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METHODS OF SHUTTING OFF WATER IN OIL AND GAS WELLS

BY

F. B. TOUGH

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INTRODUCTION.

This bulletin deals with a topic that is exceedingly wide, and will doubtless be under consideration and discussion so long as there are enough known deposits of oil and gas remaining in the earth to make their revelopment profitable. The Bureau of Mines has repeatedly called attention to the importance of protecting oil or gas sands from the encroachment of water, and the purpose of this paper is to summarize existing knowledge of methods and devices.

Water may gain access to an oil-bearing formation from several sources—from water sands above or below those containing the oil, or by encroaching through the oil sands as the oil is withdrawn. In short, it may enter a well from the "top, bottom, or side." Such ingress of water is a most serious detriment to the recovery of oil from the ground.

As the art of drilling and developing oil properties has progressed, increasing thought, labor, and money have been expended on various methods, devices, and equipment for arresting the migration of water from its normal subsurface position into the porous strata containing valuable oil or gas accumulations.

At an early stage in the oil-field development of California it became evident that considerable modification of accepted drilling practices was necessary in order to meet the conditions imposed by the poorly consolidated shale, clay, sand, and bowlder beds penetrated, as well as the hard layers of sandstone and calcareous shale, which vary greatly in thickness, hardness, and frequency. These hard streaks are commonly called "shell," and are so reported in the well logs. As deeper and deeper territory was prospected, drillers from the older fields of the East, as well as from Texas and Louisiana fields, took part in the operations. The practice evolved was thus based on the wide experience of a most cosmopolitan group of men who, considered as a group, were not hampered by being limited to the knowledge of the practice at any one locality.

The first part of this paper deals with the California methods of shutting off water in oil and gas wells. Subsequent chapters are devoted to a brief description of some methods used in the Mid-Continent and the Gulf fields for shutting off water, and contain some suggestions for modifying California methods to make them applicable in these localities. No effort is made to cover in detail all of the Mid-Continent or Gulf methods for handling water troubles.

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DEFINITIONS OF TERMS.

Various patents have been issued by the United States Patent Office that cover partly or entirely a particular process or method of shutting off water. In this report names, such as "Grahm float plug," "Perkins process," and "Baker sure-shot plug," are employed in the same sense as applied in field operations where the process or appliance was observed. Such names are used with quotation marks to indicate that no responsibility for their legal correctness is assumed. Frequently two men working in different fields will solve a similar problem in practically the same way, and each without any knowledge of the other's work. Thus it is no reflection on any man's work if a certain operation be described as having been conducted by some one else.

The word "cement" refers to a good grade of Portland cement. Several manufacturers are now marketing a cement especially proportioned and ground for use in oil wells. Of course any of the various methods of cementing can be used with any suitable cementing material.

The term "shell" is used to denote layers of hard sandstone or hard calcareous shale penetrated by the drill.

The term "blowing" a well refers to the practice of permitting the gas to blow unrestrained in order to free the well of accumulated water, or for any other purpose.

"Mud flush" is the muddy water used for the purpose of flushing drill cuttings out of the hole, as distinguished from "mud fluid," applied for sealing off porous strata. A full discussion of what constitutes mud fluid in well-drilling operations is given on page 59.

The term "mudding" refers to the application of mud fluid to a well. A well to which the mud-fluid method has been applied is said to be "mudded."

The term "water shut-off" refers to shutting off a water-bearing sand in the well by any of the methods used.

A "formation" shut-off is had when the hole is so cased that the casing makes a tight fit with the walls of the hole, without the use of cementing material or packers.

A "formation" packer is a packer of rubber, burlap, or other material which presses against a formation penetrated and makes a tight fit between the casing and the walls of the hole.

HARMFUL EFFECT OF WATER ON PRODUCTION OF OIL AND GAS.

As the present paper deals exclusively with ways and means for excluding water from an oil well or a gas well or from strata containing oil or gas, consideration may first be given to the damage occasioned when water is admitted by improper drilling. A few observed facts, rather generally recognized in the production of petroleum, have a direct bearing on the subject. These are stated briefly in the following discussion:

When a new well is being drilled in virgin or slightly depleted territory, little water will "run away" or enter the oil-bearing sands, and the small volume so entering is readily ejected by the gas and is pumped out. The greater the degree of depletion of the oil contained in the sand in the vicinity of a well, the more readily will the sand take water, and, likewise, the more difficult is the removal process. An important factor is the greater surface tension of water as compared with that of oil. Another important factor is the decrease in the expulsive force coincident with the exhaustion of the gas. Water once admitted to the depleted sand hangs tenaciously in the interstices, thus retarding the flow of oil to the well. A new well in a partly depleted field or sand may suffer in this respect just as an old well being redrilled.

It is well recognized in California, Mid-Continent, and Gulf coast fields, and probably elsewhere, that such ingress of water is usually attended by a great decrease in the volume of oil produced by the well or wells affected. In addition to the causes just stated, the chilling effect of the water on oils of paraffin base may cause the formation of wax in the sand adjacent to the well and further retard production.

Many operators in eastern fields contend that a small volume of salt water, which is usually of a higher temperature than fresh water, has a beneficial effect on production, as its heat tends to offset the refrigerating effect of the expanding gases as they enter the well. If any such beneficial effect can justly be attributed to the action of salt water, the effect will probably be limited to sands in which the water is present with the oil. The effect of such water is very different from that of water let into a well from an unproductive sand. Although the writer has no data to demonstrate that the salt water can not have the beneficial effect mentioned, he is of the opinion that the theory has been too widely applied as a justification for the presence of water admitted to productive sands by inefficient or careless drilling operations.

Even if it can be proved that as regards a particular drilling operation the entrance of a small volume of salt water has actually increased the daily production of oil, the condition is not justified until the operator can also demonstrate that the increase in production more than compensates for the cost of pumping the water and of replacing corroded tubing, casing, pumps, and other piping and fittings. Also the operator should be prepared to offer some conjecture as to whether the increase in daily production represents a greater ultimate extraction of oil from the property. It might happen that a temporary stimulation of production would not increase the total recovery of oil.

DATA ON CALIFORNIA WELLS.

The detrimental effect of water on some California wells is clearly shown in the following extract from Bulletin 73 of the California State Mining Bureau:[a]

The diagram here presented (fig. 1 and shows that
well 1-C was the first in the group
in amount accompanied by an equal
other
ell 1-C

It is instructive to not
flooded the oil sands and l

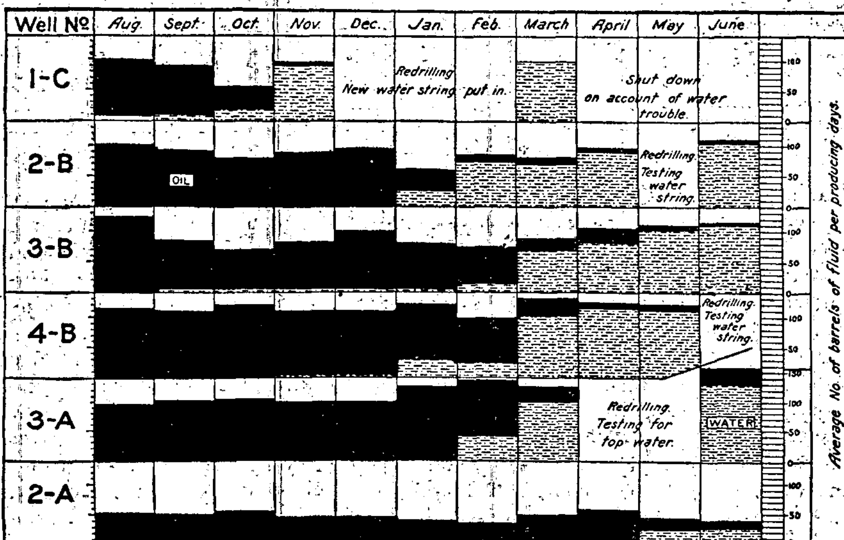


FIGURE 1.—Diagram showing volume of oil and water produced by certain wells.

wells of the group as shown in the diagram. Another instance, from the Kern River district of the California fields, also reported by the California State Mining Bureau, will suffice for the present purpose.

An investigation was made by the State Mining Bureau engineers, which resulted in recommendations for repair. In order to expedite matters, it became necessary for the State officials to assume full charge of the well, and, with the consent of the owner, place a specially selected crew of workmen on the job. The crew was furnished by the Santa Fe Co., and did excellent work.

[a] First annual report of the State oil and gas supervisor of California, fiscal year 1915–16, State Mining Bureau, 1917, p. 114.

The daily production of oil and water from affected wells, before and after repairs, is shown in the following table:

Data showing results of efforts to exclude water from certain oil wells in California.

Well.	Production before repairs.		Production after repairs.	
	Oil.	Water.	Oil.	Water.
	Barrels.	*Barrels.*	*Barrels.*	*Barrels.*
Alma Jr. No. 1	Trace.	150	7	0
Alma Jr. No. 2	0	12,000	Trace.	100
Alma Jr. No. 5	Trace.	200	10	Trace.
Alma Jr. No. 11	Trace.	250	1	40
Alma Jr. No. 12	Trace.	200	10	25
Santa Fe No. 1	3	32	4	10
Santa Fe No. 2	0	1,440	(a)	(a)
Santa Fe No. 6	5	250	4	20
Santa Fe No. 10	5	400	5	10
Santa Fe No. 14	5	5	5	10
Santa Fe No. 18	7	1,000	7	25
Total	25	15,927	59	240

a Not yet rigged for pumping.

It is worthy of special note that no new mechanical methods were necessary to successfully plug the well. The success of the undertaking is due to the fact that a thorough investigation of conditions was made in a scientific and methodical manner by the trained men of the State Mining Bureau, who determined which well of the group was admitting the water to the oil sands, as well as the most efficient means for excluding it. * * *

The repair work cost in the neighborhood of $10,000, required about five months time, and resulted in the elimination of two compressor plants, previously employed in lifting about 15,000 barrels of water daily, which is now excluded from the wells. Elimination of the two compressor plants saves nearly 100 barrels of fuel oil daily, and stops other operating expense amounting to about $500 per month. This saving amounts to about $115 per day. Besides these economies, the production of oil from affected wells has been slightly increased, making the total daily saving about $150, which is a yearly profit of over 500 per cent on the expenditure for repairs.

EXAMPLES FROM OKLAHOMA FIELDS.

A similar instance from the Cushing pool in Oklahoma may be of interest. Offsetting wells along the common property line of two adjacent properties were making great volumes of water and small volumes of oil. One of the companies, on the recommendation of the Bureau of Mines, cemented the bottoms of five of its wells. This work resulted in more than doubling the total oil production and in reducing the water to approximately one-quarter of its former volume. The other operator refused to consider similar work in his wells and when last interviewed was still pumping oil and water in unchanged volumes.

The superintendent of an Oklahoma property stated that he mixed a batch of cement and poured it into a well having about 1,800 feet of water in it. Finding that the cement did not set, he concluded that it would not set under a head of water. Had the cement set after having been poured through such a column of water it would have been a most remarkable cement. Cement may be carried into a sand by a rapidly moving current of water where it is quickly filtered out as later described under the "McDonald method" of cementing, but to pour cement either dry or neat through a static column of water, thus permitting it to settle gradually to the bottom of the well, a process that may require several hours or days, is not to be considered.

Some oil men contend that cement will not set under water, particularly salt water. The general use of cement in California and Louisiana under both fresh and salt water has absolutely demonstrated that such an opinion is untenable. The thousands of cubic yards of concrete in breakwaters and other marine construction might also be cited.

The detrimental effect of water on gas production is too well recognized to require more than passing mention. It is common practice to blow a gas well periodically in order to remove accumulated water. If a well is allowed to fill too far with water, the flow of gas will decrease and may entirely cease. Many good gas wells have been entirely and permanently killed by allowing water to stand on the productive sands for a considerable length of time. This effect is due partly to the ready compressibility of gas, and partly to the fact that gas has no capillary force with which to oppose the ingress of water.

MEANS FOR PREVENTING WATER TROUBLES.

A most important phase of shutting off water can only be indicated here. It involves ways and means for studying conditions in a field to enable the adoption of the best and most economical methods for handling water and production problems in new wells, and for repairing damage caused by improper drilling, or failures in materials of older wells.

An accurate and comprehensive series of records covering operations and their results constitute the foundation for such work. Mere logs of wells, no matter how complete, do not suffice. Records for each well should be kept showing the rates of production, and the percentage of impurities, such as water, emulsion, sand, and mud. Such gages should be taken at regular and not too infrequent intervals, and the results should be recorded on a special form prepared with due regard for convenience in filing. Such production records are in addition to those of lease production, pipe-line runs, and storage.

Dealing with the water problem in oil fields may be considered in two separate phases, as follows: Drilling precautions to prevent the incursion of water into pay strata; remedying such intrusion after it has commenced. If any assurance was to be had of the universal success of drilling precautions there would be little or no need for keeping the records mentioned. Costly experience has demonstrated that no such success can rationally be expected. The keeping of such records is much like fire insurance. If there are no fires, the insurance is unnecessary, but if fires do occur, the insurance is most desirable.

Similarly, when the presence of water is observed in a field or a part of a field, it is of small value to hurry around taking cuts every day on the production from each of the wells within the affected area. If cuts taken at regular intervals are available, synchronous curves may be plotted, showing the increase in water and the decrease in oil produced by each well of the group. These will show in which well, or group of wells, the water first appeared, and will assist in tracing its course. Moreover, if careful note has been made of the natural water levels and other characteristics of waters penetrated in drilling, such as sulphur content, salt content, or whether fresh or alkaline, and the temperature, etc., it may be possible to determine, or, at least, form a reasonably well-grounded opinion as to whether the water is from above or below the productive sands.

A certain company takes samples of all water encountered if a representative sample can be obtained. The samples are appropriately marked and are stored in half-gallon corked bottles. Most of such samples are never used, but occasions have arisen where information based on a comparison of the chemical analyses of two such samples was worth to the company many times the cost of collecting the samples and making the analyses.

It is most important to realize that the collecting and recording of such data is really inexpensive and can usually be effected without putting on extra employees to handle the work. If some one arranges a convenient set of forms for the use of the foreman, or whoever is best situated for doing the work, and supplies the necessary apparatus for making the tests, the most difficult step has been taken. After the new duties have been explained and assigned to an employee, his hearty cooperation can nearly always be relied upon.

Such records should be in duplicate, at least, and filed in widely separated places, such as field and city offices, as a protection against total loss by fire.

An excellent discussion of this subject with reproductions of forms in use will be found in Bulletin 73 of the California State Mining Bureau.[a]

[a] First annual report of the State oil and gas supervisor of California, fiscal year 1915–16, State Mining Bureau, 1917, pp. 110–116.

When water troubles have been narrowed down to one or a few wells, bridging, packer, or other tests may become necessary to definitely determine the source of the water, and to indicate the proper means for excluding it.

The rubber wall packer is considered a suitable testing device, though packers may also be used with hemp or other fiber as a packing material, either woven or loose, when set inside a string of casing. A good example of this usage is the operation of the "Crumpton packer," as described in subsequent pages.

Various kinds of "formation" packers (rubber, lead, or other material used to make a tight fit between the casing and the wall of the hole) are used in the Mid-Continent and Eastern fields for shutting off water. Generally the packing material is rubber. It is well known that rubber is soluble in petroleum and many of its fractions, and will harden under water or in the air, thus losing the elastic property that makes it valuable as a packer. Therefore its use as a permanent packing material for oil or gas wells can not be considered. Experience has shown that gas wells frequently will blow out large chunks of the rubber packers set in them to shut off water. The only safe use of the formation packer in oil and gas wells, for any more than a temporary shut-off, is when a large quantity of hemp or fiber is used, and in addition mud fluid is circulated and allowed to remain back of the casing and above the packer. Thus, if the packer ever fails, the mud will rush into the well, making the source of the trouble evident, requiring immediate repair or plugging. Even this use is permissible only where no other means are available to accomplish the desired end.

PROBLEMS INVOLVED IN EXCLUDING WATER.

In making an intelligent effort to keep water out of a barn or a house or an oil or gas well one must first discover as best he can where the water is getting in. As regards a well, all possible sources must usually be considered and checked off by elimination until the problem is solved. In the California fields, besides top and bottom waters, there are large and important areas where one or more water-bearing sands are encountered between productive beds. In some localities there are two of these intermediate water sands with valuable oil and gas bearing strata above and below each water sand. Each productive stratum is separated by 10 to 200 feet of shale from the nearest water sand above or below it. Obviously the water conditions of any one well in such territory might be the basis of a long treatise, and a method of shutting off water might be advisable under some conditions that would not be best suited for another well under somewhat different conditions. Again, it may become necessary to use a different method in shutting off intermediate water than has been used in shutting off top water in the same well. The physical conditions of the hole, such as friction on the working string of casing and the position of lost tools or pipe that may have been sidetracked or drilled past, the exact purpose of the job, and the apparatus available, all enter as factors in the selection of a method for shutting off water at a particular well.

For convenience all the chief methods of shutting off water are described here as they are used in shutting off top water before the oil sands have been tapped by the bit. A general discussion of variations in the methods when they are used for shutting off bottom or intermediate waters is also presented.

DETERMINATION OF PROPER SIZE AND WEIGHT OF CASING FOR WATER STRINGS.

Stated in its simplest form, the problem of shutting off top water is to make a water-tight joint between a string of casing and the wall of the hole at some impervious stratum above the productive sands and below the water horizons. Another and equally important consideration that is sometimes overlooked is the necessity of using casing of such weight that it will not collapse when the hole is bailed dry. Every water string should be so designed that it will stand the severe test of being bailed absolutely dry without danger of collapsing the casing, although, of course, it is not always practicable to apply the test. In an area of high gas pressure bailing all the fluid out of a water string will often cause a dangerous blow-out. A blow-out of this kind might easily cause the formation to cave around the bottom of the casing and spoil what would have been an effective and permanent water shut-off. Such local conditions, however, do not relieve the operator of the obligation of so designing his water string that it will not fail when production has decreased to the point where the well is tubed far below the bottom of the water string and all the fluid pumped from it. Every operator knows when he commences to drill that eventually the well will be pumped for every gallon of oil that will seep into it, and he should drill with this result in mind or not drill at all. That is, he should either put the hole down properly or else go out of business before he ruins his own and, what is more regrettable, his neighbor's property also.

The most ardent optimist of the oil business—and if it were not for the optimist it is doubtful whether there would be any oil business—knows that the resistance of a water string to collapsing pressure decreases with age and usage. If the string of casing when new be not properly designed as to size and weight to withstand the maximum pressure to which it will ultimately be subjected, what chance has it to do its work after it has been in the ground 5 or 10 years? These considerations bring out the important question, "What is the best method of computing the size and weight of casing to be used for a particular water string?" A prerequisite to such a computation is a fairly reliable estimate of the probable maximum pressure tending to collapse the casing.

To get such an estimate we may consider a well with the water string properly set in which the water rises to the ground surface on the outside, all the fluid having been removed from the interior of the pipe. These conditions give a minimum pressure at the bottom of the water string that is proportional to the depth at which the water is shut off, the pressure decreasing toward the surface, where it becomes zero. For convenience the maximum external pressure in pounds per square inch may be computed by multiplying the depth of the water shut-off in feet by the factor 0.434. Such a method does not consider the pressure that might be occasioned by sloughing of the side of the hole. However, the force of such a cave-in can not be computed on the basis of fluid pressure and is so variable that it can only be roughly estimated. If the external fluid is drilling mud with a specific gravity of about 1.10 as compared with water, the external pressure will be increased by 10 per cent. This difference is more than covered by the factor of safety, which likewise covers the fact that salty water shows a greater pressure than the factor 0.434 will give.

There are times in the life of a well when a shifting sand will shear off a string of casing or collapse it, or even two or three strings may be squeezed together until the sucker rods are held fast. Such conditions, as a rule, can not be foreseen and are most difficult to cope with. Sometimes previous experience in a certain locality with a particular formation may suggest extra precautions, so that the operator will use the heaviest pipe he can get for that part of the string exposed to the troublesome stratum. However, the suggested method of computing the external pressure on a water string has generally been found entirely satisfactory.

PRESSURES ALLOWABLE ON COMMERCIAL WELL CASINGS.

The next step in the design of a water string is to determine the pressures that may be safely carried on the various sizes of commercial well casings. The most authentic information at hand on this subject is that published by Stewart.[a] This paper formed the basis of a study by C. Naramore and R. S. Hazeltine, at Coalinga,

[a] Stewart, R. T., Collapsing pressures of Bessemer steel lap-welded tubes, 3 to 10 inches in diameter: Trans. Am. Soc. Mech. Eng., May, 1906, pp. 730–822.

Cal., in 1911. Later, Hazeltine presented a paper[a] on the results of Stewart's work as applied to the needs of the oil industry. Either of these papers will repay a thorough study by anyone facing water problems in drilling wells.

The following abstract from Stewart's paper is of especial interest:

This research was undertaken for the purpose of supplying an urgent demand for reliable information on the behavior of modern wrought tubes when subjected to fluid collapsing pressure. Every means known to engineering science that could aid in the accomplishment of this undertaking has been used, and every possible effort made to get at the truth and have the research yield trustworthy data. It was planned and executed under the immediate direction of the author, at the McKeesport works of the National Tube Co., and has occupied for its completion, during a period of four years, the time of one to six men.

Results of present research.—The principal conclusions to be drawn from the results of the present research may be briefly stated as follows:

1. The length of tube, between transverse joints tending to hold it to a circular form, has no practical influence upon the collapsing pressure of a commercial lap-welded steel tube so long as this length is not less than about six diameters of tube.

2. The formulas, as based upon the present research, for the collapsing pressures of modern lap-welded Bessemer steel tubes, are as follows:

$$P=1{,}000\left(1-\sqrt{1-1{,}600\frac{t^2}{d^2}}\right) \quad \text{(A)}$$

$$P=86{,}670\,\frac{t}{d}-1{,}386 \quad \text{(B)}$$

Where P = collapsing pressure, pounds per square inch.
d = outside diameter of tube in inches.
t = thickness of wall in inches.

Formula A is for values of P less than 581 pounds, or for values of $\frac{t}{d}$ less than 0.023, while formula B is for values greater than these.

These formulas, while strictly correct for tubes that are 20 feet in length between transverse joints tending to hold them to a circular form, are, at the same time, substantially correct for all lengths greater than about six diameters. They have been tested for seven sizes, ranging from 3 to 10 inches outside diameter, in all obtainable commercial thicknesses of wall, and are known to be correct for this range.

By the foregoing formulas one may compute the probable collapsing pressure for any commercial size of casing.

Methods have been given for determining the probable pressure that will be carried on the water string of a particular well, and also the method for computing the collapsing pressure of the casing; it remains to discuss the proper safety factors to use. Quoting again from Stewart's report:

Not one of the several hundred tubes tested failed at a pressure lower than 42 per cent less than the probable collapsing pressure, while 0.5 per cent of the number of tubes failed at 37 per cent and 2 per cent at 25 per cent less than

[a] Haseltine, R. S., Collapsing pressure of steel tubes: West. Engineering, vol. 1, July, 1912, pp. 295–297.

that pressure. In other words, with an actual factor of safety of 1.75, * * * not one of the tubes tested would have failed.

It would appear that:

1. For the most favorable practical conditions, namely, when the tube is subjected only to stress due to fluid pressure and only the most trivial loss could result from its failure, a factor of safety of 3 would appear sufficient.

2, When only a moderate amount of loss could result from failure, use a factor of 4.

3. When considerable damage to property and loss of life might result from a failure of the tube, then use a factor of safety of at least 6.

4. When the conditions of service are such as to cause the tube to become less capable of resisting collapsing pressure, such as the thinning of wall due to corrosion, the weakening of the material due to overheating, the creating of internal stress in the wall of the tube due to unequal heating, vibration, etc., the above factors of safety should be increased in proportion to the severity of these actions."

These recommendations by Stewart are absolutely sound engineering, and if a safety factor of 3 were used in oil-well work some costly redrilling jobs might be avoided. At the same time such a procedure would not only increase the cost of material, but would frequently necessitate decreasing the size of the next string of pipe to be inserted in the well, a serious disadvantage. The drilling proverb, "Keep the hole as big as you can as long as you can" is not to be lightly ignored.

Suppose, for example, it were necessary to shut off water in a well at a depth of 3,000 feet and a safety factor of 3 was to be used, Table 1 following shows that 6¼-inch, 28-pound casing should fail with a water column of 9,380 feet. One-third of this, or 3,126 feet, would then be the permissible depth at which the casing could be used with a safety factor of 3. Similarly, 8¼-inch, or larger, sizes would not meet the requirements with so large a safety factor. If no mistake occurs and the hole can be finished with one more string of pipe, nothing larger than 6¼-inch open hole, or 4¼-inch casing, can be used. In many localities a 4¼-inch hole is undesirably small, and if any misfortune is met with, such as a failure to make a successful water shut-off with the 6¼-inch string, either a costly redrilling job has to be done or the hole must be finished with a 3-inch liner into the oil sands or else the well must be abandoned.

TABLE 1.—*Collapsing pressures and capacities per linear foot of lapwelded steel casing of sizes commonly used in California.*

Size.	Weight per foot.	Outside diameter.	Inside diameter.	Thickness.	Collapsing pressure per square inch.	Equivalent water column.	Water column with safety factor of 2.	Capacity per linear foot.	Capacity per linear foot.
Inches.	*Pounds.*	*Inches.*	*Inches.*	*Inches.*	*Pounds.*	*Feet.*	*Feet.*	*U. S. gallons.*[a]	*Cubic feet.*
4¼	16	4.750	4.082	0.334	4,710	10,850	5,425	0.6792	0.0908
4½	12.85	5.000	4.506	.247	2,900	6,680	3,340	.8281	.1107
4½	15	5.000	4.424	.288	3,610	8,320	4,160	.7982	.1067
5⅝	20	6.000	5.352	.324	3,290	7,580	3,790	1.1677	.1561
6¼	20	6.625	6.049	.288	2,380	5,480	2,740	1.4916	.1994
6¼	24	6.625	5.921	.352	3,220	7,420	3,710	1.4295	.1911
6¼	26	6.625	5.855	.385	3,650	8,410	4,205	1.3974	.1868
6¼	28	6.625	5.791	.417	4,070	9,380	4,690	1.3667	.1827
6⅝	20	7.000	6.456	.272	1,980	4,560	2,280	1.6988	.2271
6⅝	26	7.000	6.276	.362	3,100	7,140	3,570	1.6061	.2147
6⅝	28	7.000	6.214	.393	3,480	8,020	4,010	1.5739	.2104
6⅝	30	7.000	6.154	.423	3,850	8,870	4,435	1.5440	.2064
7⅝	26	8.000	7.386	.307	1,940	4,470	2,235	2.2240	.2973
8¼	28	8.625	8.017	.304	1,670	3,850	1,925	2.6204	.3503
8¼	32	8.625	7.921	.352	2,150	4,950	2,475	2.5583	.3420
8¼	36	8.625	7.825	.400	2,630	6,060	3,030	2.4962	.3337
8¼	38	8.625	7.775	.425	2,880	6,640	3,320	2.4648	.3295
8¼	43	8.625	7.651	.487	3,510	8,090	4,045	2.3863	.3190
9⅝	33	10.000	9.384	.308	1,280	2,950	1,475	3.5899	.4799
10	40	10.750	10.054	.348	1,420	3,270	1,635	4.1210	.5509
10	45	10.750	9.960	.395	1,800	4,150	2,075	4.0440	.5406
10	48	10,750	9.902	.424	2,030	4,680	2,340	3.9976	.5344
10	54	10.750	9.784	.483	2,510	5,780	2,890	3.9026	.5217
11	47	11.750	11.000	.375	1,380	3,180	1,590	4.9334	.6595
11	60	11.750	10.772	.489	2,220	5,120	2,560	4.7307	.6324
11⅝	40	12.000	11.384	.308	840	1,940	970	5.2827	.7062
12½	40	13.000	12.438	.281	500	1,150	575	6.3083	.8433
12½	45	13.000	12.360	.320	750	1,730	865	6.2298	.8328
12½	50	13.000	12.282	.359	1,010	2,330	1,165	6.1497	.8221
12½	54	13.000	12.220	.390	1,210	2,790	1,395	6.0869	.8137
13½	50	14.000	13.344	.328	640	1,470	735	7.2598	.9705
15½	70	16.000	15.198	.401	790	1,820	910	9.4150	1.2586

[a] Figures in this column determined by multiplying corresponding values in cubic feet by 7.4805.

Shutting off water at a depth of 3,000 feet is not uncommon in some of the California fields. In fact, in parts of the east side of the Coalinga field the water strings must be set between 3,500 and 4,000 feet deep. The example cited shows that no matter how desirable a safety factor of 3 may be, it can not be generally applied to modern drilling conditions. Therefore, a safety factor of 2 has been tacitly adopted in California practice, and so far has given rather general satisfaction. The factor of 2 is sometimes shaved a little, but the practice is not to be recommended.

One fortunate circumstance is that while a string of casing is being subjected to severe drilling stresses such as pulling, driving, and jarring, the external and internal fluid pressures on the pipe are equalized. Not until the string is landed and the fluid lowered within it is any collapsing tendency developed; thus drilling and collapsing stresses are not coexistent.

As mentioned, the static pressure developed on a water string increases in proportion to the depth at which the water string is set below the natural water level of the locality. Therefore it is unnecessary to have the upper part of the pipe as heavy as the lower part. To illustrate, suppose a water shut-off was to be made at 2,900 feet with 10-inch casing. The string could be inserted in the following sequence and yet have a safety factor of at least 2 at every joint in the string.

Specifications for 2,900-foot 10-inch casing having safety factor of at least 2 at every joint.

Sequence.	Length.	Weight of casing.
	Feet.	*Pounds.*
1 (bottom of hole)	560	54
2	280	48
3	440	45
4 (top of hole)	1,620	40
Total	2,900	

Although two weights of pipe are commonly used, and sometimes three, in making up the string, the use of more than three weights is rare. The table of collapsing pressures for different sizes and weights of casing given in Haseltine's paper [a] has been widely used among operators as a standard for determining the proper weights of casing to use for various jobs. Some operators have found by experience that it is advisable to increase the weight of casing with the depth of the hole when the pipe is to be used as a water string. The writer took occasion to ask a successful drilling foreman of wide experience and recognized ability what weights of pipe he would advise using for water strings at various depths. In round numbers his estimates were practically the same as those shown in Table 1 in the column "Water column with safety factor of 2." His estimates were from experience, as he did not use the table for collapsing pressures. This example is cited here to indicate that good practice as developed by experience, involving many costly failures, is in accord with experimental data.

CLASSIFICATION OF METHODS FOR SHUTTING OFF WATER IN OIL AND GAS WELLS OF CALIFORNIA.

In general the methods of shutting off water may be classified under two main headings, as follows:

1. Setting the casing in the formation with or without mud fluid, and with or without a mechanical packer.

[a] Haseltine, R. S., Collapsing pressure of steel tubes, West. Eng., vol. 1, July, 1912, pp. 295–297.

2. Setting the casing after cementing material of one kind or another has been placed between the casing and the wall of the hole.

In all probability the landing method of shutting off water has been used ever since the first water string was set. The method depends primarily on locating a stratum that is impervious to water even when the effective thickness is only the length of the casing shoe, perhaps 18 inches. This method when used in connection with mud fluid has been so thoroughly described by Lewis and McMurray[a] that there is little to be added here. In drilling a well, when it has been decided to case off the top water at a certain stratum the last 10 to 20 feet of hole is drilled smaller, and the casing is then set firmly into it. The weight of the casing is usually sufficient to force the shoe to a good firm seat.

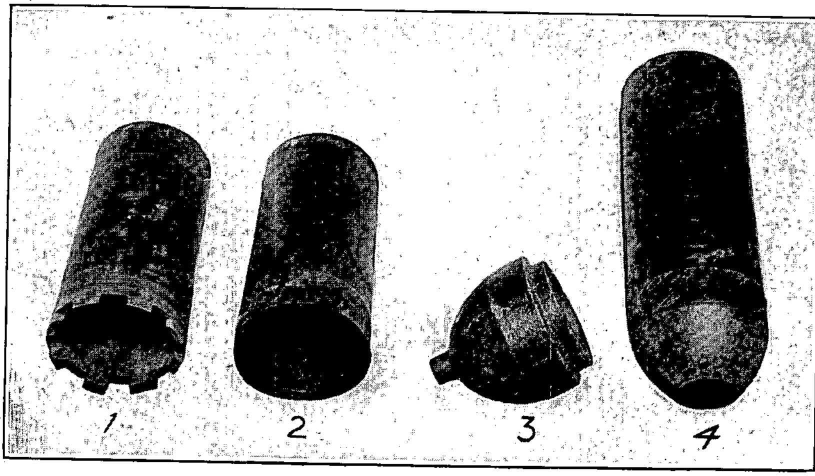
Some operators drive the casing until there is a sharp rebound of the drive clamps. Driving a water string is not advisable, and is seldom done now except where landing has been unsuccessful and the operator is taking his only chance of saving another string of pipe. Even under these conditions he must be careful or he may make a bad matter worse. Of course, this refers only to driving a water string, and has no connection with driving a loggy string of pipe in order to loosen it.

The practice of pulling up a string of casing a joint or two from the bottom, throwing out the calf-wheel clutch, and allowing the casing to race back into the hole in order to seat it firmly, is not to be recommended; such a practice is likely to "pinch" the shoe or bend the casing at or near the shoe joint. The drilling troubles thus precipitated will not be discussed here as they are well known to drillers.

Instead of using a plain casing shoe, various types of tapered shoes and long shoes up to 20 feet in length have been used. The tapered shoe, of course, seats more tightly than a plain one. Plate I, *A*, shows a plain shoe. An effective form of tapered shoe is used by the Shell Co. of California, in casing its rotary-drilled holes. The shoe is there known as the "McDuffey shoe." It is illustrated in figure 2. This shoe is sometimes referred to as a barrel shoe, as it is tapered at both ends. For convenience in the shop it is made in three rings screwed together. The purpose of the bottom taper is the same as that on any other tapered shoe. The object of the taper on the upper end of the shoe is to give better opportunity for the mud in the hole to settle down and fill any crevices between the shoe and the sides of the hole.

The long shoe is commonly made by putting a sleeve of pipe or protector rings over the shoe joint and turning it down in a lathe to

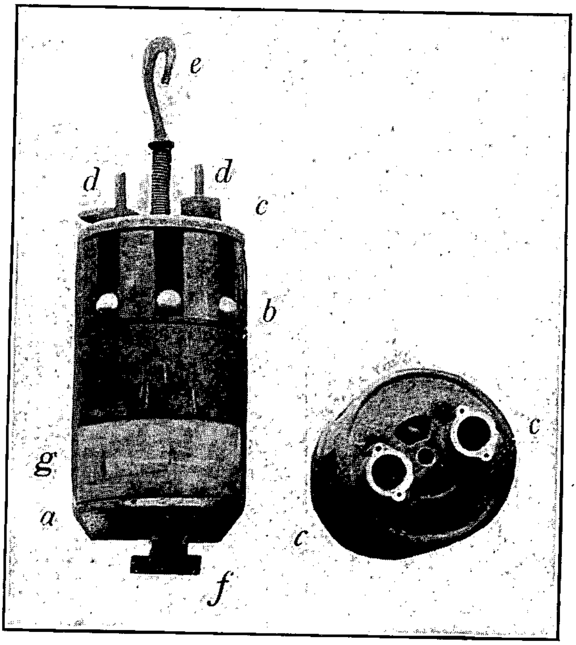
[a] Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, 86 pp.



A. CASING SHOES.

1, Baker shoe; *2,* plain shoe; *3,* "grahm" cast-iron float plug in the rough; *4,* plain shoe with "grahm" float plug screwed into it. The casing shoes are made of tempered steel.

B. "SURE-SHOT" CEMENTING PLUG.



C. HALL CEMENT PLUG.

the desired diameter. The purpose of the long shoe is to give greater contact surface between the shoe and the landing formation. Although most strata when in thin layers are somewhat pervious, a fairly thick layer of the same material is frequently entirely impervious to the passage of water. The long shoe is designed to take advantage of such a condition.

It is necessary in nearly all parts of the California fields to keep the hole full of water or mud fluid at all times during the drilling. Drilling with a dry hole is almost unknown. Thus, in drilling through the alternating and rather cavey shales, sands, and clays the fluid becomes somewhat mud laden both inside and outside of the casing, even when only clear water has been run into the hole. When the casing is landed for a "formation" shut-off this fluid tends to settle between the pipe and the walls of the hole and to improve the immediate effectiveness and the permanency of the job. As these conditions pertaining to the use of mud-laden fluid are not at all dependent on whether the casing is cemented or landed, they are present in all types of water jobs and play a more or less important part in shutting off the water. The writer is inclined to believe that the part thus played by the mud is rather more important than is often realized.

If the formation in which the water string is to be set is a "shell," which would ordinarily have to be reamed to let the casing through, the small hole is drilled a foot or 18 inches into the shell and the

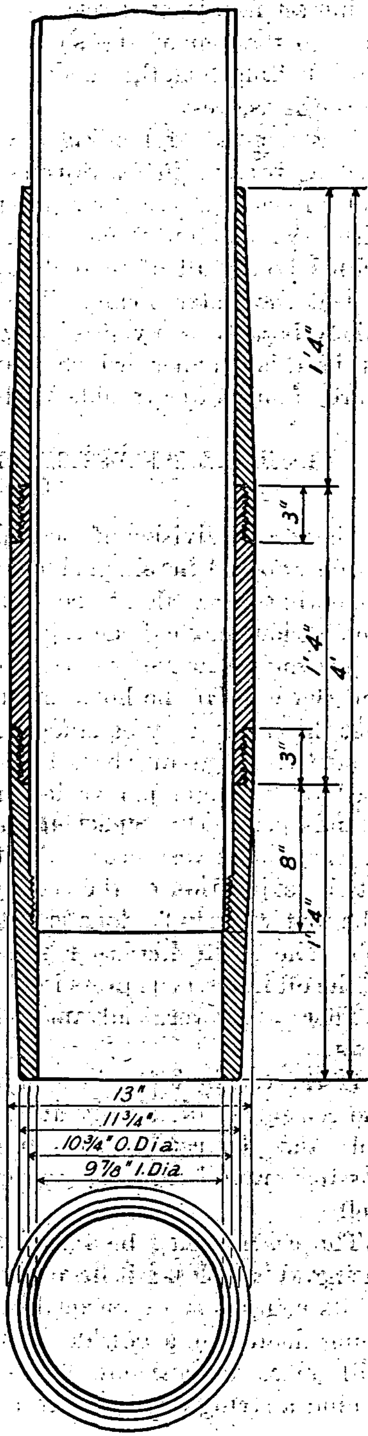


FIGURE 2.—McDuffey barrel shoe.

casing set into it, as described. The driller usually keeps the casing close to the top of the shell when using cable tools, and keeps a tight drilling line, thus making a close hole but little larger than the tools themselves.

This method of landing a water string without cement is little used at present in California fields except in rotary-drilled holes and in shallow territory where there is little water to contend with. As a matter of fact, even in such territory, and also in rotary-drilled holes full of mud fluid, it is usual among the operators to cement the water string. The landing method is described herein chiefly because many producing wells have had their water strings set in this manner, which may be responsible for a considerable share of the water trouble in these fields at the present time.

GENERAL DISCUSSION OF METHODS AND OBJECTS OF CEMENTING.

The second division of methods of shutting off water in the classification adopted herein includes all methods and processes in which cementing materials of one kind or another are used inside the well. The various methods described in the following pages have as their object the placing of the cement between the casing to be cemented and the wall of the hole, and at or near the bottom of the hole so that the casing may be landed on bottom, thus preventing the liquid cement from running back inside the casing. The quantity of cement used on a single job varies from one-half ton to 30 tons (2,000 pounds per ton). Sufficient time, usually 10 days or 2 weeks, and in exceptional instances a month, is allowed for the cement to set. At the expiration of the setting time work on the well is resumed. The first work to be done is to test the effectiveness of the cementing job. The California law regulating water shut-offs and other phases of the oil industry is presented on pages 97 to 115.

There are several advantages to be gained by cementing, as follows:

If the casing is set in a hard stratum there is every chance for the cement to fill closely all irregularities between the wall of the hole and the casing, thus preventing water or other fluid from passing around the shoe of the water string to the interior of the well.

The cement may be forced several hundred feet up behind the casing, thus holding it firmly in position and reducing the possibility of its being bent by unequal settling of the walls of the hole, or of being dented by a bowlder sloughing in against it. Two instances will suffice to show how far cement may be forced with pumps up behind a string of pipe. At a well in the west side of the Coalinga field a string of 8¼-inch casing was cemented at 1,100 feet, with 248 sacks of cement pumped in by the tubing method. The cement was pumped up behind the casing until it came out at the surface. At another well in the Buena Vista Hills district of the Midway field the water string had been cemented at about 3,000 feet. When the well was abandoned and an attempt made to recover the upper part of the water string after the bottom had been plugged, the water string was found to be cemented to the next larger string of pipe, the shoe of which was at about 2,000 feet. Thus the cement had risen 1,000 feet outside of the water string.

Many operators cement water strings in a rotary hole even where it is generally assumed that the mud will be sufficient to make a water-tight job without the use of cement. The purpose of this practice is more to reinforce and support the pipe than to perfect the seal. Also, it is hoped that the cement will retard deterioration of the casing from corrosion. The operators believe that this use of cement is somewhat like carrying fire insurance on a building. A well is a costly improvement to a piece of property and is worth protecting, as the loss to the operator if water breaks into the well and destroys a valuable oil sand would exceed the cost of the well many fold. Sometimes such a hole can be plugged and the destruction arrested, but owing to lost tools or casing, or to a crooked hole, it may be mechanically impossible to plug the hole properly. It is the old story of the ounce of prevention versus the pound of cure.

Another important advantage in cementing a water string is in filling up between the casing and the wall of the hole with a material that takes its initial set within a day or two. A firm mass is thus built around the casing which, though it may not make a perfectly water-tight bond either between itself and the casing, or between itself and the formation, will afford the mud and cavings an excellent opportunity as they settle in the hole to seal every crevice and pour in or around the cement mass. The cement thus acts like a nonrotable wall packer, affording the mud the best possible chance to do its work.

The value of cement as a safety factor on a water shut-off is well illustrated at a well in the Sunset field. This well was sunk with a rotary drill to approximately 2,400 feet, and the 10-inch casing was set with no other casing in the hole. The driller stated that the last 20 feet of the hole had shown a little gas and oil in the shale. It would have been extremely difficult to have plugged such an open hole 20 feet from the bottom and have the plug solid enough to cement on it, as the hole would probably have caved in before the job could have been completed. Moreover, the "showing" seemed insignificant, and the casing was not to go through the oil-bearing shale, but merely to extend into it for 20 feet. Accordingly the casing was put

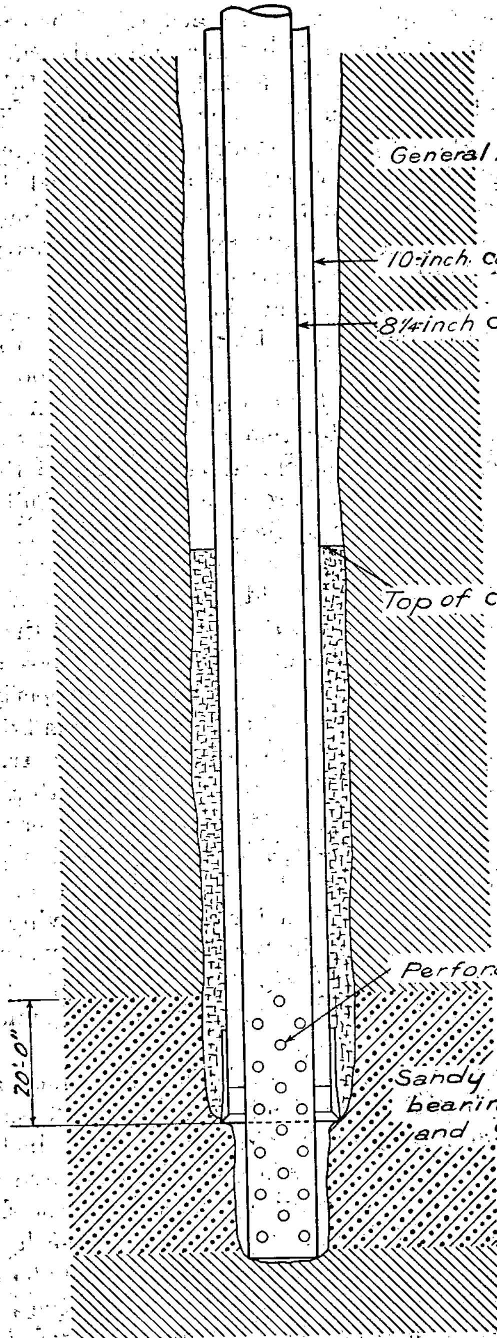


FIGURE 3.—Well in Sunset field in which water string extends 20 feet into oil-bearing stratum, yet the cement successfully shut off water in shale above.

in and cemented by the "Perkins process," 4 tons of cement being used. (See fig. 3.) Further work demonstrated that this oil-bearing shale was about 40 feet thick and constituted the only pay stratum penetrated by the well. Incidentally the well proved to be a good producer for that locality, and no water troubles were encountered. The cement had evidently been forced up behind the pipe and made a shut-off above the oil-bearing shale, leaving the bottom joint of the water string extending 20 feet into this formation without letting any water into it.

One more noteworthy instance may be cited from the Buena Vista Hills of the Midway field. There a well flowed for about two years, making several hundred barrels of clean oil daily. Finally production ceased, and when cleaning-out tools were run into the hole, it was found that both the oil and the water strings were bent near the bottom of the water string. The oil string was pulled, but parted near the bottom of the 6⅝-inch water string. The two lower joints of this 6⅝-inch string were ripped off and drilled up to straighten the hole. Fearing that this work might have broken the cement outside of the remaining part of the water string, the company had the water bailed out of the hole to the 1,800-foot level. For several hours there was no change in the water level. As the string of 6⅝-inch pipe was holding back flowing water, the test was believed to be adequate. Additional evidence of the efficiency of the cementing was furnished later when the redrilling was completed, as the well again became a producer of clean oil. It is interesting to note that this water string had been cemented with only 35 sacks of cement, which had been placed with a dump bailer such as that shown in Plate II, for by this method the cement is not forced as high outside of the water string as can be done by a pumping method.

The two instances cited will suffice to show the value of making a water shut-off as permanent as possible whether the danger of top water is seemingly small or is great. In fact, it has been the experience of the Bureau of Mines engineers that water conditions where comparatively easy to overcome may be overlooked and neglected.

DUMP-BAILER CEMENTING PROCESS.

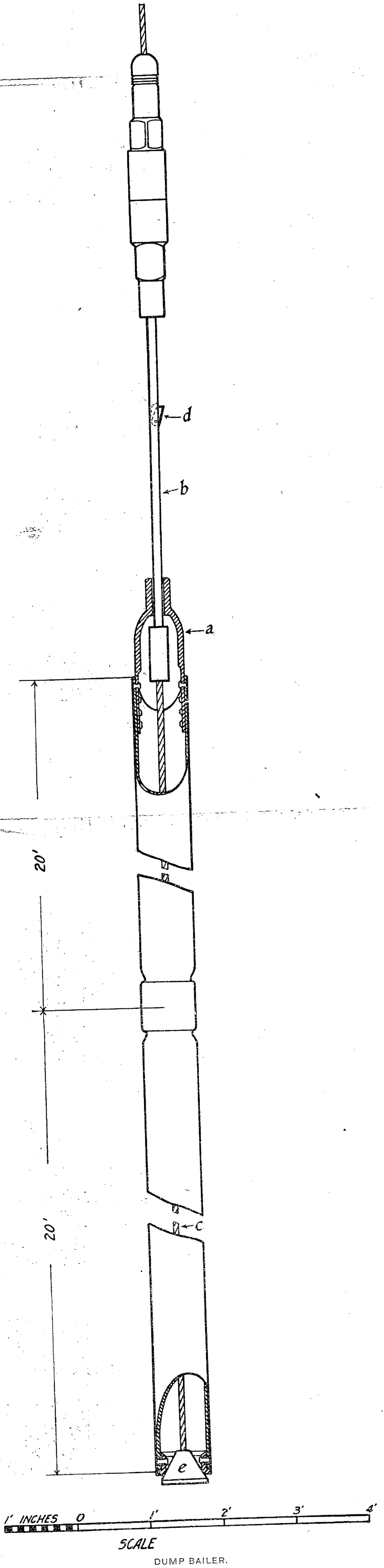
GENERAL REMARKS.

In cementing a string of casing with the dump bailer, the liquid cement is lowered to the bottom of the hole with a bailer which, as its name indicates, discharges or dumps its load instead of picking it up like the ordinary bailer. By this method 2 or 3 tons of cement is dumped into the bottom of the well. As many runs are made with the bailer as may be necessary to deposit the entire quantity of cement to be used. The required quantity can almost never be lowered in one load. After this is done, the casing is pulled up 20 to 40 feet off bottom, or so that the shoe will be above the cement level. The casing is filled with water and then closed at the top with a steel plug, or other suitable fitting, and is lowered firmly to the bottom of the hole. There being no outlet at the top of the casing for the water, the cement can not enter at the bottom, so it takes the only open course and rises outside the casing, filling the space between the casing and the walls of the hole.

DESCRIPTION OF DUMP BAILER.

There are several types of dump bailers in use; also, there are several ways to transform an ordinary dart bailer into a makeshift dump bailer, but such makeshifts are unsatisfactory and likely to cause trouble. A satisfactory type of dump bailer is the one shown in Plate II. The shell of this bailer is of two joints of pipe swaged to connect in a coupling of the same external diameter as the joints. As the bailers vary in size according to the size of casing in which they are to be used, dimensions are omitted here. The bail *a* terminates in a bottle neck through which the rod *b* is free to slide. The enlargement at the lower end of this rod is bored as a rope socket to receive the $\frac{5}{8}$-inch wire dump line *c*. The rod is provided with a latch *d*, in general design similar to that on the shaft of an old-fashioned umbrella. The upper end of the rod is threaded to screw into the bottom of a tool joint. This joint has a pin on its top to make up with the box of the rope socket so that the dump bailer may be run on the drilling line. Riveted to the bottom of the bailer is an annular steel valve seat. The valve *e* is of steel and in the form of a truncated cone. Of course, a ball would do the work as well as the cone. The wire line, or chain if preferred, which connects the rod *b* with the cone, must be babbitted, or otherwise securely attached to both rod and cone, as the entire weight of the bailer and contents must be carried by the dump line or chain. It is worth noting that if either of these two babbitted connections fail, only the cone, or at worst the cone and the dump line, will be left in the hole, as the shell of the bailer will hang on the butt of the rod *b*.

When this bailer is run to bottom, the rod slips down through the bottle neck in the bail, thus throwing about 3 feet of slack in the connecting cable. When the bailer is lifted again the latch engages with the bail and the entire device is brought to the surface with the valve dangling about 3 feet below the valve seat. There is thus no possibility of the bailer not discharging its contents. In running such a bailer in a hole full of fluid it tends to float if lowered too rapidly. The latch will then trip the bailer and discharge the contents. Such an accident is particularly apt to occur when the fluid level is-



DUMP BAILER.

several hundred feet below the surface. Such premature unloading may take place without the driller's knowledge and go undetected until the job is found to be unsuccessful. All this trouble will be avoided by care in lowering the bailer slowly enough, allowing no slack in the drilling cable. In the type of construction illustrated in Plate II, more than two joints of pipe may be used if so desired.

METHOD OF USE.

In order to reset the latch for another run, the shell of the bailer must be supported and the rod lowered enough to allow the latch to be pushed into the rod and so held until the rod is pulled up through the bottle neck. This can be done more conveniently with the top of the bailer near the derrick floor than by resting the bottom of the bailer on the floor. A convenient method is to have two pieces of timber 4 by 6 inches by 2 feet coped to fit the bailer, with two long bolts connecting their ends. By drawing the bolts tight the wood clamps will grip the bailer and, resting on the top coupling of the casing, hold it while the latch is set. The bolts may be loosened and the bailer lowered through the clamps, which are then in place when the bailer is again raised through them.

The dump-bailer method is frequently used when a water string is to be set with a relatively small amount of cement, say, less than 2 tons. The cement is mixed in a box on the derrick floor in batches according to the capacity of the bailer. After cement has been wet, it should not be held over for the next batch. Surplus cement, after the bailer has been filled, should be discarded. A convenient rule is to figure that each sack of cement when mixed will occupy 1.15 cubic feet. This, of course, allows for the excess of water used to obtain the necessary fluidity, as well as to prevent the cement from taking its initial set too quickly.

The bailer latch is set and the bailer hung in the hole with the shell seated on the cone valve *e* so that the top of the shell comes level with the floor and under a spout or swing pipe leading from the cement box. The bailer is then loaded and run to bottom in the manner described. It is advisable to have a bailer large enough so that the period from the time the first batch of cement is wet until the job is completed will not exceed two hours. It is important to have enough men with hoes at work to insure that the mixing of each batch is commenced as soon as the last of the preceding batch has left the mixing box, and that the mixed cement will not have to be kept waiting for the bailer. Frequently, while a driller and tool dresser are lowering and dumping a bailer, pulling out and resetting the latch and getting the bailer in position for the next charge of cement, the other men get the cement ready to pour. This is the ideal arrangement, but one dares not speed up the bailer movements to any great degree, and as more than five hoes in, say, a 10-sack mix, does not accelerate mixing, the controlling time factor is the depth of the hole. Nevertheless, when cementing a deep hole care can be taken that the mixed cement does not have to wait for the bailer. If the dry cement is piled into the high end of the mixing box away from the outlet, and a nozzle be used on the water hose so that a high-pressure stream of water may be played back and forth across the box impinging on the pile of cement so as to cut and mix it in slices 2 to 4 inches thick, the cement not only mixes more quickly, but with fewer lumps, and consequently requires less hoeing than if mixed entirely with hoes.

During cementing, the hole should be kept full of water, if possible. After all the cement has been dumped, the casing is filled with water and set, as described. The well should be left undisturbed at least 24 hours before the pressure within the casing is released. After this time it is advisable to stretch the casing as much as experience has shown is allowable. The casing is then hung on clamps in this position so that it is held both at the top and the bottom; otherwise the pipe tends to bend from its own weight.

CEMENTING PLUGS AND THEIR USE.

Occasionally it is desirable to cement a hole that can not be filled to the top with water, as the water runs away in a sand that has a natural water level some considerable depth below the derrick floor, so that all the available water that can be run into the hole will not raise the natural water level, nor continuous bailing greatly lower it. The best solution for such a problem may be to use one of the other cementing methods described in subsequent pages.

Sometimes equipment for the other methods is not available so that the dump bailer must be used. Again conditions may arise that make it undesirable to pump large quantities of cement back of the casing. The chief difficulty of cementing with the dump bailer in a hole in which the natural water level is low is that after the cement has been mixed and placed there will be an air column above the water in the casing. This air will compress as the casing is lowered, thus allowing the cement to remain at practically the same level inside the casing as outside. Moreover, if the casing has been set on bottom, filled with water, and the fittings put on, when the casing is lifted the water will immediately run out, washing the cement away from the bottom of the pipe. Of course, the height of water column that would be required to give sufficient weight to force the cement up back of the casing and still not entirely out of it, could be calculated. Such a calculation is necessarily based on numerous fundamental assumptions, and the results are untrustworthy.

"SURE-SHOT" CEMENT PLUG.

For cementing a hole in which the water level is low, a device such as the "sure-shot cement plug"[a] (Pl. I, *B*, p. 22), or the "Hall cement plug"[b] (Pl. I, *C*), may be used. These two devices are for identically the same purpose, that is, to tightly close the bottom of the casing to be cemented after the cement has been dumped through the casing into the bottom of the hole so that when the casing is lowered into the liquid cement the plug will not allow any cement to reenter the casing, but will force it up on the outside. In other words, these plugs are designed to do the work of the column of water and the tight head, previously described. With the exception of a few small parts, both of these plugs are made of thin cast iron so they can be easily drilled up after the cement has set.

The sure-shot plug (Pl. I, *B*) is lowered into the hole by attaching the eyebolt at the top to the dart of the bailer. If the water resistance tends to stop the passage of the plug, the weight of the bailer will push down on the eyebolt, thus opening the valve in the bottom of the plug, permitting the water to flow through the plug. The plug has in its shell four slots through which may slide stove bolts that hold the lugs to the body of the plug. This construction will be clear by inspection of Plate I, *B*. There is no spring tending to close the valve at the base of the plug. This is done by the weight of the casing. The casing is lifted till the shoe is clear of the cement before the plug is inserted. On passing out of the casing the slips slide down the conical shaped body of the plug resting firmly on the base at *a*. When the bailer is picked up, the slips will be pulled up firmly under the casing shoe and stopped in this position, thus plugging the bottom of the casing, which is then set on bottom, displacing the liquid cement. A quick jerk with the sand line will pull the eyebolt out of the cast poppet valve, and thus release the bailer, which pulls the eyebolt with it to the surface.

This plug may not make a water-tight joint at the shoe, and a little cement may work back into the casing, though the writer has never heard of such an occurrence, and is of the opinion that any such leakage will be negligible. Such a small leak as might be afforded between this plug and the shoe will generally be stopped when the plug and shoe are forced into the landing formation by the great weight of casing. This plug is characterized by extreme simplicity of construction, and can be moved up and down in the casing as occasion may necessitate until such time as it has reached its destination. Not until such destination is reached does it become impossible to pull the plug back to the surface.

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[a] Patented by Carl Baker, of Coalinga, Cal.

[b] Manufactured by the Bunting Iron Works, of Coalinga, Cal.

HALL CEMENT PLUG.

The Hall cement plug (Pl. I, *C*) is attached to the dart of the bailer by the eyebolt *e* and pushed down the hole in exactly the same manner as the Baker plug. The valve in the bottom is opened by the pressure of the bailer on the eyebolt extending through the center of the plug.

There are two sets of steel balls which act as slips. The set *b* shown in the longitudinal grooves in the main body of the plug prevents it from being pulled or pushed up the casing. The other set of balls are much smaller diameter and placed in the ball cups *c* around the vertical rods *d*. These rods are firmly attached to the base of the plug *a* and extend upward through the ball cups *c* on the cap of the plug. As the longitudinal grooves are deeper at the upper ends than at the lower, the balls in them rest against the casing at all times and wedge between the casing and the inclined grooves at the first upward movement of the plug. This upward movement is occasioned by a pull on the eyebolt when the plug has reached its destination. The eyebolt being attached to the valve *f* closes it and at the same time pulls up the base *a*. This squeezes the rubber *g* tightly against the casing, making a water-tight contact. The balls in the cups *c* grip the rods and so hold them that the base *a* can not slip away from the main body of the plug, thus holding the rubber firmly in its compressed position.

Care must be taken to have a suitable and substantial mark on the sand line so as to stop the plug in the bottom joint of the casing and yet not let the plug leave the pipe. If this plug is run below the casing in all probability it will hang on the edge of the shoe and can not be pulled back into the casing. Even if by chance it should start back into the casing the balls at *b* would prevent its getting high enough to allow the rubber *g* to set in the pipe. After the plug is lodged in the pipe, the string is lowered to the bottom just as with the sure-shot plug.

With the Hall plug there will always be 5 to 10 feet of cement in the casing beneath the plug, as to attempt placing the plug closer than this to the shoe would entail risk of getting it below the casing. However, there should be no difficulty in drilling out such an amount of cement. When using this plug a driller must remember that after it has once started into the casing there is no chance to pull it out without drilling it up, as to pull it back as much as 6 inches sets it so that it will go neither up nor down.

TUBING METHOD OF CEMENTING.

The tubing method of cementing casing in wells is subject to many variations and modifications. The essential features are that the liquid cement enters the well through tubing usually 2 to 3 inches in diameter which extends to within a few feet of the bottom, inside of the casing that is to be cemented. Some provision must be made to prevent the cement from backing up between the tubing and the casing, and to force it to go up between the casing and the wall of the hole. For this purpose a packing device of some kind is used which seals off the annular space between the tubing and the casing. The packing device may be placed at either end of the string of tubing or at any intermediate point. For mechanical convenience it is customary to put the packing device either at the bottom or the top of the tubing.

In cementing a well by the tubing method the driller should make sure that fluid will circulate before any other work such as putting in tubing is started. If water can not be forced from inside of the casing around the shoe and up outside of it, it is obviously useless to try to force cement through. Assuming that it has been possible to get circulation with water or mud fluid, the tubing may be inserted with the packer on the bottom. A disk packer is frequently used for such jobs, although any other type of packer meeting the general requirements will do. The cement is mixed and pumped by the method described under the discussion of the upper packer, or tight-head method of cementing with tubing, on pages 34 to 37. After the cement has been mixed and pumped in under the packer and followed by sufficient water to flush the tubing clear of cement, a stopcock, or gate, at the top of the tubing is closed, and the casing is lowered to the bottom of the hole. After the casing is thus set on bottom, the tubing, together with the packer, should be pulled up enough to free the packer before any residual cement has an opporunity to set. After the packer has been thus loosened, water is pumped down the tubing and back to the surface between the tubing and the casing in order to wash out any cement from inside the casing. The tubing is then pulled out, bringing the packer with it. This done, it is advisable to completely fill the casing with water and close the top with a plug or other suitable fitting, and to leave the hole in this condition while the cement sets. In fact, a column of water should be kept inside of the casing after any cementing job in order to counteract the tendency of the liquid cement to run back into the casing through any stray channel under the shoe. Some operators go so far as to set a pump to hold a certain water pressure on the casing, perhaps 50 pounds per square inch or more, as may be required. The pump is watched and is so regulated as to counteract any leakage in the fittings and to maintain a steady pressure on the well.

The disadvantage of the bottom packer is that it may leak cement under high pressure and by-pass so much of it above the packer that the packer can not be pulled. The operator will then have to drill the cement and the packer out of the bottom of the water string, with perhaps a joint or two of tubing. To avoid the possible loss of tubing there should be a left-hand thread connection between the tubing and the packer. Even though sufficient cement may have been forced outside of the casing to make a water-tight job, the severe pounding of the tools while drilling up cement and junk will probably crack the outside cement and may even tear a hole in the water string itself.

This disadvantage has been overcome by omitting the packer at the bottom of the well and using one at the top instead.[a] There are several top packing devices in use. Two forms of top packers, or tight heads, as they are commonly called, are shown in Plates III and IV. Another form is shown in Plate V, *A*.

In addition to changing the position of the packing devices, there are several variations in the method of mixing and pumping the cement into the tubing. One of the best systems in use is that operated by William F. Scott, of Taft, Cal.

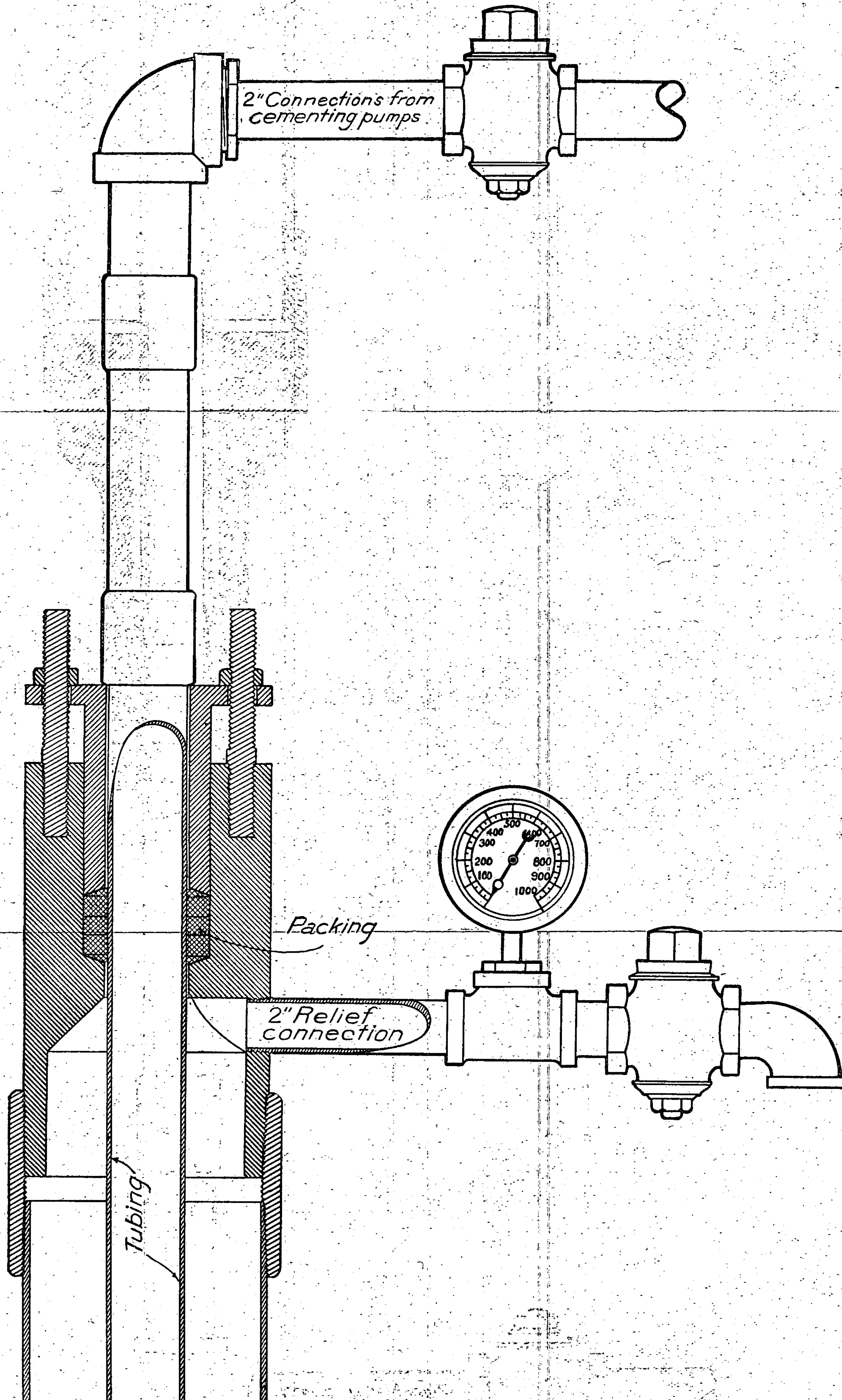
CONSTRUCTION AND OPERATION OF SCOTT CEMENTING OUTFIT.

As shown in Plate VI, the Scott outfit is mounted on a stout wagon to facilitate its transportation. It is hauled by team or motor truck to a convenient position near the well to be cemented. The main features of the outfit are the wagon, water tank, cement mixer, single-cylinder steam engine to drive the mixer, cement pump, small suction tank, and top packer or tight casing head.

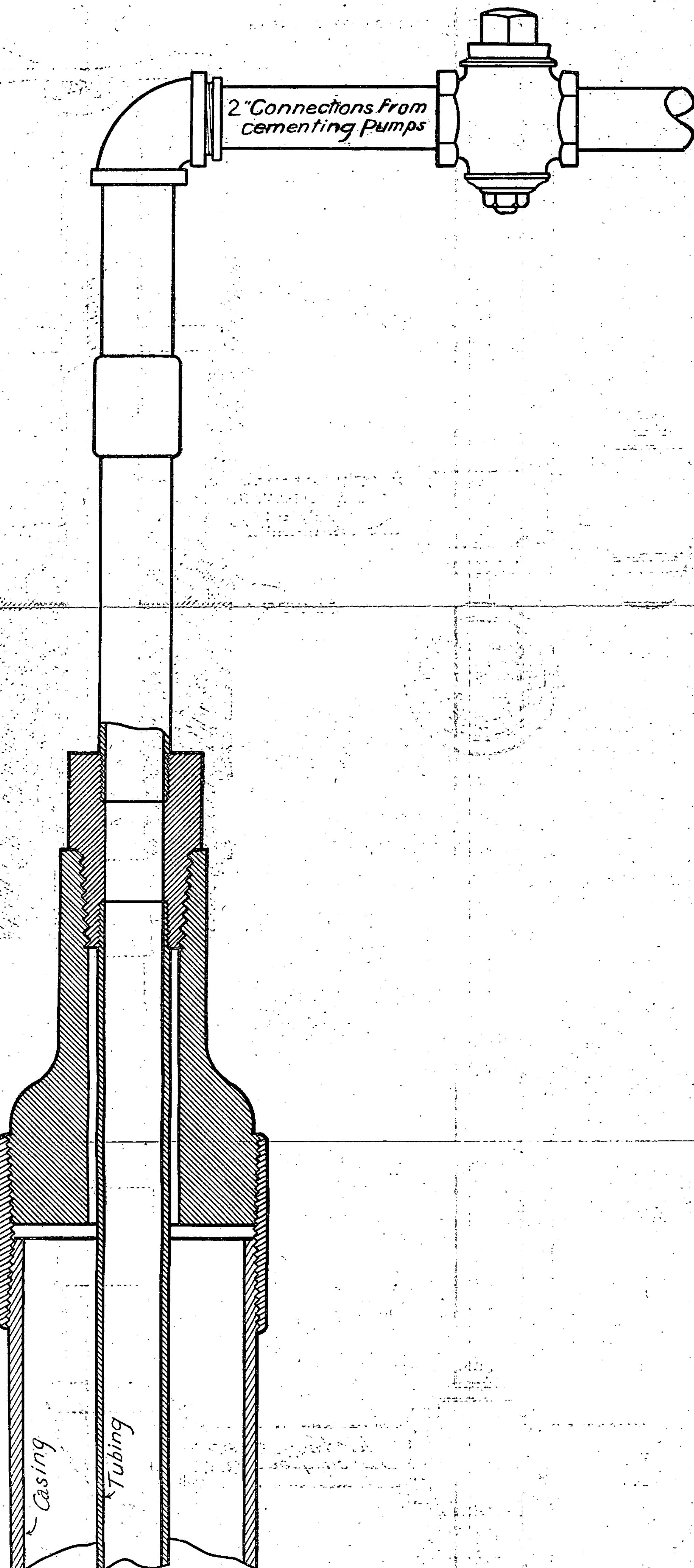
The water tank is a galvanized-iron tank of convenient size, securely mounted on the rear of the wagon and fitted with a 3-inch flange in the bottom connected to the 3-inch suction line to the pump. This line has a 2-inch intake from the main water-supply line, and also has a 2-inch branch discharging into the top of the tank. This tank is used for gaging the water pumped after the cement.

The cement mixer was built by Mr. Scott according to his own design. The mixing barrel is a piece of 12½-inch casing about 6½ feet long with a feed hopper as shown in the illustrations. This hopper feeds the dry cement to the mixing barrel below. The feed is regulated by a sheet-iron door operated by a lever *a* (Pl. VI, *A*). To insure uniform feed and to break up any lumps in the dry cement, thus preventing it from clogging in the hopper, there is a shaft fitted with radial iron pins. The pins are about 3 inches long, made of ¼-inch round iron. The end of this shaft and its drive sprocket are shown at *b*. This sprocket is chain driven from a jack shaft, which is in turn driven from a sprocket on the main-line shaft of

[a] See Wiggle, W. P., Method of cementing walls of a hole: U. S. patent 1057789, Apr. 1, 1913.



CEMENTING HEAD OF STUFFING-BOX TYPE.



HONOLULU CEMENTING HEAD.

the mixer, thus causing the small feeding shaft to rotate at a greatly reduced rate of speed compared to the speed of the line shaft.

The end of the mixing barrel under the feed hopper is closed by an ordinary cap to fit 12½-inch 10-thread casing. In the cap are three holes. The central hole admits the drive shaft, and acts as a bearing for it. The other holes, one on either side of the center, admit water into the mixing barrel. The two intakes provide a more uniform distribution of water than would be possible with only one. The line shaft is flanged directly to the engine shaft, thus gaining strength, simplicity, and compactness by a straight-line drive. The bearing at the discharge end of the mixer is held by a semicircular cap as shown in Plate VI, *B*. This cap is held in place by three cap screws, and thus can be easily removed. The cap screws also permit accurate centering of the line shaft when adjustments may be necessitated from the replacing of broken mixing blades. The small three-bolt shaft coupling shown at *c* (Pl. VI, *A*) may be disconnected and the adjacent sprocket taken off, thus leaving the line shaft free to be removed for cleaning and repairs.

The 2-inch line shaft has a set of cast-iron mixing blades (Pl. V, *B*) mounted on it. These blades are cast with lugs on one side of the hub and notches at 90° to them on the opposite side. When a set of blades are slipped on the shaft the notches on the one will mesh with the lugs on the next adjacent hub, thus each successive blade is held at 90° to the one preceding it. Such an arrangement causes the entire set to rotate as a unit without any radial slip. Two blades at each end of the set and one or two in the middle are attached to the shaft with set screws. This construction permits the easy and quick replacement of broken blades and obviates any machine work on them except that necessitated by the set screws. The blades being of cast iron may break if a large nut, bolt, or other piece of iron gets into the mixer by accident along with the cement. It is far better to have a broken blade in the mixer than a shutdown in its operation. Obviating a shutdown after the mixing of cement has once started is most important, as the wet cement would not only have opportunity to set in the mixer, but delay might mean failure of the entire cementing job. The mixing blades are about 6⅛ inches long from the center of the hub to the periphery. The pitch of the blades is such that, as one looks into the discharge end of the mixer the shaft must rotate in a clockwise direction. This direction of rotation tends to clear the cement away from the bottom of the feed hopper.

If the main shaft of the mixer rotates at 400 revolutions per minute, a ton of cement (20 sacks) can be mixed in 2½ to 3 minutes. The cement passes through the chute at the discharge end of the mixer into small suction tank *d* (Pl. VI, *A*), from which it is taken directly by the pump and forced into the well without the necessity of working it at all with hoes. The mixing is entirely mechanical, thus reducing labor and accelerating the process.

The engine used is a single-cylinder, $4\frac{1}{2}$ by 5 inch, Clark steam engine, and gives entire satisfaction.

A 10 by 4 by 10 inch Snow duplex pump is used to force the cement into the tubing. This pump will deliver at about 750 pounds gage pressure.

A small galvanized-iron tank of about 20 cubic foot capacity is used as a suction tank. Almost any strong tank or box of 10 to 20 cubic foot capacity will do for the purpose. The tank should not, however, be of a low squatty design. The object is, of course, that the suction tank carry as small a quantity of cement as possible so it will be drawn off by the pump as fast as it is mixed, allowing no time for any settling to take place in the suction box.

The top packer, or tight head, is designed in many forms.

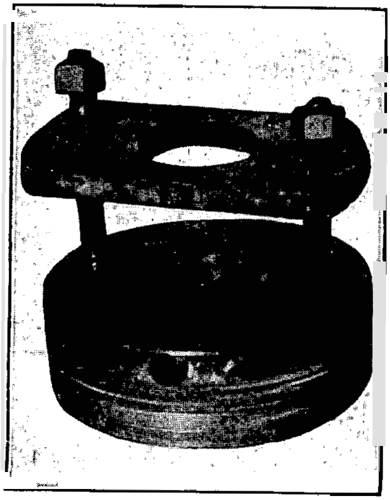
Plate *V*, *C* shows the tight head used by Mr. Scott when cementing a string of $8\frac{1}{4}$-inch casing. The sack wrapped around the tubing is more to illustrate the necessity of packing than to recommend the method illustrated. Ordinarily when this head is used a steel plate bored to take the tubing is slipped over the last joint before it is set up. This rests under the top coupling of the tubing and presses soft hemp or other packing into the annular space between the tubing and the tight head.

Plate V, *A*, shows a tight head used successfully in the Coalinga and Sunset fields.[a] This head is bored to allow passage of the 3-inch tubing, but not a coupling, and must therefore be slipped onto the last joint of tubing before the latter is set up. The head is then screwed into the top coupling of the casing to be cemented. The rim of the hole through the casing head has a small bevel turned around it to receive a ring of hydraulic packing that is put around the tubing and under the coupling. The follower plate may be drawn firmly down on top of the coupling by the stud bolts if necessary.

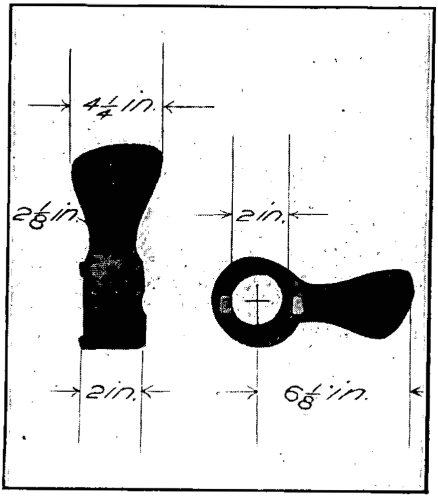
Some operators in the Midway field have had difficulty with various types of tight heads that require packing to make a tight joint between the tubing and the casing head. The trouble was occasioned by leakage around the packing toward the finish of the cementing job, when the highest pressure is naturally used. To get around this difficulty the Honolulu casing head shown in Plate III (p. 34) was designed and has proven satisfactory. In this head the packing is replaced by threaded connections.

In using either the Honolulu or the Southern Pacific Co. head, the tubing must be lifted in order to provide a relief vent for washing surplus cement out of the tubing and casing after the tubing has

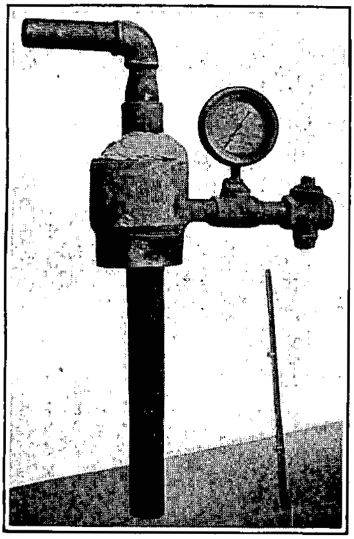
[a] Made and used by the fuel department, Southern Pacific Co.



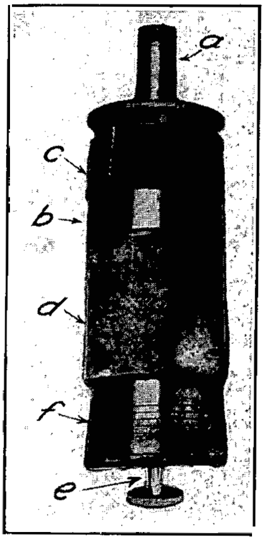
A. CEMENTING HEAD, KERN TRADING OIL CO.



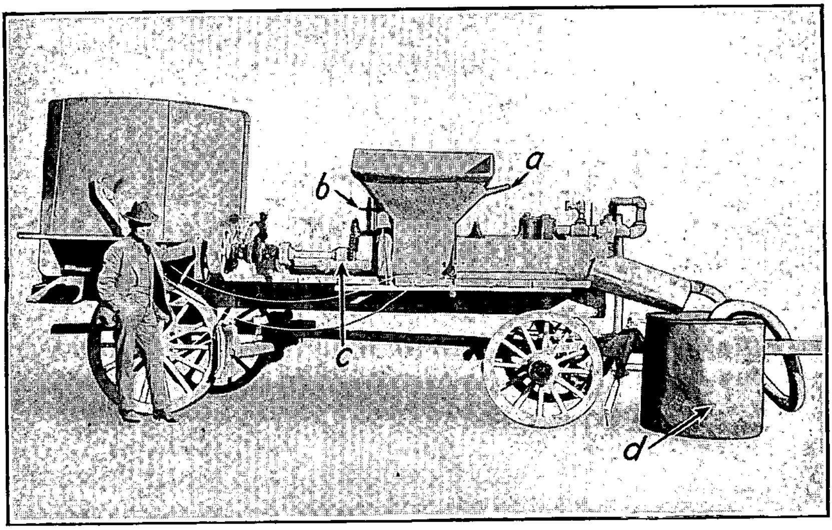
B. MIXER BLADES OF SCOTT CEMENTING OUTFIT.



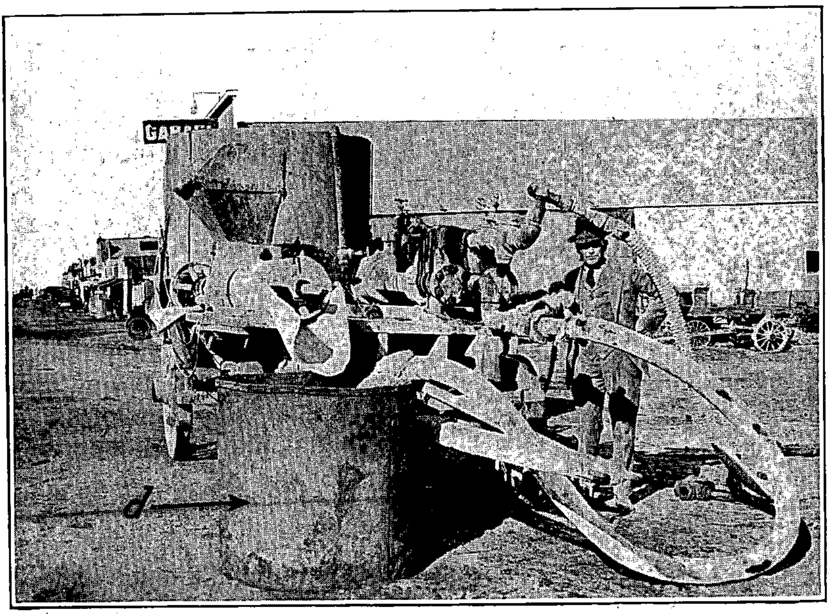
C. SCOTT TIGHT HEAD.



D. BAKER CEMENT CONTAINER.



A. SCOTT CEMENTING OUTFIT, VIEWED FROM SIDE.



B. SCOTT OUTFIT; VIEW OF DISCHARGE END.

been landed. With a Scott head this operation is accomplished by opening the 2-inch stopcock near the pressure gage.

The tight head of the stuffing-box type (Pl. IV, p. 35) consists of a stuffing box and follower drawn down by two ⅞-inch stud bolts. The tubing will work through this gland, or, if preferable, a coupling may be set on top of the follower, thus pressing the packing more firmly together, as shown in the drawing. With this type of head it is not necessary to set the weight of the tubing on the follower gland to compress the packing, hence the bottom of the tubing may be set at any desired depth without regard to the position of couplings at the surface. It is believed that this form of stuffing box if thoroughly packed will prevent leakage under the most severe conditions.

CONDITIONS UNDER WHICH TUBING METHOD IS USED.

The tubing method is applicable to cementing water strings that are not likely to "freeze" on standing while the tubing is being inserted. In general, the usual practice is that the tubing method is not used in the hole where mud flush has been circulated during drilling. Like every other generality, this one has exceptions. For instance, one of the large companies in the Midway field used the tubing method in cementing water strings in a rotary-drilled hole. When this company has finished making the hole and is ready to set casing, the drill pipe is pulled out and the tubing stood in the derrick before the casing is started. The tubing may then be inserted far more quickly after the casing is all in the hole than would be possible if it had to be inserted by single joints.

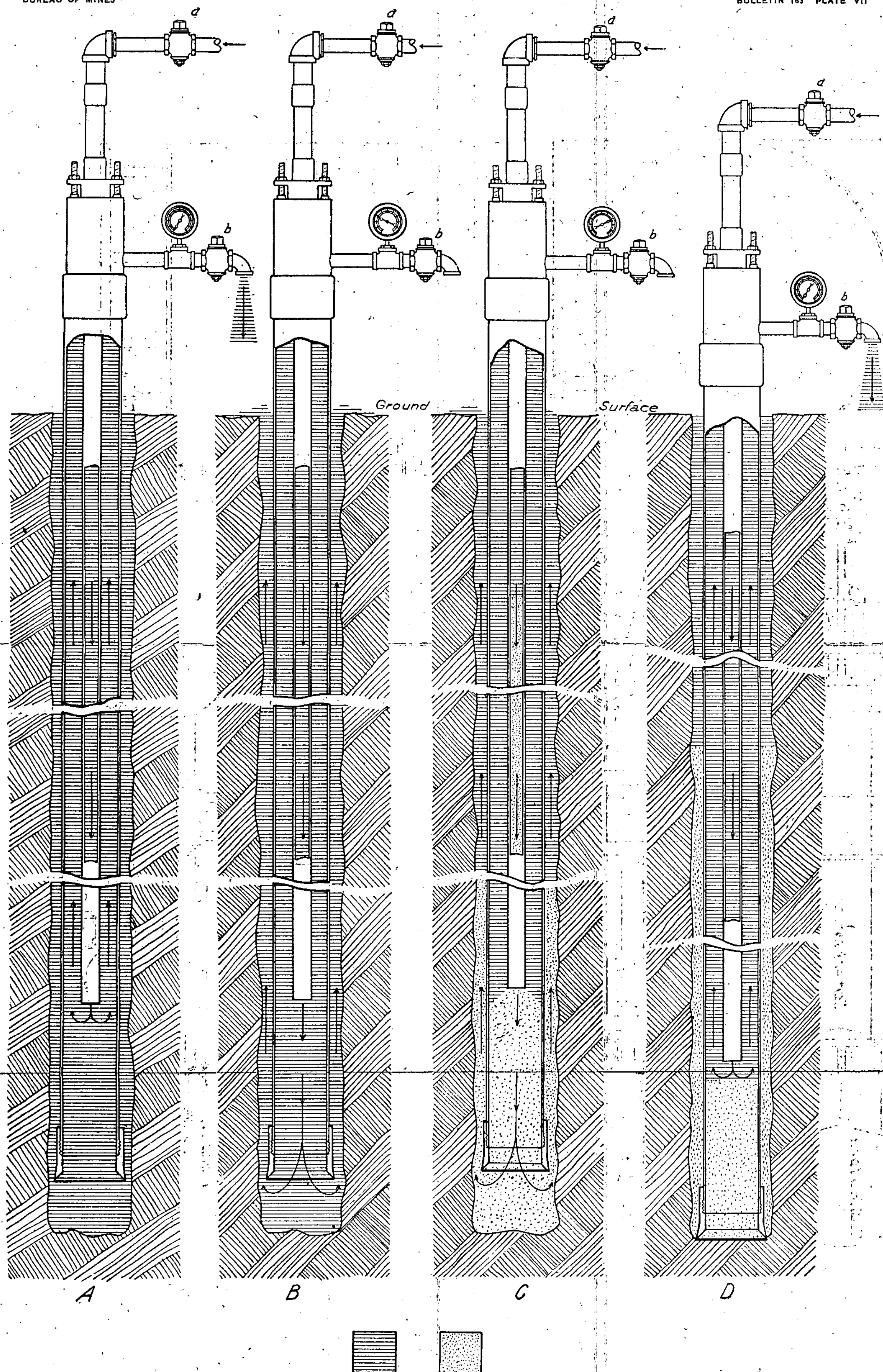
CEMENTING BY TUBING METHOD WITH SCOTT OUTFIT.

The Scott cementing equipment is used in connection with the tubing method, but the mixing and pumping mechanism may be and, as a matter of fact, is used for cementing without the use of tubing.

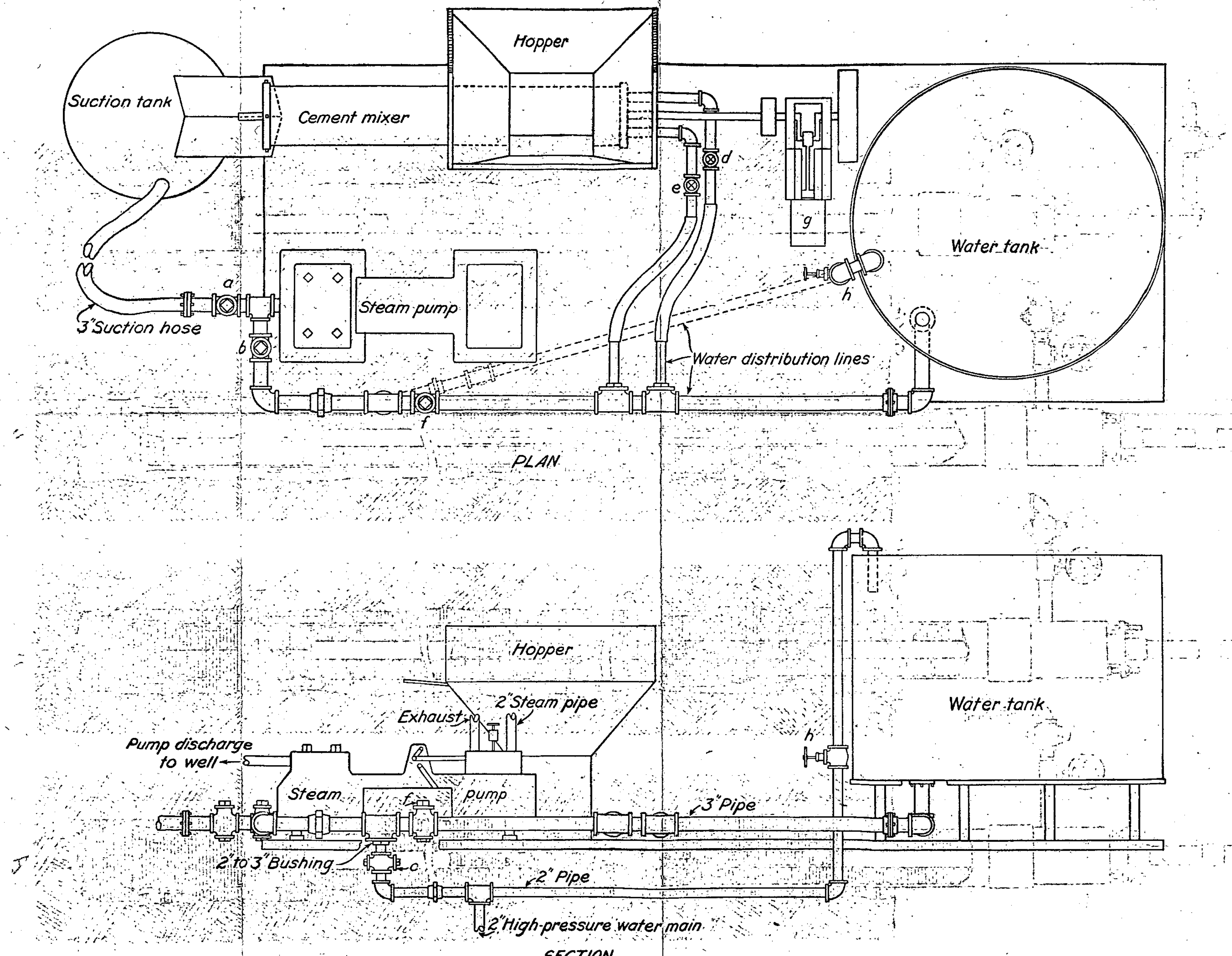
In cementing with the Scott outfit the first step, as in all other tubing methods of cementing, is to get circulation. This is done either with pumps at the well or with the cementing pumps. Sufficient water must be stored in temporary tanks at the well to mix the cement and to displace all the cement from the tubing, and more water than this, either in tanks or in a reliable pipe-line system, is desirable for reasons given later. The outfit is set up near the derrick and connected with the local steam and water supply lines. A small platform is built beside the mixing machine with a walk to the ground. This must be so arranged and the dry cement so placed that there will be no delay in feeding the mixture. As stated, this machine handles a ton of cement, or 20 sacks, every 2½ or 3 minutes; that is, a sack every 8 or 9 seconds. All wires or strings must be taken off the sacks before mixing is started. It has been found advisable to have the cement handled by four men, two working at a time and relieving each other at frequent intervals. If more than two are dumping cement at a time they will get in each other's way and retard rather than accelerate the work. When everything is in readiness, clear water is pumped into the tubing at *a*, Plate VII, until returns flow from the relief pipe *b* at the casing head. The relief cock is then closed with the pump still operating and with the casing 3 or 4 feet off bottom. This should start the circulation around the casing as shown in view *B*, Plate VII. Water is then started through the mixer by opening valves *e*, *d*, and *a*, Plate VIII, and closing stopcock *b*. The mixing engine *g* and the pump are started and the dumping of cement into the hopper is commenced. The most satisfactory consistency for the cement mixture is determined by experience. If the mixture is sufficiently thin to be readily handled by the pumps it has an excess of water. A cement should never be mixed any thinner than this unless an effort is being made to force it back into a sand, or some other such object is in view. Even the thickest mixture that can be handled by the pumps has a considerable excess of water. This method of estimating the fluidity is rough, but satisfactory. A small excess of water doubtless retards the setting of the cement, but does not weaken it to a dangerous degree.

Before actual cementing is commenced, a computation must be made so that the operator will know how many inches of water must be pumped out of the gage tank to equal the volume of the string of tubing. If the gage tank regularly mounted on the outfit has insufficient capacity for any particular job, an auxiliary tank must be set. If such an auxiliary tank is placed near enough to the pump the water may be drawn from it by merely dropping the 3-inch suction hose into it, thus reducing the amount of pipe fitting. After all the cement has been mixed and pumped into the tubing, the computed volume of water with usually a small excess, 10 per cent or less, is pumped on top of the cement (*C*, Pl. VII). This is accomplished by closing *c* and *h* (Pl. VIII) and gaging the water in the tank at the same time. In this way the water passes through the mixer and flushes it clean. When this is accomplished stops *b* and *f* are opened and *a*, *d*, and *e* are closed, thus by-passing the mixer and sending the water directly to the pump. When all the wash water is in, the casing is set firmly on the bottom of the hole. Under normal conditions this will stall the pumps. By opening the relief valve *b* (see Pl. VII and *c*, Pl. VIII) at the casing head all cement that may have remained either in the tubing or in the casing above the bottom of the tubing will be washed out by merely keeping the pump going.

After getting circulation at the beginning of the job, it is unnecessary to stop the pump or the movement of cement or circulating



DIFFERENT STAGES OF CEMENTING OIL AND GAS WELLS BY TUBING METHOD.



PLAN AND SECTION OF SCOTT CEMENTING OUTFIT.

fluids until the job is entirely completed and the casing is safely landed. If the operator does not wish to have to drill any cement out of the casing the tubing may be lowered to within a few inches or a foot of the bottom and all the remaining cement flushed out by water being pumped into the tubing. Notwithstanding the difference in the specific gravities of cement and water, it is a remarkable fact that a large slug of liquid cement with water both above and below it may be pumped down a string of 3-inch tubing, and if desired can be pumped again to the surface through the space between the tubing and the casing without excessive intermingling between the cement and the water.

It must be borne in mind that no barrier, not even a cement sack, is used between the cement and the water in this process. A striking instance of pumping cement back to the surface between the tubing and the casing occurred at one of the Pacific Midway Oil Co.'s wells in the Sunset oil field where liquid cement was pumped into a 10-inch hole, about 1,600 feet deep, through tubing. It was desirable in this particular well to pump in all the cement that the hole would take, so 18 tons (360 sacks) was mixed and pumped in. Of this amount 2 or 3 tons was washed back to the surface. When the cement came to the surface it was in such usable condition that a tank was placed to catch it. The tank full of liquid cement was hauled to a garage on the property where the cement was mixed with sand and used for laying a concrete floor in the building. This condition of the cement after being returned to the surface is the rule, not the exception.

Of course, if the tubing happened to extend only a few inches into the liquid cement at the bottom of the hole, only those few inches of cement would be washed back, and the cement might then be so diluted on reaching the surface that it would not set; but where, say, a ton or more of cement is involved, it may be washed back to the surface in fair condition. In most instances of this kind there is no useful purposes to which the return cement may be put, so it is usually wasted. Fortunately it is usually possible to estimate rather closely the requirements of the particular job.

The reader may wonder why so much discussion should be devoted to the setting of the returned cement when the chief concern is how it sets underground. One important reason is that if the cement sets after being returned to the surface, any failure to set underground can not logically be attributed to the character of the cement nor to the method of mixing and placing it. Another reason is fully discussed under "Casing System of Cementing without Plugs," on pages 50 to 53.

SPECIAL METHOD OF MIXING CEMENT.

The Shell Co. of California uses an ordinary concrete mixer fastened in the discharging position. The mixer is set to dump into a long mixing box about 2 feet square in cross section, and approximately 20 feet long (Pl. IX, *A*). A hose discharges water into the mixer continually as the cement is dumped in. Men with mortar hoes finish mixing the liquid cement as it travels from the concrete mixer at one end of the long box to the 6-inch suction at the other. From the box the cement is taken by the pumps and delivered to the well.

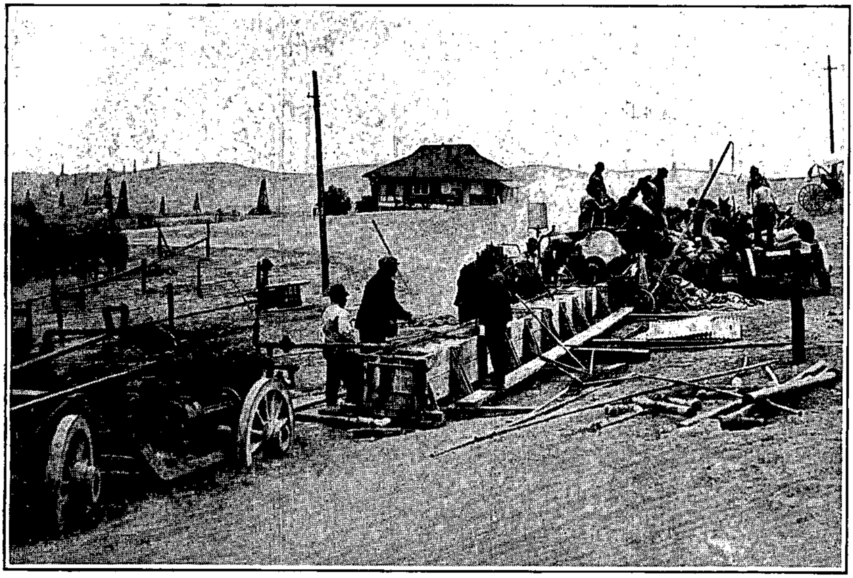
The two pumps, shown in the left foreground of Plate IX, *A*, are mounted on a low truck. One pump is for low pressure and the other for high pressure, and they are 10 by 6 by 12 inches, and 10 by 3 by 12 inches in size, respectively. The suction manifold is so connected that it will take either cement from the long box or water from a 3-inch connection into the same manifold. The discharge manifold and the steam connection to these pumps are so arranged that the operator may change from the low to the high pressure pump, or vice versa, without stopping the flow of liquid through the tubing.

Some companies have a hose connected to the pump-discharge manifold so that the cement may be picked up by the suction and circulated through the pump back into a mixing box, thus making the pump serve also as mixer. This method increases the wear and tear on the pump and necessitates mixing all the cement before putting any of it into the well.

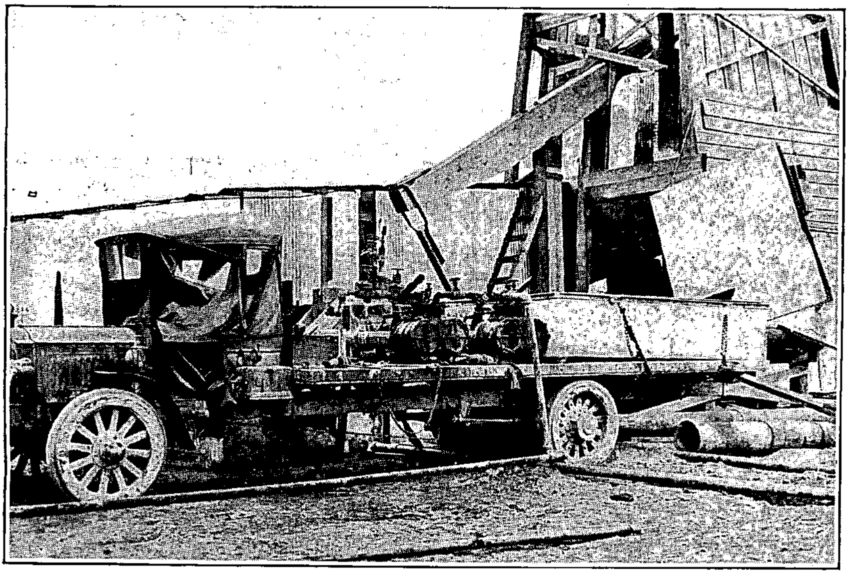
USE OF ONE-PLUG METHOD WITH TUBING.

A variation of the tubing method not extensively used at present consists in placing a swaged nipple on the bottom of the tubing and using a wooden bullet-shaped plug, having a disk of leather or rubber belting nailed to the flat end. This plug, point down, is inserted into the tubing on top of the column of cement, and is pumped down with water in the usual way. The plug will stop when it reaches the swage nipple, thus stalling the pumps and indicating the end point and affording a check on the computations. This check is the one advantage over the common method as described above. The disadvantages are as follows:

1. Cement often adheres to the sides of the tubing and subsequently settles on top of the plug, or else the plug works down into the cement leaving as much as 6 or 7 joints of the tubing filled with cement. The tubing thus filled either has to be junked or else the cement must be drilled out at considerable expense.



A. SHELL CEMENTING OUTFIT AT WORK.
Photo by C. W. McAlester, Coalinga, Cal.



B. PERKINS CEMENTING OUTFIT WITH STEAM AND WATER CONNECTIONS MADE.

2. It is impossible to wash cement out of the bottom of the tubing or casing after the latter has been set.

3. If circulation is interrupted, all cement not already back of the casing is left inside of it to be drilled out.

USE OF THE BAKER CEMENT CONTAINER.

The "Baker cement container"[a] is a device to be used under certain conditions when cementing with tubing. The container is primarily designed for use when circulation may be obtained, but when it is impossible to get a tight seat for the casing on the bottom of the hole. The condition may be caused by lost tools which have been sidetracked and subsequently fallen in against the casing, or the casing may have become "collar bound" so it may be moved 5 or 10 feet, but not enough to clear the couplings. If the cementing job be attempted under such conditions by the ordinary tubing method, or any of the other methods, an opportunity is afforded for the cement to run back into the hole from behind the casing when the job is allowed to stand.

The container is built of cast iron and is attached to the bottom of the tubing by a left-hand nipple *a*, Plate V, *D* (p. 36). This nipple connects with the lower cone-shaped part of the container *b*. When the container has been lowered to the shoe joint, or as near the bottom of the casing as may be desirable, pulling the container up a few inches or a foot is sufficient to cause the slips *c* to wedge against the inside of the casing, holding the upper section of the plug firmly in the casing. Thus the rubber *d* is spread by the cone-shaped base *f*, making a tight seal between the plug and the casing. When the cement is pumped down the tubing it will readily pass the valve *e* which is seated by a spiral spring. The cement can not, however, pass back through this valve or around the container to get above it, and must therefore pass around the casing shoe and follow the course of circulation.

When all the cement has been pumped in, the tubing is disconnected from the plug by unscrewing the left-hand nipple *a*. Any residual cement in the tubing may be pumped out and to the surface, just as in the ordinary tubing method. The container is prevented from slipping down the casing after being disconnected from the tubing only by the friction hold of the slips and the pressure of the cement on the bottom of the container. However, if the cement has not pressure enough to hold the container in place, not much is likely to run back into the hole. As the container is built of light cast iron it is easily drilled up after the cement has set.

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[a] Baker, R. C., Cement container: U. S. patent 1035674, Aug. 13, 1912.

ADVANTAGES OF TUBING METHOD.

The advantages of the tubing method may be summarized as follows:

1. The method requires less time after the initial wetting of the cement to completion of the job than any other method yet devised.

2. The operator can leave any desired quantity of cement inside the casing.

3. The storage space required for wash water is less than that required for the casing method of cementing.

4. When a standard-tool hole is to be cemented by the tubing method the volume of water unavoidably circulated around the casing ahead of the cement is only the contents of the string of tubing. This is a considerable advantage if the formation back of the pipe has a tendency to cave.

DISADVANTAGES OF TUBING METHOD.

Disadvantages of the tubing method may be enumerated as follows:

1. Time is required to run in a string of tubing. This usually has to be laid down after the job in single joints and rolled away from the rig to permit unloading of pipe for the oil string, as well as other equipment.

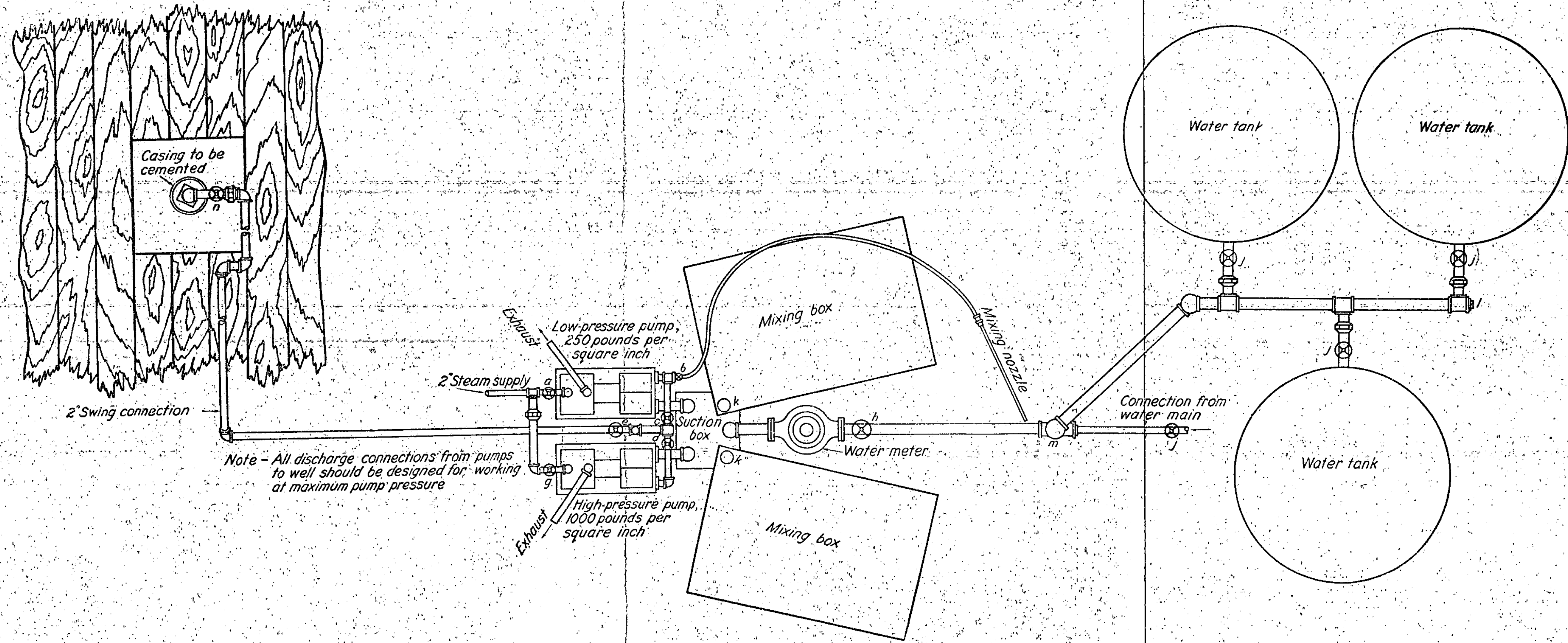
2. Although the tubing method is quicker than the casing method, after the cement is wet the aggregate time required to do the job is considerably greater on account of handling the tubing. For this reason some form of casing method is very popular among operators for mud-flush holes—particularly for holes drilled with rotary tools. This is because of a desire to reduce the delay to a minimum, especially in a rotary hole, as the wall of an uncased hole in California will not stand long. Also in a tubing job either the drill pipe must be laid in single joints as it is pulled out and the tubing must be stood up or else casing will have to be done with a string of tubing as well as a string of drill pipe standing in the derrick, impeding the work of casing the hole.

CASING METHOD OF CEMENTING.

In cementing casing by the casing method the liquid cement is pumped down inside the casing itself without the use of tubing, bailers, or other containers of any kind. There are two general methods of performing this operation, as follows:

1. A plug or barrier of suitable material and construction is used below and another above the column of cement, separating it from the other fluids in the hole during its passage down the casing.

2. No plug or barrier of any kind is used, either below or above the column of cement during its passage.



PLAN OF PERKINS CEMENTING SET-UP.

USE OF TWO PLUGS (PERKINS PROCESS).

The former method is commonly known in California as the "Perkins process,"[a] the main features of which are as follows:

1. The circulation is established downward through the casing and up outside it.

2. Plug No. 1 is inserted at the top of the casing. The fittings are then replaced and the cement pumped in on top of this plug.

3. When the desired amount of cement has been pumped into the casing the pumps are shut down and plug No. 2 is inserted on top of the cement. The fittings are again replaced. Water is then pumped in on top of plug No. 2, forcing it down the hole. Thus the slug of cement travels down inside the casing, pushing plug No. 1 and the water or drilling mud ahead of it and having a column of water behind it. (See Pl. XIII, p. 48.) The plugs not only keep the cement from intermingling with the other fluids in the hole, but play a most important part in the mechanical operation of the process. Each outfit consists of a 3-ton motor truck on which the pumps are mounted; two pumps, low and high pressure, 10 by $4\frac{1}{2}$ by 10 inches and 10 by $3\frac{1}{2}$ by 10 inches; two or more galvanized-iron boxes for mixing the cement.

MIXING AND SUCTION BOXES.

Unless more than 10 tons of cement, 200 sacks, is to be used, the two boxes regularly carried as part of the equipment will have sufficient capacity. The larger of these boxes is 10 by 6 feet by 2 feet deep inside. The smaller box is of the same depth, but 4 inches shorter in each of the other dimensions. During transportation one box may be placed inside the other. Each box has a 2-inch angle iron around the rim to stiffen and reinforce it.

Plate IX, *B* (p. 40) shows an outfit backed in beside a rig and with the steam end of the pumps connected. The mixing boxes were still chained on the rear of the truck when the photograph was taken. Each box has one-half of a 4-inch flange union riveted to the bottom as a reinforcement for the discharge opening. One of these outlets is shown in Plate IX, *B*, protruding from the bottom of the mixing box almost directly above the rear wheel of the track. These outlets must be placed one in the upper left-hand corner of the first box and the other in the upper right-hand corner of the second box as one looks into the boxes. Such an arrangement permits the boxes to be placed as shown in Plate X, one on either side of the suction box and with the discharge openings over it. These discharge openings are closed by wooden stoppers while the cement is

[a] Perkins, A. A., and Double, Edward, Method of cementing oil wells, U. S. patent 1011484, Dec. 12, 1911.

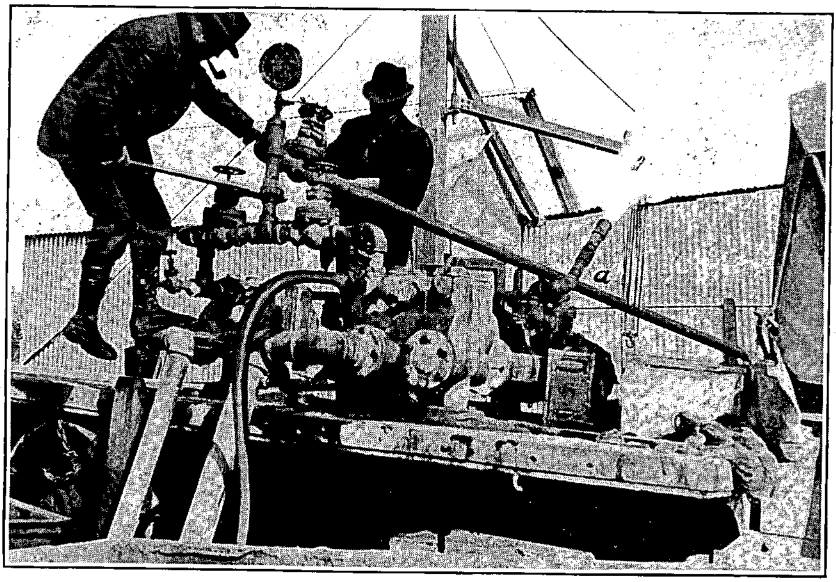
being mixed. The stoppers may be pulled out part or all the way, thus regulating the flow of cement into the suction box.

The suction box is of galvanized iron reinforced around the rim with 2-inch angle iron. The box is 2 feet deep and 2 by 3 feet at the top. The sides slope to a bottom 1 foot 10 inches by 2 feet 10 inches, thus having a batter of one-half inch to the foot. A pit is dug beside the truck for the suction box, which is set with its rim flush to the ground surface. By this arrangement the mixing boxes may rest flat on the ground and yet have their discharge openings set over the edge of the suction box, thus saving the labor and expense of elevating the mixing boxes. A 3-inch suction pipe from the high-pressure pump and a 4-inch pipe from the low-pressure pump are dropped into the suction box. (See Pl. XI, *A*.) This illustration also shows the 1-inch mixing hose in the central foreground and the corners of the mixing boxes as they are set. When the photograph was taken the cement had been mixed and the wash water was being pumped into the casing. The exhaust steam from the pump in the background may be noted.

PLUGS.

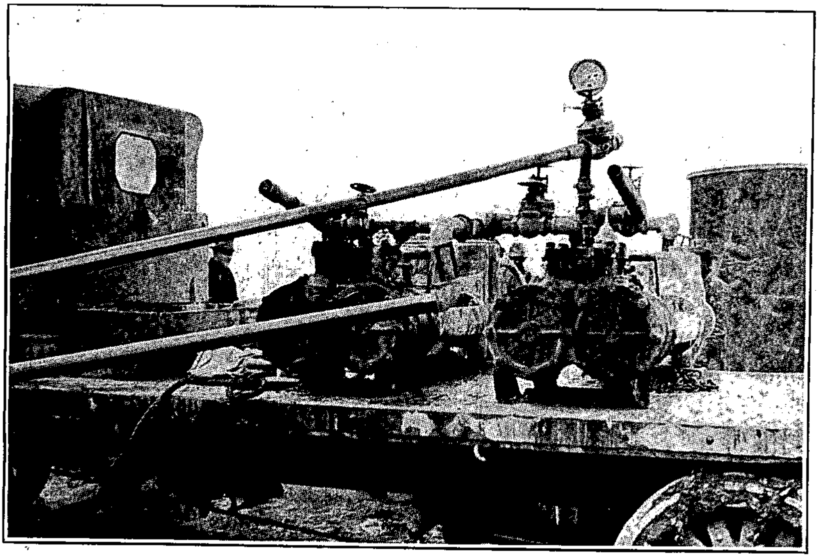
The two plugs, although differing in detail, have many points of construction in common. The bodies of both plugs, or barriers, as they are termed in the patent specifications, are commonly made of California redwood, though any good clear soft wood, such as white pine or sugar pine, would have ample strength. As these plugs must be drilled up after the cement has set, the softer the wood can be, and yet do its work, the better it is for the purpose. This requirement is kept in mind in making No. 2 plugs, which are turned down between the two ends to remove superfluous stock. The bodies are fitted with wooden stud bolts 1 inch in diameter with 4 threads per inch in the plugs for 4½-inch casing, and 1½ inches with 3 threads per inch for sizes used in 6¼-inch and larger casings. The stud bolts are in one or both ends of the plug according to its design and are held in place by transverse wooden pins, the white ends of which show plainly in the photographs reproduced as Plate XII. The flat washers or disks are made of ordinary rubber belting, such as is used for the standard rig.

Plug No. 1 is made in two designs. The first type is the tall, bottle-necked plug shown to the left of each group of plugs in Plate XII, *A*. It has a rubber washer at the top and at the bottom. The bottle neck is immediately under the upper washer, which is held in position by a single wooden disk on top of it. These plugs are 3 feet long over all. This length is approximately constant for use in all sizes of casing. This type is used for all jobs except where a "Graham" cast-iron guide (*4*, Pl. I, *A*, p. 22) or similar device is

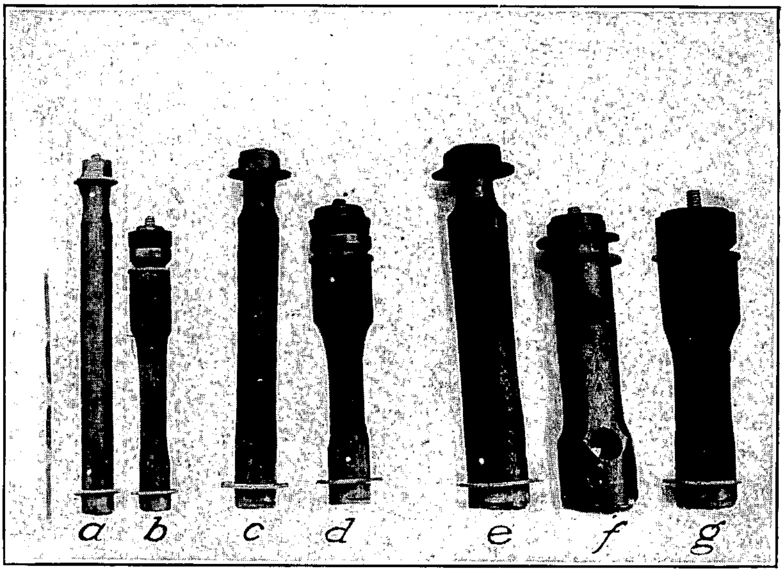


A. SUCTION AND DISCHARGE END OF PERKINS CEMENTING OUTFIT.

Note heavy (1,500-pound) fitting on end of discharge line, also 1-inch mixing hose connected into the discharge of the low-pressure pump. Two-inch line to well is shown at *a*.

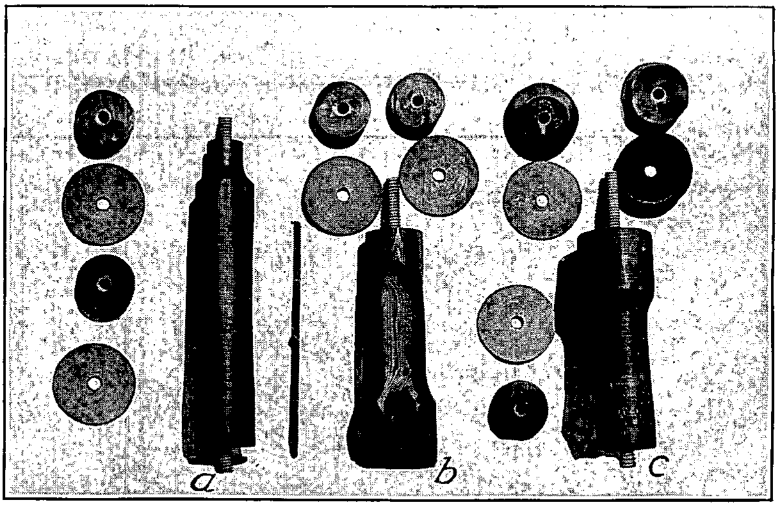


B. STEAM END OF PERKINS CEMENTING OUTFIT.



A. PERKINS CEMENTING PLUGS.

a, *b*, Plugs for use with 4½-inch, 15-pound casing; *c*, *d*, plugs for 6⅝-inch, 28-pound casing; *e*, *f*, *g*, plugs for 8¼-inch, 36-pound casing.



B. PERKINS CEMENT PLUGS DISMANTLED.

All three plugs are for use in 8¼-inch, 36-pound casing. Plug *a* is for use when no float plug is used on casing shoe (see *a* and *b* in Plate XII, *A*. Plug *b* is for use when float plug is used (see Nos. 3 and 4 in Plate I, *A*, also Plate XIII). Plug *c* is the upper or second plug and is of same design for all uses, varying only in dimensions to fit size of casing employed.

used. Such a guide, or float plug, as it is termed in the catalogue, is commonly used for setting casing in a rotary hole. Plate XIII (p. 48) shows a shoe guide on the casing represented in the different views and illustrates clearly the necessity of altering the design of the first plug for such jobs. As the wooden plug can not pass out through the shoe guide, it is necessary to provide some means for the cement to by-pass and get out around or through the plug in order to be ejected from the casing. Plates XII and XIII show one method of meeting this need. Two washers are put near together at the top of this type of plug and the base is enlarged to prevent any chance of its passing through the shoe guide. No washers are used on the lower end. In order to permit the cement to pass out of the casing after the shoe guide has arrested the plug, a 3-inch hole is bored vertically into the bottom and joins others from either side of the plug, thus forming a Y. The pressure of cement on top of the plug bends down the rubber disks, as shown in *C*, Plate XIII, allowing the cement to pass through the Y and out the bottom of the plug.

Plug No. 2 is of the same construction for all kinds of jobs, differing only in diameter, which is such as may be required to fit varying sizes of casings. The essential difference between it and the No. 1 plugs is in the leather cup placed on the top. This cup is much like the leather cups commonly used in oil-well pumps, but is of larger diameter. The object of this leather is to effectively prevent liquid from above the plug passing around it at any time during the job, and without regard as to whether the progress of the plug has been arrested or not.

For plugs to fit 6⅝-inch casing and smaller sizes, the rubber washers have a diameter one-eighth of an inch greater than the internal diameter of the corresponding size of casing. For 8¼-inch casing and sizes larger, each washer has a diameter one-fourth inch greater than that of the casing.

The various wooden disks are turned out of Oregon pine with the grain running across the disk, at right angles to the grain in the body of the plug when set up. The disks also have flattened places or wrench squares on them. Owing to their shape, these disks are more easily broken or split than the redwood body of the plug, and hence are made of harder wood. Oregon pine, which is much like the ordinary Eastern yellow pine in physical characteristics, is generally used for the disks.

WATER METER.

The water meter is provided to measure the volume of wash water as it is pumped in on top of the second plug. Water should pass the meter at sufficient rate to complete the cementing job in an hour. Of course, many successful jobs take a greater length of time than this, but one hour seems about the maximum limit for desirable conditions. As the pumps are usually slowed down toward the end of the job, owing to the increased pressure, the meter should have a capacity of approximately 50 per cent over the average rate of supply for the entire job in order to pass a large volume of water during the earlier stages of operation.

Unless a most reliable water supply in adequate quantities is at hand, local storage must be provided, not only equal to the volume of the casing that is to be cemented, but a little in excess of this volume. It usually happens that such local storage has only a small static head above the meter and suction box. Under these conditions a small duplex pump about 4½ by 3 by 4 inches, set up to force the water to the meter, will overcome the difficulty and accelerate the entire job.

MIXING HOSE AND NOZZLE.

The hose is a 1-inch high-pressure line connected to a fitting on the low-pressure discharges (see Pl. X, p. 42, and Pl. XI, *A*, p. 43). This pump will deliver at about 400 pounds pressure per square inch, which is far more than is required for mixing purposes. The nozzle consists of a piece of ½-inch pipe, 3 or 4 feet long and securely clamped into the end of the hose.

OPERATION OF TWO-PLUG PROCESS.

All water reaching the cementing outfit must run through the meter and be handled by the pumps. (See Pl. X, p. 42.) Circulation should be established either with the mud pumps at the well or with the pumps of the cementing outfit. After the fluid or water is circulating, the casing should be set on bottom a few times to see whether the pumps will be stalled by so doing. If they are, no cement is apt to run back into the casing after it is permanently landed. As a number of hours or even days may be consumed in getting good circulation, the cement must be protected from moisture and should not be dumped until everything is in readiness for it. It should then be divided between the mixing boxes and piled in the ends opposite the discharge openings. By running water into the suction box through the meter it may be pumped through the 1-inch hose and the mixing nozzle under a strong pressure. While this is being done the valves *c* and *d* (Pl. X, p. 42) of the discharge line into the well should be closed. By playing this powerful jet back and forth across the pile so as to slice it in thin layers, the cement is mixed more easily and more thoroughly than with hoes alone. In addition to the mixing nozzle there should be 4 to 6 men with hoes at each mixing box.

While the cement is being mixed, part of the crew is engaged in removing the steel bushing from the top of the casing and inserting plug No. 1. In reference to the water-supply connections at *m* (Pl. X) it is important that the high-pressure line have a straight connection into the low-pressure line from the storage tanks to the meter. Numerous set-ups have been observed in which this feature was overlooked and the high-pressure line connected at 90° into the low-pressure manifold. The result of such a connection frequently is that the high-pressure stream divides on entering the manifold, part going to the meter and part backing up into storage tanks, thus making it impossible to use water from the high-pressure line and the storage tanks simultaneously.

There is a top and bottom to each plug, and if either is put in wrong end up serious difficulty is likely to follow. After the first plug has been inserted and the casing connections replaced, everything is in readiness to receive the cement.

The pump man, after opening valves *e* and *c* (Pl. X) starts the low-pressure pump while one of the mixing gang pulls the stopper from the cement-box outlet at *k*, and lets the liquid cement run into the suction box as fast as the pump removes it. The mixing boxes are emptied in this way one after the other. Throughout this operation the stopcock under the pressure gage connection should be kept closed to prevent the gage from becoming fouled with cement. When the cement has all been pumped into the well, the pumps are run a few strokes on water to clear them and the discharge line of cement, and are then shut down. The fittings are removed from the casing for the insertion of plug No. 2. While this is being accomplished the meter must be carefully read and the reading recorded. When the connections are again made at the well, the pumps are started, water being run through the meter to the suction box (Pl. X). It is well to measure the volume of the liquid cement in the boxes before pumping it into the well. A ton of cement when mixed and wet occupies about 23 to 30 cubic feet. By computing the volume of the casing (see Table 1, p. 20), it is impossible to predict with a fair degree of accuracy the meter readings at which the first and second plugs, respectively, should strike bottom. Of course, if everything goes all right the pumps will stall when the second plug reaches the first (see *D*, Pl. XIII), and there would be no need of the meter were it not for the absolute necessity in some jobs of knowing in advance when the first plug is due to reach the bottom of the casing.

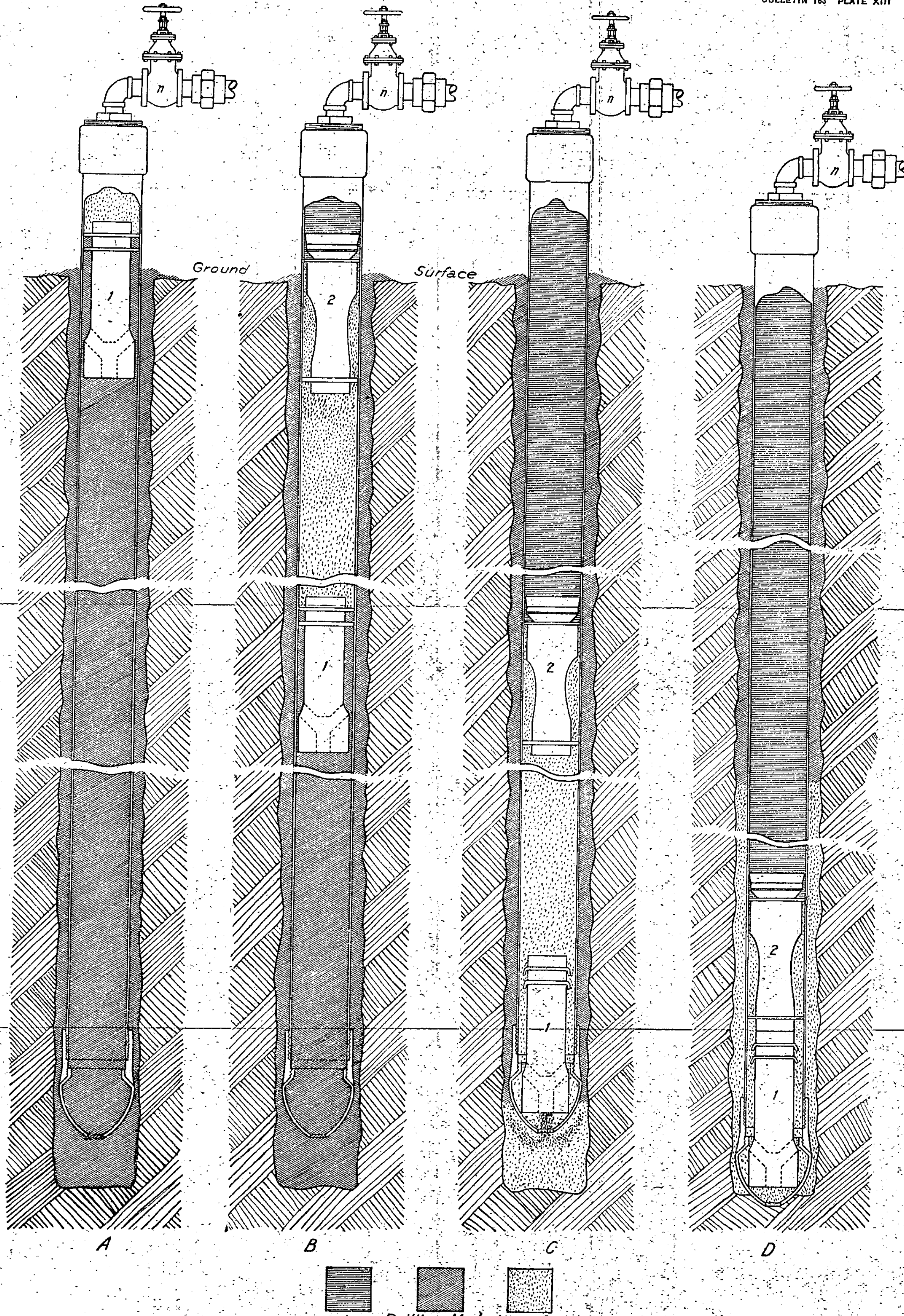
Unfortunately this system has one point in common with every other oil-well device yet devised in that it will sometimes not work out as expected. When trouble occurs it is usually due to a cave-in shutting off the circulation, or a split joint in the casing allowing the cement to pass out the side of the pipe, or to some such cause, for which the cementing process is not to blame.

Normally the weight of the cement as it descends in the casing is sufficient to cause a pressure less than atmospheric on the discharge connections from the pumps. The immediate result of this reduced pressure is a speeding up of the pumps, the action being really that of a siphon. This siphoning effect gradually diminishes until the first plug has reached the shoe guide (*C*, Pl. XIII), or the bottom of the hole, or until the various liquids inside and outside of the casing have established equilibrium. After equilibrium has been attained the pressure will begin to build up to perhaps 200 to 250 pounds per square inch by the time the second plug has encountered the first (see *D*, Pl. XIII). When this occurs, there is usually a perceptible jump to 300 or 400 pounds per square inch. The valve *n* (Pls. X and XIII) is closed and the casing is set on the bottom. In every job observed the entire computed amount of water was used, and usually an excess of 10 to 30 cubic feet was needed. This excess represents 0.75 to 3 per cent of the total wash water used.

So much for a well with which everything goes according to schedule. Sometimes an operator is forced to take a chance on trying to cement a well when conditions are not favorable. Suppose that everything has started all right and the pumps have been forcing the cement down the hole for one-half hour and the pressure builds up and reaches 300 or 400 pounds. The question immediately arises, Are the plugs down, or has the hole caved sufficiently to retard circulation? The meter, of course, gives the answer. If the computed volume of water has been run through the meter, it is time to set the casing; if not, the high-pressure pump must be used.

As it is impossible to foretell whether the high-pressure pump will be needed, all fittings on the discharge line must be designed to withstand the high pressure. In this connection 250-pound fittings are not to be considered high-pressure fittings, merely because they will probably withstand a pressure of 800 or 900 pounds before bursting. Only fittings rated by the manufacturer to work at as high a pressure as the maximum delivery of the high-pressure pump should be used. An operator who does not provide fittings of such a character is guilty of criminal negligence, and the mere fact that he may have used low-pressure fittings a thousand times before is no mitigation for job 1001, on which a fitting blows up and kills some one. This paragraph applies to other phases of the oil business as well as to cementing.

Ordinarily from the computations one can tell about when the first plug should reach its destination and can be watching the pump carefully at this stage. A slight momentary tendency to slow down can usually be noticed, followed by a couple of quick strokes of the pump. Resting one's hand on the pump will usually facilitate in detecting such a vibration. Although it is not absolutely necessary



CROSS SECTION SHOWING DIFFERENT STAGES OF THE "PERKINS PROCESS" FOR CEMENTING OIL AND GAS WELLS.

to know when the first plug reaches bottom, the knowledge is a check on the general progress of the work, and is well worth observing.

The casing may be moved up and down as much and as often as the driller deems advisable while the cement is descending. When the first plug is within 100 or 150 cubic feet from the shoe, as shown by the meter, the driller should lower the casing until the shoe is only a foot or 18 inches off bottom. This will not hinder circulation, but will prevent the first plug from going entirely out of the casing, thus leaving it as a firm stop on which the second plug may land. This procedure should be followed even when a shoe guide is used, such as is shown in Plate XIII, as such a guide may be broken or pulled off the casing and should not be trusted alone to stop the plugs.

As soon as the second plug has stopped, the valve *n* (Pl. XIII) is closed and the casing lowered to bottom, as described. Ordinarily, this valve should be left closed for at least 24 hours after the casing has been set in order to leave a column of water on top of the plugs to prevent the cement from running back into the casing if the shoe has not made a water-tight seat on the formation. It is hardly necessary to say concerning this cementing process, as is true with others, if there is an accident which causes the cement to lodge in the casing the cement should be cleaned out immediately before it has a chance to set.

In this process there is usually some difference in the action of the pumps when the well has been drilled with ordinary standard tools and when it is in a rotary or mud-flush hole. In a hole filled with mud fluid the fluid is forced out of the casing by the water on top of the plugs, and there comes a time when the weight of the column of mud, cement, and water inside the casing is less than that of the mud fluid outside of the casing. From then on to the completion of the job the pumps must compensate for this difference of pressure, which increases steadily until the second plug reaches the first; in other words, the pumps must compensate for the difference in specific gravity of the cement and the mud as compared with that of the water. For this reason in a hole filled with mud fluid the pressure will frequently commence to build up before the first plug reaches bottom. However, the increase is more rapid after the plug has reached bottom, for the cement as well as the mud is being raised back of the casing.

Suppose that the pumps do not steadily build up the pressure and the meter shows, say, 75 per cent of the water already in. Whenever this happens it is advisable to get a handful of the returns and see if they have any odor of fresh cement about them. One can often detect the odor of cement in the muddy returns long before he can see the cement. Sometimes a hole in the casing or a split joint will allow the cement to pass into the returns without going around the shoe. Every now and then, say two or three times while the cement is being pumped down, the driller can lower the casing to bottom. If this procedure did not shut off circulation when first tried it will not do so at a later stage of operations, but, on the other hand, if it did shut off circulation before the job was started and will not do so later, the chances are that the casing has parted, probably well down in the hole; otherwise the driller would have noticed the jump when parting occurred. It is entirely possible in a shallow hole with a large quantity of cement that the latter may circulate clear to the surface in a normal and successful job. Ordinarily such excess of cement will not be used in a shallow hole. If the foreman in charge becomes convinced that something has gone wrong and that the best policy is to pull the casing, mud fluid, where available, should be started in immediately on top of the water. The fluid will tend to keep the walls of the hole from caving if the well is in a loose formation, and also will assist in flushing the cement out of the hole so that it will not set and have to be drilled out.

In any of the pumping methods it is customary to connect the discharge line from the pumps to the casing by a long swing or other flexible connection, thus making it possible to raise and lower the casing as the job progresses.

CASING METHOD WITHOUT PLUGS OR BARRIERS.

In the foregoing pages three excellent cementing outfits for mixing and pumping cement into wells have been described. As any one of these can be used equally well on any pumping job, the only remaining step to consider is what happens after the cement leaves the pumps.

If the Scott outfit were used without tubing, or the Perkins without plugs, one would have the casing method without barriers. In other words, the liquid cement may be, and, in fact, sometimes is, pumped into the casing on top of the liquid in the hole—mud fluid or water—and is forced down the hole either by mud fluid or water above it. This procedure is like increasing the diameter of the tubing used in a tubing job till it becomes too large to go inside the casing so that the casing itself must be used instead. The wash water may be either gaged in tanks or run through a meter.

Two important questions arise in regard to this method, as follows:

1. Will there not come a time as the diameter of the tubing is increased when the cement, being heavier than the mud fluid or the water, will work down into the lighter fluid below and become so diluted that it will not set?

2. How will an operator determine the end point and know when to land his casing?

To answer the first question it is well to define limits and to consider casings between the sizes of 3 inches and 10 inches. Strings of 12½-inch casing are sometimes cemented for certain drilling advantages gained thereby, but rarely is a string of casing larger than 10 inches in diameter cemented by a pumping method. It is fair to assume that if the cement does not mingle with the other fluid in the hole under conditions favorable to intermingling it will not do so under less favorable conditions.

Citation may be made of two wells having unfavorable conditions under which the cement set. In both these wells the peculiar conditions of the job made it impossible to foretell how much cement would be required; hence a considerable excess had to be provided to insure a sufficient supply. Both illustrations are from the wide experience of Mr. F. W. Scott, of Taft, Cal., who was in personal charge of the work. One well belonged to the Pacific Midway Oil Co., near Maricopa, Cal. (See p. 39.)

The other instance involved a bottom-hole job in which it was important that the cement should fill 35 feet in the bottom of the hole, but no more. The hole was 4,135 feet deep in the east side of the Coalinga field. Forty-two sacks of cement were mixed, 40 pounds of water to 100 pounds of cement, and pumped to the bottom through 2-inch tubing. When the cement was all in, the tubing was pulled up 35 feet off bottom and the pumps started forcing water down the tubing until the cement above this point was all washed back to the surface between the 2-inch tubing and the 6-inch casing. Mr. Scott was kind enough to catch a sample of the return cement in a quart preserve jar and express it to the writer after the cement had set. Ten days after the sample had been caught, the writer broke the glass jar away from the cement and found it set hard. There had been no shrinking of the cement cake way from the wall of the jar, as was demonstrated by the highly glazed surface of the cake, and by the impress of the label pressed in the glass. When the jar was first opened the top of the cement was sufficiently soft to be easily scraped with a knife, but the lower part was hard. Though this slug of cement gave the appearance of having suffered considerable dilution when in the liquid condition it had set hard enough for ordinary well purposes.

The whole force of these instances in connection with cementing casing without the use of plugs or barriers is that they represent conditions where the cement was far more subject to dilution than in ordinary cementing of casing without plugs. When cement is pumped down tubing and forced back to the surface between the tubing and the casing against the force of gravity with all the drag of friction against casing and tubing, augmented by the riffle action of the couplings on the tubing, the agitation is considerable. The conclusion seems justified that when cement is pumped down inside casing 10-inches in diameter or smaller, without the use of plugs or barriers, the cement mixture and the other fluids in the hole tend to intermingle, though as a rule this intermingling is not serious, particularly when the cement has originally been mixed with only a small proportion of water.

The second question as to how to determine the time to land the casing brings out a serious weakness in the method. As either a meter or a gage tank may be used, the relative accuracy of gaging or metering the wash water is not the question at issue. Considering that such gaging is usually done in 50-barrel or 100-barrel tanks that have been dumped off the trucks numerous times, and had their sides dented, to be afterwards driven out to restore more or less the original shape of the tank, the writer thinks the relative accuracy of the two systems is about the same. The meter is more easily read than the low gage wet-line mark on a notched stick, particularly if the cementing is done at night. The use of the meter also reduces the chances of error by eliminating one set of computations. All things considered, assuming no errors in computations, the general average of 10 cubic feet of allowable variation between the volume of measured water and the actual capacity is a 2,500-foot hole of 10-inch casing is a close limit. This is an allowable error of about 0.7 per cent, and is here applied alike to both methods of measurement. Ten cubic feet in 10-inch casing occupies about 18 linear feet; that is, an operator's computations should allow for leaving at least 18 feet of cement in the casing to obviate the possibility of washing the cement away from the shoe. He may find either no cement or about 36 feet of it in the casing, according to whether the allowable error has been plus or minus. Many operators do not object to this feature and sometimes require that 10 to 20 feet of cement be left in the hole.

There are two causes for such a requirement—first, the fear that too much water will pump the cement not only to the bottom but up outside the casing and away from the shoe joint to a point where it is not needed. An excess of water will undoubtedly produce such a result. The second cause is the claim that the latter part of a batch of cement is "mushy" and had better be cleaned out of the hole later than to be put behind the casing and not do its work. This contention is supported by the results at numerous wells, where the cement left inside the casing had a few feet (at some wells 20 feet) of mushy, chalky deposit on top, the underlying cement being set hard. So firmly is this conviction held by some operators that even when using the two-plug method they drop a timber 4 by 4 inches by 20 feet long into the casing between the plugs, which will stop the second plug 20 feet above the first, thus leaving this amount of cement in the bottom of the casing. This practice does not refer to instances where a timber, say 10 feet long, is used to obviate the danger of both plugs escaping from the casing.

It seems probable that the "mushy" cement constitutes that which has adhered to the inside of the casing and gradually settled to bottom much diluted, or is composed of good cement left inside the casing and prevented from setting by mechanical agitation, such as the working of gas or some other cause.

On the other hand, there is a serious disadvantage to drilling hard cement out of a water string. Any pounding or grinding inside the casing has a tendency to crack and loosen the cement mass formed around the exterior of the pipe. If some form of casing method is to be used, the writer would prefer the two-plug system without the use of a timber between the plugs, unless, owing to certain peculiar conditions of the hole, such a timber should be necessary to prevent the second plug as well as the first from escaping.

ROTATION OF CASING DURING CEMENTING.

Some operators have devoted considerable attention to the possibility of cement channeling around the casing instead of forming a solid sleeve between the casing and the wall of the hole. The results of such an occurrence and the means for preventing it by underreaming when cable tools are in use are discussed in subsequent pages. Underreaming is not applicable to water strings set in a rotary-drilled hole.

Some three or four years ago an effort was made by the Standard Oil Co., operating in the Kern River field, to overcome the channeling difficulty and to insure a more uniform distribution of cement around the casing by rotating the casing while cementing was in progress. The rotation was accomplished by the use of tongs. The practice was discontinued.

Recently, in the spring of 1917, Mr. Richard Sperry, of the General Petroleum Corporation, developed a system for rotating water strings while cementing, and he has used it extensively on the Belridge property of the company. Water strings on this property are cemented at approximately 600 feet below the surface in rotary holes. After the hole has been drilled to the required depth, the casing is inserted and circulation is obtained with the pumps in the usual manner. The casing is set on a spider which rests on the rotary table, as shown in Plate XIV, *A*. The spider is prevented from slipping by steel pins set in the sockets in the top of the rotary table designed to take the adjusting screw posts of the grip rings.

The casing is handled with the swivel. The table is rotated continuously at about 16 revolutions per minute while the cement is being pumped down. As the "Perkins process" is used, some quick and convenient method must be provided for the insertion of the plugs into the casing. The heavy steel flanges at *a* (Pl. XIV, *A*) are for this purpose. These flanges are held together by eight wing bolts attached to the lower flange.

On the face of the upper flange is a concentric groove to take hydraulic packing which seats on the bottom flange and prevents leakage. Mechanically this system as a rule operates with entire satisfaction, though an occasional crooked hole may preclude the possibility of rotating the casing. Just to what degree the procedure will increase the percentage of successful jobs is as yet unknown, as few holes cemented in this way have been tested to date.

All threaded connections between the rotary table and the swivel should be left-hand in order to prevent their backing off. Although the proper number and size of the bolts in the flange depends on the weight of the casing, the friction of the formation, and other such considerations, it must be kept in mind that such a fitting is not designed for pulling a loggy string of pipe. When such work is to be done, elevators of a suitable kind must be used.

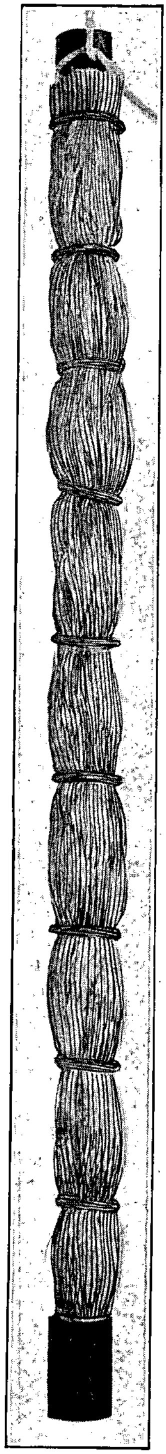
QUANTITIES OF CEMENT USED.

To attempt an estimate of the amount of cement required, even in a general way, is much like trying to estimate the number of bricks in an ordinary house without knowing the thickness of the walls, or the length, breadth, or height of the house. There are obviously many variable factors, such as the volume of the annular space between the casing and the wall of the hole, assuming that the latter is a true cylinder concentrically surrounding the casing; or any caving that may have taken place during drilling, as well as fissures, crevices, or pervious strata into which the liquid cement may percolate; also, in some wells it may be desirable to force the cement a long way up behind the casing, whereas in others it may not.

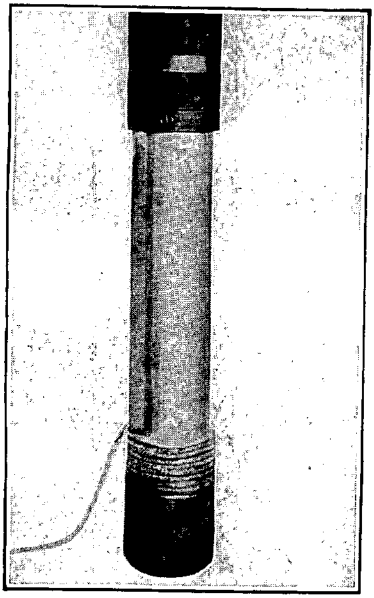
It will thus be seen that the man in charge of the particular operation must depend chiefly on his own judgment, estimates, and computations. Nevertheless, the figures following are offered in order to give persons unfamiliar with California practice a quantitative idea of the character of cementing operations there, but the figures should be construed merely as approximate.

Each hole is assumed to be in good condition, with no large caves or other unusual conditions. The figures are prepared to cover cementing of the casing at least 1,500 feet below the surface. For shallower jobs, less cement than the quantities given is used.

A. METHOD OF ROTATING CASING WHILE CEMENTING WITH PERKINS OUTFIT.



C. STONE PACKER.



B. CRUMPTON PACKER.

Approximate quantity of cement used per job in cementing water strings with any one of the pumping methods, according to California practice.

Size of casing.	Quantity of cement used, tons.
10-inch	6 to 12
8½-inch	4 to 8
6¼-inch	3 to 7
4¼-inch	2 to 4

PROPER CONDITION OF HOLE AND OF CEMENT MIXTURE.

Numerous general conditions affecting the various cementing processes have been left for consideration as a whole rather than under each method.

The ultimate shape of the cement mass when set and its distribution, radially as well as vertically, have much to do with its effectiveness. It is well known that a string of casing will not hang concentrically within the hole, that neither casing nor hole will be absolutely straight, and that at many points the casing will be in contact with the wall of the hole. It is impractical to drill a hole enough larger than the casing to prevent conditions such as described. When the cement is forced up the hole outside the casing there will be no cement at such points of contact, and there will be a deposit on the opposite side of the casing (see *B*, fig. 4) ranging from 3 or 4 inches up to several feet thick in caving formations. A local projection of the wall in contact with the casing here or there will probably not jeopardize the result of the cementing job. If, however, the contact points are so numerous that they constitute a line of contact connecting a water sand above with the bottom of the casing, thus permitting the water to flow into the oil or gas bearing strata along this line, as indicated by the arrows in *B*, fig. 4, the cementing job has failed. When this condition arises the cement is said to have channeled around the casing.

The casing is not protected at the contact points from corrosive water, and, although it would be highly desirable to protect completely the entire string of casing against contact with ground water, such protection is mechanically impossible with cement alone.

A, figure 4, in the writer's opinion represents a typical well-performed cementing job in a mud-fluid hole. The cement has been forced up around the irregular projections of the sides of the hole, filling the large crevices, and trapping mud here and there in the smaller crevices. It seems unlikely that the cement would wash all the mud out of these small spaces. On this feature hinges a much-argued question as to the advisability of a thick mixture, 40 pounds of water to 100 pounds of cement, or a thin mixture, 60 pounds of water to 100 pounds of cement. The writer's advice is to use the

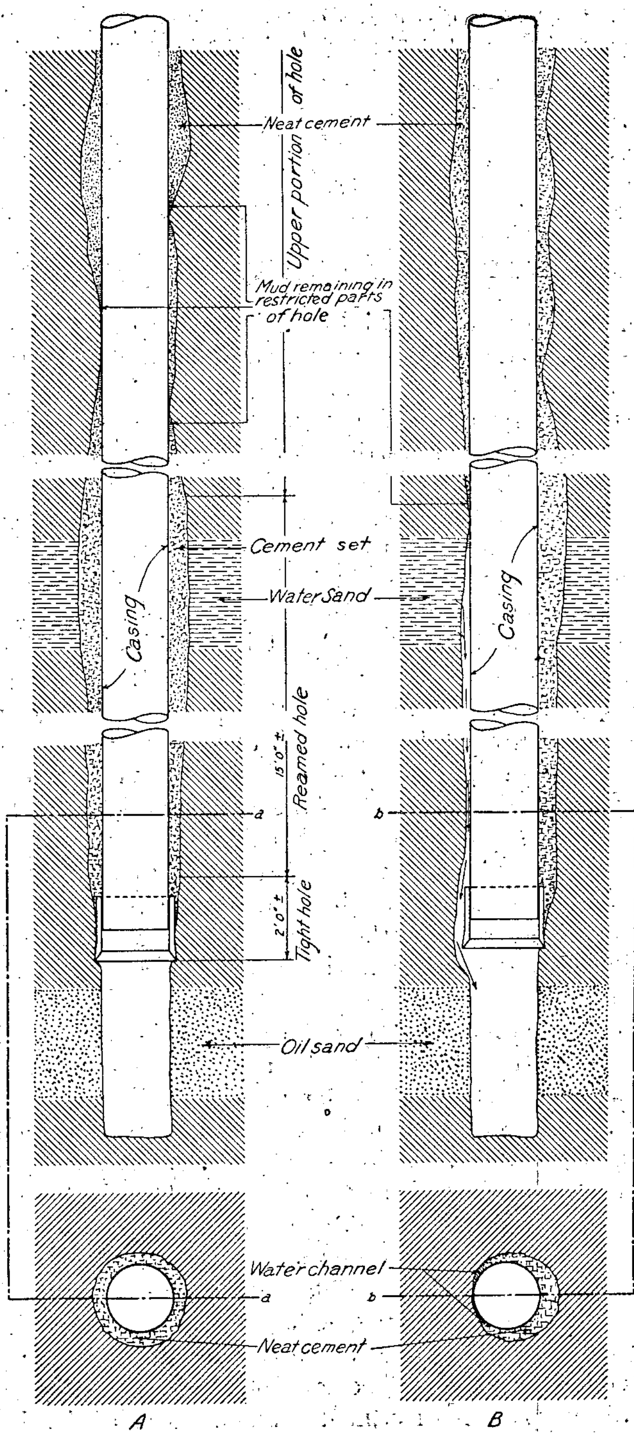


FIGURE 4.—Cross section of cement filling around casing in a well. *A*, Where the hold has been underreamed; *B*, where there has been no underreaming.

thick mixture, and if the physical conditions of the hole make it unwise to thin the mud, or, for other reasons, washing of the hole is deemed advisable, 5 to 15 barrels of water may be run ahead of the cement in either tubing or casing methods. This advice is based on the well-known fact that Portland cement when mixed thin will grade out on settling, leaving a fairly compact cake at the bottom of the column after long standing, and grading to a mushy chalk at the top. Intimate contact of cement particles is essential to a firm bond and proper setting in the cement mass. When cement is mixed with an excess of water the finer particles settle more slowly than the coarser ones, thus producing the grading tendency and attendant weakening of the mass. The greater the excess of water the more pronounced are these effects. Cement manufacturers have worked faithfully and with considerable success to develop a cement that will show this grading action as little as possible, but have not been able entirely to overcome it even in the best cements on the market. Some of the ordinary cements made for building purposes will not set at all if mixed with 60 per cent or more of water by weight.

It may be worth while for anyone cementing wells to take a thin batch of cement and let it set under water in a quart preserve jar or a tall bottle. After 10 days, when the container is broken off and the cement is tapped with a nail or point of a lead pencil, the variation in hardness from bottom to top will be evident. Moreover, any cement when mixed with a great excess of water has its ultimate strength greatly reduced, and the time required for it to set is also greatly increased, a most important factor in cement used in oil or gas wells. Moreover, when cement is mixed with more water than is needed to satisfy the chemical requirements, the water will work to the top, or, differently expressed, the cement will settle through the water to the bottom of the containing vessel, whether it is a jar, a concrete form, or an oil well. Hence, as regards a thin mixture in a well, the cement will tend to settle to the bottom of cavities and crevices, leaving the water to fill the upper parts, thus defeating one of the chief objects of cementing. Although it is difficult to eliminate this caving tendency, it can be reduced to a minimum by filling all irregularities of the hole as completely as possible with a permanent material. Any cement mixture that is fluid enough to pump will contain an excess of water, and the settling action described will take place to a greater extent as the excess of water is increased. Hence this condition should not be augmented by adding an unnecessary excess of water. It seems probable that there will be no cement in some small spaces surrounding points where the casing is in contact with the wall of the hole. These spaces will doubtless be small, judging from the sharp impression made by a mold on cement mixed as here advised, and taking into consideration that in a well the cement is under the pressure of a column of water or mud that in some wells amounts to a thousand pounds per square inch. These minute spaces will naturally be filled either by the mud fluid or by water, according to which material happened to occupy the hole when the cementing job commenced. *A*, figure 4 (p. 56), illustrates this condition in an irregularly shaped hole, with cement filling the larger spaces and mud the smaller crevices.

Although it is practically, if not physically, impossible to prevent contact at some points between a string of casing and the wall of the hole, it is practicable when using cable or pole tools to prevent such contact from occurring within 10 or perhaps 20 feet of the bottom of the water string by enlarging the lower part of the hole by underreaming. Such enlargement of the hole must not extend too far vertically. In the writer's judgment 15 feet vertically is a good average for underreaming, but the larger the diameter of the reamed part of the hole, the better. If a casing shoe is used, as is universal in California practice, it is advisable to leave a couple of feet of tight hole at the bottom of the well. (See *A*, fig. 4.) If the hole is reamed for any great distance, say 40 to 60 feet, the casing will probably come into contact again with the wall near the bottom and defeat the entire object of the reaming. On the other hand, if only the lower 10 or 20 feet of hole is enlarged, the constricted part above will center the casing and hold it entirely clear of the walls below.

The advantages gained by the use of cement may be summarized as follows:

1. All large spaces are filled with a firm, impervious material which will tend to prevent sagging or bending of the pipe, and, by filling the cavities before nature gets a chance to do it, will retard caving of the walls of the hole.

2. The cement will prevent the escape of the mud fluid from behind the casing.

3. Cement has been known to form a water-tight barrier between oil and water sands cased off behind the same string of pipe, thus preventing intermingling of the oil and the water.

PREPARING A WELL FOR CEMENTING.

There has been considerable controversy on the advisability of washing a hole free from mud, or as nearly free as possible, before the cement mixture is pumped in. When cement was first coming into general use for oil and gas well purposes, oil men considered it absolutely essential to thoroughly wash the hole with water prior to cementing. Experience gained with the use of mud flush in the rotary and circulatory systems of drilling has occasioned a revision of opinion. Instead of being a detriment, mud fluid is now rather generally considered a benefit to cementing operations.

Before further discussion, it is well to define the term "mud fluid." Such a fluid may vary from clear water with a specific gravity of 1 as the lower limit to a pasty mass of mud with a specific gravity of about 1.45 as the upper limit for California muds. Mixtures of mud fluid used in drilling in different California fields range in specific gravity from 1.05 to 1.15, that is, they are 5 to 15 per cent heavier than water.[a] The term "mud fluid" is erroneously applied at times to a mixture of mud containing fragments of shale and sand. Such cuttings may thicken the mud fluid but should not be considered as a part of it, as they will settle in a hole and bridge above the couplings of a string of casing and cause it to "freeze" or to become "collar bound." If this mixture be run through a flume or settling tanks to remove the cuttings the remaining fluid will not settle except to a limited extent, after which the settling action practically ceases, provided the air is excluded. J. O. Lewis, petroleum technologist of the Bureau of Mines, conducted some interesting experiments on the settling of mud fluid and has in the bureau's San Francisco laboratory samples of mud fluid taken from drilling wells. They are in long glass tubes. Some of these have stood in the tightly closed tubes for two years. If a slender glass rod be inserted in any of these tubes it will settle immediately by its own weight to the bottom of the tube; in other words, in two years' time there has been no appreciable tendency for the mud to harden or cake. In its present condition, after standing two years, this mud could be handled by pumps almost as easily as when obtained from the drilling well, and is a good illustration of what is meant by the term "mud fluid."

Besides having the mud free from drill cuttings it must be thin enough to be lifted on the rising column of cement. If the mud is allowed to thicken it will become so plastic that it will hang tightly in the more restricted parts of the hole and allow the cement to break through at one or two points and thus channel. The mere fact that there is a considerable difference between the specific gravity of heavy mud and that of even a thin cement mixture does not mean that the cement will lift the column of mud ahead of it, as the factor of viscosity, or, as regards thick muds, one might say plasticity, is important. To illustrate, a mixture of mud[b] so thick that it would

[a] Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, p. 14.

[b] The clay used was from rotary-drilled holes in the Sunset Midway field, California.

not drop out of an inverted beaker had a specific gravity of 1.41, as compared with water, yet a cement mixture with 60 per cent of water by weight would have a specific gravity of 2.2. If cementing with such mud and cement mixtures were possible, it is unlikely that the cement would lift such a column of thick mud without channeling through it.

Wherever mud flush is being used, care should be taken to have all the fluid in the hole free from cuttings before cementing operations are commenced. After the hole has been drilled, circulation should be maintained, and, if necessary, the mud should be thinned until all cuttings have settled out in the flume. This precaution may cause a delay of an hour or two, but will usually save several hours before a job is finished.

In setting casing into a rotary hole, where this precaution has not been taken, it frequently happens that when the casing is still several hundred feet off bottom the fluid in the hole is so thick with cuttings that the pumps delivering at 400 pounds per square inch fail to start circulation. Not infrequently under such conditions the casing is pulled up 40 to 60 feet into the derrick with the pumps operating to keep it full of mud. The fittings at the top of the casing are then closed and the casing is lowered as rapidly as possible into the hole. This method will doubtless set up, within the pipe, pressure far greater than the capacity of the pumps and will often start circulation around the shoe, or sometimes through the side of the casing by splitting a joint of the pipe with the consequent trouble and loss.

The internal pressure thus set up is most difficult to compute, as the condition of the hole, the thickness of the mud, and many other factors unknown and variable enter into the problem. For example, if the hole is crooked much of the weight of the casing may be carried by friction. The velocity with which the pipe is lowered also plays an important part in the pressure built up.

It was impossible to obtain experimental data as to the amount of pressure so developed, for the reason that as soon as the danger was realized by the operating and contracting companies, they issued orders that when circulation could not be started with the pumps, the casing must be pulled out of the hole until the pumps could start the mud, when the casing was to be worked to bottom with pumps maintaining circulation all the way.

EFFECT OF AGITATION ON CEMENT IN A WELL, AND PRECAUTIONARY MEASURES.

Putting cement into a hole in which there will be any considerable agitation by movement of water or gas is useless. Such agitation will either prevent the cement from setting at all, or will cause it to set in such a loose condition that cementing will be far less effective than a good landing job, with a column of mud back of the casing and with no cement at all. By proper use of mud-laden fluid such conditions have been overcome at many wells.

In shutting off top water two methods are used for quieting gas—the use of mud fluid and the use of hydraulic lime. Local, geological, and mechanical conditions vary so greatly that it is difficult to generalize in regard to the best method of procedure. If the casing is set in an open hole there is no way to make a satisfactory seal between it and the wall of the hole; thus any water or gas encountered is free to heave all the mud out of the hole from behind the casing if there is sufficient pressure in the sand. If the agitation is not violent, it can often be quieted by circulating thick mud fluid into the casing and up outside it. If trouble from gas or water can be foreseen from previous drilling, it is advisable to set and, perhaps, cement a larger string of casing above the troublesome sands. When they are reached with the water string the space between the pipes can then be closed off with gas clamps. The mud can then be pumped in under high pressure. This method has another great advantage—the operator may use thinner mud which is not so easily cut or made to froth from gas pressure as a thick fluid, and it will also penetrate much farther into the gas or water sands.

After such a mudding job has been completed, and usually from time to time during it, the water string must be moved up and down the hole about 25 feet or enough to "pass couplings." This will prevent mud from building up on the pipe and the sides of the hole, thus restricting the subsequent passage of cement to a small channel with the consequent results already discussed. The cement may then be placed by any of the various methods to suit the conditions.

All cementing processes depend for their success on two fundamental requisites which the operator should fulfill to the best of his ability, or not use cement at all. These are (1) effective preparation of the hole to receive the cement, and (2) thorough mixing of the cement in the smallest proportion of water that will give the necessary fluidity.

Too frequently experienced men become so accustomed to an oft-repeated piece of work that the work is performed mechanically. Thus cement is sometimes mixed with a large excess of water and pumped into a hole that is gassy and is poorly prepared to receive the cement. If the two requirements previously mentioned are faithfully met and a good grade of Portland cement is used, the operator has every reason to look for a successful shut-off. When about to cement for the first time it is advisable to make a few tests with the cement to be used and the water available for mixing it. If the local supply is satisfactory and the cement mixed with it will set firmly under water and in a reasonable time, the operator may proceed as described. There will be little opportunity for underground water to interfere seriously with the setting of the cement, as such water will usually be driven back from the hole by fresh water or mud. Of course, such interference is chemically possible, and when thorough washing of the hole, before cementing, was in vogue, the chances of such interference were greatly augmented. However, if the hole is properly prepared and the cement mixed with suitable water, the writer is of the opinion that the character of the underground water need not occasion great anxiety.

USE OF PACKERS.

The use of packers for shutting off water can hardly be treated in detail with any degree of satisfaction without going deeply into the subject of drilling methods.

The packers used in California practice are usually placed either on tubing or on small sizes of casing in order to restrict the diameter of the well to promote flowing. Packers are also set on casing below a leak in the water string, thus preventing the water from entering the productive part of the hole. A wall packer, in the sense that it is set in the wall of the hole and not inside another string of casing, is almost never used in the poorly consolidated shales and clays constituting the formation overlying the oil zones in these fields.

An exception is the packer built by Mr. C. W. Stone, of Maricopa, Cal., for a special job in the Sunset field, where a flowing water sand had to be cased off in order to utilize the oil measures below. Several attempts made with the usual cementing and mudding methods gave only temporary success. A packer that proved successful was made around the shoe joint with old bull rope and bail wire. To make the packer, the shoe joint was placed with the upper end down on the derrick floor. A board at the roof made a convenient place from which to work. Hemp bull ropes were cut in 35-foot lengths and untwisted. The strands were doubled and the loop ends tightly wired to the pipe immediately under the shoe until the compressed hemp mat was flush with the outer edge of the shoe and extended entirely around the pipe. The loose hemp was tied every two or three feet with a strand of soft rope, as shown in Plate XIV, *B* (p. 54). The packer was then complete, and, after being turned right end up, was placed as the bottom joint on the string of casing. Of course, such a packer might be placed anywhere in the string so as to set wherever most desirable. As the packer entered the hole each soft rope string was cut, thus leaving the long strands of hemp free to spread out at any enlargement of the hole. When the pipe was set any movement of the water past the packer drew the loose hemp into the passage and automatically clogged it. Mud settling on top of the packer also assisted in its effectiveness. This type of packer has three great advantages, as follows: Effectiveness; nominal cost (old bull rope and bail wire); does not occasion material difficulty if the casing is to be pulled.

BOTTOM-WATER JOBS.

When a water sand has been penetrated at the bottom of the well below the productive formation and separated from it by a parting, it is not always easy to plug off the water so tightly that when the fluid is all pumped from the hole the plug will have sufficient strength to hold back the water. A reinforced-concrete plug has proved effective in many such wells. The reinforcement consists of old wire drilling cable cut into 10-foot or 12-foot lengths. These are burned sufficiently to draw the temper. Each piece is doubled on itself and fastened with bail wire to others treated and bent in the same way. All the free ends of the cable are laid the same way in the bundle, which is of such size that it will slide freely down through the casing. These bundles are dropped into the casing with the bent ends down and the cut ends up, so that the package will not catch in the pipe and hang, for if such a wad of annealed wire ever bridges in the casing it would cause much trouble. As an extra precaution against such an occurrence, tin cans may be used over the lower end of the bundle. The cans, must of course be wired on tightly. The hole is thoroughly cleaned out before the first bundle of wire line is put in. Each bundle is tamped firmly into place with the tools, a flat-bottom bit being used. This process is repeated until a firm foundation has been built and the soft wire mass wadded thoroughly into the irregularities of the hole. On top of this mass a canister containing wet concrete is then lowered, being attached to the tools with wire, and is broken up with the tools and pounded down on top of the wire line. The canister is made of light galvanized iron 4 or 5 feet long and of any convenient diameter to suit the size of the hole. These canisters should have soldered joints and pointed bottoms to obviate any danger of catching on the sides of the casing.

Concrete of about the same consistency as for surface work is mixed in a box on the derrick floor and poured into a canister. Several canisters may be placed before more wire line is put in. The plug is thus built up of alternating layers of concrete and wire line pounded together until the hole is filled to the desired point. The plug is then allowed to set quietly with the hole full of fluid for 10 days or 2 weeks. This method usually gives a substantial plug, but should not be used if there is much likelihood of deepening the well, as it makes a plug that is difficult to drill out.

Nearly all oil or gas wells diminish in diameter with depth, hence in plugging off bottom water, any bailer or other container used must generally be of small diameter. This necessitates more runs to cement a deep hole and is objectionable, owing to the greater amount of time required to run the bailer or container to bottom and pull it out for another trip. For example, in a 3,500-foot hole 4½ inches in diameter, it is a tedious task to dump 35 to 40 sacks of cement, and very likely the first part will take its initial set before the last batch can be dumped. To avoid this difficulty a string of tubing may be run in and hung a few feet off bottom with both the hole and the tubing full of water. The entire amount of cement to be used can then be mixed in one batch and poured by a swing connection from the mixing box into the top of the tubing. Water can then be immediately run into the tubing on top of the cement. By its own weight the cement will gravitate quickly to the bottom of the hole and set there in a solid mass. This system is, of course, one variation of the tubing method as applied to bottom-hole work without the use of pumps.

If the bottom water has sufficient head to make it flow, it is likely to wash the cement away before it can set, thus leaving a water channel through the plug which will wash larger and allow more and more water to pass as time goes on.

A most ingenuous and highly successful scheme for handling such conditions was used by Mr. C. W. Stone, of Maricopa, Cal. He collected a quantity of old hemp rope, unraveled it, and chopped the strands into pieces about 4 inches long. These were wadded into tin containers of 4-inch stove-pipe joints about 3 feet long. Each joint was battered in at one end to prevent the escape of the hemp. Of course, different conditions will require more or less hemp or burned wire line, but in this particular instance 12 tins of chopped hemp were put on bottom, care being taken not to break the tins. If the tins are broken at this stage of the work, the whole plan is defeated, as the hemp will be washed away by the flowing water. Four bundles of burned wire line 4 feet long were then run in on top of the tins, each bundle being pushed firmly to bottom with the tools. When the fourth bundle had been placed, the tools were hitched to the beam, and tamping commenced. A flat-bottom bit was used, and the tamping was continued until the wire had been firmly driven down on top of the hemp. This tamping broke the tin containers, liberating the chopped hemp which rose with the water current and lodged in the mat of wire line above. Under such conditions the hemp would naturally be carried by the water first into the more open channels, and later into the more restricted water courses, and so on until all flow stopped. More hemp and more wire line might have to be used in some jobs than in the one described. In this instance several layers were used until finally the flow of water diminished, getting less and less at each stroke of the tools until it ceased flowing altogether. A concrete cap was then placed on top of the plug and built up to the desired level. Generally these layers are made 5 to 10 feet thick. Mr. Stone has tested these plugs by permitting them to stand 42 hours after the water level has been lowered 2,000 feet in the hole and found them satisfactory.

When feasible it is good practice to drill clear through a bottom water sand and 5 or 10 feet into the shale below, clean the hole thoroughly, and build the plug from the bottom of the hole up through the water sand and well up into the formation above. The plug then takes a position like the core of a stopcock and is subjected to lateral pressure from all sides but not to the heaving thrust exerted on a plug extending only a little way into the water sand, where reliance is placed entirely in the hold the plug may have in the overlying formation.

To indicate what the heaving tendency of a flowing water sand may be on a plug that does not extend into and form a tight seal with the formation below the sand, assume that the bottom water rises to the ground surface in a 2,000-foot hole. When all fluid is removed from the hole, the plug will be under a heaving pressure equal to the static pressure of a 2,000-foot column of water. This pressure is equal to 870 pounds per square inch, or a heaving pressure of about 22 tons on a plug in an 8-inch hole.

TESTING A WATER SHUT-OFF.

Whenever the character of the formations and methods of drilling will permit, the driller should observe and note in the log book any peculiar characteristics of water encountered, such as freshness or salinity and sulphur content, also the natural level of the water in the hole, and whether there is any change in water level when various sands are encountered.

After the cementing has been done and the time allowed for setting has elapsed, the effectiveness of the work must be tested. The mere fact that the job has been done in a workmanlike manner and by approved methods does not fulfill an operator's obligation to himself, his neighbor, or society in general. The test consists of two phases. In the first phase the water is bailed out, leaving a dry hole, or, at least, the water should be lowered sufficiently below the natural water level of the locality to create a reasonable external pressure on the casing—1,000 to 2,000 feet is usually sufficient. The well is then allowed to stand 8 to 24 hours, or more. This part of the test is made before any residual cement has been drilled out of the casing, and is for the purpose of demonstrating that there is no leak of any kind in the pipe itself. In the second phase of the test the residual cement is drilled out and a few feet of new hole is drilled ahead of the casing. Unless there is danger of a gas blow-out or some other weighty consideration is adverse, all the fluid should be bailed out of the well and the hole allowed to stand 12 to 24 hours. If the test shows that the cementing job is not satisfactory, corrective measures must be taken. If the second part of the test shows that the water is not shut off, effort must be made to determine whether the water is coming around the shoe or through a leak in the pipe itself. If the water is coming through a leak in the pipe and not around the shoe, drilling may be continued and the well completed in the usual way. After the inner or oil string has been set, it may be cut off somewhere between the shoe of the water string and the leak, and the upper part pulled out and set back on top of the lower section with a packer between the two sections, thus preventing the water from entering the oil sands by way of the hole in the water string. The packing should be of more permanent material than rubber.

Plate XIV, *C* (p. 54) shows a packer known in the West Side Coalinga field as the "Crumpton packer." It is used to combat corrosive water. Much trouble has been experienced in this part of the field by ground water eating through the water strings after a few years' exposure. The packer illustrated is set by the weight of the upper part of the oil string. This packer is strong and simple in construction. The packer has a sliding inner sleeve about 5 feet long, so arranged that it can not pull entirely out of the outer sleeve that is screwed into a coupling on the bottom of the upper section of the oil string. The inner sleeve is wrapped with square hydraulic hemp packing, as shown in the illustration. Any machine shop experienced in making oil-well devices can turn out one of these packers without a working drawing.

USE OF HYDRAULIC LIME FOR SHUTTING OFF WATER.

Realizing that well cementing as commonly practiced was not always effective, Mr. E. A. Starke, chemist for the Standard Oil Co. of California, applied himself to the problem of devising improvements. Backed by the liberal financial support and hearty cooperation of his company, Mr. Starke has done much experimental work in the laboratory and in the field with various kinds of cementing materials. If results of this work were published, they would form a valuable contribution to the literature of petroleum, and it is hoped that some day the industry may be so enriched. The material in this section is used by the courtesy of the Standard Oil Co., which furnished the data, Mr. Starke making many valuable suggestions.

As outlined previously, the problem that confronted the operators was how to make a water-tight and permanent shut-off in the poorly consolidated shales and clays overlying the oil measures in some of the California fields. This work is especially difficult when there is agitation in the hole by seepage of gas or by flowing or migrating water. In the early days, in shallow territory and with otherwise favorable conditions, water could be shut off with a fair degree of satisfaction by landing a water string, as has been seen. Cementing was introduced and greatly increased the effectiveness of easy jobs and made possible others that had formerly been impossible. As drilling methods progressed, even cement was not entirely satisfactory at some wells, as it did not set. At first the suggestion was made that cement would not set in contact with oil. Laboratory tests demonstrated that cement will not only set in contact with oil but when mixed with a considerable quantity of oil along with the water.

If a water shut-off is to be made in a well which has not entered the oil or gas sands, and if there is only one string of casing in the hole, so that pump pressure can not be applied, it may be difficult, and perhaps impossible, to get sufficiently high pressure with mud to plug the pores of a gas or water sand. If the mud is excessively thick the cement tends to break through it and "channel" up the pipe instead of surrounding it in a solid mass. To thin the mud may cause a blow-out of gas which will in all probability "freeze" the pipe.

In general, there are three avenues of approach to the problem outlined, as follows:

1. To get a cementing material that will set under agitation and also possess the other requisites of moderate cost, ease of handling, etc.

2. To get a cementing material that will stop the agitation so that Portland cement will set, and that also possesses the desirable commercial and mechanical qualities.

3. To get a cementing material that possesses qualifications of both the first and second class.

The Standard Oil Co., as a result of its varied experiments, is using hydraulic lime as the material to be classed under the second of the three headings mentioned—that is, for retarding or eliminating agitation that would prevent the setting of Portland cement.

Hydraulic lime has properties differing widely from those of an ordinary hydrated building lime. The latter, when mixed with water to form a putty, will remain under water in this condition indefinitely, whereas hydraulic lime sets firmly under water. The setting is gradual, and although a pat will be fairly firm after standing 24 hours in air it would probably require 18 to 24 days to set firmly under water. This test may be made in an ordinary drinking glass, and perhaps save some costly mistakes. Although such a test is a guide, the author has not sufficient data on the use of hydraulic lime to state that every lime that will set hard under water is fit to use in shutting off water in drilling operations. An operator contemplating the use of hydraulic lime will do well to make the test mentioned and other rough tests, such as the thickening effect when dry lime is mixed with the drilling mud. All such test mixtures should be allowed to set under water.

CHEMICAL PROPERTIES OF HYDRAULIC LIME.

Table 2, following, presents analyses of different brands of cement and of hydraulic lime. One is struck with the similarity of the constituents and the diversity of their proportions. The cements represented in the table are typical of the best grades of Portland cement, manufactured especially for oil-well purposes, and vary little from each other in chemical composition. Of course, the fineness to which a cement is ground has much to do with the time required for its setting, a feature not shown by the chemical analysis. The analyses of hydraulic lime show wide variation. The German lime, although somewhat high in silica and low in iron oxide and alumina for use as Portland cement, would seemingly sinter to a fair grade of natural cement. There is an essential difference between hydraulic lime and cement. Cement rock, either natural or proportioned by analysis, is sintered to incipient fusion and then ground very fine to manufacture cement. Hydraulic lime, in contrast, is burned and hydrated, but is never sintered.

TABLE 2.—*Chemical analyses of cement and hydraulic lime.*

Constituent.	Formula.	Brand of Portland cement.			Brand or source of hydraulic lime.[d]				
		Golden gate cement.[a]	Santa Cruz oil-well cement.[b]	Mount Diablo oil-well cement.[c]	German.	Pacific Lime & Plaster Co., San Francisco.	Cartersville, Ga.	Mankato, Minn.	Common or quick lime.[e]
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica	SiO_2	20.89	19.38	22.36	25.87	19.51	15.04	18.10	1.00
Ferric oxide	Fe_2O_3	3.37	5.31	2.51	} 8.13	12.40	.72	5.02	1.30
Alumina	Al_2O_3	7.09	7.15	7.17					
Lime	CaO	63.47	63.70	62.39	55.44	39.20	51.12	40.68	97.00
Magnesia	MgO	1.32	2.13	1.39	1.14	20.61	29.53	29.17	.70
Sulphuric anhydride	SO_3	1.19	1.48	1.45	1.44	1.65	Trace.	2.05	....
Ignition loss	....	1.54	1.04	2.09	1.96	.46	3.54	4.56	....
Manganese oxide	MnO	....	....	....	....	....	....	.42	....
Carbon dioxide and volume.	....	....	....	....	6.02	6.17	....	....	....
Specific gravity	....	3.12	3.20	3.12	....	....	....	....	....

[a] Pacific Portland Cement Co., San Francisco, Cal. Analysis made by the company.
[b] Santa Cruz Portland Cement Co., San Francisco, Cal. Analysis made by the company.
[c] Cowell Portland Cement Co., San Francisco, Cal. Analysis made by the company.
[d] Analysis furnished by Dr. E. A. Starke, San Francisco, Cal.
[e] Marks, L. S., Mechanical engineer's handbook, 1916, p. 568.

Interesting and instructive as the chemical analyses are, they do not alone furnish the knowledge of physical properties that is so important. The calcium and magnesium in hydraulic lime are in the hydrated form—$Ca(OH)_2$ and $Mg(OH)_2$—but contain no water of crystallization. The name "hydraulic" comes from the property of setting under water. Without this property a lime can not properly be classed as hydraulic lime. The hydraulic lime used by the Standard Oil Co. is manufactured by the Pacific Lime & Plaster Co., of San Francisco. It is not a natural lime, but is proportioned and mixed by analysis. Such a lime has a marked advantage over a natural hydraulic lime in that its components may be varied at will to give it special qualities for certain kinds of work, as is possible with Portland cement.

When hydraulic lime comes into contact with finely divided silica and the aluminum silicates of the shales and clays, it combines to form complex gelatinous silicates the exact chemical formula of which is not known. This jellylike mass not only swells perceptibly in setting but adheres tenaciously to the walls of the hole. Any carbon dioxide in the gas of a well will react with the calcium oxide of the lime to form chalk, the reaction causing a further swelling of the mass. When such action takes place between the grains of a sand the result is to cement the sand into a compact mass surrounding the hole. The lateral thickness of this mass is, of course, dependent on the depth of penetration of the lime solution into the formation. It is frankly admitted that a neat hydraulic lime has a tensile strength of only about two-thirds of that developed by neat cement. Such a consideration has little to do with the value of cementing material in an oil well, so long as the material will set and when set will have a tensile and compressive strength sufficient to stop the flow of water or gas from agitating the Portland cement that is placed between the lime-plastered wall of the hole and the casing to be cemented.

Milk of lime (finely divided hydrated lime that has been steam slacked) will in some wells combine with the silicates and aluminates of the formation to form gelatinous silicates, and will prove as satisfactory as hydraulic lime. This reaction depends upon the favorable chemical and physical properties of the formation and therefore can-not be universally relied upon. If hydraulic lime containing finely divided silica and iron and aluminum oxide is used, its essentials are self-contained and hence it has a far better chance to do its work under unfavorable conditions than the milk of lime, and is therefore preferable.

Hydraulic lime is mixed separately with water and pumped into the well ahead of the cement. When the two-plug or Perkins system of cementing is used the lime solution is pumped into the casing on top of the column of mud and ahead of the first plug; thus the cement follows immediately behind the lime solution in its course down the inside and up the outside of the casing. The main advantage claimed for the use of hydraulic lime is that when a solution of mud, as ordinarily used in drilling, is mixed with a solution of hydraulic lime a muddy sort of plaster is formed which so coats the formation as to greatly reduce and often entirely prevent agitation from gas or moving water. This action takes place when the hydraulic lime passes out of the casing and mingles with the mud in the bottom of a well. The writer suggests further that this mixture of lime and mud will make a firmer bond with the formation than neat Portland cement, and that the Portland cement will in turn adhere more firmly to the mud and lime plaster than it will to the ordinary mud-smeared side of a hole.

SPECIAL USES OF HYDRAULIC LIME.

If mud flush is circulated continuously as drilling progresses, the mud usually fills the pores of porous sands or gravels. Occasionally the mud runs away into such sands or gravels instead of returning to the surface. Circulation is immediately lost. Nearly every driller has either had such an experience at one time or another or knows of where it has occurred, and realizes the difficulty of reestablishing circulation. Teams are often kept busy for days hauling mud and manure, sawdust, etc., to be mixed with the mud in an effort to clog the passages. The Standard Oil Co. handled an obstinate hole of this kind in the Antelope Hills by mixing hydraulic lime and manure with the mud in the suction box. This mixture filled the channels in the sand and circulation was restored. Though the lime may have cost money, whereas the other materials were free, the difference was more than offset by the difference in hauling and labor charges, to say nothing of the risk of allowing the hole to cave. This risk increases greatly the longer the time before circulation is restored. For work of this kind the dry lime may be shoveled into the liquid mud and mixed with shovels or hoes, and by circulating it through mud pumps. The lime need not be mixed with water and then poured into the mud.

There is still opportunity for investigation and improvement in this phase of exclusion of water from oil and gas wells. If hydraulic lime, or some other more suitable substance that will set hard after being mixed thin, is forced into each water sand when encountered, thus changing the sand into a hard lens of impervious and permanent sandstone surrounding the casing, much expense may be saved in drilling operations. It might be possible with such a system to drill wells with cable tools and use only one string of pipe, whereas under present practice one or two additional strings are used as conductor pipes and water strings. The saving thus effected would be great, provided the cost of sealing the sands could be kept moderate.

If such a process were developed, it could be applied to intermediate water, permitting simultaneous production from the oil sands above and below the water with the use of only one string of surface casing or an oil string in territory where the oil sands did not stand up well enough to make an open hole possible. To handle intermediate water by such a method would, of course, require a packer of some kind set below the upper producing sand and above the intermediate water sand. The packer would prevent the lithifying solution from entering the upper oil measures, and thus, perhaps, seriously affecting production.

It is the writer's hope that the foregoing discussion may not only acquaint operators with what has so far been done in the use of hydraulic lime, but may induce them to conduct further investigations bearing on the subject and to make their results known, whether successful or not. A knowledge of the limitations of a process is just as essential as an understanding of its scope.

WATER PROBLEMS IN THE MID-CONTINENT FIELDS AND METHODS FOR HANDLING THEM.

Far too much drilling has been done in the oil industry at large with a view to striking oil and then selling or leasing the property rather than with the intentions of operating the wells until the last barrel of commercially recoverable oil has been marketed and the wells have been thoroughly and effectively plugged. Moreover, it may be said that some operators have manifested more interest in obtaining a clearance paper in the form of a "plugging affidavit" than in seeing that the plugging has been properly done. Such operators, through ignorance or criminal indifference, will frequently employ a contractor who is far more interested in getting his money than in fulfilling his contract.

It is difficult to conceive of conditions that make it permissible to abandon an oil, gas, or prospect well without effectively plugging it as the casing is withdrawn. An excuse for not plugging an abandoned hole is occasionally heard to this effect: "The well would not make a bailer of oil a week, so there was no use going to the expense of plugging a hole like that." The knowledge that water may travel through a sand from a nonprofitable well and spoil many valuable oil wells and much property or perhaps embarrass some future mining operations is not so general as might be desired.

GENERAL CONDITIONS IN MID-CONTINENT FIELDS.

In the Mid-Continent fields there are three outstanding requirements regarding protection from water, as follows: (1) Protection of a valuable formation from a water stratum shut off behind the same casing, (2) shutting off water from the hole by casing, and (3) shutting off bottom water.

With mud fluid the first requirement can be met, and mud fluid should be used wherever the formation to be protected is of value anywhere in the district. In regard to the second requirement, all too little effort is made toward a permanent shut-off, and the writer believes that much of the water trouble, whereby production is decreased or producing expenses increased, is caused by top water breaking into the hole from around the shoe and through leaking joints or casing that have become corroded.

Bottom water is likewise a cause of much trouble and expense. The engineers of the Bureau of Mines who have investigated conditions in the Mid-Continent fields are all of the opinion that a great reduction in costs and loss of production could be effected by the repair of old wells and by greater care in shutting off water in new wells. One of the greatest opportunities to-day for increasing efficiency in the Mid-Continent old fields is in the correction and prevention of water infiltration.

Common faults in the Oklahoma fields are as follows: Not setting casing up tight enough, not using good casing shoes, not selecting good casing seat, using rubber-wall packers for permanent shut-offs, nonconformable shut-offs, not protecting casing against corrosive water, and not insisting on absolutely tight shut-offs.

These evils arise partly from the contract system wherein the drillers of the wells have little interest in making permanent shut-offs and partly from a lack of appreciation on the part of the operators of the harm resulting from insecure shut-offs. Operators should insist that contractors make shut-offs that will be permanent instead of lasting only until the well is completed. Such temporary results are obtained with the rubber wall packers, which experience has shown to be far from reliable. Another tendency is for the operator to be satisfied when the water is "practically shut off," but experience shows that the little trickle of water in time enlarges and becomes a stream. Later in the well's life, the operator complains about how much water comes in the same sand with the oil.

Cable tools are almost universally used in the Mid-Continent fields, and frequently without a calf wheel to handle the casing. The formations stand up well, so that drilling may be done without simultaneously carrying the casing. Usually the hole is made to a certain point according to local requirements, and then the entire string of casing is set at one time, as contrasted with usage in caving formations, in which the casing must be inserted a joint at a time, and often in short lengths of 5 or 10 feet, in order to keep the shoe in close proximity to the bottom of the hole. In the Mid-Continent fields it is customary to employ a casing crew under contract when a string is to be set. The joints are usually set up by hand, frequently with only a rope sling. It is only with the deeper strings that the engine is used for setting up the pipe. Of course, even heavy casing will not stand the pull of a drilling engine on ordinary chain tongs without damage. When a producing well is to be shot to stimulate production, the water string often is pulled up well above the shot. Whenever possible, the water string should be set far enough above the producing sand to be safe from the damage of a shot, so that there will be no need of moving the string. Then if the hole back of the pipe be filled with fluid and the fluid in the pipe be baled or swabbed till its level is below the bottom of the water string before the shot is fired, the likelihood of damaging the pipe even by a heavy shot is decidedly lessened. The feature to be emphasized is the possibility of pulling a string of casing with several hundred feet exposed to the formation after it has been set for several years. In most California fields this can not be done.

Difficulties in the Mid-Continent region are accurately summarized by Lewis and McMurray,[a] as follows:

The natural conditions affecting the conservation of oil and gas are unusually complex in the Mid-Continent fields. There are a large number of sands containing gas, oil, or water, so that the drill may penetrate many different sands, and in every conceivable combination. Plate XV shows the combination of sands found in parts of the Oklahoma fields. At Blackwell, Okla., gas sands are found at intervals from within a few hundred feet of the surface to a depth of 3,400 feet. Gas is nearly always found associated with an oil pool, and may be in the higher parts of the same sand as the oil, or in sands above or below the oil sand. Pressures as great as 1,300 pounds per square inch have been found in some of the deeper wells and flows over 50,000,000 cubic feet daily have been reported from a number of wells. The formations resemble those in the fields of States farther east, and the wells are usually drilled under contract by the dry-hole method.

Under such complex conditions drilling in a dry hole is wasteful and dangerous, and to fully protect all the formations by the use of casings, packers, and bradenheads is often either impracticable or impossible. Occasionally the gas will interfere or prevent drilling until the pressure has been reduced. The gas is developed faster than it can be marketed, and to finish the well so as to keep it stored in the ground without waste delays the completion of the well by the dry-hole method and adds to the expense.

Operators on Indian lands in Oklahoma have been required by the Interior Department to conserve the gas and oil resources, and the authorities of the State of Oklahoma are requiring other operators to take similar precautions. The protective work is largely done with mud fluid, and many of the leading operators, both in Oklahoma and Kansas, are using this method, even where not legally compelled to do so.

[a] Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, p. 51.

In working up a new system of procedure, or in adapting an old one to new conditions, a few failures are to be expected, but these, if properly studied, become material assets by reason of the knowledge they furnish. Such failures have occurred with the use of mud-laden fluid in parts of the Mid-Continent field. Sometimes an operator will use muddy water, or else will pump into the well the muck from the mud sump, including sand, lime, and shale cuttings mixed together; another will have trouble with the pipe "freezing" before it can be set. One such instance was reported when the casing was entirely free to move about 5 or 6 feet up or down, but would neither pull above nor go below these limits.

SUGGESTIONS ON USE OF MUD FLUID AND CEMENT IN MID-CONTINENT FIELDS.

Since the use of mud fluid has become general in the Mid-Continent oil fields, local operators are developing special practices. Probably 2,000 wells have been mudded in and many of the operators are becoming experts in its use. The contentions of the Bureau of Mines have been amply justified, both as to the benefits of the proper use of mud fluid and as to the harmful results when improperly used. Success or failure has hinged primarily upon two factors—(1) the thickness of the fluid and (2) its freedom from sand, limestone cuttings, or coarse materials.

As stated elsewhere, mud fluid, being fluid, will not be shut off at the casing seat, but the casing must be set in such manner as to retain fluid behind it. However, mud fluid will force water back into its native formation and prevent it from entering the hole and thus gaining access to other formations behind the casing. In this way valuable oil, gas, or fresh-water and salt-water strata can be protected from an intermingling of their various contents though all lie behind the same casing. Several strings of casing, each securely landed, would otherwise be necessary.

The experience of the Empire Gas & Fuel Co. in the Eldorado and Augusta fields, Kansas, amply justifies this statement. Though the gas sands have been protected from underlying water sands only by mud fluid in the wells drilled to the deeper oil sands, water has failed to invade them, and the gas wells require only the occasional "bleeding" usually necessary. The operations in these fields demonstrate that it is entirely practicable to develop an oil field and at the same time protect and utilize the gas in overlying sands.

METHODS FOR SETTING CASING WITH MUD FLUID.

There are several methods in use for setting a string of casing with mud fluid back of it, and no one of these can be termed the best

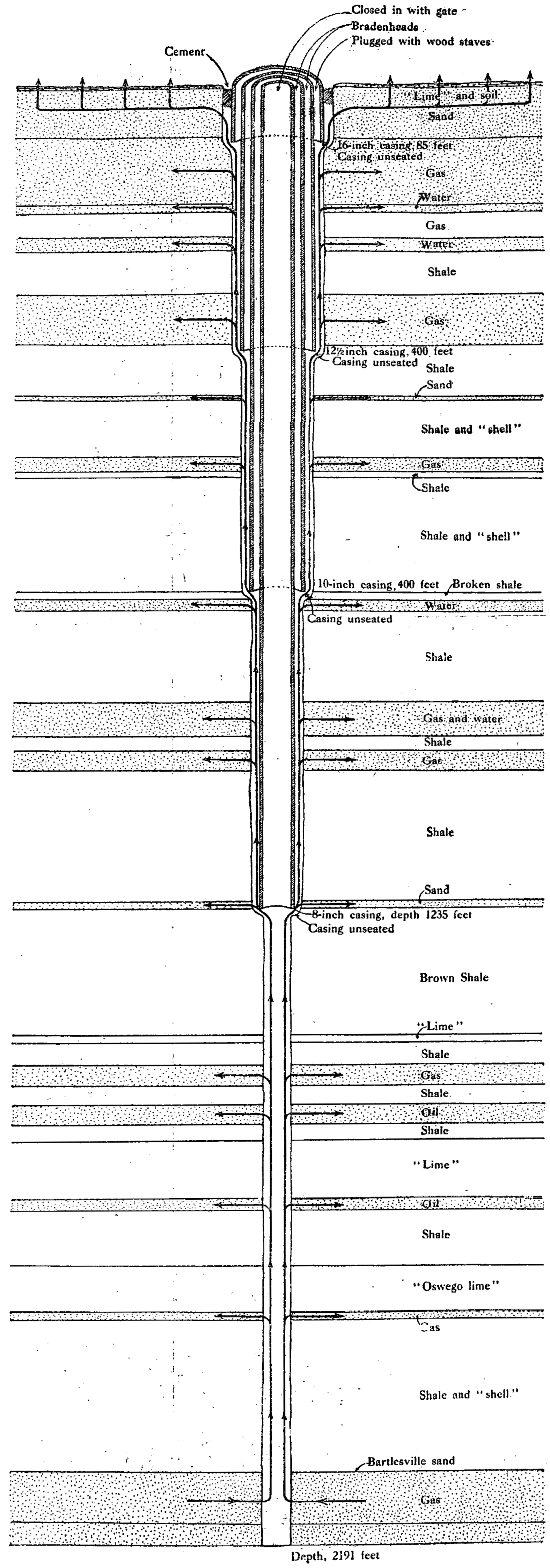


DIAGRAM OF WELL IN OSAGE COUNTY, OKLA.

Shows condition of well and way in which gas escaped to surface. Well was completed May 8, 1914, with an open flow estimated at 22,000,000 cubic feet. When shut in the gas cut under each string of casing, which were landed in shale, and escaped into the other sands. Gas had reached the surface as far as 600 feet from the well, and for a radius of 300 feet was issuing from the ground in large volume, when inspected on August 11, 1915.

or proper method for all conditions. Like all other oil-field operations, this should be done in the cheapest way that is consistent with safety and good mining.

For convenience, the various methods are summarized as follows:

1. Filling the hole with mud fluid with a dump bailer, or through tubing, so that the wall of the hole will not be unduly washed. The casing is then pumped down as the mud circulates.

2. Inserting the casing to within a few feet of bottom and pumping the mud into it, finally circulating the fluid.

3. Inserting the casing and setting it on bottom, filling it with mud fluid and lifting it off bottom, and continuing pumping until satisfactory circulation is obtained.

In all these methods ultimate circulation is essential, and some means should be provided for testing the specific gravity for the outgoing as well as the ingoing mud fluid. By this means the operator will be able to determine when no further dilution of mud takes place from water in the hole, and by inspection of the mud he may determine when gas and oil, if any are behind the casing, are completely "mudded off."

Method 1 requires more time than either of the others, but may be applied wherever method 2 or 3 can be safely used, whereas neither of the latter two methods may always be applicable where No. 1 is safe; therefore method 1 is recommended when a doubt exists as to the advisability of using method 2 or 3.

Method 3 has been successfully used in the Eldorado and Augusta fields of Kansas. The Empire Gas & Fuel Co. has "mudded" some 300 strings of 12½-inch, 10-inch, and 8¼-inch casing set at an average depth of about 1,500 feet. After the 8¼-inch has been "mudded" and set as a water string at approximately 2,400 feet, the 10-inch and 12½-inch casings, which were also "mudded," are pulled. There has been only slight difficulty in pulling these strings after they have set one to seven months, and the practice has been amply justified in the localities mentioned.

This company reports the use of mud of 1.40 and 1.60 specific gravity without difficulty. This is heavier than engineers of the Bureau of Mines had thought would pass through the pumps. There is a greater variation in the relative specific gravity and fluidity of muds than had been anticipated. For example, the tests on all the previous recommendations had been made with mud from California fields, and the mixture of such mud with a specific gravity of 1.41 (41 per cent heavier than water) was so stiff that it would not run from an inverted glass and could not have been pumped.

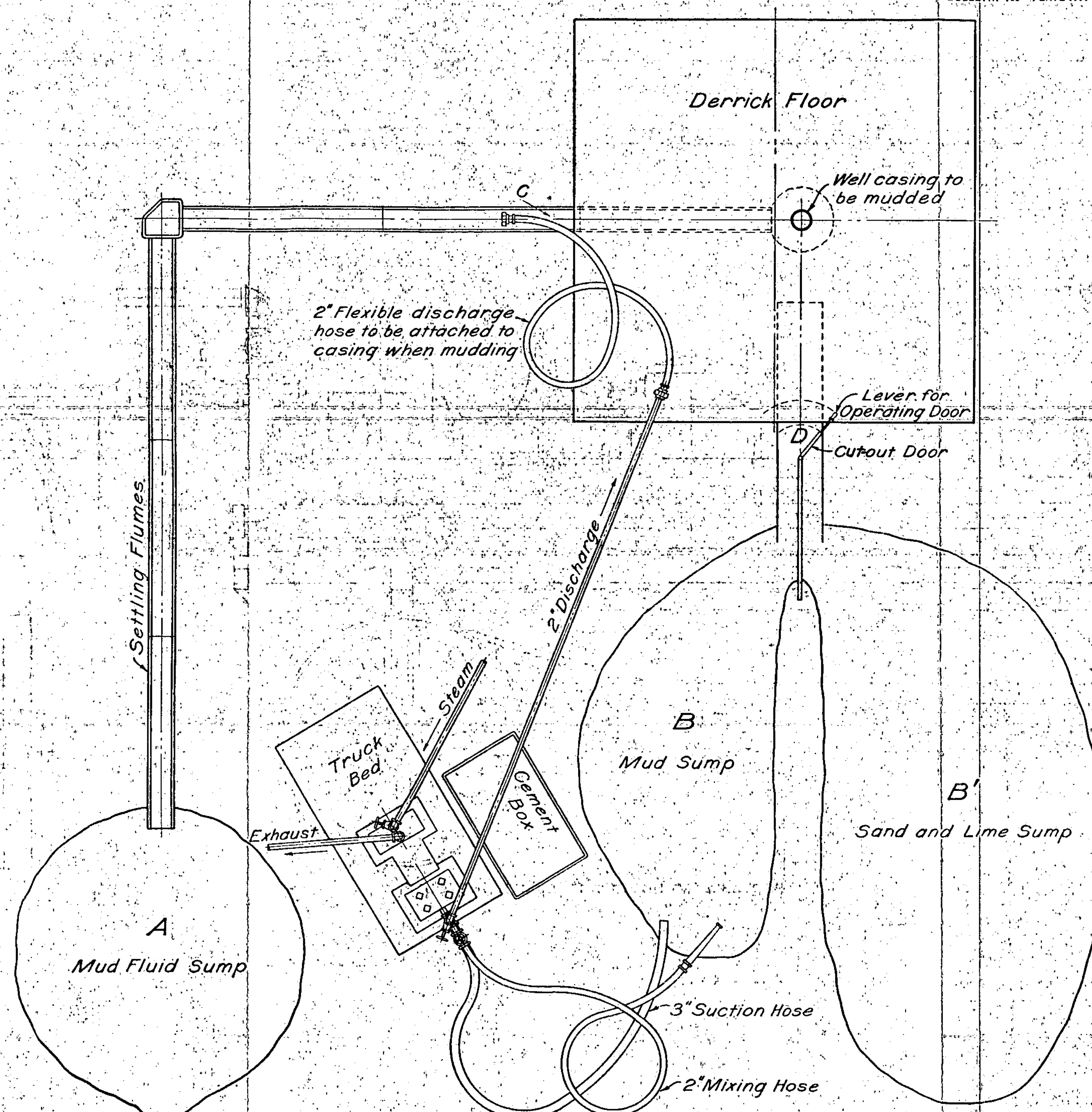
The experience of the Empire company has shown not only that it is possible to reclaim the casing landed in mud fluid, but that much less trouble is experienced than in pulling the casing from other wells in the same field in which such fluid was not used. Great care is always exercised to exclude sand and limestone cuttings from the fluid put into the hole.

Method 3 proved unsatisfactory for use in many wells sunk through the gas sands of the Cushing field, as the rush of mud around the bottom of the casing when the casing was lifted from its seat, frequently occasioned collapsing and sometimes bursting of the pipe. As a rule, in the Kansas fields mentioned, there is considerable water in the hole, both inside and outside of the casing. Thus when the casing is lifted, the internal column of mud fluid has to overcome the pressure of the external water column and its inertia, resulting in a greatly reduced velocity of the fluid as it passes out of the casing. Although there is water in the Cushing field in large quantities, in the early days it was usually blown out of the hole from behind the casing by the gas pressure as fast as it would enter the hole, thus eliminating any back pressure from the water.

In all three of the methods for placing mud fluid, considerable emphasis has been laid on circulation. Circulation is recommended when the casing is to be subsequently pulled, and is desirable on other jobs even if the sole object is the protection of strata behind the casing. However, it may occur that such protection is desirable where the necessary apparatus for circulation is unavailable. It may then be permissible to proceed as follows: Fill the hole with mud fluid; insert the casing, and seat it firmly on bottom; then remove the fluid from within.

PREPARATION OF MUD FLUID.

To prepare the mud, the sump is divided into two parts, each with a separate dump box. Throughout the drilling work, efficient supervision is maintained to insure that the mud is dumped into one box and the other drillings into the other. When the well is ready for mudding, a pump mounted on a specially constructed truck and provided with suction and discharge connections, similar to those shown in Plate XVII (p. 77), is hauled up beside the mud sump. The mud fluid is mixed to the desired consistency by circulating it through the pump and the mixing hose back into the mud sump. The specific gravity is determined by an hydrometer, so constructed as to eliminate any error of reading due to the viscosity of the mud fluid. When the mud emerges at the surface it is run into the sand pit and not returned to the well. This process is continued until no more cuttings or sand come up with the mud, and until the returned fluid is of a satisfactory specific gravity. The casing is then set firmly on bottom to afford a tight seat which will retain mud behind the pipe when the fluid within has been removed.



COMPOSITE DIAGRAM SHOWING ARRANGEMENT FOR THREE MUDDING OPERATIONS THAT MAY BE COMBINED IN PRACTICE. THE THREE FEATURES ARE: (1) THE DIVIDED SUMP AND CONTROL DOOR; (2) SETTLING FLUMES AND CORNER BOX; AND (3) THE BOX FOR MIXING CEMENT.

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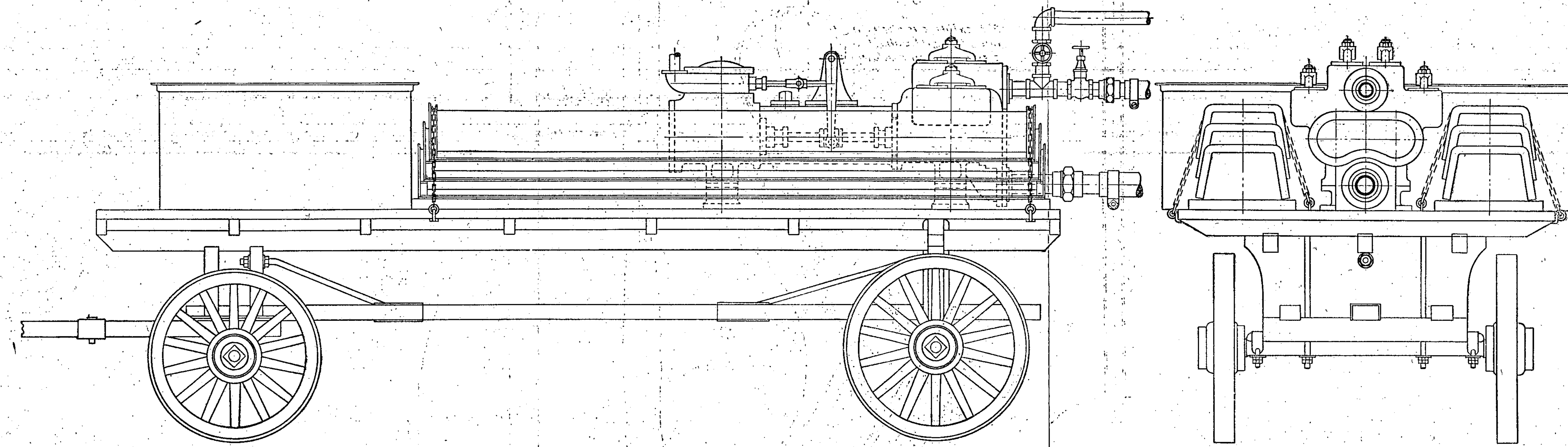


PORTABLE MUDDING AND CEMENTING OUTFIT.

The object of using a thick mud is twofold—first, to make the mud more effective against gas pressure; and, second, to get sufficient weight of mud without forcing it so far back into the oil or gas sand that it will penetrate into the nearby wells, as might occur if thin mud were used.

It is not an uncommon sight in the Eldorado fields to see two or even three wells within 100 feet of each other, each producing from different horizons and protected from the effects of unsystematic casing only by mud fluid.

Of course, this method of preparing mud may be used with any of the methods mentioned for getting it behind the pipe. The mud that collects at the lower end of the limestone and sand sump may also be used, as the coarse material settles out nearer the derrick.

The fact that mud from the limestone and sand sump has been used indicates that further experience may show that if the drillings receive proper settling before use the use of two sumps may be unnecessary. If a company is drilling only a few wells, or for some other reason the adequate supervision and inspection of mud throughout drilling operations is inconvenient, it would be an advantage to have available an outfit for preparing mud from the unseparated drillings. Such an outfit might be operated either by an association or local company, or under contract, and in the hands of a competent man would doubtless be satisfactory. Both contract and association systems have been used with entire success for handling the cementing operations in California fields.

A tentative design for a mudding and cementing outfit is illustrated and described below. Plate XVI shows the general arrangement, including a divided sump. Such an outfit may be used with either the one or the two sump system of handling the cuttings. Further experience may also indicate the desirability in some localities of a more thorough settling of mud than would be obtained by the sump method alone, particularly if the pipe is to be recovered after standing with mud behind it for a number of years. Plate XVII shows views of a portable mudding and cementing outfit mounted for transportation.

PROPOSED MUDDING AND CEMENTING OUTFIT FOR MID-CONTINENT USE.

The proposed mudding and cementing outfit shown in Plates XVI, XVII, XVIII, and XIX is designed with the following objects in view:

1. To prepare mud fluid effectively and to circulate it in a well.
2. To have the outfit so mounted that it can be set up at a well and repacked with a minimum expenditure of time and labor.

3. To use the equipment for a cementing outfit when cementing is to follow the use of mud.

The combined use of mud and cementing seems to the writer the most practicable method for much of the Mid-Continent work.

In the Mid-Continent fields cementing the water string is open to the following objections:

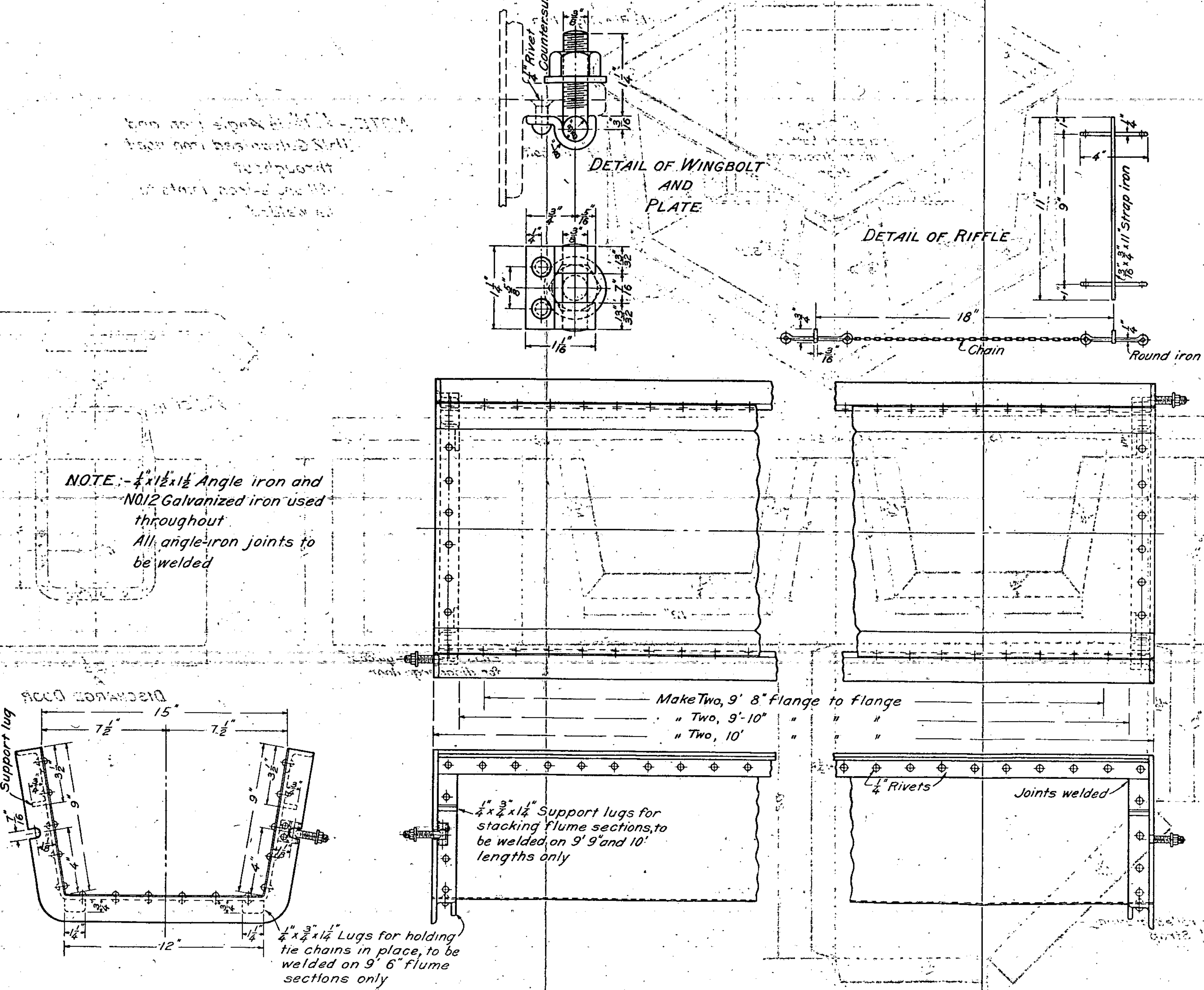
1. If the job on being tested after the cement has set 10 days or so proves a failure, considerable expense is entailed for redrilling or for putting in new casing, and frequently a reduction in diameter of the hole is necessary. When a well is to be abandoned, only that part of the casing above the cement is recoverable.

2. The cementing job itself is expensive and delays drilling considerably. This is particularly objectionable to drilling contractors.

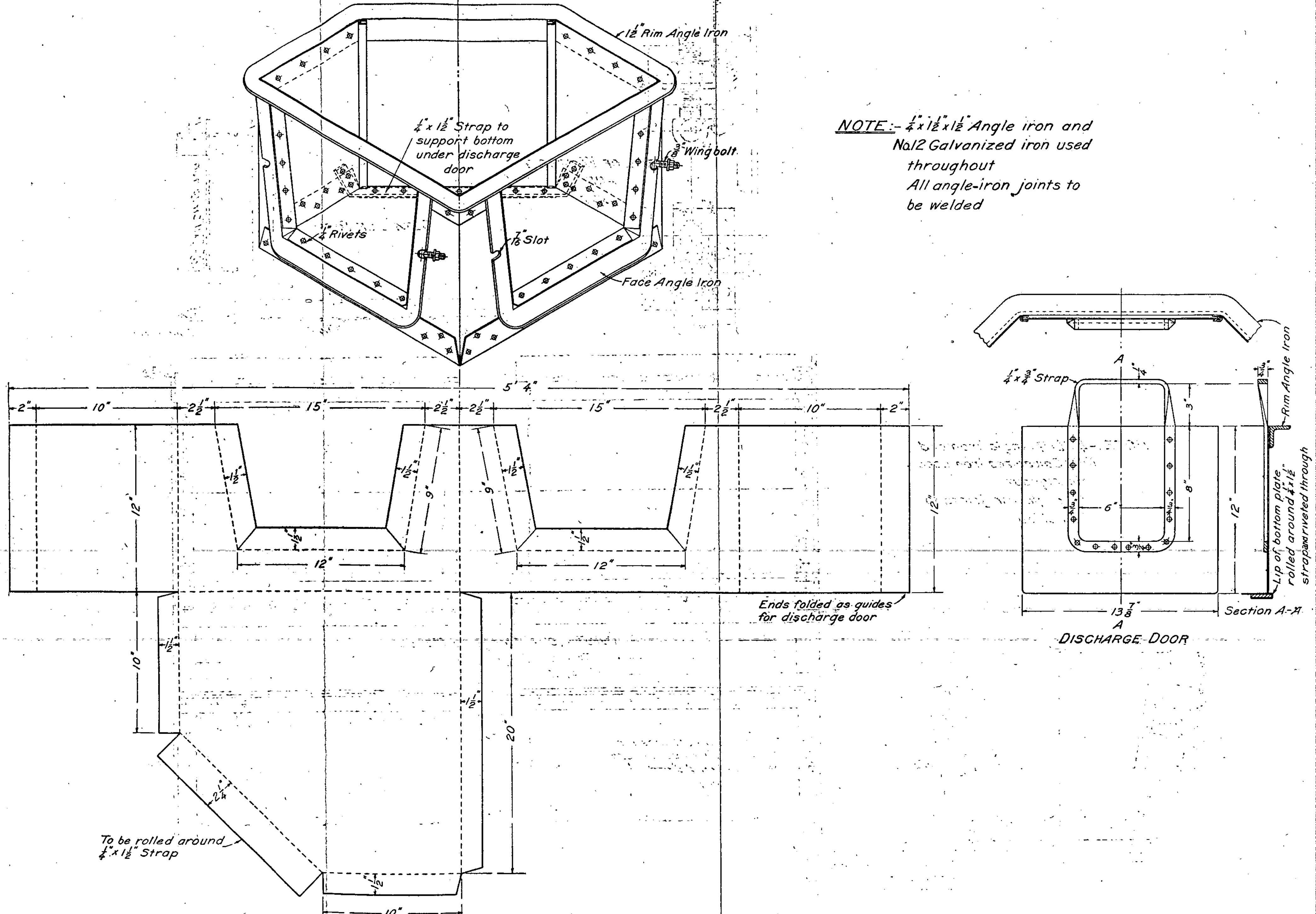
To offset these disadvantages there is the one great advantage that a water string properly set up and "mudded" and cemented in the firm formations such as are common in these fields should be permanent throughout the life not only of the well but of the field.

Certain details regarding correct setting of the casing are important. A water string of, say, 8-inch pipe requires just as much force and probably more care to properly set up the joints than the same size pipe line. Frequently oil-well casing has a finer thread than line pipe, making "stabbing" (starting of joints) without cross-threading more difficult, and therefore requiring more constant vigilance. Moreover, the string must sustain the tensional stress of its own weight in addition to an occasional severe pull. After it is set it must withstand a severe collapsing pressure during its entire period of usefulness. If there is a leak in a pipe line, it appears when the line is tested, as does a leak in a water string. A leak in a pipe line can easily be repaired, whereas a leak in a water string may be attributed to "poor cement," or perhaps to "a stray water sand just below the pipe." The writer recommends that, in setting up the water string of an oil or gas well, the threads of each joint be cleaned of dirt and grit and then be painted with some suitable dressing, such as oil and white lead, and each joint set up firmly with the engine. This latter requirement necessitates some type of casing tongs that will distribute the pressure as uniformly as possible around the pipe, for ordinary chain tongs if used with the engine are almost sure to damage the casing. The force exerted by an engine is ample to crimp the pipe ends when they are forced into contact or to strip the threads. Judgment born of experience is the only guide for avoiding such trouble.

A steel casing shoe is advisable, particularly for the longer water strings. The suggestion of reaming the hole, as previously described (see fig. 4, p. 56, is also applicable here. The pumps used for circulating mud fluid may be used also for cementing, thus



FLUMES AND RIFFLES FOR PORTABLE MUDDING OUTFIT.



CORNER BOX FOR PORTABLE MUDDING OUTFIT.

maintaining circulation throughout the entire job. If the hole has been filled with mud fluid and the casing set without circulation, the cementing may be done by the dump-bailer method. As a rule, it will be unnecessary to use large quantities of cement—only sufficient to fill back of the water string for 40 to 60 feet above the shoe.

DESCRIPTION OF OUTFIT.

The mudding and cementing outfit, suggested for use in the Mid-Continent fields, is shown in Plate XVII mounted on a lumber wagon, so that it may be hauled from well to well either by a motor truck or a team. Were a contractor or association to operate the outfit, the use of a motor truck might prove advantageous. This must be determined by local conditions.

The design here presented is offered only as a suggestion to illustrate the possibility of developing a systematic and efficient method of procedure for such operations. The experience gained in the construction and use of such a plant as the one here outlined almost invariably suggests improvements to be made and apparatus that may be eliminated partly or totally, without impairing the utility of the whole. The three main parts of the outfit here described are:

1. Truck (motor or other type) of not less than 2 tons rated capacity.
2. Mud pump with necessary fittings and hose.
3. Settling flumes and cement box.

The pump should be of a type designed to handle mud fluid and of a capacity equal to that of an ordinary duplex steam-driven mud pump, 8 by 5 by 10 inches or 10 by 6 by 10 inches. The pump may be driven by any convenient power, according to local conditions. It may even be found convenient to provide for driving a geared pump from the engine of the truck. A duplex steam pump is shown in Plate XVII.

A settling flume 60 feet long is divided into six sections of approximately equal length and a corner settling box. These are shown mounted on the truck in Plate XVII and, in detail, in Plates XIII, XVI, and XIX. The general arrangement of parts when set up at a well is shown in Plate X (p. 42).

The design calls for No. 12 (United States standard) galvanized iron, reinforced around the end and along the edges of the flume sections with $1\frac{1}{2}$-inch angle iron weighing 2.34 pounds per foot. Wherever the angles at the ends of the flume or in the sides of the corner box meet the rim angles, the joints should be coped and welded with an oxy-acetylene torch. All sheet iron should be tightly riveted with $\frac{1}{4}$-inch rivets to the angle irons. It will be noticed that the bottoms of the lateral flumes as shown enter the respective sides of the corner box about 2 inches above the bottom of the latter, thus affording a catch pocket for the cuttings. The discharge door at the opposite corner of the box affords a quick and convenient means for removing these settlings.

Each flume section (see Pls. XVIII and XIX), as well as the corner box, is fitted with two wing bolts at diagonally opposite corners, with corresponding slots at the other corners. By this arrangement the various sections may be held firmly, end to end, in any convenient arrangement. This feature permits any combination of flume and corner box that the local topography or other conditions make desirable.

A set of removable riffles, made in six 10-foot sections having the general form of a rope ladder, is provided. The riffles, each 11 inches long and made of $\frac{3}{16}$ by $\frac{3}{4}$ inch strap iron, correspond to the rungs and should be placed about 18 inches apart. The sides of the ladder may be made of signal cord or galvanized-iron chain. Each section should be provided with snap hooks at one end and rings at the other, in order to facilitate combining them to fit any arrangement of flume. These "ladders" may be attached to a couple of suitable rods, one extending across the end of the flume at the well and the other across the aperture of the corner box connected to the discharge flume. These rods, of course, need not be attached to the flume in any way and can be made of the same material as the riffles, and should be about 19 inches long and have two drilled holes to take the snaps. Some provision must be made to hold the riffles on edge. One way of doing this is shown in Plate XVIII. Whenever the riffles become clogged with débris they may be lifted out and the flume cleaned with a square-nosed shovel, in far less time and much more thoroughly than if the riffles were stationary.

HANDLING AND CARE OF FLUMES.

The specifications for flumes and corner box provide for light construction, so light, in fact, that 2-inch angles may be found more desirable than the $1\frac{1}{2}$-inch angles prescribed. Owing to the light construction it is necessary to handle the flumes with some care. It will be noticed that the flumes are made in lengths as follows: Two flumes, 10 feet long; 2 flumes, 9 feet 10 inches long; 2 flumes, 9 feet 8 inches long. Thus, when the flumes are inverted they may be stacked compactly. Lugs are shown welded on the end angles in the two long and the two intermediate sections to support the sections inverted on them and to prevent the sections from wedging together. It is assumed that during transit these flumes will be held firmly to the truck with chains, and lugs are provided at the bottom corners of each end angle of the two short flumes to hold the chains on the angle irons and prevent the chains from slipping to the galvanized-iron bottom.

SETTING UP THE FLUMES.

The higher end of the settling system is to be placed close to the well so that the returns will run into it. The lower end is to discharge into the mud pit *A* (Pl. XVI, p. 37). A slope of 1 foot in 20 provides a good grade for the flumes, this gradient to be altered as experiment may dictate. A partition of boards fitting the inside of the flumes is to be placed at some such point as *C* in Plate XVI, to prevent any mud from going toward the well during preliminary settling. If two sumps are used, shale and slate cuttings are supposed to be segregated in the sump *B* by means of the cut-out device shown at *D*, consisting of a door with flaps of belting nailed to its outer and lower edges, in order to insure comparatively tight contact whichever way it may be swung. By a tiller arrangement, easily made by bending a piece of 1-inch pipe, this door may be swung so as to send the sand and limestone cuttings into the one side of the sump, and the cuttings from shale, slate, or clay into the other. By placing the door outside the derrick and extending the tiller handle inside, cleaning around the door is facilitated, and the handle is also out of the way, on whichever side it may be swung. With these arrangements there is no excuse for an imperfect segregation of cuttings, as there is only one place to dump the bailer. By mounting back of the tiller a board scribed with the words "sand" and "mud" at its respective ends, the chances of error in operation will be reduced to a minimum. Such a sign will also serve as a reminder until the operation of the device becomes as much second nature as turning the throttle at the "headache" post to the left in order to shut off steam.

OPERATION OF MUDDING AND CEMENTING OUTFIT.

To prepare mud for use it is picked up from the sump *B* through the pump suction and circulated through the mixing hose back to the sump until a considerable quantity has been mixed. It is then discharged into the flume at *C* ahead of the wooden partition so that it will flow toward the corner box and around to the receiving sump *A*. It may be found convenient to eleminate the sump *A* and set the flume so that the mud fluid will be returned to sump *B*, minus the settlings, or it may be found more desirable and equally efficacious to use the sump *A* and only one main sump instead of sumps *B* and *B′*, thus eliminating the segregation of mud while drilling.

When the sump *A* is filled, the mud from it may be transferred to the well by operating the respective discharge valves and transferring the discharge line from the flume to the connections on the well casing. The mud is then admitted to the well by whichever system has been found most effective in the particular locality (see p. 74) and the well is thoroughly "mudded."

A cement box 4 by 7 by 2 feet is specified, which should permit mixing 2 tons of dry cement with water in one batch. In the Mid-Continent field this quantity will probably be sufficient for the majority of cementing jobs.

COST OF FLUMES, RIFFLES, AND CORNER AND CEMENT BOXES.

To obtain a reliable estimate of the probable cost of the flumes, riffles, and corner and cement boxes, the plans were submitted to a large manufacturing company on the Pacific coast. This company can supply the stated parts, fabricated, for $225 f. o. b. San Francisco, Cal. This figure is based on the prices of labor and material in November, 1917, and includes an allowance of 10 per cent for profit.

BOTTOM WATER.

Bottom water is common in the Mid-Continent and the Illinois fields. The bottom water is frequently found throughout a wide lateral extent. The term "bottom water" as commonly used in these fields refers to water underlying the oil and in the same sand with it, with no impervious stratum present to separate the water-bearing part from the productive part of the sand. A most successful method for excluding the water from a well under such conditions is that developed in the Illinois fields and known as the McDonald process.

M'DONALD PROCESS FOR CEMENTING OFF BOTTOM WATER IN OIL AND GAS WELLS.

The McDonald process was developed by W. W. McDonald, of Robinson, Ill. It has been briefly described in a bulletin[a] of the Illinois Geological Survey. This process is especially useful in a well that has been drilled or shot into bottom water, or where water has encroached on and claimed the lower part of an oil sand as depletion has progressed. It is particularly valuable in a shot hole, because its effectiveness is in no way impaired by any irregularity in the shape of the hole, nor by crevices or fissures.

For successful operation of the process, it is essential that the water sand take water when the level in the well is raised above the natural level of the water to be shut off. These conditions are typical of the underlying water in the Illinois pools.

Figure 5 shows a cross section of a well being cemented by the McDonald process. The tubing, usually 2-inch, is lowered into

[a] Kay, F. H., Petroleum in Illinois in 1914 and 1915: Illinois State Geol. Survey Bull. 33, 1916, pp. 87–88.

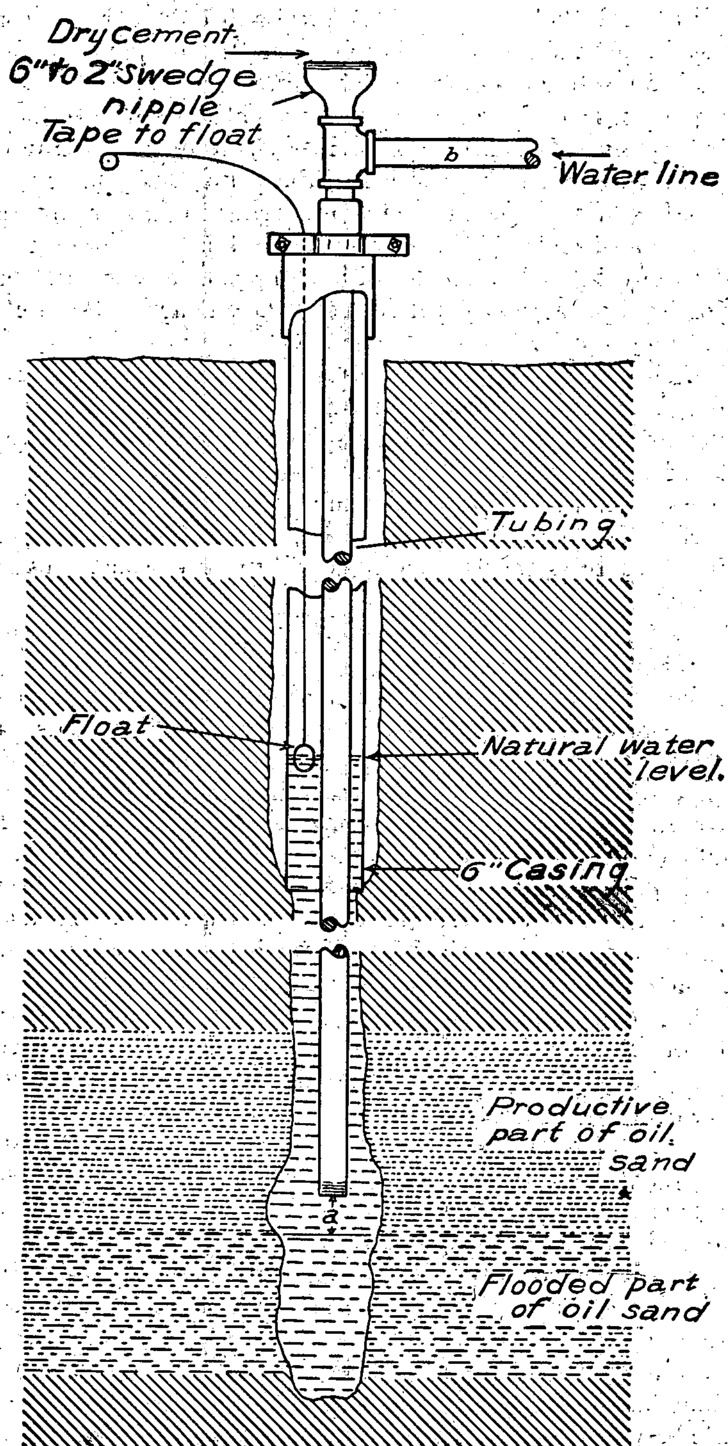


FIGURE 5.—Well being cemented by McDonald process.

the well until the bottom end is 2 to 4 feet above the plane of contact between the oil and the water-bearing part of the sand. This distance is designated *a* in figure 4. Determination of the exact situation of this plane may be difficult or even impossible. If the well has been shot into water, this difficulty is obviously simplified. In any event the operator estimates the position of the plane, taking care to keep on the safe side the first time, and preferring to make a low rather than a high estimate. If insufficient cement is used, more may be added at any time; but if the oil-bearing part of the sand be entirely or partly plugged off with cement, the damage to the well may be difficult to repair.

Tubing is commonly inserted with a wooden plug in the bottom to exclude oil. The plug may be knocked out either by exerting pressure on the column of water in the tubing or by running in a couple of sucker rods on a line. Further experimentation may show that the water run down the tubing before cementing, as later described, will rinse the tubing sufficiently free of oil to prevent any ill effect from it, thus perhaps making the wooden plug unnecessary.

If necessary, the tubing may be set over to one side of the hole to afford room for the float that is run on a steel measuring line. After the plug has been knocked out of the tubing and the natural fluid level of the hole measured, water, preferably fresh, is run or if necessary pumped into the tubing through the connection shown at *b* (fig. 4). This water will run away into the water sand. As the water runs down the tubing, dry cement is sprinkled into the 2 to 6 inch swage nipple, serving as a funnel, on top of the tubing. The cement is put in slowly, a handful at a time, at such a rate that one sack of cement will be placed per hour. Ordinarily two to four sacks of cement is sufficient for the job. Water is, of course, kept continually running down the tubing as the cement is added.

As the water runs away into the sand, the cement particles are caught in the interstices between the grains. The action is identical with that of a sand filter. As the voids become more and more clogged with cement, greater and greater pressure is required to force the water into the sand. Consequently the fluid level in the hole is correspondingly raised. When the level has reached about 500 feet above normal, no more cement is put in, and the flow of water is maintained only long enough to flush all cement out of the tubing. This done, it may be advisable to pull out a joint or two of tubing to preclude any possibility of the cement setting around the bottom of the string.

The water level is then allowed to settle back to a point 15 or 20 feet above the normal for the hole. The object is to obtain a close balance between the fluid pressures on either side of the cement with a slight advantage in favor of the internal pressure as a precaution against any tendency there may be of the underground water forcing the cement back into the hole or causing sufficient agitation to keep it from setting. This status is maintained for about 24 hours by keeping a man at the well who runs in water in order to maintain the fluid level. Then the cement is allowed to set for a week or 10 days and the job is tested by pumping. If not enough cement has been used, the entire operation may be repeated as often as may be necessary to extend the plug up to the desired point in the hole. A time-saving variation is to run a small bob on a measuring line inside the tubing as soon as the cement has set firmly enough that its level may be detected with the bob and line. Then if insufficient cement has been used, more may be added without further delay.

In this process the cement fills the interstitial spaces and crevices in the water sand for some distance from the hole, in addition to forming a solid plug in the lower part of the hole. The process has marked advantages over merely filling the bottom of the hole with liquid cement.

Question may arise as to why the cement does not enter and collect in the pores of the oil-bearing parts of the sand, clogging them also. The explanation lies partly in the relative specific gravities of the water, cement, and oil, but chiefly in all probability in the immiscibility of water and oil, which naturally repel each other. Whatever the reason may be, the fact that the cement-bearing water selects the water-bearing part of the sand has been so thoroughly established for the Illinois conditions by Mr. McDonald's work that this phase of the problem need not deter a prospective user of the process. This statement applies only when the operator takes precautions to avoid the use of too much cement, which would, of course, plug off the oil as well as the water.

After the cement has set on such a job, to pump the water out of the oil sand and bring the oil back into the well may require several days, or a week.

USE OF LEAD PLUGS OR LEAD WOOL FOR SHUTTING OFF BOTTOM WATER IN A WELL.

In many parts of the Mid-Continent and eastern fields good use has been made of lead plugs for shutting off bottom waters where a strong, unshattered, and impervious stratum exists between the oil and the water sands. Lead billets or lead wool may be used. Before the lead is inserted the hole is plugged up to or bridged at the point where the lead is to be used. Wool is usually introduced in small bundles and tamped on top of the bridge or plug. Perhaps 200 to 500 pounds of lead wool will be thus used in a well, each bundle being firmly tamped before the next is placed.

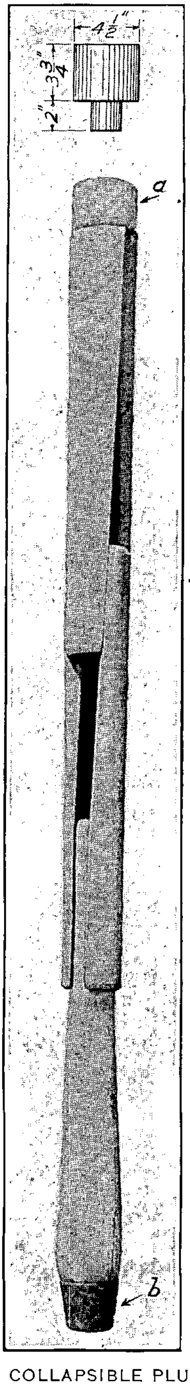
There are many ways of manipulating the billet form of plug, two types of which are shown in Plate XX. The type shown in Plate XX, *A*, has a collapsible wooden base, which is held together by thin wire nails. This base is protected at the bottom by a tapered iron ferrule and is capped by the lead billet. When this plug is introduced into the casing and tamped with the tools on an obstruction such as the bridge, the wooden base telescopes, and, owing to the batter of its members, clearly shown in the plate, spreads to a firm hold on the side of the hole, thus increasing the strength of the bridge and affording a base on which to commence pounding the lead. The plug illustrated is to run inside a $5\frac{3}{16}$-inch hole. The other plug consists of a hollow cylinder of lead 3 or 4 feet long and of suitable diameter for the hole, with a tapered cast-steel mandrel. When in place the lead cylinder is expanded against the wall of the hole by driving the mandrel down into it with the tools. As shown in the plate, the mandrel is cast with a mill set to eliminate any chance, however small, of the mandrel working up out of the plug. This type of plug has a much larger effective bearing on the wall of the hole than that previously described, but is also more expensive, owing to the larger quantity of lead used. Neither type has as good an opportunity to fill an irregular-shaped hole as the lead wool. The chief advantage of the lead plug is the short time required to plug off bottom water when it is used. Moreover, no time is lost waiting for cement to set, as in the cementing methods.

Obviously a lead plug should not be used in soft formations, no matter how impervious they may be.

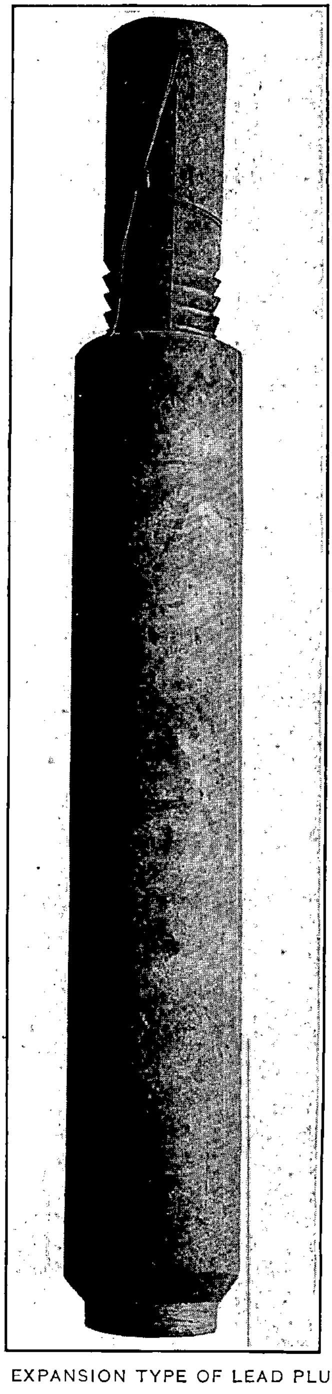
It is the opinion of the writer that in most wells the use of a concrete plug and perhaps some burned-wire line, as described under California practice, has a far better chance to be effective, as a cement plug will readily take the exact shape of a shattered or irregularly shaped hole. On the other hand, the stratum may be of such a character that a lead plug will not form an effective seal. In other words, it is not advisable to assume that underground conditions of an undeterminable character are favorable.

WATER PROBLEMS OF THE GULF OIL FIELDS.

In the oil fields of the Gulf coast of the United States cable tools are used only for redrilling, or perhaps for small deepening jobs. Practically all drilling is done by the rotary system. The physical characteristics of the formations penetrated are in a general way similar to those of the formations in the California fields. In both localities the drill penetrates poorly consolidated interbedded shales, clays, and sands, which offer comparatively little resistance to drilling. The chief difference between the formations of the two sections



A. COLLAPSIBLE PLUG.
a, Lead billet; *b*, iron ferrule.



B. EXPANSION TYPE OF LEAD PLUG.

as regards drilling is that in the Gulf fields there are fewer hard, thick streaks or "shells," as they are commonly called, usually consisting of sandstone and impure limestone. Also, in the Gulf fields the shales constitute a much smaller and the clays a greater proportion of the strata penetrated than in California and usually give less trouble from caving.

NEED OF KNOWLEDGE OF SUBSURFACE GEOLOGY BASED ON COMPLETE WELL LOGS.

Although the value of the rotary system of drilling has been fully demonstrated in Texas and Louisiana, as well as in parts of California, the rotary system has one serious drawback, in that with this system it is difficult to determine with exactitude the character of the formations penetrated. Stated differently, the driller when drilling in a rotary hole filled with mud fluid is more likely to pass through a good oil sand and record it as sandy shale showing colors of oil than when cable tools are being used without mud and with the casing carried close to the bottom of the hole. Doubtless many drillers will disagree with this statement, but it has been rather generally accepted by those equally familiar with both methods of drilling.

In the Midway field of California, where rotary tools and cable tools have been used side by side, this feature has become well recognized. In that field oil sands have been penetrated with the rotary drill and have been recorded as sandy shale showing colors of oil and passed as unprofitable, the formation later delivering 500 to 1,000 barrels of oil a day for a long period of time. Such an instance was recently reported from the early drilling in this field. A company about to abandon an old well that had been drilled with a rotary drill tested an upper showing that had been cased off when the well was sunk. The result was a large yield of oil.

When rotary drills are used, difficulty is experienced in correlating strata in adjacent wells so as to set the various water strings in the same stratum to prevent water from migrating into productive strata.[a]

Under these conditions there is, of course, all the more necessity for careful and detailed geological work. In this connection two facts should be recognized.

First. The permanency of a driller's employment depends largely on his sustaining a reputation as a "hole maker." That is what he is paid for, and if he does not make the hole some one else will. Therefore his interest naturally centers around this feature of his

[a] For further discussion of conformable water shut-offs, see McMurray, W. F., and Lewis, J. O., Underground waste in oil and gas fields and methods of prevention: Tech. Paper 130, Bureau of Mines, 1916, 28 pp.

work, and the nature of the material drilled is of secondary importance except when it shows considerable gas or oil. This statement is not intended to belittle the importance of the driller's log, for in such work he is the eye of the geologist. The geologist should learn from the driller as much as possible about drilling methods so that he may properly interpret the logs and know what value can be placed on various samples.

Second. The geologist or engineer must maintain an intimate first-hand acquaintance with the drilling wells and must be so equipped that he can wash many of the samples at the well. He should obtain the driller's opinion not only of the material itself but as to how likely it is to be fairly representative of the part of the hole from which it is supposed to come. The driller, the geologist, and the company that employs them will profit by such cooperation. This is no idealist's dream but represents everyday practice in the mining of metallic as well as nonmetallic deposits, including oil. Nowhere in the United States do the natural conditions demand such work more urgently than in the Gulf fields. This is true not merely because it is difficult to obtain accurate samples with the rotary method of drilling, which experience has demonstrated is best suited for the local conditions, but because the chief oil-bearing strata of the district are covered by an overlap and do not come to the surface.[a] Their existence is proven entirely by the drill. Since all estimates as to the character, distribution, and continuity of beds of such prime economic importance is dependent on data obtained from well drilling, the utmost care should be used in obtaining all the information possible by proper sampling, and all data so obtained should be recorded and disseminated among operators for their mutual benefit.

Some companies operating in the Gulf fields have very efficient geological departments that are giving careful attention to such detailed technical work.

It has also been reported that some experimentation is in progress to develop a device that will pick up an accurate sample of formation from a rotary hole. This is a move in the right direction, and if such a device is perfected it should be of great value to the industry wherever rotary drilling is used.

Figure 6 shows a set of typical conditions assumed to illustrate the erroneous conception that may be formed of underground conditions if drilling data are incomplete, and the resulting economic loss.

View *A* is assumed to show the actual sequence of stratification. Well 1 is shown penetrating the water sand, but the log made no mention of it, although by good fortune the water string was landed

[a] Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, 1903, p. 23.

below it, and the well proved a good producer from the oil sand beneath. Well 2 was drilled by a neighboring operator who had been given as complete a log of well 1 as was in existence. However,

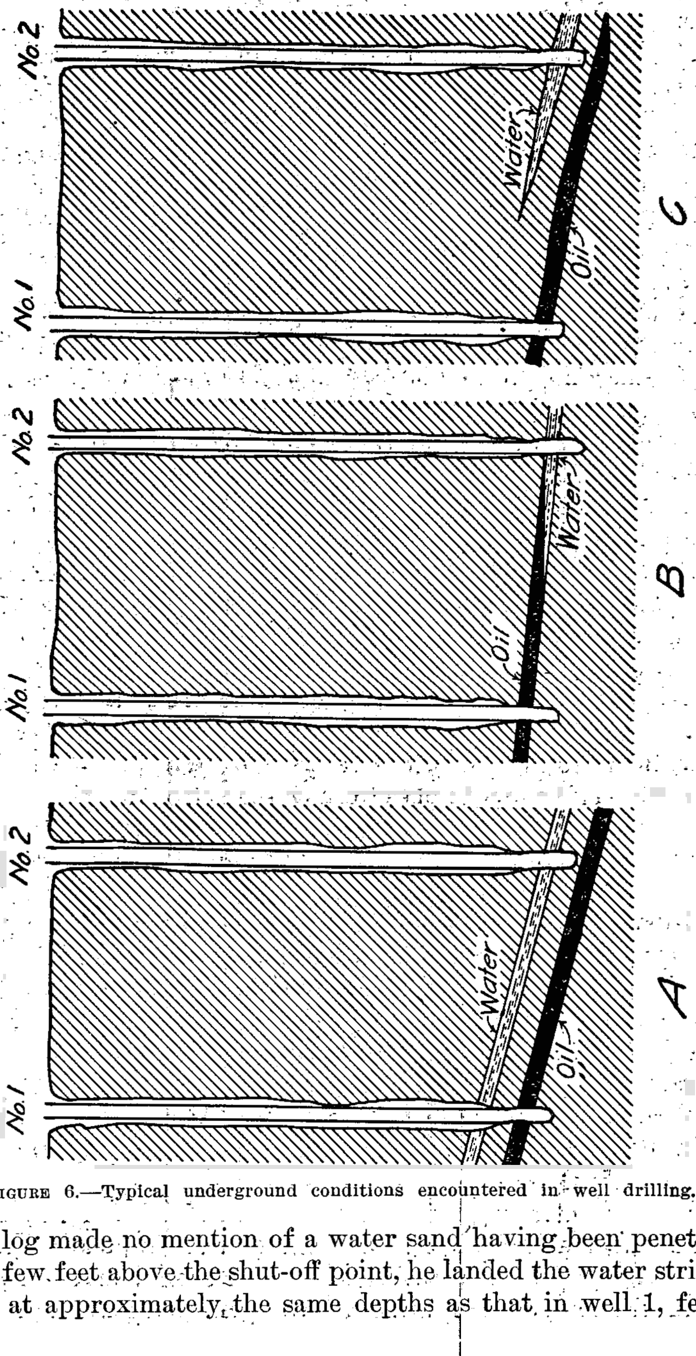


FIGURE 6.—Typical underground conditions encountered in well drilling.

as the log made no mention of a water sand having been penetrated only a few feet above the shut-off point, he landed the water string in well 2 at approximately the same depths as that in well 1, feeling perfectly safe as the log of well 1 showed no sand of any kind for a couple of hundred feet above the oil sand.

The water sand in well 2, owing to its position just below the shut-off point where the oil sand was expected, might excusably be misinterpreted as indicating either an edgewater condition, as shown in *B*, or a lenticular condition, as shown in *C* of the figure. If lenticular conditions happened to be considered probable, further drilling in well 2 might tap the oil sand, exposing it to the ingress of the water above and occasioning a costly repair job or the abandonment of the well. For reasons stated later, the use of the bootleg to shut off water is not considered advisable practice, and it is therefore not suggested as an available method of procedure under these circumstances.

If the water in the water sand was not detected when penetrated by well 2 and the oil and gas commenced flowing when the productive sand was encountered, another set of conditions would arise. The internal gas pressure in the well might hold or support the mud plastered over the water sand, thus temporarily excluding the water from the well. After a period of perhaps a week, or even more, the pressure would decrease and the water enter the well. The gross production might remain approximately the same, but the net oil production would be greatly diminished. As the oil and water sprayed into the atmosphere together there would be great danger of their becoming emulsified. Moreover, the water would probably soon spread through the oil sand and flood out well 1 also. If this happened the true underground conditions would probably never become known.

This illustration might be varied to fit many types of conditions, but the details given will suffice to show the actual financial loss that may be occasioned by an incompletely kept log of the formations above those containing the gas or oil. The loss of money as well as of otherwise recoverable oil unfortunately is not as fully realized as if the preventability of the loss were more generally recognized. Such losses are considered preventable, as had the water sand in well 1 been recorded, drilling in well 2 would have been continued with utmost caution, perhaps at the cost of a little time, until the water sand had been passed before the water string was set.

The writer does not wish to leave the impression that in his opinion lenticular conditions do not exist in the Gulf fields, but rather that through lack of data they may be assumed to exist more frequently than is the case.

An inherent advantage of the rotary system of drilling over ordinary cable-tool drilling has greatly reduced the injurious effect on a field from unsystematic casing of wells. The advantage referred to is that the rotary hole is automatically plastered with mud during the drilling, and the annular space between the wall of the hole and the casing is left filled with mud fluid when the water string is set, thus tending to prevent intermingling and dissipation of the contents of various sands above the point where the casing is set. To a great extent throughout the Gulf fields water strings are landed in sticky clay or gumbo.

Cementing of the water strings is practiced more in the fields of Louisiana than in those of Texas. The cement is usually placed by the casing method with one or two plugs, and although the work is in general executed similarly to that described in the section on California practice, there are many differences in detail. In Louisiana practice the second plug is usually a cylindrical piece of wood, about 18 inches long and of ½ inch smaller diameter than the casing through which it is to work. To the bottom of this plug is nailed a wooden leg 2 inches by 4 inches by 3 or 4 feet long. On the top of the plug is nailed a disk of rubber belting which snugly fits the inside of the casing. In addition, four or five cement sacks are wadded on top of the belt rubber to act as packing. The first plug, when one is used, consists of a sack of shale cuttings twisted or rolled to fit the size of the pipe.

When circulation of the mud around the casing has been obtained and everything is in readiness for the cementing, the pipe is set on bottom and several stands of the 4-inch drill pipe, closed at the lower end, are lowered into the hole, thus displacing sufficient mud fluid to make room for the cement. The first plug, if used, is introduced and the cement is run in on top of it. The upper plug is placed on top of the cement, the pump connections are made to the casing, and the mud pumps are started after the casing has been lifted a foot or 18 inches off bottom. The cement is mixed with clean sand, in a ratio of two parts of cement to one of sand. The mixture, having a mushy consistency, is poured into the casing through a spout from the mixing box on the derrick floor. This feature is very different from the practice in California where no sand is used for this type of work, and the cement is mixed with water to such a consistency that it may be picked up by suction and pumped into the casing. Also it is not advisable in California to permit the full weight of the casing to set on the botton for any considerable length of time, as the pipe will probably freeze if allowed to set long enough to displace the fluid with the drill pipe. In Louisiana practice, the regular drilling mud is used through the pumps to force the cement mixture down the casing. Such a procedure requires considerably less pump pressure than if clear water were used, owing to the greater specific gravity of the mud. Of course the mud can not be put through a meter, and no measurement is made of the amount used. The end point of the job is determined entirely by the action of the pumps when the leg of the plug reaches the bottom of the hole. If everything has gone right the pumps will stall when the plug reaches bottom, and the casing is then set immediately. If there is any trouble, causing the plug to hang up in the casing, it is pushed to bottom with drill pipe which is, of course, standing in the derrick.

The circumstance most likely to cause trouble on such a job is a cave-in of the hole, which will shut off circulation. As in the Gulf fields the formations penetrated usually stand up well in a rotary-drilled hole, this danger is reduced to a minimum, making the system as used highly satisfactory for that locality. In cementing a string of 6-inch casing of, say, 2,500 feet it is customary to use about 25 sacks of cement and 12 sacks of sand. By the use of sand a greater volume of cementing material is obtained with comparatively small increase in cost, and without seriously reducing its strength, although, of course, such a mixture does not have the strength of neat cement.[a] If sand is to be used in this sort of a job, the mixture should be rather thick or mushy, as in a thin mixture the sand tends to settle to the bottom of the slug of cement as it passes down the pipe, and thus prevent the uniform distribution of sand and cement around the outside of the casing.

"BOOTLEG-PACKER" SYSTEM.

Although effort is made to set the water string in a suitable stratum between the lowest upper water and the first oil sand, this is not always accomplished; and as 6-inch pipe is customarily used for water string in 2,000-foot or 2,500-feet territory, such a failure becomes serious. It would probably be difficult, if not impossible, in many wells to loosen such a string of casing even were it landed without cementing, and to set or cement the string of 4½-inch casing would permit nothing larger than 3-inch pipe in the sands, thus restricting the size of the hole to an inconveniently small diameter. To obviate such a condition the "bootleg" has been devised and is often used, but is not recommended.

The "bootleg" (fig. 7) is made of canvas or leather riveted or sewed into the shape of an upturned truncated cone with the smaller end the same size as the exterior of the string of pipe on which it is to rest. The upper end is larger, so as to rest against the wall of the hole, but must, of course, be small enough to collapse and pass through the next larger pipe shown as of 6-inch diameter in the figure. The bottom of the "bootleg" is fastened with wire wrapping

[a] Humphrey, R. I., and Jordan, William, jr., Portland cement mortars and their constituent materials, results of tests made at the structural materials testing laboratories, Forest Park, St. Louis, Mo.: U. S. Geol. Survey Bull. 331, 1908, pp. 56–79.

to the $4\frac{1}{2}$-inch casing just above a coupling and is placed at such a point on the string that it will set in a stratum of gumbo when the pipe rests on the bottom. The gumbo must, of course, be below the

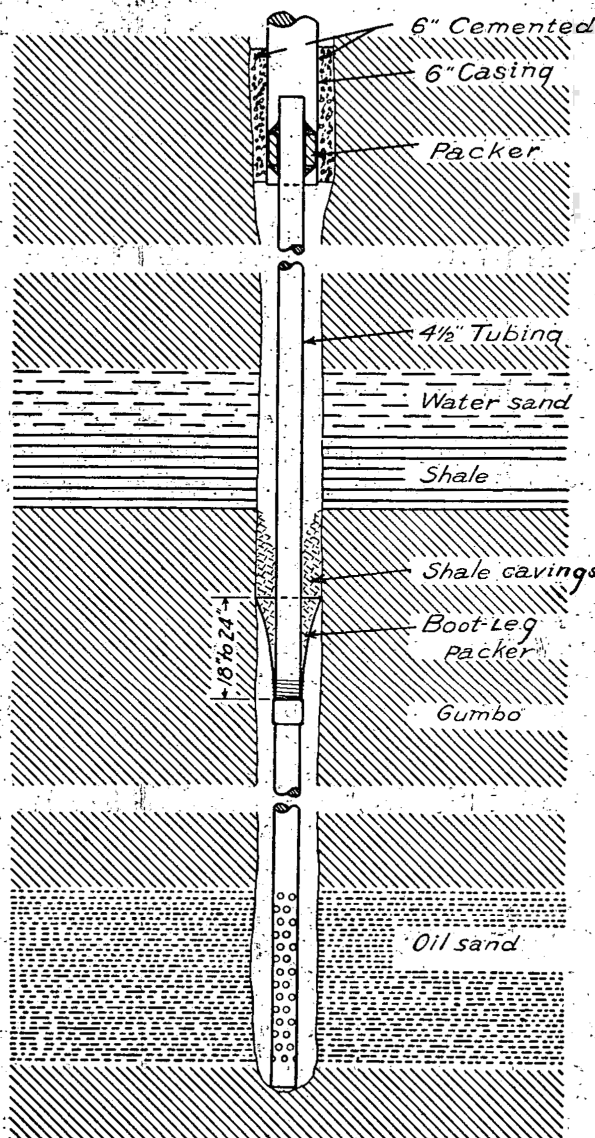


FIGURE 7.—"Bootleg" packer. Packer is made of canvas or leather sewed or riveted.

water sand, and ideal conditions require a bed of shale above the gumbo to furnish the requisite cavings.

The shale cuttings and mud are expected to settle around the "bootleg" from above and make a tight joint between the casing and the gumbo. The action is similar to starting a bridge in a hole by using a forked stick. Neither the bootleg nor the forked stick hold any considerable weight; merely enough to arrest the settling of débris until the latter commences to bridge. Sometimes in order to save casing the inner string, shown as of 4½ inch diameter in the figure, is fitted with a packer to set in the bottom joint of the 6-inch pipe. The upper part of the 4½-inch string is then backed off at a left-hand nipple above the packer and pulled out.

Of course, a "bootleg" job should be tested as far as possible, but a thoroughly satisfactory test is not possible. If the well is pumped and brought in as a clean producer, then the "bootleg" has probably been successful; but if some water comes with the oil there is always a doubt as to whether the "bootleg" is leaking or whether the water is encroaching on the oil sands, or whether it is working around the 4½ to 6 inch packer, and the very nature of the device precludes testing its effectiveness before drilling into the oil-bearing strata. No matter which way the water gains access to the well, the string with the "bootleg" on it must be pulled out. Then either another "bootleg" must be tried or the 4½-inch string must be set as a water string, which is by far the preferable method.

When water has not been properly shut off it sometimes shows immediately, but even then the well is usually pumped for a while with the hope that cuttings will settle around the "bootleg" and make a successful job. On the other hand, if the well has sufficient gas pressure to hold back the inflow of water temporarily, several days or weeks may elapse before the gas pressure is dissipated sufficiently to permit the ingress of water. The water will then probably make its appearance in the form of emulsion. At this stage of the well's life water on the sands is more serious than before the gas pressure is dissipated, because the sands will take more water and will not have the expelling force of the gas to remove it when the repair work has been completed.

To pull the 4½-inch string may or may not be possible according to the amount of friction on the string and other factors. Even if the 4½-inch string is loosened, it can not be removed without letting the mud from behind it into the oil sands, which are, as stated, in a most receptive condition and will probably never relinquish all of the mud and water thus admitted. Such results will not always follow the use of a "bootleg." There are doubtless walls in which water is shut off with such a device now producing in the Gulf coast fields after a long period of activity, never having shown any serious volume of water. Nevertheless, when a company attempts to use a "bootleg" it takes a chance of spoiling valuable property and diminishing the gross oil recovered from it, merely to make a comparatively small saving in first cost.

METHODS USED IN GULF FIELDS FOR PLUGGING OFF WATER SAND IN BOTTOM OF WELL.

An effective method of placing concrete for a bottom-hole job is the use of cement sacks. The concrete must be mixed to a thick consistency and the sack rolled in at the edge to form a canvas cylinder of such a size that it will slide freely in the casing. The sacks of concrete are pushed to the bottom and tamped into place with the tools. The process is continued until the plug is brought to the desired point. The precautions of properly cleaning the hole before work is commenced, described in the section on California practice, should be taken. If reinforcement is desired, burned-wire line may be used at intervals throughout the plug.

A successful plug has been built by using only the sacks from which cement has been dumped but not shaken, thus leaving some cement adhering to the inside of the sacks and retained in the fiber of the fabric. Six or eight sacks are wadded into a bundle and pushed down the casing with the tools and finally tamped to bottom with a string of free casing. The plug is thus built up, and when complete is held in place not only by friction but also by the weight of the casing which is set upon it. Only a few such jobs have been reported, but all of these have been successful.

SUMMARY.

Suggestions offered herein for handling the water conditions of the Gulf fields may be summarized as follows:

1. No effort should be spared to obtain as complete a log of each well as possible. A detailed knowledge of the three or four hundred feet of formation overlying the productive measures is far more important as a guide to subsequent drilling than a mere knowledge of the characteristics of the oil sands themselves.

2. Drilling data should be freely exchanged among neighboring operators.

3. If it be determined to get nothing smaller than a $4\frac{1}{2}$-inch casing into the pay sands, an 8-inch water string should be set; then the 6-inch string may be used as a water string if the 8-inch pipe fails to exclude all the water. Moreover, the entire string of pipe, used for excluding water, should be left in the well. The upper part of a water string should never be cut off or otherwise removed from an active well. It may be recovered when the well is to be abandoned, if the hole is properly plugged.

The insurance against damage to the well and the property by leaving the entire water string in is worth many times the interest on the money tied up in the extra string of pipe.

ENFORCEMENT OF WATER PROTECTIVE LEGISLATION.

Another desirable feature not discussed in the foregoing text is the enforcement of adequate legislation regarding water protection, as an operator naturally hesitates to execute expensive work on his wells for precautionary measures without some guaranty that his neighbors will maintain their wells in an equally good condition. As a prerequisite to such legislation, the majority of operators must be alive to the exigencies of the situation and cooperate to inform the legislature of their needs and to assist it in drafting legislation. It is probable that the cost of effectively enforcing such a law would have to be met by a tax levied on the industry benefited.

Such work under the proper State department has several advantages. Every operator is held to a like character of work. A small company that can not afford to maintain a competent engineering department has the benefit of such a department by the payment of a comparatively small tax adjusted on an equitable basis according to the size of the company and its operations, a tax which it can easily afford and will usually be entirely willing to pay.

Finally, a few "standpatters" who are so constituted by nature that they assume a reactionary attitude toward all progress are forced to safeguard their own wells and property for their own protection and the public good.

CALIFORNIA LAWS RELATING TO OIL AND GAS WELLS.

California laws relating to the protection of natural resources of petroleum and natural gas flow:

AN ACT Establishing and creating a department of the State mining bureau for the protection of the natural resources of petroleum and gas from waste and destruction through improper operations in production; providing for the appointment of a State oil and gas supervisor, prescribing his duties and power, fixing his compensation; providing for the appointment of deputies and employees, providing for their duties and compensation; providing for the inspection of petroleum and gas wells; requiring all persons operating petroleum and gas wells to make certain reports; providing procedure for arbitration of department rulings; creating a fund for the purposes of the act; providing for assessment of charges to be paid by operators and providing for the collection thereof; and making an appropriation for the purposes of this act.

[Approved June 10, 1915. Amended 1917. Chapter 759.]

The people of the State of California do enact as follows:

Establishment of department—Appointment of supervisor.

SECTION 1. A separate department of the State mining bureau is hereby established and created to be known as the department of petroleum and gas. Such department shall be under the general jurisdiction of the State mineralogist. He shall appoint a supervisor who shall be a competent engineer or geologist, experienced in the development and production of petroleum, and who shall be designated the "State oil and gas supervisor," and whose term of office shall be four years from and after the date of his appointment.

Appointment of assistants—Compensation.

SEC. 2. For his services in the general supervision of said department the State mineralogist shall receive as compensation $1,400 annually, which shall be in addition to his compensation fixed in section 2 of the act of June 16, 1913, relating to the State mining bureau. The secretary of the State mining bureau shall receive for his services in connection with the department of petroleum and gas a sum not to exceed $600 annually, which sum shall be in addition to his compensation paid from the funds of the State mining bureau.

The supervisor shall receive an annual salary of $6,000, and shall be allowed his necessary traveling expenses. The State mineralogist may, at the request of the State oil and gas supervisor, and subject to the civil-service laws of the State, appoint one chief clerk at a salary of not to exceed $1,800 annually; twelve office assistants or stenographers, each at a salary not to exceed $1,200 annually; four geological draftsmen, each at a salary not to exceed $1,500 annually; four petroleum engineers, each at a salary not to exceed $2,400 annually; twelve inspectors, each at a salary not to exceed $1,800 annually.

The additional salary herein authorized to be paid to the State mineralogist and the secretary of the State mining bureau, and the salaries of the supervisor and of the deputies, clerks, stenographers, assistants, and other employees, shall be paid out of the funds hereinafter provided for at the times and in the manner that salaries of other State officers and employees are paid.

Duties of supervisor.

SEC. 3. It shall be the duty of the State oil and gas supervisor so to supervise the drilling, operation, and maintenance and abandonment of petroleum or gas wells in the State of California as to prevent, as far as possible, damage to underground petroleum and gas deposits from infiltrating water and other causes and loss of petroleum and natural gas.

Appointment of deputies and attorney.

SEC. 4. It shall be the duty of the State oil and gas supervisor to appoint one chief deputy and five field deputies, one for each of the districts hereinafter provided for, and prescribe their duties and fix their compensation, which shall not exceed $4,000 per annum for the chief deputy and not to exceed $3,600 per annum for each field deputy. Such deputies shall serve during the pleasure of the supervisor. He shall also employ an attorney at a compensation not exceeding $3,000 per year, payable out of said fund, who shall also be attorney for each district board of commissioners; such commissioners may allow additional compensation to such attorney in actual litigation. The supervisor, the deputies, and the attorney shall not be subject to the civil-service act.

Duties of deputies.

SEC. 5. Each deputy appointed by the supervisor shall be a competent engineer or geologist, experienced in the development and production of petroleum. At the time said deputy is appointed, notice of such appointment shall be transmitted in writing to the board of commissioners of the district for which said deputy is appointed. Said notice shall be given either personally or by mailing a notice of said appointment to the post-office address of each commissioner. No appointment shall be final until a period of 10 days shall have elapsed from the mailing of said notice to said commissioners. In the event the majority of the commissioners notify said oil and gas supervisor in writing before the expiration of 10 days from the date of said notice that the appointment of said field deputy is disapproved by them, then and in that event said field deputy shall not be appointed, but said oil and gas supervisor must appoint some other individual, as in this section provided. Each field deputy shall maintain an office in the district for which he is appointed, convenient of access to the petroleum and gas operators therein. The office shall be open and the deputy shall be present at certain specified times, which shall be posted at such office.

SEC. 6. It shall be the duty of each deputy to collect all necessary information regarding the oil wells in the district, with a view to determining the presence and source of water in the oil sand, and to make all maps and other accessories necessary to determine the presence and source of water in the oil sands. This work shall be done with the view to advising the operators as to the best means of protecting the oil and gas sands, and with a view to aiding the supervisor in ordering tests or repair work at wells. All such data shall be kept on file in the office of the deputy oil and gas supervisor of the respective district.

Records and their use.

SEC. 7. The records of any and all operators, when filed with the deputy supervisor as hereinafter provided, shall be open to inspection to those authorized in writing by such operators, to the State officers, and to the board of commissioners hereinafter provided for. Such records shall in no case, other than those hereinafter and in this section provided, be available as evidence in court proceedings, and no officer or employee or member of any board of commissioners shall be allowed to give testimony as to the contents of said records, except at such court proceedings as are hereinafter provided for in the review of the decision of the State oil and gas supervisor, or a board of commissioners, or in any proceedings initiated for the enforcement of an order of the supervisor, or any proceeding initiated for the enforcement of a lien created by this act, or any proceeding for the collection of the assessment levied under and pursuant to the provisions of this act, or in criminal proceedings arising out of such records or the statements upon which they are based.

Orders by supervisor—Agents of operators.

SEC. 8. It shall be the duty of the supervisor to order such tests or remedial work as in his judgment are necessary to protect the petroleum and gas deposits from damage by underground water, to the best interests of the neighboring property owners and the public at large.

The order shall be in written form, signed by the supervisor, and shall be served upon the owner of the well, or the local agent appointed by such owner, either personally or by mailing a copy of said order to the post-office address given at the time the local agent is designated, or if no such local agent has been designated, by mailing a copy of said order to the last known post-office address of said owner, or if the owner be unknown by posting a copy of said order in a conspicuous place upon the property, and publishing the same in some newspaper of general circulation throughout the county in which said well is located, once a week for two successive weeks.

Said order shall specify the condition sought to be remedied and the work necessary to protect such deposits from damage from underground waters. For this purpose each operator or owner shall designate an agent, giving his post-office address, who resides within the county where the well or wells are located, upon whom all orders and notices provided for in this act may be served.

Rejection of supervisor's orders, and appeal.

SEC. 9. The well owner or his local agent may within ten days from the date of service of any order from the supervisor, file with the supervisor or his deputy in the district where the property is located, a statement that the supervisor's order is not acceptable and that appeal from said order is taken to the board of commissioners. Such appeal shall operate as a stay of any order issued under or pursuant to the provisions of this act.

Districts, commissioners, election, recall.

SEC. 10. For the purposes of this act the State shall be divided into five districts, as follows:

District No. 1, including the counties of Los Angeles, Riverside, Orange, San Diego, Imperial, and San Bernardino.

District No. 2, the county of Ventura.

District No. 3, including the counties of Santa Barbara, San Luis Obispo, Monterey, Santa Cruz, San Benito, Santa Clara, Contra Costa, San Mateo, Alameda, and San Francisco.

District No. 4, including the counties of Tulare, Inyo, and Kern.

District No. 5, including the counties of Fresno, Madera, Kings, Mono, Mariposa, Merced, and all other counties in California not included in any of said other districts.

There shall be elected at the times and in the manner hereinafter provided, district oil and gas commissioners for each such district, as follows:

For district number one, five; for district number two, five; for district number three, five; for district number four, seven; for distict number five, five.

Said district oil and gas commissioners shall be elected by vote of the companies, individuals, copartnerships, or associations, who shall have been assessed, and whose names shall appear on the last record of assessments (next preceding such election) for and on account of the fund in this act provided to be raised, within said districts respectively, said vote to be taken at a meeting to be held in each of said districts respectively, and on the third Monday in September of each year, such place and the time and details of such meeting to be fixed by the state oil and gas supervisor, and of which meeting at least two weeks previous notice shall have been given by letter addressed to each of said persons, corporations, copartnerships, and associations, entitled to vote as aforesaid, at his or its post-office address or principal place of business.

At said meeting each of those entitled to vote as herein provided may be represented by one person holding the written authority of such voter to act for him at such meeting.

At said meeting each voter shall be entitled to one vote for each member of the board of district oil and gas commissioners who are required to be selected for such district. In addition thereto, in each district in which five commissioners are to be elected, each voter shall be entitled, for each one hundred dollars, or fraction thereof, which said voter shall have paid in accordance with his last assessment hereunder, to cast one vote for the two commissioners who are elected for three years; and in each district in which seven commissioners are to be elected, each voter shall be entitled, for each one hundred dollars, or fraction thereof, which said voter shall have paid in accordance with his last assessment hereunder, to cast one vote for the three commissioners who are elected for three years. In all subsequent elections the qualification of voters in the election of a commissioner shall be the same as in the election of the commissioner whose successor in office is being elected.

Said meeting shall select by ballot, by a majority vote of the votes represented, the number of persons as hereinbefore specified to act as district oil and gas commissioners for such district.

In any district entitled to seven commissioners, two shall be chosen for a term of one year, two for two years, and three for three years. In any district entitled to five commissioners, one shall be chosen for a term of one year, two for two years, and two for three years.

The chairman and secretary of the meeting shall issue a written certificate to the State oil and gas supervisor, setting forth the result of such election, and the name and address of each of the persons elected at said meeting as the district oil and gas commissioners for said district and the term for which each has been elected. No person shall be eligible as a district oil and gas commissioner who is not a resident of the district for which he is elected, nor shall any person be eligible for such position who is not actually engaged in the business of oil or gas development or production, within the district.

Upon receipt of the certificate so made by the chairman and secretary of any such meeting, the state oil and gas supervisor shall issue a certificate of election to the respective persons in said certificate named as the district oil and gas commissioners for said district and for the periods of one, two, or three years from and after the first Monday in October, 1917, as shall be shown in such certificate, and until their respective successors shall have been elected.

Within thirty days after their appointment by the State oil and gas supervisor, the district oil and gas commissioners for each district shall meet at a time and place within the district to be designated by the State oil and gas supervisor, and shall thereupon select one of the number as chairman.

The deputy supervisor of the district shall be ex officio secretary of said board, and shall keep a record of its proceedings, and his office shall be the office of the commissioners.

Said commissioners shall serve without compensation, except their necessary traveling expenses. The traveling expenses of said commissioners and all actual expenses incurred by or under order of said commissioners in the hearing and determination and carrying out of orders appealed to them, shall be certified to said state supervisor, and when audited by him and by the State board of control shall be paid from said fund.

On the third Tuesday in September of each year at an hour and places in said respective districts to be fixed by the State oil and gas supervisor, and of which notices shall have been given as hereinbefore specified, the successor of each of the district oil and gas commissioners whose term of appointment shall expire that year, shall be elected and qualified in the manner and subject to the provisions hereinbefore set forth, and the term of each shall be for a period of three years from and after the first Monday in October next succeeding.

All, either, or any of the district oil and gas commissioners elected in any district may be recalled by the votes of a majority of the qualified votes of the district entitled to vote as to such commissioners respectively. In case there shall be filed in the office of the State oil and gas supervisor, a written petition, signed by not less than forty per cent of those entitled to vote as to the election of any commissioner or commissioners, asking the recall of such commissioner or commissioners, said State oil and gas supervisor shall, within ten days thereafter, order, and give notice of, a special election in such district to fill the office or offices of the commissioner or commissioners named in said petition for recall; and shall cause notice to be given of said election in the manner, and for the time required for regular election, and said notice shall fix the time and place of such election.

At such election, the commissioner or commissioners named in such petition for recall shall be voted upon as though candidates for election for the unexpired portion of the term for which they, respectively, were originally elected, and any other candidate or candidates may, at the same time, be voted upon. It shall require a majority of all the qualified votes entitled to vote for such commissioners, respectively, to constitute an election. In case less than a majority of all qualified votes shall be cast for any candidate, said recall shall be deemed to have failed as to the commissioner concerning whose office such vote was taken; and in case such commissioner himself shall receive a majority of the votes, said recall shall be deemed to have failed, and in either of such cases, such commissioner shall continue to serve until the expiration of his term as though no such special election had been held. But in case any person other than such commissioner shall receive a majority of the votes for such unexpired term, then such recall shall become effective and the office of the commissioner so recalled shall be vacant and upon written certificate of such election being filed with the State oil and gas supervisor, the person so chosen and elected for such unexpired term shall become the successor of the commissioner so recalled, and a certificate of his election for such unexpired term shall be issued and transmitted to him by the State oil and gas supervisor. And like proceedings shall be had in case more than one commissioner shall be included in said petition for recall.

In all recall elections qualifications for voters and the numbers of votes which they will be entitled to cast shall be the same as they respectively were in the election of the commissioner as to whom such recall election is being held.

In case of vacancy caused by the death, resignation, or removal from district or ceasing to be engaged in the business of development or production of oil or gas in the district as to the office of any commissioner, such vacancy shall be filled until the next annual election by the State oil and gas supervisor, who shall appoint to fill such vacancy an eligible person nominated in writing by the remaining commissioners of such district.

Upon any subject in which any commissioner is personally interested, or upon which any corporation, copartnership, association, or individual by whom he is employed is directly interested as a party, such commissioner shall not be entitled to sit or vote.

The board of commissioners shall be entitled to call upon the supervisor for advice and written report upon any matter referred to the board of commissioners, and the supervisor shall be entitled to call meetings of the commissioners at the office of the field supervisor upon five days' written notice to obtain their written advice upon any matters relating to his work within their district.

Complaint, investigation, and order.

SEC. 11. Upon receipt by the supervisor or deputy supervisor of a written complaint specifically setting forth the condition complained against, signed by a person, firm, corporation, or association owning land or operating wells within a radius of 1 mile of any well or group of wells complained against, or upon the written complaint specifically setting forth the condition complained against, signed by any one of the board of commissioners for the district in which said well or group of wells complained against is situated, the supervisor must make an investigation of said well or wells and render a written report, stating the work required to repair the damage complained of or stating that no work is required. A copy of said order must be delivered to the complainant, or if more than one each of said complainants, and if the supervisor order the damage repaired a copy of such order shall be delivered to each of the owners, operators, or agents having in charge the well or wells upon which the work is to be done. Said order shall contain a statement of the conditions sought to be remedied or repaired and a statement of the work required by the supervisor to repair such condition. Service of such copies shall be made by mailing to such persons at the post-office address given.

Testimony.

SEC. 12. In any proceeding before the board of commissioners as herein provided, or in any other proceeding or proceedings instituted by the supervisor for the purpose of enforcing or carrying out the provisions of this act, or for the purpose of holding an investigation to ascertain the condition of any well or wells complained of, or which in the opinion of the supervisor may reasonably be presumed to be improperly drilled, operated, maintained, or conducted, the supervisor and the chairman of the board of commissioners shall have the power to administer oaths and may apply to a judge of the superior court of the State of California in and for the county in which said proceedings or investigation is pending for a subpœna for witnesses to attend at said proceeding or investigation. Upon said application of said supervisor or said chairman of said board of commissioners said judge of said superior court must issue a subpœna directing said witness to attend said proceeding or investigation: *Provided, however,* That no person shall be required to attend upon such proceeding, either with or without such books, papers, documents, or accounts unless residing within the same county or within thirty miles of the place of attendance. But the supervisor or the chairman of the board of commissioners may in such case cause the deposition of witnesses residing within or without the State to be taken in the manner prescribed by law for like deposition in civil actions in superior courts of this State, and to that end may, upon application to a judge of the superior court of the county within which said proceeding or investigation is pending, obtain a subpœna compelling the attendance of witnesses and the production of books, papers, and documents at such places as he may designate within the limits hereinbefore prescribed. Witnesses shall be entitled to receive the fees and mileage fixed by law in civil causes payable from the fund hereinafter created. In case of failure or neglect on the part of any person to comply with any order of the supervisor as hereinbefore provided, or any subpœna, or upon the refusal of any witness to testify to any matter regarding which he may lawfully be interrogated, or upon refusal or neglect to appear and attend at any proceeding or hearing on the day specified, after having received a written notice of not less than ten days prior to such proceeding or hearing, or upon his failure, refusal, or neglect to produce books, papers, or documents as demanded in said order or subpœna upon such day, such failure, refusal, or neglect shall constitute a misdemeanor, and each day's further failure, refusal, or neglect shall be and be deemed to be a separate and distinct offense, and it is hereby made the duty of the district attorney of the county in which said proceeding, hearing, or investigation is to be held, to prosecute all persons guilty of violating this section by continuous prosecution until such person appears or attends or produces such books, papers, or documents or complies with said subpœna or order of the supervisor or chairman of the board of commissioners.

Final decision, and order by commissioners.

SEC. 13. Within ten days after hearing the evidence the board of commissioners must make a written decision with respect to the order appealed from, and in case the same is affirmed or modified, shall retain jurisdiction thereof until such time as the work ordered to be done by such order shall be finally completed. This written decision shall be served upon the owner or his agent and shall supersede the previous order of the supervisor. In case no written decision be made by said board of commissioners within thirty days after the date of notice by the supervisor as provided in section ten hereof the order of the supervisor shall be effective and subject only to review by writ of certiorari from the superior court as provided in section fourteen hereof.

Repair of wells by supervisor—Review by superior court.

SEC. 14. On or before thirty days after the date of serving an order of the supervisor, provided for in section eight hereof, or in case of appeal to the board of commissioners on or before thirty days after date of serving the decision of the board, as provided in sections twelve and thirteen hereof, or in the event review be taken of the order of the board of commissioners within ten days after affirmance of such order, the owner shall commence in good faith the work ordered and continue until completion. If the work has not been so commenced and continued to completion, the supervisor shall appoint agents as he deems necessary, who shall enter the premises and perform the work. Accurate account of such expenditures shall be kept and the amount paid from the fund hereinafter created upon the warrant of the State controller. Any amount so expended shall constitute a lien against the property upon which the work is done. The decision of the board of commissioners in such case may be reviewed by writ of certiorari from the superior court of the county in which the district is situated if taken within ten days after the service of the order upon said owner, operator, or agent of said owner or operator as herein provided, or within ten days after decision by the board of commissioners upon petitions by the supervisor. Such writ shall be made returnable not later than ten days after the issuance thereof and shall direct the district board of oil and gas commissioners to certify their record in the cause to such court. On the return day the cause shall be heard by the court unless for good cause the same be continued, but no continuance shall be permitted for a longer period than thirty days. No new or additional evidence shall be introduced in the court before the cause shall be heard upon the record of the district board of oil and gas commissioners. The review shall not be extended further than to determine whether or not

1. The commission acted without or in excess of its jurisdiction.
2. The order, decision, or award was procured by fraud.
3. The order, decision, rule, or regulation is unreasonable.
4. The order, decision, regulation, or award is clearly unsupported by the evidence.

If no review be taken within ten days, or if taken in case the decision of the board is affirmed, the lien upon the property shall be enforced in the same manner as the other liens on real property are enforced, and shall first be enforced against the owner of the well, against the operator and against the personal property and fixtures used in the construction or operation thereof, and then if there be any deficiency against the land upon which the work is done, upon the request of the supervisor, the State controller must in the manner provided in section forty-four of this act, bring an action for the enforcement of said lien.

Casing—Water shut-off.

SEC. 15. It shall be the duty of the owner of any well now drilled, or that may be drilled in the State of California, on lands producing or reasonably presumed to contain petroleum or gas, to properly case such well or wells with metal casing, in accordance with methods approved by the supervisor, and to use every effort and endeavor in accordance with the most approved methods to effecutally shut off all water overlying or underlying the oil or gas-bearing strata, and to effectually prevent any water from penetrating such oil or gas-bearing strata.

Whenever it appears to the supervisor that any water is penetrating oil or gas-bearing strata, he may order a test of water shut-off and designate a day upon which the same shall be held. Said order shall be in written form and served upon the owner of said well at least ten days prior to the day designated in said order as the day upon which said shut-off test shall be held. Upon the receipt of such order it shall be the duty of the owner to hold said test in the manner and at the time prescribed in said order.

Abandonment of well.

SEC. 16. It shall be the duty of the owner of any well referred to in this act, before abandoning the same, or before removing the rig, derrick, or other operating structure therefrom, or removing any portion of the casing therefrom, to use every effort and endeavor in accordance with methods approved by the supervisor, to shut off and exclude all water from entering oil-bearing strata encountered in the well. Before any well is abandoned the owner shall give written notice to the supervisor, or his local deputy, of his intention to abandon such well and of his intention to remove the derrick or any portion of the casing from such well and the date upon which such work of abandonment or removal shall begin. The notice shall be given to the supervisor, or his local deputy, at least five days before such proposed abandonment or removal. The owner shall furnish the supervisor, or his deputy with such information as he may request showing the condition of the well and proposed method of abandonment or removal. The supervisor, or his deputy, shall, before the proposed date of abandonment or removal, furnish the owner with a written order of approval of his proposal or a written order stating what work will be necessary before approval, to abandon or remove will be given. If the supervisor shall fail within the specified time to give the owner a written order such failure shall be considered as an approval of the owner's proposal to abandon the well, or to remove the rig or casing therefrom.

Commencement of drilling.

SEC. 17. The owner or operator of any well referred to in this act shall, before commencing the work of drilling an oil or gas well, file with the supervisor, or his local deputy, a written notice of intention to commence drilling. Such notice shall also contain the following information: (1) Statement of location and elevation above sea level of the floor of the propsed derrick and drill rig; (2) the number or other designation by which such well shall be known, which number or designation shall not be changed after filing the notice provided for in this section, without the written consent of the supervisor being obtained therefor; (3) the owner's or operator's estimate of the depth of the point at which water will be shut off, together with the method by which such shut-off is intended to be made and the size and weight of casing to be used; (4) the owner's or operators' estimate of the depth at which oil or gas-producing sand or formation will be encountered.

After the completion of any well the provisions of this section shall also apply, as far as may be, to the deepening or redrilling of any well, or any operation involving the plugging of any well or any operations permanently altering in any manner the casing of any well: *And provided further*, That the number or designation by which any well heretofore drilled has been known, shall not be changed without first obtaining a written consent of the supervisor.

Log of well—Prospect well.

SEC. 18. It shall be the duty of the owner or operator of any well referred to in this act to keep a careful and accurate log of the drilling of such well, such log to show the character and depth of the formation passed through or encountered in the drilling of such well, and particularly to show the location and depth of the water-bearing strata, together with the character of the water encountered from time to time (so far as ascertained) and to show at what point such water was shut off, if at all, and if not, to so state in such log, and show completely the amounts, kinds, and size of casing used, and show the depth at which oil-bearing strata are encountered, the depth and character of same, and whether all water overlying and underlying such oil-bearing strata was successfully and permanently shut off so as to prevent the percolation or penetration into such oil-bearing strata; such log shall be kept in the local office of the owner or operator, and together with the tour reports of said owner or operator, shall be subject, during business hours, to the inspection of the supervisor, or any of his deputies, or any of the commissioners of the district, except in the case of a prospect well as hereinafter defined. Upon the completion of any well, or upon the suspension of operations upon any well, for a period of six months if it be a prospect well, or for thirty days, if it be in proven territory, a copy of said log in duplicate, and in such form as the supervisor may direct, shall be filed within ten days after such completion, or after the expiration of said thirty-day period, with the field supervisor, and a like copy shall be filed upon the completion of any additional work in the deepening of any such well.

The State oil and gas supervisor shall determine and designate what wells are prospect wells within the meaning of this act and no reports shall be required from such prospect wells until six months after the completion thereof.

The owner or operator of any well drilled previous to the enactment of this act shall furnish to the supervisor or his deputy a complete and correct log in duplicate and in such form as the supervisor may direct, or his deputy, of such well, so far as may be possible, together with a statement of the present condition of said well.

Test of shut-off.

SEC. 19. It shall be the duty of the owner or operator of any well referred to in this act to notify the deputy supervisor of the time at which the owner or operator shall test the shut-off of water in any such well. Such notice shall be given at least five days before such test. The deputy supervisor or an inspector designated by the supervisor shall be present at such test and shall render a report in writing of the result thereof to the supervisor, a duplicate of which shall be delivered to the owner. If any test shall be unsatisfactory to the supervisor he shall so notify the owner or operator in said report and shall, within five days after the completion of such test, order additional tests of such work as he deems necessary to properly shut off the water in such well and in such order shall designate a day upon which the owner or operator shall again test the shut off of water in any such well, which day may, upon the application of the owner, be changed from time to time in the discretion of the deputy supervisor.

Production reports.

SEC. 20. It shall be the duty of every person, association, or corporation producing oil in the State of California to file with the supervisor, at his request, but not oftener than once in each month, a statement showing amount of oil produced during the period indicated from each well, together with its gravity and the amount of water produced from each well, estimated in accordance with methods approved by the supervisor, and the number of days during which fluid was produced from each well, the number of wells drilling, producing, idle, or abandoned, owned or operated by said person, association, or corporation: *Provided,* That upon request and satisfactory showing a longer interval may be fixed by the State oil and gas supervisor as to such reports in the case of any specific owner or operator.

This information shall be in such form as the supervisor may designate.

Penalty.

SEC. 21. Any owner or operator of a well referred to in this act, or employee thereof, who refuses to permit the supervisor or his deputy to inspect the same, or who willfully hinders or delays the enforcement of this act, and every person, firm, or corporation who violates any provision of this act, is guilty of a misdemeanor and shall be punishable by a fine of not less than $100 or by imprisonment in the county jail for not less than thirty days, or by both such fine and imprisonment.

Police power of the State.

SEC. 21*a*. The charges hereinafter provided for are directed to be levied by the State of California as necessary in the exercise of its police power and to provide a means by which to supervise and protect deposits of petroleum and gas within the State of California, in which deposits the people of the State of California are hereby declared to have a primary and supreme interest.

Charges assessed.

SEC. 22. Charges levied, assessed, and collected as hereinafter provided upon the properties of every person, firm, corporation, or association operating any well or wells for the production of petroleum in this State, or operating any well or wells for the production of natural gas in this State, which gas wells are situate on lands situate within two miles, as near as may be, of any petroleum or gas well the production of which is chargeable under this act, shall be used exclusively for the support and maintenance of the department of petroleum and gas hereinbefore created, and shall be assessed and levied by the State mineralogist and collected in the manner hereinafter provided.

Charges on oil.

SEC. 23. Every person, firm, corporation, or association operating any petroleum well or wells in this State shall annually pay a charge to the State treasurer at a uniform rate per barrel of petroleum produced for the preceding calendar year at the time and in the manner hereinafter provided, based upon a verified report as herein provided.

Charges on gas.

SEC. 24. Every person, firm, corporation, or association operating any gas well or wells in this State shall annually pay a charge to the State treasurer based upon the amount of gas sold in the preceding calendar year, at a fixed rate per thousand cubic feet, at the times and in the manner hereinafter provided, based upon a verified report as herein provided.

Charges on land.

SEC. 25. Every person, firm, corporation, or association owning any oil land, as determined by the supervisor, shall annually pay a charge to the State treasurer at the time and in the manner hereinatfer provided, which charge shall be a uniform rate per acre. Said charge shall be based upon a verified report as provided herein: *Provided, however*, That such lands so assessed shall not be called upon to pay more than one-tenth of the total charges or moneys proposed to be assessed, levied, and collected under the provisions of this act for any one year.

SEC. 26. The charges assessed, levied, and to be collected under the provisions of this act shall be in addition to any and all charges, taxes, assessments, or licenses of any kind or nature paid by or upon the properties assessed hereunder.

Annual financial estimate.

SEC. 27. The State mineralogist shall annually, on or before the first Monday in March, acting in conjunction with the State board of control, make an estimate of the amount of moneys which shall be required to carry out the provisions of this act.

At the time of making such estimate the State mineralogist shall report to the State board of control the amount of money in the petroleum and gas fund on the day such estimate is made, less the amount of money necessary for the support of the department of petroleum and gas for the remainder of the fiscal year, and the amount of such estimate shall in no event exceed the difference between the amount thus determined as remaining in the petroleum and gas fund at the end of the fiscal year and the sum of $150,000.

Annual reports by owners.

SEC. 28. The State mineralogist shall prescribe the form and contents of all reports for making the charge or other purposes to carry out the intent and provision of this act, which form shall be mailed in duplicate to the person, firm, corporation, or association owning property or assessed under the provisions of this act.

SEC. 29. Every person, firm, corporation, or association chargeable under the provisions of this act shall, within ten days after the first Monday in March of each year, report to and file with the State mineralogist a report, in such form as said officer may prescribe, giving any and all items of information as may be demanded by said report and necessary to carry out the provisions of this act, which report shall be verified by such person or officer as the State mineralogist may designate.

SEC. 30. If any person, firm, corporation, or association chargeable under the provisions of this act shall fail or refuse to furnish the State mineralogist within the time prescribed in this act the verified report provided for in this act, the State mineralogist must note such failure or refusal in the record of assessments hereinafter in this act provided for, and must make an estimate of the petroleum or gas production or landed area to be assessed of any such person, firm, corporation, or association, and must assess the same at the amount thus estimated and compute the charge thereon, which assessment and charge shall be the assessment and charge for such year. And if in the succeeding year any such person, firm, corporation, or association shall again fail and refuse to furnish the verified report required by this act, the State mineralogist shall make an estimate as aforesaid, which estimate shall not be less than twice the amount of the estimate made by him for the previous year, and shall note such failure or refusal as above provided, and the said estimate so made shall be the assessment or charge for said year. In case of each succeeding consecutive failure or refusal the said State mineralogist shall follow the same procedure until a true statement or report shall be furnished.

Penalty.

SEC. 31. Any person, firm, corporation, or association failing or refusing to make or furnish any report which may be required pursuant to the provisions of this act, or who wilfully renders a false or fraudulent report, shall be guilty of a misdemeanor and subject to a fine of not less than $300 nor more than $1,000, or by imprisonment in the county jail not exceeding six months, or both such fine and imprisonment for each such offense.

Extension date for filing reports.

SEC. 32. The State mineralogist may, for good cause shown, by order entered upon his minutes, extend for not exceeding thirty days the time fixed in this act for filing any report herein provided for.

Rate of assessment.

SEC. 33. On or before the third Monday before the first Monday in July of each year the State mineralogist shall determine the rate or rates which shall produce the sums necessary to be raised as provided in section twenty-seven of this act. Within the same time the said State mineralogist shall extend into the proper column of the record of assessments hereinafter provided for, the amount of charges due from each person, firm, corporation, or association.

SEC. 34. Between the first Monday in March and the third Monday before the first Monday in July in each year, the State mineralogist must assess and levy the charges as and in the manner provided for in this act. The assessments must be made to the person, firm, corporation, or association owning or operating the property subject to assessement hereunder on the first Monday in March. If the name of the owner is unknown to the State mineralogist, such assessment must be made to unknown owners. Clerical errors occurring or appearing in the name of any person, firm, corporation, or association whose property is properly assessed and charged, or in the making or extension of any assessment or charge upon the records which do not affect the substantial rights of the payer, shall not invalidate the assessment or charge.

Equalization.

SEC. 35. The State mineralogist and the chairman of the State board of control and the chairman of the State board of equalization shall constitute a board of review, correction, and equilization, and shall have all the powers and perform such duties as usually devolve upon a county board of equalization under the provisions of section three thousand six hundred and seventy-two of the Political Code. The State mineralogist shall act as secretary of said board and shall keep an accurate minute of the proceedings thereof. Said board of review, correction, and equalization shall meet at the State capitol on the third Monday before the first Monday in July of each year and remain in session from day to day until the first Monday in July for the purpose of carrying out the provisions of this section.

Publication of assessment notice.

SEC. 36. On the third Monday before the first Monday in July of each year the State mineralogist shall cause to be published a notice, one or more times, in a daily, or weekly, or semiweekly newspaper of general circulation published in the counties of Fresno, Kern, Los Angeles, Orange, Ventura, and Santa Barbara and such other counties as may contain lands or produce oil or gas charged under and pursuant to the terms and provisions of this act, if one be published therein, otherwise in a newspaper of general circulation published in the county nearest to such county designated herein in which no such paper is published, that the assessment of property and levy of charges under and in pursuance of this act has been completed and that the records of assessments containing the charges due will be delivered to the State controller on the first Monday in July, and that if any person, firm, corporation, or association is dissatisfied with the assessment made or charge fixed by the State mineralogist he or it may, at any time before said first Monday in July, apply to said board of review, correction, and equalization to have the same corrected in any particular. The said board shall have the power at any time before said first Monday in July to correct the record of assessments and may increase or decrease any assessment or charge therein if in its judgment the evidence presented or obtained warrants such action. Costs of such publication in any county shall be paid from the petroleum and gas fund: *Provided, however*, That the omission to publish said notice as hereinbefore and in this section provided shall not affect the validity of any assessment levied under or pursuant to the provisions of this act.

Record of assessment.

SEC. 37. The State mineralogist must prepare each year a book in one or more volumes, to be called the "Record of assessments and charges for the petroleum and gas fund," in which must be entered, either in writing or printing, or both writing and printing, each assessment and levy or charge made by him upon the property provided to be assessed and charged under this act, describing the property assessed, and such assessments may be classified and entered in such separate parts of said record as said State mineralogist shall prescribe.

SEC. 38. On the first Monday in July the State mineralogist must deliver to the State controller the record of assessments and charges for the petroleum and gas fund, certified to by said State mineralogist, which certificate shall be substantially as follows: "I, ______, State mineralogist, do hereby certify that between the first Monday in March and the first Monday in July, 19____, I made diligent inquiry and examination to ascertain all property and persons, firms, corporations, and associations subject to assessment for the purpose of the petroleum and gas fund as required by the provisions of the act of legislature approved June 10, 1915, providing for the assessment and collection of charges for oil protection; that I have faithfully complied with all the duties imposed upon me by law; that I have not imposed any unjust or double assessment through malice or ill will or otherwise; nor allowed any person, firm, corporation, or association or property to escape a just assessment or charge through favor or regard or otherwise." But the failure to subscribe such certificate to such record of assessments and charges for oil protection, or any certificate, shall not in any manner affect the validity of any assessment or charge.

Payment of charges.

SEC. 39. The charges levied and assessed under the provisions of this act shall be due and payable on the first Monday in July in each year, and one-half thereof shall be delinquent on the sixth Monday after the first Monday in July at six o'clock p. m. and unless paid prior thereto fifteen per cent shall be added to the amount thereof, and unless paid prior to the first Monday in February next thereafter at six o'clock p. m. an additional five per cent shall be added to the amount thereof, and the unpaid portion, or the remaining one-half of said charges, shall become delinquent on the first Monday in February next succeeding the day upon which they become due and payable, at six o'clock p. m.; and if not paid prior thereto five per cent shall be added to the amount thereof.

Publication of notice of payments due.

SEC. 40. Within ten days after the receipt of the record of assessments and charges for oil protection the State controller must begin the publication of a notice to appear daily for five days in one daily newspaper of general circulation published in each of the counties of Fresno, Kern, Los Angeles, Orange, Ventura, and Santa Barbara and such other counties as may contain lands or produce oil or gas charged under or pursuant to the terms and provisions of this act, if one be published therein; otherwise, for at least two times in a weekly or semiweekly paper of general circulation published therein, or if there be neither a daily nor weekly nor semiweekly paper of general circulation published in any one of such counties, then the publication of the notice for such county shall be made in a similar manner in a newspaper of general circulation published in the county nearest such county, specifying: (1) That he has received from the State mineralogist the record of assessments and charges for oil protection; (2) that the charges therein assessed and levied are due and payable on the first Monday in July and that one-half thereof will be delinquent on the sixth Monday after the first Monday in July at six o'clock p. m., and that unless paid to the State treasurer at the capital prior thereto, fifteen per cent will be added to the amount thereof, and unless paid prior to the first Monday in February next thereafter at six o'clock p. m. an additional five per cent will be added to the amount thereof, and that the remaining one-half of said charges will become delinquent on the first Monday in February next succeeding the day upon which they become due and payable, at six o'clock p. m., and if not paid to the State treasurer at the capital prior thereto five per cent will be added to the amount thereof. Costs of such publication in any county shall be paid from the petroleum and gas fund.

Charges become lien.

SEC. 41. The assessments and charges levied under the provisions of this act shall constitute a lien upon all the property of every kind and nature belonging to the persons, firms, corporations, and associations assessed under the provisions hereof, which lien shall attach on the first Monday in March of each year. Such lien shall be enforced and said charges collected by an action by the State controller as provided in section 44 of this act.

Charges payable to treasurer.

SEC. 42. All charges assessed and levied under the provisions of this act shall be paid to the State treasurer upon the order of the State controller. The controller must mark the date of payment of any charge on the record of assessments for the petroleum and gas fund and shall give a receipt for such payment in such form as the controller may prescribe. Errors appearing upon the face of any assessment on said records of assessments or over charges may be corrected by the controller by and with the consent of the State board of control, in such manner and at such time as said controller and said board shall agree upon.

Protest of charges.

SEC. 43. Any person, firm, corporation, or association claiming and protesting as herein provided that the assessment made or charges assessed against him or it by the State mineralogist is void, in whole or in part, may bring an action against the State treasurer for the recovery of the whole or any part of such charges, penalties or costs paid on such assessment, upon the grounds stated in said protest, but no action may be brought later than the third Monday in February next following the day upon which the charges were due, nor unless such person, firm, corporation, or association shall have filed with the State controller at the time of payment of such charges, a written protest stating whether the whole assessment or charge is claimed to be void, or if a part only, what part, and the grounds upon which such claim is founded, and when so paid under protest the payment shall in no case be regarded as voluntary.

Whenever, under the provisions of this section, an action is commenced against the State treasurer, a copy of the complaint and of the summons must be served upon the treasurer, or his deputy. At the time the treasurer demurs or answers, he may demand that the action be tried in the superior court of the county of Sacramento, which demand must be granted. The attorney employed by the State oil and gas supervisor must defend such action: *Provided, however*, the said mineralogist may at the request of the said oil and gas supervisor employ additional counsel, the expense of which employment shall be paid from the petroleum and gas fund. The provisions of the Code of Civil Procedure relating to pleadings, proofs, trials, and appeals are applicable to the proceedings herein provided for.

A failure to be in such action within the time herein specified shall be a bar against the recovery of such charges. In any such action the court shall have the power to render judgment for the plaintiff for any part or portion of the charge, penalties, or costs found to be void and so paid by plaintiff upon such assessment.

Delinquent charges.

SEC. 44. The State controller shall, on or before the thirtieth day of May next following the delinquency of any charge as provided in this act, bring an action in a court of competent jurisdiction, in the name of the people of the State of California, in the county in which the property assessed is situated, to collect any delinquent charges or assessments, together with any penalties or costs, which have not been paid in accordance with the provisions of this act and appearing delinquent upon the records of assessments and charges for the petroleum and gas fund in this action provided for.

The attorney for the State oil and gas supervisor shall commence and prosecute such action to final judgment and the provisions of the Code of Civil Procedure relating to service of summons, pleadings, proofs, trials, and appeals are applicable to the proceedings herein provided for. The State mineralogist may employ additional counsel to assist the attorney for the State oil and gas supervisor, and the expense of such employment shall be paid from the petroleum and gas fund.

Payments of the penalties and charges, or amount of the judgment recovered in such action must be made to the State treasurer. In such actions the record of assessment and charges for oil protection, or a copy of so much thereof as is applicable in said action, duly certified by the controller showing unpaid charges against any person, firm, corporation, or association assessed by the

State mineralogist is prima facie evidence of the assessment upon the property, the delinquency, the amount of charges, penalties, and costs due and unpaid to the State, and that the person, firm, corporation, or association is indebted to the people of the State of California in the amount of charges and penalties therein appearing unpaid and that all the forms of law in relation to the assessment of such charges have been complied with.

First assessment March, 1916.

SEC. 45. The first assessment under the provisions of this act shall be as of the first Monday in March, nineteen hundred sixteen, and the reports of petroleum production and sales of gas herein provided to be assessed shall be reported for the calendar year ending December thirty-first, nineteen hundred fifteen. The lands herein provided to be assessed and charged shall be assessed to the owners thereof as of the first Monday in March, nineteen hundred sixteen.

Disposal of funds.

SEC. 46. All the moneys heretofore paid to the State treasurer under or pursuant to the provisions of this act and deposited to the credit of the oil protection fund, shall be withdrawn from said fund, which is hereby abolished, and deposited to the credit of the petroleum and gas fund which is hereby created. All of the moneys hereafter paid to the State treasurer under or pursuant to the provisions of this act shall be deposited to the credit of the petroleum and gas fund. All moneys in such fund shall be expended under the direction of the State mineralogist, drawn from such fund for the purpose of this act upon warrants drawn by the controller of the State, upon demands made by the State mineralogist, and audited by the State board of control. Of the moneys in said petroleum and gas fund, when such action has been authorized by the State board of control, the State mining bureau may withdraw, without at the time furnishing vouchers and itemized statements, a sum not to exceed $500, said sum so drawn to be used as a revolving fund where cash advances are necessary. At the close of each fiscal year, or at any other time, upon demand of the board of control, the moneys so drawn shall be accounted for and substantiated by vouchers and itemized statements submitted to and audited by the board of control.

SEC. 47. All moneys received in repayment of repair work done under the order and direction of the supervisor as hereinbefore provided, shall be returned and credited to the petroleum and gas fund.

Annual report by supervisor.

SEC. 48. On or before the first day of October of each and every year the supervisor shall submit a report in writing to the State mineralogist showing the total number of barrels of petroleum produced in each county in the State during the previous calendar year, together with the total cost of said department for the previous fiscal year and the net amount remaining in the petroleum and gas fund available for the succeeding fiscal year's expense, also the total amount delinquent and uncollected from any assessments or charges levied under or pursuant to the provisions of this act. Such report shall also include such other information as the supervisor may deem advisable. The State mineralogist shall make public such statements promptly after receipt of the same from the supervisor for the benefit of all parties interested therein.

Recording of leases.

SEC. 49. The owner or operator of any lands or tenements subject to assessment under this act shall, within six months after this act goes into effect, file with the supervisor a certificate which shall contain the names of all the parties claiming an interest in or to said lands and full description of the property and the names of all parties in interest where such interest is held by lease, license, or assignment.

Definitions.

SEC. 50. Whenever the term "supervisor" is used in this act it shall be taken to mean the "State oil and gas supervisor"; the term "oil" shall include petroleum"; the term "petroleum" shall include "oil"; the term "gas" shall mean natural gas coming from the earth; the term "operator" shall mean any person, firm, or corporation drilling, maintaining, operating, pumping, or in control of a well in any territory which the supervisor determines to be oil or gas producing territory; the term "owner" shall include "operator" when any oil or gas well is operated or has been operated or is about to be operated by any person, firm, or corporation other than the owner thereof; and the term "operator" shall include "owner" when any such well is or has been or is about to be operated by or under the direction of the owner, except that all the provisions of this act relating to assessments for the purposes of this act based upon the annual production of oil or petroleum or sale of gas, as set forth in sections twenty-two to forty-five, inclusive, of this act, shall apply only to a person, firm, or corporation operating an oil or petroleum or gas well, and shall not apply to the owner of such well if some person, firm, or corporation other than such owner has been actually operating the well during the whole period for which such annual charge is made, but in the event that the actual operation of any such well changes hands during such period the charge shall be apportioned upon the basis of the oil or petroleum or gas produced, and the lien provided for in section forty-one of this act shall be a lien against the property of each and all such operators.

Appropriation first year.

SEC. 51. There is hereby appropriated out of any moneys in the State treasury not otherwise appropriated the sum of $20,000, which said sum shall be immediately transferred by the State controller on the books of his office from the general fund to the "oil-protection fund" created by section forty-six of this act.

The above-mentioned fund shall be available for the uses of the State mineralogist for the maintenance of the department of petroleum and gas and for the necessary expenses of the controller in carrying out the provisions of this act. When the collections paid to the State treasurer, as herein provided, equal the sum of $30,000, then said sum of $20,000 shall be retransferred from the oil-production fund to the general fund. The moneys received into the State treasury through the provisions of this act are hereby appropriated for the uses and purposes herein specified.

Constitutionality.

SEC. 52. If any section, subsection, sentence, clause, or phrase of this act is for any reason held to be unconstitutional, such decision shall not affect the validity of the remaining portions of this act. The legislature hereby declares that it would have passed this act, and each section, subsection, sentence, clause, and phrase thereof, irrespective of the fact that any one or more other sections, subsections, sentences, clauses, or phrases be declared unconstitutional.

Incorporated cities.

SEC. 53. This act shall be liberally construed to meet its purposes, and the supervisor shall have all powers which may be necessary to carry out the purposes of this act, but the provisions of this act shall not apply to any land or wells situated within the boundaries of an incorporated city where the drilling of oil wells is prohibited.

Repeal of previous law.

SEC. 54. That certain act entitled "An act to prevent injury to oil, gas, or petroleum bearing strata or formations by the penetration or infiltration of water therein," approved March 20, 1909, together with all acts amendatory thereof and supplemental thereto and all acts in conflict herewith, are hereby repealed. Nothing herein shall be construed as affecting the provisions of the act of June 16, 1913, establishing a State mining bureau.

TO PREVENT WASTING OF NATURAL GAS.

AN ACT Prohibiting the unnecessary wasting of natural gas into the atmosphere; providing for the capping or otherwise closing of wells from which natural gas flows; and providing penalties for violating the provisions of this act.

[Approved March 25, 1911.]

The people of the State of California, represented in senate and assembly, do enact as follows:

SECTION 1. All persons, firms, corporations, and associations are hereby prohibited from willfully permitting any natural gas wastefully to escape into the atmosphere.

SEC. 2. All persons, firms, corporations, or associations digging, drilling, excavating, constructing, or owning or controlling any well from which natural gas flows shall upon the abandonment of such well, cap or otherwise close the mouth of or entrance to the same in such a manner as to prevent the unnecessary or wasteful escape into the atmosphere of such natural gas. And no person, firm, corporation, or association owning or controlling land in which such well or wells are situated shall willfully permit natural gas flowing from such well or wells wastefully or unnecessarily to escape into the atmosphere.

SEC. 3. Any person, firm, corporation, or association who shall willfully violate any of the provisions of this act shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punished by a fine of not more than $1,000 or by imprisonment in the county jail for not more than one year, or by both such fine and imprisonment.

SEC. 4. For the purposes of this act each day during which natural gas shall be willfully allowed wastefully or unnecessarily to escape into the atmosphere shall be deemed a separate and distinct violation of this act.

SEC. 5. All acts or parts of acts in conflict herewith are hereby repealed.

SEC. 6. This act shall take effect immediately.

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PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

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