sump or tank near the well, where much of the sand and water is drawn off before the oil is delivered to the flume.

The flumes are made of soldered, galvanized iron with a 12-inch bottom and flaring sides about 12 inches high, and they are supported by timber frames made of 2 by 4 inch or 2 by 6 inch lumber used as posts and braces. The bottom of a flume is generally supported by a 12-inch board, held in place by crosspieces to the frame. At many flumes supporting posts rest on concrete piers. A runway is built along a flume that is more than 5 or 6 feet above the ground.

The California fields that use flumes to transport oil are in a hilly region and full advantage is taken of the topography to gain the desired gradient for the flume, and at the same time to keep the flume as near the ground as possible.

TRAPS FOR SAVING GAS AT OIL WELLS.

Traps for saving gas at oil wells have been discussed in a Bureau of Mines publication,[24] whose author summarizes the advantages

[24] Hamilton, W. R., Traps for saving gas at oil wells: Tech. Paper 209, Bureau of Mines, 1919, 34 pp.

gained by the use of gas traps and the general principles involved in gas-trap construction, as follows:

SUMMARY OF ADVANTAGES GAINED BY USE OF GAS TRAPS.

Traps are used under varying conditions of pressure, from vacuum to a pressure above atmospheric. The principal advantages obtained by the use of traps under vacuum, but not under pressure, are as follows:

1. Increased gasoline content of the gas.
2. Elimination of a part of the storage losses.

When the gas is taken under pressure the advantages gained, which are not obtained when operating under vacuum, are:

1. Decreased tendency of the well to produce sand.
2. Decreased trouble from collapsed casing.
3. Decreased tendency of oil and water to emulsify.
4. Increased gasoline content of oil shipped.
5. Removal of vapors from gas and improvement of gas for transportation long distances in pipe lines.

With either vacuum or pressure traps, or with traps working at atmospheric pressure, the operator gains the following benefits:

1. Increased quantity of gas available for use or sale, hence decreased consumption of other fuels.
2. Minimized danger from fires.
3. Decreased loss of the lighter fractions of the oil.

As gas once lost is gone forever, any one of the above advantages should be enough to cause the universal use of gas traps.

GENERAL PRINCIPLE INVOLVED IN GAS-TRAP CONSTRUCTION.

The basic principle of gas-trap construction is simple. The mixture of oil and gas is allowed to flow through a chamber large enough to reduce the velocity of the mixture to the point at which the oil and the gas tend to separate. The gas, seeking the top of the chamber, is drawn off free of oil; the oil is drawn off at a lower point and the escape of the gas through the oil discharge opening is prevented. Traps have been constructed to meet a variety of conditions, and it is safe to say that the gas can be saved from any well that is under control; also if a trap is properly installed there should seldom be interference with the production of oil.

Plate XXXI, *B*, at *d*, shows a small building housing a gas trap in the Big Muddy field, Wyo. Plate XXXII, *A*, at *b* and *c*, shows two gas traps made from old boiler shells welded and made gas tight with the acetylene blow-torch. The gas lines leading from gas traps are shown at *d* and *e* and the lines leading to the gas trap and delivering oil and gas from the wells are shown at *f* and *g*. The oil-discharge pipes to the production tank *a* are on the rear of the gas traps and are not shown.

STOREROOMS, SHOPS, AND YARDS.

In the older oil fields near manufacturing centers, or near stores or shops of oil-well supply companies, the storerooms, shops, and yards of the operating oil companies are not so complete as in isolated fields. The former companies can get supplies, repairs, and equipment promptly. But when the field operations are extensive, or when they are some distance from supply sources, a great saving in money, time, and labor is generally secured by fully equipped storerooms, shops, and yards.

The storerooms carry general supplies and necessary repair parts. The shops may include foundry, machine shop, woodworking shop, boiler shop, automobile and truck repair shop, and, in some fields, tubular-derrick shop. The yards afford room for storage and salvage of lumber, timber, pipe machinery, and junk.

Plate I, *B* (p. 4) shows the storeroom, shop, and yards of an oil company in the Santa Maria field, California.

The salvage of old pipe as seen in the yards of the Standard Oil Co., Taft, Calif., illustrates one of the many savings made by the oil companies. The pipe is first straightened if crooked. The length of pipe is placed on a long, narrow truck running on a track and put under a die attached to one end of a steel beam pivoted in the middle and operated from the other end by a connection to the piston of a gas-engine cylinder, the power being furnished by compressed air. The pipe is then placed on the moving truck *a* at the pipe-clearing machine shown in Plate XXXII, *B*, and is moved forward in front of the revolving shaft *b*, to which are attached a number of flail-like pieces of steel, *c*, and a steel brush. The flail-like pieces strike the pipe as it moves by, loosening the scale and dirt; the revolving steel brush removes the loose particles. The pipe is taken to the pipe-cutting machine, that cuts off the ends with old threads. The pipe is then painted and placed in stock. It is not threaded until about to be used.

RECORDS AND FORMS.

The keeping of books or records and the use of warehouse forms are discussed by C. G. Smith, in a Bureau of Mines bulletin.[25] In the introduction of this bulletin Smith says:

With the accountant rests the responsibility of providing the management with reports setting forth the details of the business expressed in fitting terms as well as in dollars and cents. These reports are a means whereby efficiency may be maintained, waste prevented, oil obtained and sold, and money suitably reinvested. They also enable a concern to study the progress of its business in order to conserve to the utmost the possible benefits from an exhaustible deposit of mineral wealth. When managements realize the extent of the waste at their properties more attention will be given to the character of the accountancy records.

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[25] Smith, Clarence G., Cost accounting for oil producers: Bull. 158, Bureau of Mines, 1917, 123 pp.

Smith further says, under the heading "Warehouse Forms" on page 63 of the bulletin:

The "warehouse" account is sometimes used to record the movement of only such supplies as are actually taken at the warehouse and delivered from it. The bills of purchase for property supplies are distributed in the voucher record to other accounts as well as to "warehouse." The warehouse report is then not a complete record of supplies used during the period. An advantage of this system is that the warehouse is charged only with the materials that will be given out by it.

Again, the warehouse account often is used as a clearing account for all bills of purchase for property use. All bills approved by the superintendent of the property are charged to warehouse and all charges for material for facilities are credits to warehouse. When a bill includes items directly chargeable to a facility, the field clerk, at the time he approves the bill, issues a charge against that facility. A brief description of the bill and its reference is written on the charge, so that all of the details do not have to be entered in the bill. Advantages of using the warehouse account as a clearing account are as follows: *a*, One file contains all the monthly material charges against a facility; *b*, both the field and the main office have a copy of the detail; *c*, the bookkeeping in the main office is greatly simplified, not only in the voucher record, but also in the detailed cost records.

The method used by the Empire Gas & Fuel Co. for keeping records of oil-field activities has been described by Severson [26] as follows:

To eliminate misunderstanding in orders issued, and also to obtain the desired information as to construction and operating activities, records are necessary, but such records should be of such character as will give exactly what is desired and still not overburden the office force. Records applying to construction work should be of such nature as to give enough data to check up men doing the work and give such cost information as will show when you are working within your estimates, and also give you such information as will give you an opportunity to estimate closely on future work.

With the Empire company, a general order is issued, upon a request. This order may have to be executed by every individual of a department. Therefore, in order to eliminate misunderstanding, that the various foremen may be able to check the various kinds of work included in the order, suborders are issued. The suborder should give to the man who is to perform the work the exact nature of the work and approximate cost, and show him what accounts or orders to which the work should be charged, also if the apparatus used on the work is such that will require maintenance and attendance.

Space should be left on the suborders to give the factory and company numbers and all necessary remarks regarding the apparatus. When such suborders are issued, they contain the name to whom they are issued, the approximate time the work should be started, and the approximate time that the work is expected to be finished. A copy of this suborder should be kept in the office, and a copy given to the storeroom keeper. The storeroom keeper, upon receipt of this copy, would know that he is authorized to deliver material.

In order to carry out the full details of the order, the storeroom keeper should keep an accurate check of the material delivered and the man who receives the original order should show the time and material used. When the order is completed the job is done, and the foreman's report should agree

[26] Severson, S. B., Manner of keeping records: Petroleum, vol. 7, July, 1919, p. 27.

as to time and material with the timekeeper and the storeroom keeper. If apparatus is used in the compliance of the order that requires maintenance and attendance, the company and factory numbers are placed on the order by the foreman, to be transferred to records in the office and kept for assistance in future operation.

Considering that the ultimate development of the field will require probably 1,000 installations, it is apparent that records will be invaluable from the operating standpoint. The time to obtain the records of all the apparatus is during the installation period, as otherwise they may be forgotten, and if they are, it will require the services of men to go over the entire installation to obtain what information is needed. As the operation organization progresses, more records will be needed, showing the results of motor inspections, line inspections, substation services, well outages, meter tests, and so on.

ROADS AND TRANSPORTATION.

PUBLIC ROADS.

Most of the oil fields of the eastern United States were developed, reached maximum production, and declined to only a small part of former production years before the automobile and motor truck were generally used. Consequently, most of these oil fields have very bad roads, suitable for haulage only by team or tractor, except those through which improved State or county roads happened to have been built.

Many of the Mid-Continent and California fields have been developed since automobiles and motor trucks became the chief means of transportation, so that these fields have benefited by State and county highway improvements. In many parts of Texas, Louisiana, Oklahoma, and Kansas the main highways that serve the oil fields chiefly are of the best type of macadam, asphalt, or concrete construction.

Some large oil fields, however, such as Salt Creek, Wyoming, have had very poor roads that have been practically impassable at times during winter and spring.

PRIVATE ROADS.

The best type of construction for private roads in oil fields depends on the type of the public roads, the size of operations, and climatic conditions. Private roads that are better than the public roads of the district are seldom warranted, and often an inferior type is satisfactory.

In many of the California fields well-graded and oiled dirt roads have satisfactorily met transportation needs. The oil companies in that State have spent large sums in the building of roads. Steam shovels have been used for doing much of the grading. The 12 miles of graded road connecting the east and west Elk Hills oil fields was built by some of the companies in those fields at a reported cost of $350,000. Dirt roads, such as those used in the California fields, are not very serviceable during winter in districts where there is much frost and snow. Road material is entirely lacking in many of the Mid-Continent fields, so that dirt roads, both public and private, have been the only type available. Corduroy and plank roads and bridges are used in some fields in swampy country, as in some of the oil fields of Louisiana.

Most of the private roads in the oil fields of the eastern United States are nothing more than trails which are only improved enough to permit the passage of a team and loaded wagon. As these oil fields were developed years ago, at present an improved type of road to an individual property is not warranted.

One company in the southern Illinois fields, in an area where several small streams are repeatedly crossed, uses bridges made from old casing and pipe supported on concrete piers. Four lengths of 6 or 8 inch casing are used for stringers. Old 2-inch tubing and pipe cut in 8-foot lengths laid side by side across the casing as flooring are held in place by a piece of 2-inch pipe placed on top of each end of the pipe flooring at the sides of the bridge and firmly bolted to the outside casing stringer.

Good service from a dirt road, as demonstrated by the public roads in most rural districts, depends largely on proper drainage and also on frequent grading, especially when the road is drying after a prolonged rain.

FIELD ORGANIZATION.

An efficient organization is a prime requisite in oil-field practice. The scope and type of organization of course depends upon the number of wells pumping, the distance to towns and industrial centers, and the extent of the prospecting and development work being carried on in the same or other oil fields.

Figure 17 outlines the organization of one of the larger oil companies operating in the Mid-Continent fields, mostly in areas where the company has had to build its own camps and do its own construction and repair work.

COST OF DEVELOPMENT AND EQUIPMENT OF A TYPICAL OIL-WELL PROPERTY.

As an example of the elements of cost that enter into the development and equipment of a pumping oil-well property, one of the larger companies in the Mid-Continent field supplied the data and costs shown in Table 9; they apply to one of its properties which has

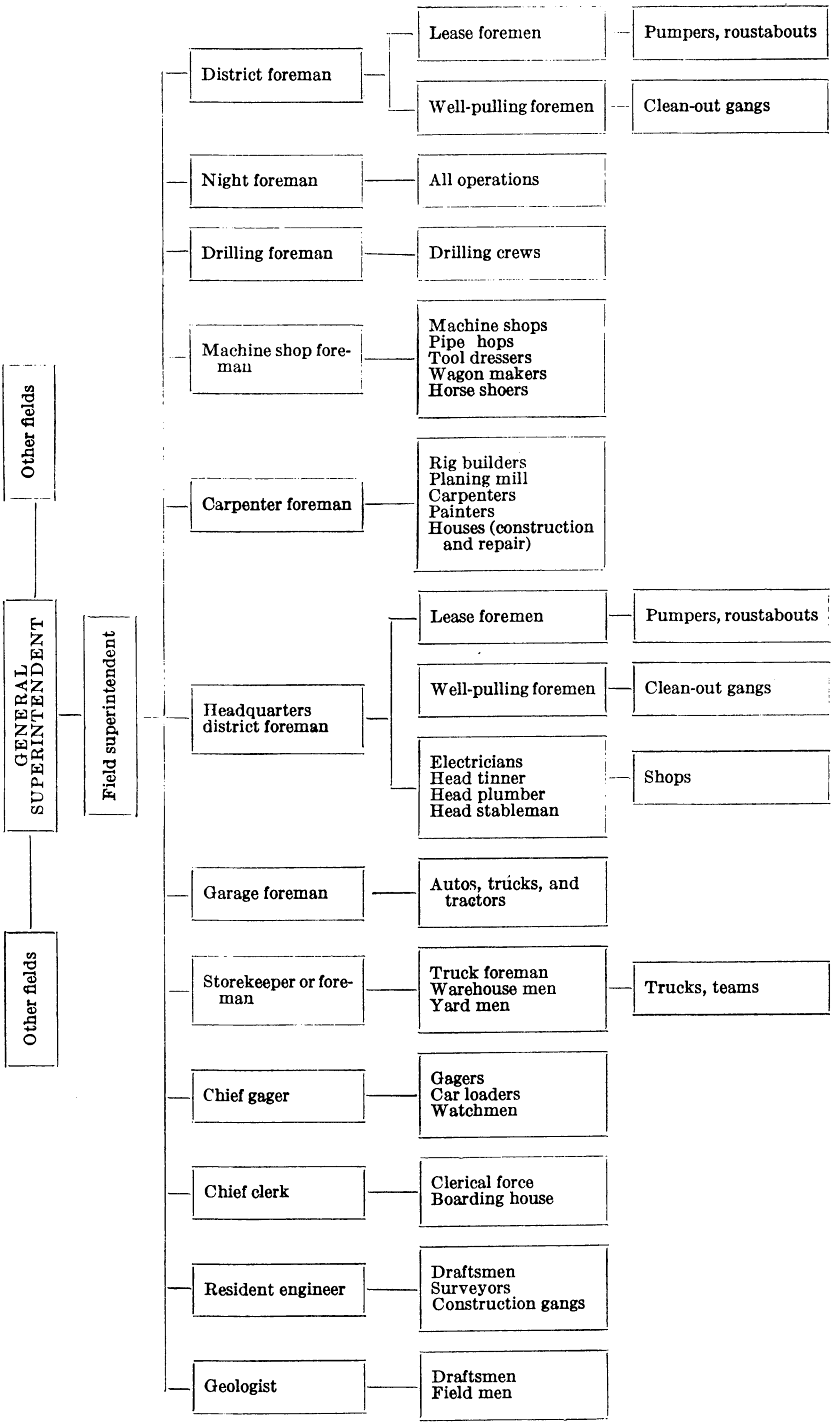

FIGURE 17.—Outline of typical oil-field organization.

33 wells averaging 600 feet deep pumped by a central power, or jack plant, from one sand, and 10 wells averaging 2,500 feet pumped individually on the beam from another, deeper, sand.

All of these wells were drilled with standard tools and were equipped for pumping and put into operation before 1921. The 33 shallow wells showed an average cost of $1,819.30; the 10 deeper wells, $19,418.80.

Equipment costs and scales of wages differ from year to year; and the cost of drilling to corresponding depths in other oil fields may differ widely. But if these facts are taken into consideration, the costs given in Table 9 may be used as a basis for estimates. When costs in different fields are compared the widest variations found are in the cost of drilling, especially at greater depths, and with different methods.

TABLE 9.—*Cost of development and equipment of a typical oil-well property.*

Cost of representative well 652 feet deep, fully equipped, pumped by a power or jack plant.

One Oklahoma over-pull jack	$29.37
One 2-way casing head, with one-hole top	3.25
One flanged iron stuffing box	1.15
Casing:	
20 feet of 35-pound, 11-inch casing, at $1.55 a foot	31.00
80 feet of 24-pound, 8¼-inch casing, at $1.25 a foot	100.00
573 feet of 17-pound, 6⅝-inch casing, at $0.84 a foot	481.00
Tubing and rods:	
634 feet of 4½-pound, 2-inch tubing, at 20 cents a foot	126.80
10 feet of 2-inch anchor, at 20 cents a foot	2.00
1 foot of 2-inch perforation	.71
625 feet of ⅝-inch rods, at 6.1 cents a foot	38.13
11 feet by 1⅛ inch polish rod	3.66
1¾-inch brass standing valve	2.51
1¾-inch working valve	1.67
6-foot working barrel	7.56
Two combination clamp connections, at 81 cents each	1.62
Ajax pattern turnbuckle	2.80
Bleeder and lead line connections:	
Four 2-inch tees, at 68 cents each	2.72
Three 2-inch plugs, at 12 cents each	.36
One 2-inch flange union	.90
Three 2-inch nipples, 3 inches long, at 15 cents each	.45
Two 2-inch nipples, 6 inches long, at 21 cents each	.42
One 2-inch nipple, 10 inches long	.36
One 2-inch ell	.80
One 2-inch by 3-inch swedge nipple	1.53
One 3-inch collar	.35
One 1-inch by 2-inch bushing	.26
One 1-inch nipple, 4 inches long	.07
One 1-inch nipple, 6 inches long	.10
One 1-inch stopcock	1.06
One 1-inch tee	.35
One 1-inch plug	.05

TABLE 9.—*Cost of development and equipment of a typical oil-well property*—Continued.

Bleeder and lead line connections—Continued.	
Two short pieces of 2-inch pipe, at 20 cents a piece	$0.40
One 2-inch check valve	2.44
Drilling of 652 feet, at $1 a foot	652.00
Day work on well and equipment	155.00
Water, 20 days, at $12 a day	240.00
Gas, 20 days, at $20 a day	400.00
Teaming	17.50
Total	2,310.35

Cost of representative well 2,472 feet deep, fully equipped, pumped on the beam.

Rig, 60 feet, steel	$1,154.00
One corrugated-iron engine house, concrete floor	364.00
One four-way casing head, with one-hole top	4.68
One 250-barrel wooden tank (for water)	150.00
Casing:	
67 feet of 70-pound, 15½-inch casing at $4.12 a foot	276.04
944 feet of 50-pound, 12½-inch casing at $2.41 a foot	2,275.04
2,052 feet of 24-pound, 8¼-inch casing at $1.25 a foot	2,565.00
43 feet of 5 3/16-inch liner at 72 cents a foot	30.96
Tubing and rods:	
One foot of 2-inch perforation	.71
20 feet of 2-inch anchor at 20 cents a foot	4.00
2,466½ feet of 4½-pound, 2-inch tubing at 20 cents a foot	493.30
2,462½ feet of 11/16-inch rods at 7½ cents a foot	184.69
One 25-horsepower second-hand gas engine	786.22
One hot-tube ignition	60.00
Six 2-inch tees at 68 cents each	4.08
Five 2-inch plugs at 12 cents each	.60
Two 2-inch check valves at $2.44 each	4.88
One 2-inch gate clip	5.78
One 2-inch stop cock	2.13
Two 2-inch nipples, 12 inches long, at 42 cents each	.84
One 2-inch flange union	.90
Five 1-inch tees at 35 cents each	1.75
Five 1-inch plugs at 5 cents each	.25
Three 1-inch stop cocks at $1.06 each	3.18
Three 1-inch lip unions at 53 cents each	1.59
Four 1-inch ells at 43 cents each	1.72
One 1-inch globe valve	1.63
Three 1-inch street ells at 44 cents each	1.32
Five 1-inch plugs at 5 cents each	.25
Five 1¼-inch stop cocks at $1.06 each	5.30
Three 1¼-inch nipples, 2 inches long, at 7 cents each	.21
Four 1¼-inch nipples, 4 inches long, at 7 cents each	.28
Four 1¼-inch nipples, 6 inches long, at 10 cents each	.10
Two 1¼-inch nipples, 8 inches long, at 14 cents each	.28
Two 1¼-inch nipples, 10 inches long, at 17 cents each	.34
Two 1¼-inch nipples, 12 inches long, at 20 cents each	.40
Three 1¼-inch lip unions at 53 cents each	1.59
Four 1¼-inch ells at 43 cents each	1.72
Two 1¼-inch street ells at 44 cents each	.88

TABLE 9.—*Cost of development and equipment of a typical oil-well property*—Continued.

Tubing and rods—Continued.	
One 1¼-inch indicator cock	$3.55
One ⅜-inch tee	.29
One ⅜-inch lip union	.10
Two ⅜-inch ells at 23 cents each	.46
Two ⅜-inch collars at 10 cents each	.20
Two ⅜-inch nipples, 4 inches long, at 5 cents each	.10
Two ⅜-inch nipples, 6 inches long, at 10 cents each	.20
Two 1-inch by 2-inch bushings at 26 cents each	.52
One 2-inch by 4-inch bushing	.56
Two ⅜-inch by 1-inch bushings at 13 cents each	.26
One 1¼-inch by 1½-inch bushing	.16
Two 1¼-inch by 1-inch reducers at 18 cents each	.36
One ⅜-inch by ¼-inch reducer	.10
One 1¼-inch regulator	8.04
One ¼-inch storm burner	1.85
Two 10-inch belt clamps at 30 cents each	.60
115 feet of 10-inch belting at 93 cents a foot	106.95
60 feet of 1-inch pipe at 10 cents a foot	6.00
80 feet of 1¼-inch pipe at 12 cents a foot	9.60
60 feet of 2-inch pipe at 20 cents a foot	12.00
One 8-foot working barrel	10.40
One Titus patent stuffing box	1.15
One 1¾-inch brass standing-valve	2.51
One 1¾-inch brass working-valve	1.67
One Bridgeport hanger	37.70
Bleeder and lead-line connections:	
Six 2-inch tees at 68 cents each	4.08
Five 2-inch plugs at 12 cents each	.60
One 2-inch check valve	2.44
One 2-inch stop cock	2.13
Two 2-inch flange unions at 90 cents each	1.80
Four 2-inch by 3-inch nipples at 15 cents each	.60
Two 2-inch ells at 80 cents each	1.60
One 2-inch by 1-inch bushing	.26
One 1-inch nipple, 8 inches long	.14
One 1-inch nipple, 6 inches long	.10
One 1-inch clip	1.90
Two 1-inch street ells at 44 cents each	.88
One 2-inch street ell	.95
Two 2-inch nipples, 6 inches long	.42
Drilling 2,472 feet at $1.75 a foot	4,326.00
Day work on well and equipment	1,156.25
Water, 114 days at $12 a day	1,368.00
Gas, 114 days at $20 a day	2,280.00
Teaming	228.48
Total	17,972.90

Cost of power or jack-plant installation for pumping shallow wells.

Building:	
22 by 60 by 7 feet to house power or jack plant and installation of machinery and equipment	$1,426.00

TABLE 9.—*Cost of development and equipment of a typical oil-well property*—Continued.

Engine and connections:	
One 25-hp. Superior gas engine	$1,023.00
One Wico ignitor	60.00
Valves, nipples, and connections	115.42
Standard Union Machine Co. power	750.00
120 feet belting at $1.15 a foot	138.00
36 clamp connections for power at 81 cents each	29.16
288 feet pull rods, 16 feet long, at 16.4 cents a foot	47.23
18 throw-off hooks at 78 cents each	14.04
One Union Machine Co. belt tightener	150.00
One Snow pump, 6 by 4 by 6 inches	146.00
One 250-barrel wooden water tank	175.00
Total	4,073.85

Cost of boiler house and equipment.

One boiler house, 26 by 32 by 12 feet, and installation of machinery and equipment	$1,690.00
Boilers:	
Two 30-hp. locomotive type at $1,333 each	2,666.00
One 25-hp. locomotive type	853.00
Tanks:	
One 250-barrel wooden tank	175.00
Boiler connections:	
Pipe, valves, nipples, tees, unions, gages, plugs, collars, etc	548.96
Material for subfurnaces:	
2,100 red brick at $29.94 per M	62.87
1,050 fire brick at $40 per M	42.00
180 arch brick at $42.80 per M	7.70
6 yards sand at $2.25 per yard	13.50
3 barrels lime at $2.80 per barrel	8.40
15 sacks cement at 73 cents per sack	10.95
150 pounds fire clay	1.31
750 pounds Plebrico at 2 cents per pound	15.00
Boiler covering:	
Ten 60-pound sacks of magnesia	60.00
33 sheets of $\frac{3}{8}$-inch by 20-inch by 12-foot Hyrib at $7.99 a sheet	23.37
Two barrels of bailing wire at $1.85 a barrel	3.70
250 pounds of Evertite at 4 cents a pound	10.00
Total	6,191.76

Cost of miscellaneous buildings. (Frame.)

One bunk house, 24 by 60 by $8\frac{1}{2}$ feet	$1,500.00
One 4-room house	734.00
One 4-room house	734.00
One 3-room house	607.00
One 3-room house	630.00
One boarding house, 24 by 24 feet, and having 12 by 12 and 12 by 28 foot additions	1,215.00
Two 3-room houses at $607 each	1,214.00
One fire house, 12 by 12 by 8 feet, shingle roof	234.00
One tool house, 14 by 16 by 10 feet, corrugated iron walls and roof	282.00
One tank house, 21 by 66 by 18 feet	957.00
One tank house, 32 by 32 by 16 feet	645.00
Total	8,752.00

TABLE 9.—*Cost of development and equipment of a typical oil-field property*—Continued.

Cost of dikes, ponds, and tanks.

One dike, 94 by 183 feet at 35 cents a yard	$207.00
One dike, 79 by 181 feet at 35 cents a yard	123.00
One dike, 87 by 138 feet at 35 cents a yard	144.00
One B. S. pond, at 35 cents a yard	376.00
One B. S. pond, at 35 cents a yard	103.00
Four 250-barrel steel tanks at $325 each	1,300.00
Four 374-barrel wooden tanks at $240 each	960.00
One 500-barrel wooden tank	300.00
One 800-barrel wooden tank	450.00
One 1,600-barrel wooden tank	750.00
One 800-barrel wooden tank	175.00
One 250-barrel steel tank	325.00
Twelve 4 by 8 feet gun-barrel tanks	175.00
Total	5,388.00

Cost of pipe lines and shackle lines.

Oil lines:	
14,148 feet of 2-inch pipe at 31 cents a foot	$4,385.88
6,900 feet of 3-inch pipe at 61 cents a foot	4,209.00
Steam lines:	
1,486 feet of 2-inch pipe at 31 cents a foot	460.66
Steam-line covering:	
1,486 feet of asbestos pipe covering at 27 cents a foot	401.22
60 rolls of tar paper at $3.12 a roll	187.20
300 pounds of tar at 20 cents a pound	60.00
5 barrels of bailing wire at $1.85 a barrel	9.25
Water lines:	
8,483 feet of 2-inch pipe at 31 cents a foot	2,629.73
1,456 feet of 3-inch pipe at 61 cents a foot	888.16
1,812 feet of 6-inch pipe at $1.46 a foot	2,645.52
Shackle lines:	
27,954 feet of ⅝-inch rods at 16.4 cents a foot	4,584.45
12 bull rings at $1 each	12.00
26 throw-off hooks at $2 each	52.00
Total	20,525.07

Summary of property account; 43 wells fully equipped for pumping (initial cost of the property not taken into account).

Thirty-three wells, average depth 600 feet, fully equipped to pump	$60,037.00
Ten wells, average depth 2,500 feet, fully equipped to pump	194,128.00
Power, or jack-plant, installation	4,073.85
Boiler house and equipment	6,191.76
Miscellaneous buildings	8,752.00
Dikes, ponds, and tanks	5,388.00
Pipe lines and shackle lines	20,525.07
	299,095.68
Supervision, cartage, and miscellaneous, 12 per cent	35,891.48
Total	334,987.16

OPERATING COSTS OF OIL WELLS.

COST OF PRODUCING OIL.

It is difficult to determine a general figure for the total cost of producing oil, as that cost not only includes the production or operating cost, of which the lifting cost or direct production cost is a part, but also includes amortization of capital invested, rents and royalties, depletion of oil reserves and depreciation of physical equipment.

Although many systems are used for classifying production or operating costs, the system given below is fairly representative:

1. *General expense.*—General expense includes executive salaries, clerical expense, legal expense, general office expense, taxes, insurance, rent, compensation, insurance, damages, and welfare expense.

2. *General development expense.*—General expenses of the land and leasing, and the scouting, geological, chemical, research, and engineering departments are included here.

3. *Lifting expense.*—Lifting expense covers the cost of labor and materials for the operation and maintenance of pumping or flowing oil wells; it includes the cost of operation and maintenance of all equipment directly required for delivering to the stock tanks the oil produced.

4. *Treating expense.*—Treating expense includes the cost of labor and materials for the operation and maintenance of plants used for treating oil that has become emulsified.

5. *Development expense.*—Under development expense are the amounts paid as bonus for leases; the cost of drilling wells and of obtaining new production.

6. *Other field expense.*—Here are included the cost of labor and materials for the operation and maintenance of plants for the recovery of gasoline from casing-head gas, for operation and maintenance of oil-field camps, for repairs to roads, and charges for the operation and maintenance of other equipment in use at the operating property which are not included under any of the other headings.

LIFTING EXPENSE.

Although lifting expense is only a part of the total cost of producing oil, it nevertheless gives a representative figure for purposes of comparison.

It may range from 20 to 90 per cent of the total cost of producing oil, depending on the ratio it bears to production or operating cost, which in turn varies in relation to total cost.

Table 10 shows the lifting, general, and total costs at an oil-well property where no development work was done during the period covered by the figures.

TABLE 10.—*Lifting costs, general expense, and total cost for an oil-well property with 13 wells, average depth 2,400 feet, pumped on the beam by gas engine, Cleveland district, Oklahoma.*

(Costs for first six months of 1921.)

	Six-month period.	Average, per month.
Oil sales, barrels	10,115.39	1,685.9
Distribution of lifting costs:		
Labor (on repairs)	$1,144.77	$190.79
Teaming	57.00	9.50
Water	142.00	23.67
Pumping (labor)	505.23	84.20
Supplies	61.54	10.26
Repairs	84.86	14.14
Cleaning out wells	552.38	92.06
Miscellaneous	382.73	63.79
Superintendence and office	199.57	33.26
Production taxes	303.45	50.58
Total lifting cost	3,433.53	572.25
General expense	1,151.17	191.86
Total expense	4,584.70	----------

Lifting cost, per barrel	cents	34
General expense, per barrel	do	11
Total expense, per barrel	do	45
Average daily production, per well	barrels	4.2

Table 11 shows the lifting cost for 4,497 wells on 57 different groups of properties in different oil fields of the United States. This table, which gives a comparison of the lifting costs at a number of groups of oil wells that are at different stages of development and depletion and are operating under a wide range of conditions, shows extremes of lifting cost per barrel of oil and per well per day that are hard to credit. Lifting costs frequently range from less than 3 cents a barrel at flowing wells producing several hundred barrels daily to more than $3 a barrel at wells with a daily production of less than a fifth of a barrel. On the other hand, the lifting cost per well per month may range from more than $1,000 at large flowing wells, such as those recently developed in Oklahoma, Texas, Arkansas, and California, to less than $10 at many of the old wells pumped only a few hours a week, as in most of the oil fields of New York and Pennsylvania, where the average daily production per well is less than a quarter of a barrel.

Figure 18 shows figures for each of the groups of wells given in Table 11, plotted on logarithmic paper with reference to the lifting cost per barrel of oil and the daily production of oil per well. The average lifting-cost curve was drawn as the mean of the cost and production shown by these 57 groups of wells. The three other curves paralleling the average lifting-cost curve indicate the probable lifting cost per barrel with a given decreased daily production per well, of groups of wells which, when plotted with reference to lifting cost per barrel and daily barrels per well, fall upon these curves. An unlimited number of such parallel curves can be drawn for groups of wells which when plotted do not fall upon one of the curves shown in Figure 18. To illustrate the use of the curve, ex-

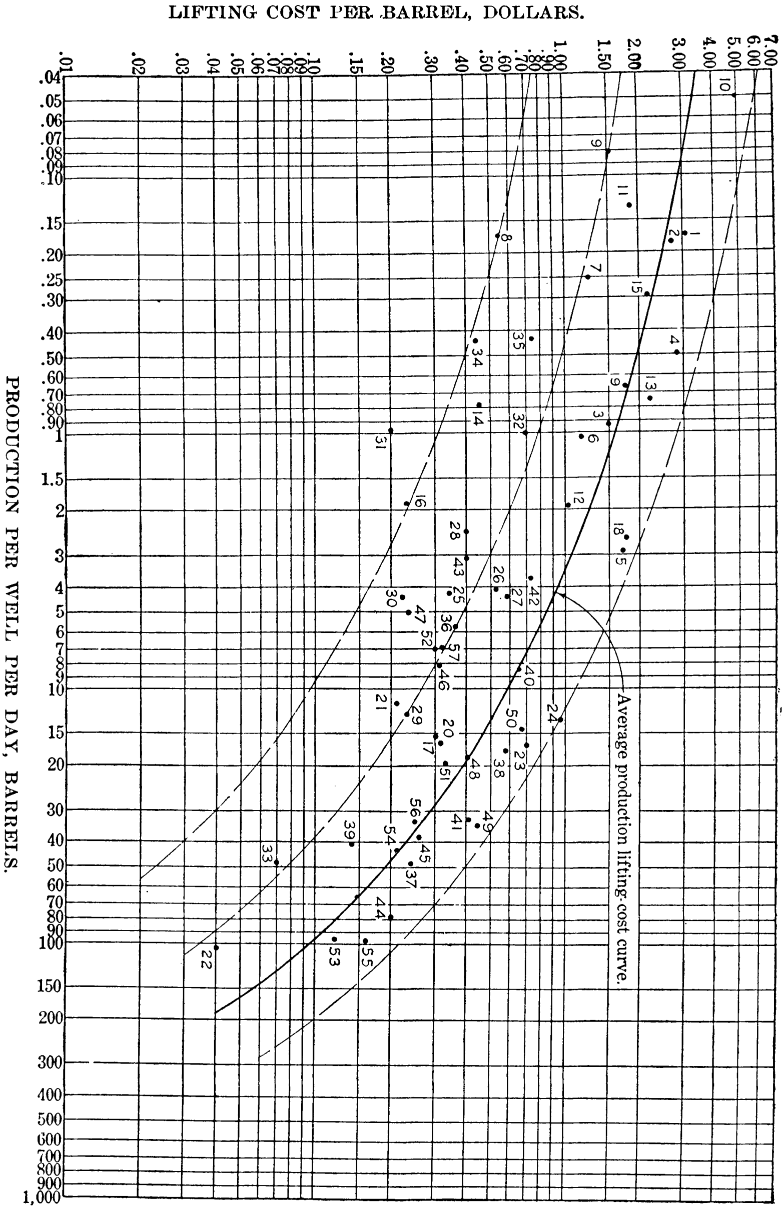

FIGURE 18.—Curves showing lifting costs for groups of wells of different daily production. (See Table 11.)

ample 29, with a daily production of 12.85 barrels and an average lifting cost of 23 cents a barrel, would probably show a lifting cost of $1.51 per barrel with a production of 0.08 barrels a day, as is shown by example No. 9, if, of course, the same cost for labor and supplies held over the period of years that would probably elapse before a well producing 12.85 barrels a day had been depleted until it produced only 0.08 barrel.

TABLE 11.—*Lifting costs of groups of wells for the first six months of 1921. (Taxes, overhead, depreciation, development, and depletion do not form a part of these costs.)*

Example No.	Location of wells.	Number of wells.	Barrels daily per well.	Lifting cost per well per month.	Lifting cost per barrel oil.	Average depth, feet.	Method of pumping.	Power used
1	Beaver County, Pa.	74	.17	15.51	3.03	1,000-1,600	Beam	Gas engine.
2	Washington County, Pa.	154	.18	14.34	2.68	1,800	do	Do.
3	McDonald pool, Pa.	57	.92	41.04	1.48	1,800	do	Do.
4	Butler County, Pa.	120	.49	41.17	2.80	1,300-1,600	do	Do.
5	Kane, Pa.	70	2.89	14.76	1.70	2,000	do	Do.
6	Bradford (field), Pa.	36	1.03	35.50	1.14	2,000-2,100	do	Do.
7	Bradford, Pa.	124	.25	9.51	1.25	1,200-1,300	Power	Do.
8	Tiona field, Pa.	103	.17	2.93	.54	1,000-1,200	do	Do.
9	Oil City (shallow), Pa.	21	.08	3.71	1.51	1,200	do	Do.
10	Tionesta, Pa.	137	.05	7.50	4.86	1,200-1,400	do	Do.
11	Pleasantville, Pa.	64	.13	7.20	1.82	800-1,000	do	Do.
12	Most fields, W. Va.	577	1.93	59.82	1.03	2,328	do	Do.
13	Monongalia County, W. Va.	61	.74	48.77	2.20	2,163	do	Do.
14	Washington County, Ohio.	65	.78	10.58	.45	300-1,200	do	Do.
15	Wood County, Ohio.	24	.29	19.05	2.13	1,200-1,400	do	Do.
16	Lawrence County, Ill.	20	1.90	13.05	.23	1,600-1,800	do	Do.
17	Big Muddy field, Wyo.	87	15.50	139.66	.30	1,000-3,200	Power and beam.	Do.
18	Graybull field, Wyo.	14	2.57	135.69	1.76	1,000	Power	Do.
19	Torchlight field, Wyo.	12	.66	34.25	1.73	600	do	Do.
20	Elk Basin field, Wyo.	49	16.32	151.77	.31	900-1,200	do	Do.
21	Grass Creek, Wyo.	73	12.58	79.25	.21	500-1,000	do	Do.
22	Salt Creek, Wyo.	65	106.00	127.20	.04	1,700	Flowing	
23	El Dorado, Kans.	268	16.61	343.75	.69	750-2,400	Beam	Electric motor.
24	Augusta, Kans.	128	13.32	379.87	.95	1,700-2,400	do	Do.
25	Cleveland district, Okla.	13	4.27	43.55	.34	2,400	do	Gas engine.
26	Glenn pool, Okla.	26	4.09	63.80	.52	1,640	Power	Do.
27	Garber field, Okla.	16	4.41	76.73	.58	1,809	do	Do.
28	Bird Creek, Okla.	45	2.44	29.28	.40	1,327	do	Do.
29	Pershing, Okla.	72	12.85	88.66	.23	2,121	do	Do.
30	Hickory Creek, Okla.	33	4.42	29.17	.22	900	do	Do.
31	Nowata County, Okla.	15	.98	5.91	.20	1,075-1,205	do	Do.
32	Washington County, Okla.	24	1.01	21.00	.69	1,300-1,350	do	Do.
33	Slick field, Okla.	62	48.10	101.01	.07	2,600-2,800	Power and beam.	Do.
34	Nowata County, Okla.	18	.44	5.81	.44	1,120-1,180	Power	Do.
35	Washington County, Okla.	59	.43	9.54	.74	470-1,350	do	Do.
36	Osage County, Okla.	172	5.71	61.67	.36	1,600-2,200	do	Do.
37	Claiborne, La.	34	48.48	349.05	.24	1,200-1,800	do	Do.
38	Caddo, La.	4	17.27	295.32	.57	2,302	Beam	Do.
39	De Soto, La.	8	40.63	170.65	.14	2,666	do	Do.
40	Eastland County, Tex.	10	8.45	162.24	.64	3,425	do	Do.
41	Burkburnett, Tex.	6	32.70	402.21	.41	1,666	Power	Steam engine.
42	Stephens County, Tex.	8	3.70	79.92	.72	2,200-3,200	Beam	Gas engine.

TABLE 11.—*Lifting costs of groups of wells, etc.*—Continued.

Example No.	Location of wells.	Number of wells.	Barrels daily per well.	Lifting cost per well per month.	Lifting cost per barrel oil.	Average depth, feet.	Method of pumping.	Power used
43	Wichita County, Tex.	9	3.07	36.84	.40	850-1,000	Power	Gas engine.
44	Goose Creek, Tex.	21	77.75	466.50	.20	3,040	Beam	Electric motor.
45	Sour Lake, Tex.	23	37.65	293.67	.26	2,215	do	Steam engine.
46	Kern River, Calif.	18	8.17	75.98	.31	750	Power	Electric motor.
47	do	226	5.00	34.50	.23	300-900	do	Do.
48	do	23	18.55	222.60	.40	1,500-2,000	do	Do.
49	Coalinga, Calif.	211	34.68	457.77	.44	2,500-3,900	Beam	Gas engine.
50	do	34	14.36	284.33	.66	1,200-2,500	do	Do.
51	McKitrick, Calif.	52	19.69	194.93	.33	500-1,200	Power and beam.	Do.
52	Midway, Calif.	24	7.06	63.54	.30	1,100	Power	Do.
53	Sunset, Calif.	345	95.83	344.99	.12	2,700-3,600	Power, beam, and flowing.	Do.
54	Maracopa, Calif.	50	43.28	272.66	.21	1,000-3,700	Beam	Do.
55	Orange and Los Angeles Counties, Calif.	148	97.37	467.38	.16	2,000-5,000	do	Gas and steam engine.
56	Santa Maria, Calif.	198	33.03	247.72	.25	2,000-4,000	Power and beam.	Do.
57	Ventura, Calif.	87	6.99	67.10	.32	600-2,500	Beam	Do.

Any such comparison as that indicated by the application of the curve to a comparison of examples 29 and 9, Figure 18, does not take account of changing conditions, such as the appearance of relatively large amounts of water with the oil, the failure of the casing or the need for the installation of vacuum pumps because of the rapid decline of production through the use of vacuum on adjoining properties. For instance, suppose that when the daily production of No. 29 had fallen to 3 barrels per well, with an indicated lifting cost per barrel of $0.50, water appears and 2 barrels of it is pumped for every barrel of oil produced. Theoretically, this would increase lifting cost from $0.50 to $1.50 a barrel, if it cost as much to pump water as oil. However the appearance of water might mean an even greater increase in cost, because of oil emulsion forming and requiring the building and operation of a treating plant.

The oil-well property at Goose Creek, Tex., described on pages 97 and 98, illustrates the great variation in cost and amount of production that sometimes results from the use of different methods of production at different wells, of practically the same depth, in the same field. There are 59 wells in the group. Of this number, 56 wells are pumped on the beam, and produce 500 to 900 barrels per well daily. The three other wells could produce 1,500 to 2,000 barrels per well daily, which is more than beam pumping could handle. Hence an air-lift system was installed and used at these latter wells. The power consumption of the 56 wells pumped on the beam averages 185,106 kw. a month for the group. The power consumption at the three wells pumped by the air-lift system averages 201,204 kw. a month for the group. In other words, the three wells require more power than the 56. By use of the air-lift system, however, an additional 1,500 to 2,000 barrels of oil is obtained daily from the three wells.

With the market price of $4 a barrel for oil in the Pennsylvania oil fields on May 1, 1923, it is quite evident from examples Nos. 1 to 11 inclusive (Table 11 and Figure 17) that the lifting cost must represent a very large part of the total cost, otherwise these wells would now be operated at a loss. Example No. 10 is the only one of the 11 examples from the Pennsylvania oil fields that is apparently being operated at a loss. However, this group of 137 wells is operated by a company having its own refining facilities so that the value of the oil is probably not based upon the prevailing market price.

In general, the less the amount of oil produced daily per well, the higher is the percentage that the lifting cost is of the total cost; conversely, the larger the amount of oil produced daily per well the lower is the percentage that the lifting cost is of the total cost.

One of the California oil companies gave the following data on the relation of lifting cost to production or operating cost for all of its oil-field operations from 1890 to the end of 1922. The cost of leases is not included in the development costs, neither are depletion, depreciation, or royalties taken into consideration. The figures are for the production of 121,000,000 barrels of oil over a period of 22 years.

Distribution of production costs for a California oil company.

	Operating cost per barrel.
Lifting cost	$0.0922
Overhead charges	.0669
Development cost	.2269
Total	.3860

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