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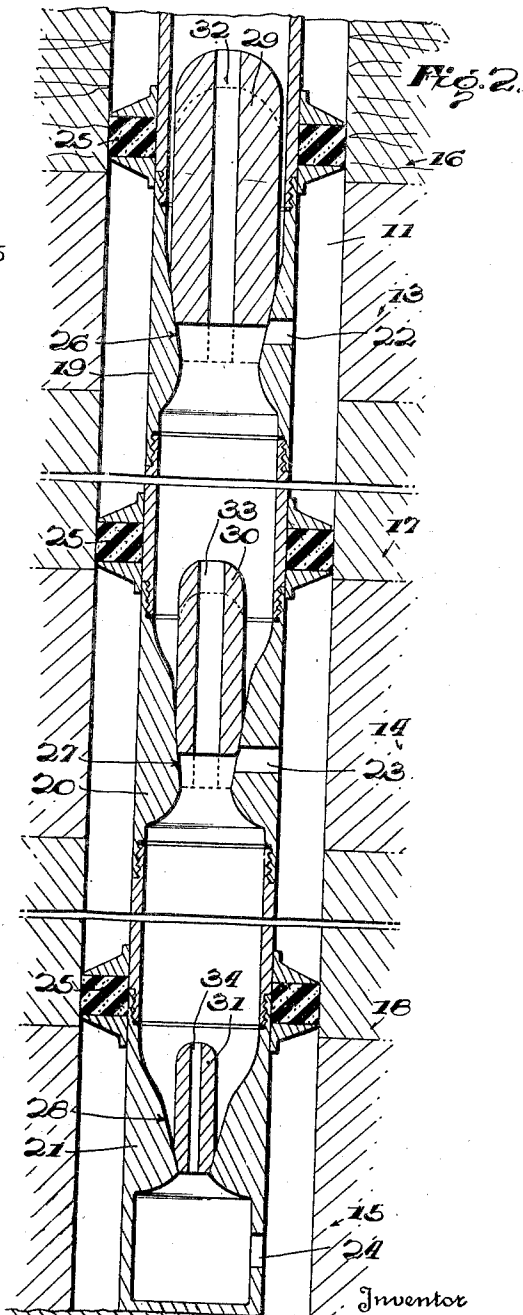
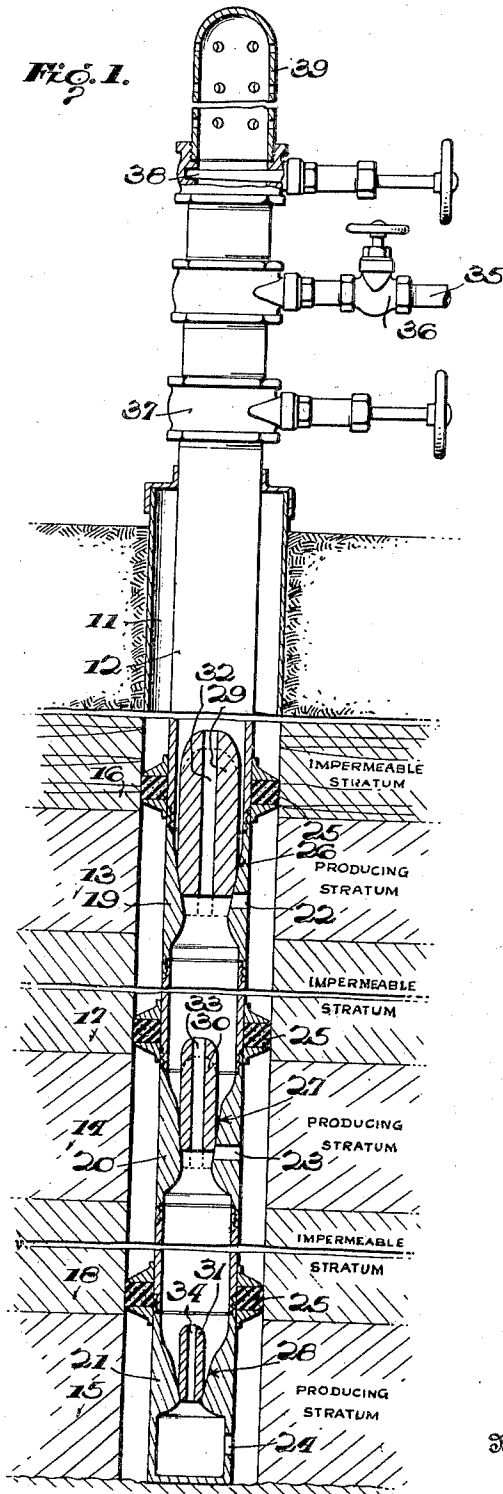
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APPARATUS FOR FLOWING WELLS

Filed Oct. 24, 1939

2 Sheets-Sheet 1



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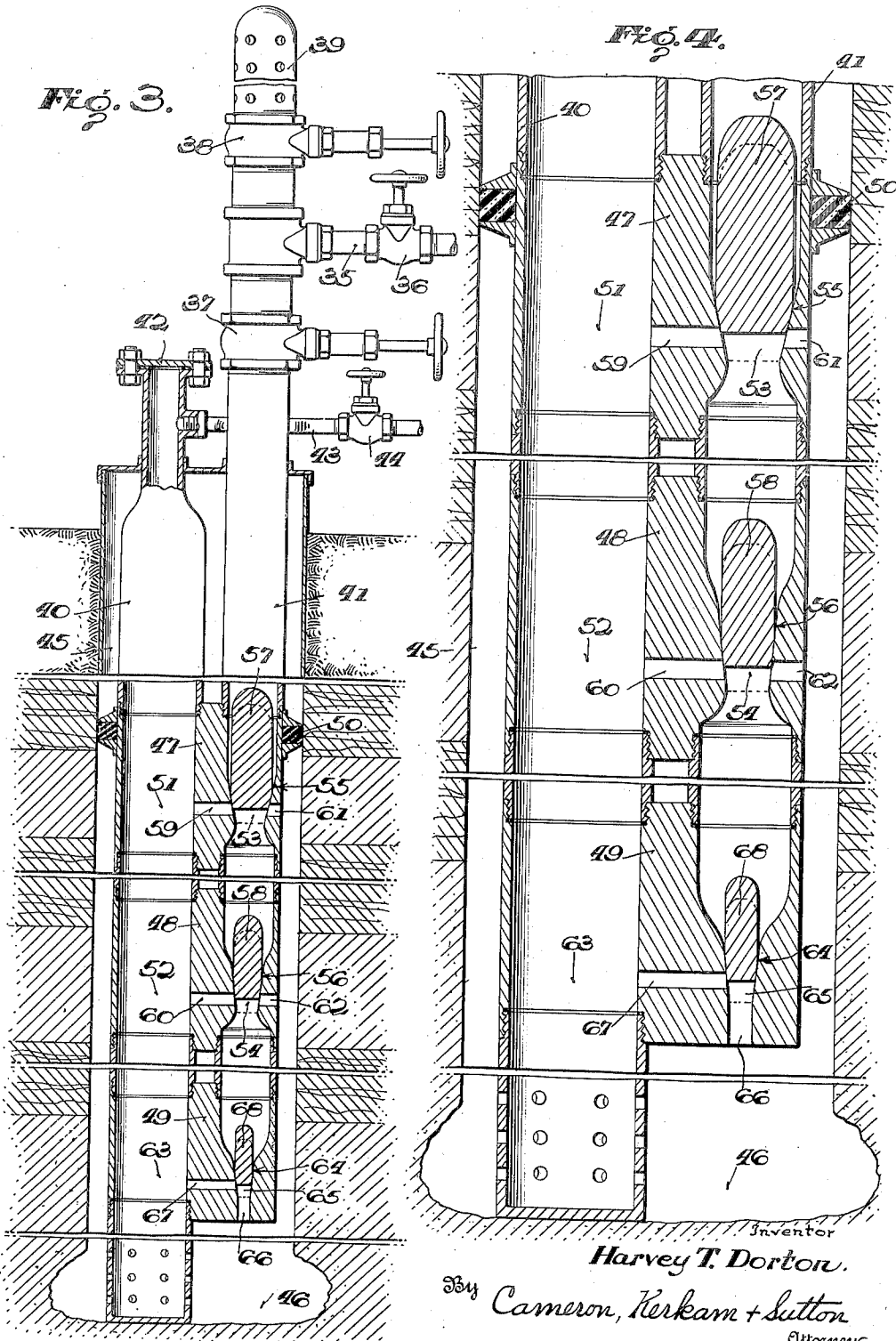
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APPARATUS FOR FLOWING WELLS

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14 Claims. (Cl. 166—2)

This invention relates to the control of fluid flow in gas and oil wells, and more particularly to methods and apparatus for selectively controlling and measuring the injection of gas or other fluid into a plurality of different strata of an oil producing sand for the purpose of artificially stimulating the recovery of oil therefrom, and for also controlling the flow of oil and gas from a producing well by the use of a series of vertically spaced ports in the well tubing which it is desired to selectively vary in effective size or completely close as the flowing progresses.

In repressuring oil producing sands by the injection of gas from a pressure well, it has been found that the permeability of the sand varies greatly in different strata, and that a materially different pressure may be required for the injection of the desired volume of gas into one stratum than is required for another. Inasmuch as it would not be economical to maintain a series of gas compressors or reservoirs discharging at different pressures into a multiplicity of strings of tubing leading to the different strata, it has heretofore been the practice to control the pressure of the gas injected by the use of pressure reducing restrictions in the tubing.

It has been found, however, that when such restriction are installed at the well heads, it is practically impossible to maintain a continuous flow of gas into a well when the atmospheric temperature is at or near freezing, without the application of heat in some form, because the expansion of the gas in passing through a flow restricting orifice reduces its temperature to a point where any liquid entrained in the gas or otherwise present at the orifice quickly freezes and clogs the latter. To avoid this difficulty, it has been proposed to install such restrictions in the well tubing at points sufficiently far below the surface of the ground to insure that the temperature of the expanded gas remains above freezing. The difficulty with this arrangement, however, is that whenever it becomes necessary to change the size of a restricting orifice—and this is a more or less frequent occurrence because of the continually changing conditions in the sand during well operation—either the entire tubing string must be removed from the well to enable replacement of the orifice fitting, or the latter must be elevated inside the tubing and another fitting lowered into place by the use of suitable tools. Both of these procedures are time consuming and occasion the loss of substantial quantities of gas because of the necessity for blowing down the well each time that the orifice fitting is changed. The

disadvantages of these prior practices are, of course, multiplied in the case where a plurality of strata in the same sand are to be repressured simultaneously, because, as far as is known, no satisfactory, commercially practicable method has hitherto been devised for this purpose which does not require the use of a separate string of tubing for each stratum.

Somewhat similar problems are also involved in restricting the production of oil and gas wells, because of the desirability from the standpoint of efficiency providing a plurality of ports in the tubing at different levels and near the face of the producing sand.

It is therefore one of the objects of the present invention to provide new and improved procedures and apparatus for controlling the flow of fluids in gas and oil wells which will overcome the difficulties and remedy the defects heretofore encountered and existing in the methods and means previously available to the art for attaining the same ultimate results.

Another object is to provide novel and simplified means for regulating and metering the flow of fluid into or out of a gas or oil well at a plurality of points located substantial distances below the surface of the ground, and for readily varying from the well head the regulatory effect of such means.

A further object is to provide a new method and apparatus for varying the sizes of a number of flow restricting fittings in a single tubing string of a pressure or producing well which does not require either the use of tools for placing and removing the fittings or the removal of the tubing string from the well.

Still another object is to provide an apparatus of novel construction by which the injection of fluid into a plurality of different strata of a pressure well may be selectively regulated and metered through a single string of tubing.

A still further object is to provide a novel method and apparatus of the character described which are capable of effecting substantial savings in the cost of oil and gas well operations wherein it is necessary to restrictively control the flow of fluid to or from the well at a number of different levels therein.

These and other objects will appear more fully upon a consideration of the detailed description of the embodiments of the invention which follows. Although two specific forms of apparatus embodying the present invention are described and illustrated in the accompanying drawings, it is to be expressly understood that these draw-

ings are for the purpose of illustration only and are not to be construed as defining the limits of the invention, reference being had for this latter purpose to the appended claims.

5 Referring now to the drawings, wherein like reference characters indicate like parts throughout the several views:

Fig. 1 is a vertical section, with certain elements shown in full and others broken away in the interest of clarity, of one arrangement of apparatus embodying the present invention adapted for controlling and metering the flow of gas or other fluid into a plurality of different strata of a pressure well for the purpose of artificially stimulating the recovery of oil from producing wells in the same field by injecting fluid under pressure into the oil producing sand;

Fig. 2 is a fragmentary vertical section, on an enlarged scale, of the flow controlling fittings of the apparatus of Fig. 1;

Fig. 3 is a vertical sectional view, similar to Fig. 1, of a second embodiment of the invention especially adapted for use in a producing well; and

Fig. 4 is a fragmentary vertical section, on an enlarged scale, of the flow controlling fittings of the embodiment of Fig. 3.

In each of the two embodiments of the invention illustrated, the apparatus disclosed is adapted to restrictively control the flow of a fluid into or out of a single string of tubing through a plurality of ports located at various distances below the surface of the ground, and includes elements, hereinafter referred to as port plugs, which determine the effective sizes of the ports, or close them entirely, and are capable of being lowered to and raised from the points of control by means of gravity and fluid pressure alone. In each instance, the points of the tubing string at which flow regulation is required are provided with fittings forming seats for the plugs and embodying ports of a fixed maximum size, the effective sizes of which are varied by the plugs, while the upper end of the well tubing is provided with a suitable arrangement of valves, pipe connections and other means by which the plugs may be raised from and lowered to their seats without the use of fishing or other tools.

Referring now more particularly to the embodiment illustrated in Figs. 1 and 2, there is indicated therein a pressure well 11 containing a single main string of tubing 12 which is adapted to extend downwardly to the producing strata 13, 14 and 15 of the oil sand into which a repressuring fluid is to be injected. In a typical oil sand, the producing strata 13, 14 and 15 are of different permeabilities and are separated from one another by impermeable, non-productive strata such as shale formations 16, 17 and 18. Since the most efficient recovery of oil from the entire sand is obtained by so regulating the flow of the repressuring fluid injected into the various strata that the strata of higher permeability are subjected to lower pressures than those of less permeability, suitable means are provided for selectively controlling and metering the flow of fluid into each of the strata 13, 14 and 15.

To this end, there are threaded into the tubing string 12 at vertically spaced points opposite the different producing strata fittings 19, 20 and 21, each of which is provided with a port 22, 23 and 24, respectively, of such size that, when unrestricted, it will pass fluid from the

interior of tubing string 12 at the maximum pressure which it may be desired to inject into the producing stratum. The fittings 19, 20 and 21 are all preferably of the same outside diameter as the tubing 12 so as to form a string of uniform size throughout its length, thereby enabling the use of identical packers 25 for sealing off from one another the individual portions of the well which communicate with the producing strata 13, 14 and 15.

In order to suitably restrict—and, when desired, completely shut off—the flow through ports 22, 23, and 24 of the gas or other fluid used for injection, fittings 19, 20 and 21 are provided with internal, downwardly tapered seats 26, 27 and 28 which are adapted to receive and support in readily removable association therewith members known as port plugs 29, 30 and 31, respectively. In the case of fittings 19 and 20, the ports 22 and 23 extend horizontally and intersect the tapered surfaces of seats 26 and 27 intermediate the upper and lower ends thereof, while in fitting 21 the port 24 is located below the tapered seat 28. In order that the plugs 29, 30 and 31 may be seated and removed in the manner contemplated by the present invention, the minimum internal diameters of the tapered seats and the maximum external diameters of the port plugs decrease correspondingly to their relative positions with respect to the top of the well. That is, the maximum outside diameter of the plug 30 adapted to cooperate with tapered seat 27 is less than the minimum internal diameter of tapered seat 26, although greater than that of tapered seat 27, so that said plug may pass freely through fitting 19, but not through fitting 20. Similarly, the maximum outside diameter of the plug 31 adapted for cooperation with tapered seat 28 is less than the minimum internal diameter of tapered seat 27, but greater than that of seat 28.

All of plugs 29, 30 and 31 are generally cylindrical in form, have their bottom ends tapered as indicated to make tight fits with tapered seats 26, 27 and 28, and are provided with vertical bores 32, 33 and 34 through which the fluid passes. Each of the plugs is also preferably rounded or tapered at its upper end as shown, and the lower surface of each tapered seat is similarly rounded or tapered, so as to insure that the plugs will pass freely upwardly through the tubing string without hanging when elevated in the manner later to be described. As is obvious from the drawings, the plugs are maintained in engagement with the tapered seats by gravity and fluid pressure alone, the tapered surfaces of the plugs and seats being accurately ground and formed of non-corrosive materials so as to insure at all times tight, but non-sticking, joints between these elements.

In order to selectively control or meter the flow of repressuring fluid through the ports 22 and 23, the lower tapered ends of plugs 29 and 30 are so designed as to overlap ports 22 and 23 and thereby reduce the effective size of said ports, as desired. In this connection, it will be understood that, in order to enable the desired variations in flow, a plurality of port plugs is provided for use with each fitting, the plugs of each set being identical in construction except that the tapered lower ends thereof are of varying lengths so as to cover more or less of the port with which they are adapted to be used. The vertical bores 32 and 33 of all plugs belonging to the same sets as plugs 29 and 30 are sufficiently large to offer

no substantial resistance to the flow of fluid downwardly through the ports 22, 23 and 24; in the form shown, the bores 32 and 33 and the ports 22 and 23 are all of the same diameter. In the case of the lowermost fitting 21, however, the regulation of flow through the port 24, which is preferably larger than ports 22 and 23 and the minimum internal diameter of tapered seat 28, is accomplished by restricting the size of the vertical bore 34, the plugs of the set adapted for cooperation with this fitting being identical except that the bores are made of different diameters so as to provide different degrees of resistance to the flow of fluid therethrough. As is indicated by the broken lines in Fig. 2, one of the plugs of each set corresponding to plugs 29 and 30 is provided with a tapered end sufficiently long to completely close its associated port 22 or 23, while one of the plugs of the set corresponding to plug 31 is made solid, rather than with an axial bore 34, so as to enable the complete closure of port 24. In all cases, the minimum internal diameters of tapered seats 26, 27 and 28 are made greater than the diameters of the vertical bores 32, 33 and 34 of the corresponding plugs 29, 30 and 31 so that the bottom ends of the plugs always present an appreciable area to whatever pressure may exist in the tubing string therebelow, a condition which is essential to the operativeness of the method and apparatus of the present invention when axially apertured plugs are employed.

For the purpose of controlling the flow of repressuring fluid into the tubing string and attaining the desired objective of raising and lowering the port plugs from the well head without the use of tools, tubing string 12 is provided at its upper end with a novel arrangement of valves and other connections which are capable of manipulation in such manner that the plugs can be dropped downwardly to their seats by gravity and elevated therefrom by the pressure of the fluid in the well.

In the embodiment illustrated, there is connected to tubing 12 an inlet line 35 leading to any suitable source of relatively high pressure injection fluid, such as a compressor or reservoir (not shown), the flow of fluid from said source into the tubing being controlled by a suitable valve 36. It will be understood that the pressure of the fluid in inlet line 35 is the maximum that would ever be required for operation of the well, and that this pressure is reduced as required by regulating the flow through the ports 22, 23 and 24 by the use of port plugs of various flow restricting characteristics. Tubing string 12 is also provided with a pair of gate valves 37 and 38, valve 37 being located below valve 36, while valve 38 is positioned at the upper end of the tubing string and serves to open the latter to the atmosphere. The body of upper or release valve 38 is preferably so constructed at its outlet side as to receive the threaded open end of a cushioning cage member 39 which is substantially cylindrical in form, closed at its upper end, and provided with a plurality of perforations which permit the escape of gas or other fluid from the interior thereof to the atmosphere. The inner diameter of cage member 39 is substantially the same as that of tubing string 12.

In operating the apparatus just described for the purpose of injecting gas or other fluid into the various strata of an oil producing sand, and assuming that the parts are in the positions indicated in Fig. 1 with upper control or release

valve 38 closed and inlet valve 36 and lower control valve 37 open, the repressuring fluid flows from the compressor or reservoir at a relatively high pressure through inlet line 35, into tubing string 12, and downwardly through the latter until it reaches port plug 29. At this point, after passing through vertical bore 32 of plug 29, some of the fluid passes outwardly through port 22 into the well, the resistance to flow through said port produced by the restriction in effective size thereof due to the overlapping of the lower tapered end of the plug 29 reducing the pressure of the fluid passing into the well to the proper amount desired for repressuring the corresponding stratum 13 of the sand, the rest of the fluid in the tubing string continuing to flow downwardly until it reaches the level of the second fitting 20 and plug 30 where a similar division of flow takes place and a similar regulation is effected of that proportion of the fluid which passes outwardly into the well through port 23 and into the adjacent productive stratum 14. The remainder of the fluid continues its downward flow through the tubing string until it reaches fitting 21 and plug 31, at which point the resistance to flow through port 24 offered by the restricted bore 34 of plug 31 reduces the pressure to the amount desired for injection into the lowermost producing stratum 15. Due to the force of gravity and the pressure exerted on the exposed areas of the upper ends of the port plugs, tight seals are maintained between the ground tapered surfaces of the lower ends of said plugs and their seats 26, 27 and 28 which prevent leakage around the outsides of the plugs without the necessity for using latching or other mechanical means for positively holding the plugs in position on said seats.

Whenever it is desired to vary the pressure of the fluid issuing from tubing string 12 through any one of ports 22, 23 and 24 into the associated producing stratum, all of the plugs 29, 30 and 31 are raised to the well head and the one which is adapted to cooperate with the fitting corresponding to the stratum in which the pressure change is desired is replaced by a plug having either a different length tapered lower end (if it is a plug corresponding to either of plugs 29 and 30) or a vertical bore 34 of different diameter (if it is a plug corresponding to plug 31).

To effect this change in plugs in accordance with the present invention, it is only necessary to close inlet valve 36 and then open upper control or release valve 38, whereupon the pressure of the back flow of gas from the well exerted against the bottom ends of the plugs, in conjunction with the resistance to upward flow of said gas offered by the relatively restricted bores of said plugs, unseats the latter and forces them to the upper end of the tubing string where they are caught in cushioning cage 39. Release valve 38 is then closed so as to permit removal of the cushioning cage and the plugs trapped therein. A plug having the proper flow restricting characteristics to effect the desired change in pressure is then substituted for the one originally used, whereupon the plugs are replaced in the upper end of tubing string 12 by first closing lower control valve 37, then opening release valve 38, and then dropping the plugs into the upper end of the tubing string in proper order where they come to rest supported on the gate of lower control valve 37. Release valve 38 is then again closed and cushioning cage 39 replaced, after which lower control valve 37 is gradually opened

until the pressure within the tubing string equalizes and the plugs drop into position on their respective seats by gravity. This replacement of the plugs may be done either all at one time or one by one. Should the velocity of the dropping plugs become so great as to involve the possibility of injury to their lower tapered ends or the seats 26, 27 and 28, this velocity may be reduced by manipulating release valve 30 so as to produce a counterflow upwardly through the tubing string which will check the fall of the plugs and permit them to be seated as lightly as desired. As is above pointed out, the maximum outside diameter of each plug is made smaller than the minimum internal diameters of the tapered seats of all of the fittings positioned above that with which said plug is adapted to cooperate, so that the plugs will pass freely through the tubing string to and from their proper seats. When the plugs reach their seats, release valve 30 is tightly closed and the repressuring operation continued by opening inlet valve 36.

When it is desired to regulate or meter the flow into the various producing strata of the well, the following procedure may be followed. After first installing a suitable meter in the inlet line 35, a port plug 31 having a vertical bore 34 of selected size, and plugs 29 and 30 having lower tapered ends of sufficient lengths to completely close ports 22 and 23, are dropped into place on their respective seats in the tubing string 12. When inlet valve 36 is then opened, all of the repressuring fluid flows downwardly to the lowermost fitting and outwardly through port 24 into the associated productive stratum 15, thus giving a direct indication on the meter at the well head of the velocity of flow of the fluid into this stratum. If the plug 31 selected does not produce the desired rate of flow, it is a simple matter to bring all of the plugs to the surface, substitute another plug 31 of different size bore, and repeat the metering operation until the plug of proper size is identified. The flow into the next higher stratum 14 is then regulated in like manner, again using a plug 29 on seat 26 which completely closes port 22 but retaining the plug 31 which was found to provide the desired flow into the lowermost stratum 15. After the flow into the middle stratum 14 has been properly regulated, the procedure is again performed with respect to the uppermost stratum 13, this time using for both of plugs 29 and 31 those which have been identified as giving the desired rates of flow through their associated ports 23 and 24.

It will be obvious that the apparatus just described is also capable of use in such a manner as to enable measurement of the relative permeabilities of the different producing strata. For this purpose, plugs effecting complete closure of their associated ports are used for the fittings of all strata except that of which the permeability is to be measured, the fitting corresponding to the latter stratum being provided with a plug of any desired flow restricting characteristics and a direct measurement being made of the amount of fluid which it is necessary to flow into the main tubing string in a given period of time in order to maintain the pressure in the tubing string constant at the well head.

In Figs. 3 and 4 there is disclosed another embodiment of the method and apparatus of the present invention which is particularly adapted for use in controlling the flow of oil and gas from a producing well, but which embodies the same

fundamental structure and mode of operation as the embodiment of Figs. 1 and 2. For simplicity, the following description will be limited to the use of the invention in connection with an oil producing well of the character wherein the oil is produced by gas lift, although it will be obvious that the same method and apparatus is equally well adapted to gas well operation. In oil wells of this type, it has been found that the flow of oil may be substantially accelerated if the main tubing string is provided with a plurality of ports at different levels through which may enter the gas which collects in the well above the oil. As the flow from the well progresses and the fluid column in the well is lowered, less energy is required from the gas entering the ports in order to lift the oil. Accordingly, it is desirable to provide means for reducing the effective sizes of the ports, or completely closing them, as desired, during the operation of the well. The present invention is particularly well adapted for this latter purpose.

In the form illustrated, the main tubing string 40 is paralleled by an auxiliary string 41 which is provided at its upper end with control valves 37 and 38, inlet line 35 and valve 36, and cushioning cage 39 similarly to the tubing string 12 of the embodiment of Figs. 1 and 2. The main tubing string 40 of this second form of the invention, however, is closed at its upper end by a blank sealing disk 42, and is provided with a take-off line 43 and a valve 44 for controlling the flow of oil out of the main tubing string into said line, the latter constituting the field line into which is delivered the oil recovered from the well.

As shown, the main tubing string 40 extends downwardly in the well 45 all the way to the "shot hole" 46 in the lowermost producing stratum 15 of the sand while the auxiliary string may terminate a suitable distance above the "shot hole," there being interposed in the tubing strings at predetermined, vertically spaced locations a plurality of ported fittings 47, 48 and 49 which are adapted to control the flow of gas from the well into the main tubing string 40 in order to assist in lifting the oil from the "shot hole" whence it enters the main tubing string 40 through the perforated lower end of the latter. These ported fittings are preferably detachably secured to the tubing strings by threaded connections, as shown, and a suitable packer 50 is provided at or above the position of the uppermost fitting 47 for sealing off the producing stratum or strata from the upper portion of the well.

The fittings 47 and 48 are of similar construction, each being adapted for connection into the tubing intermediate the ends thereof, and are respectively provided with chambers 51 and 52 of the same internal diameter as, and coaxial with, the main tubing string 40, and chambers 53 and 54 coaxial with auxiliary string 41 and of the same interior diameter as the latter except for the restrictions introduced therein by the tapered seat members 55 and 56 which are adapted to receive and support plugs 57 and 58, respectively. Fittings 47 and 48 are also provided with ports 59 and 60 connecting the chambers 51 and 52 with chambers 53 and 54, respectively, and with secondary parts 61 and 62 coaxial with and of the same diameters as ports 53 and 54, and passing through the outer walls of said fittings so as to provide communication between the interior of the well 45 and the chambers 53 and 54. Each of ports 59 and 60 and its associated secondary port extend horizontally and intersect the tapered sur-

face of the seat 55 or 56 intermediate the extremities of the latter.

Fitting 49 is adapted for connection to the lowermost end of the auxiliary tubing string, and differs from fittings 47 and 48 in that, while its chamber 63 which is coaxial with the main tubing string 40 may be open at the lower end in order to communicate with the remaining section or sections of the main string leading to the "shot hole" 46, its tapered seat 64 forms the lower end of the chamber 65 which is coaxial with the auxiliary tubing string 41, and the secondary port 66 through which the gas passes from the well 45 into chamber 65 is vertical, rather than horizontal as in fittings 47 and 48. The port 67, however, which provides communication between the chambers 63 and 65, is, like ports 59 and 60, horizontal and intersects the tapered surface of seat 64 intermediate the upper and lower ends of the latter so that the effective cross sectional area of port 67 may be varied by the lower tapered end of plug 68.

In this embodiment of the invention, the plugs 57, 58 and 68 are solid, instead of being provided with axial bores therethrough as in the case of the apparatus shown in Figs. 1 and 2, but their lower ends are tapered in the same manner as previously described in order to restrict or completely prevent the flow of gas from the well 45 through the secondary ports 61, 62 and 66 and the primary ports 59, 60 and 67 into the chambers 51, 52 and 63 which are in communication with the main tubing string 40. As in the case of the first embodiment herein disclosed, a plurality or set of plugs is provided for each of the fittings 47, 48 and 49, the plugs of each set being identical except that the lengths of the tapered lower ends thereof are different so as to enable the desired variation in effective size of the ports with which they are adapted to be associated. As is indicated in broken lines in Fig. 4, one plug of each set is provided with a sufficiently long taper to permit it to completely close its associated port. The upper ends of the plugs and the lower surfaces of the tapered seats are also rounded or tapered as previously described in order to prevent hanging of the plugs in the auxiliary tubing string, and the minimum internal diameters of said seats and the maximum external diameters of the said plugs are properly proportioned in the same manner as that pointed out in connection with the embodiment of Figs. 1 and 2 so as to enable the plugs to pass freely to and from their respective seats. It will likewise be understood that all of ports 59, 60, 61, 62, 66 and 67 are of such diameters as, when unrestricted, will enable operation of the well at its maximum capacity.

During normal operation of this second embodiment of the invention for the recovery of oil from the well, all of the control valves 36, 37 and 38 at the top of the auxiliary tubing string 41 are closed while take-off valve 44 and any other valves located in the line 43 are open, the ground pressure, supplemented by the flow of gas from the well into the main tubing string 40 through those of the secondary ports 61, 62 and 66 and primary ports 59, 60 and 67 which are not completely closed, forcing the oil upwardly through the main string into take-off line 43 which delivers it to storage or any other desired destination. In passing through the ports of the fittings 47, 48 and 49, the flow of the lifting gas is restricted to an extent determined by the characteristics of the plugs in use at the time, the latter

being selected in accordance with the level of the oil in the well and the rate of production desired.

When, as the flowing of the well progresses, it becomes desirable to change the effective size of or to completely close any of the ports, all of the plugs may be brought to the well head to enable the desired change therein by simply closing valve 44 in the take-off line 43 and opening both control valves 37 and 38, whereupon the fluid pressure in the well exerted against the solid bottom end of the lowermost plug 68 unseats the latter and forces it upwardly through the auxiliary tubing string 41, the upward flow also effecting unseating and lifting of the plugs 58 and 57 in succession and forcing all of them to the surface where they are trapped in cushioning cage 39 in the manner previously described. Then, after the desired change in plugs has been made, they may be returned by gravity to their seats by the same manipulation of valves as that described in connection with the embodiment of Figs. 1 and 2, after which the take-off or field line valve 44 may be reopened to continue flowing of the well.

It will be apparent from the foregoing description that the present invention provides both a novel method and novel means for selectively controlling the flow of fluids at a plurality of different levels in gas and oil wells which greatly facilitate well operation and overcome the disadvantages of the procedures and mechanisms heretofore used for the same general purpose. By the present invention it has been made possible to quickly and easily change the size of any one of a plurality of flow regulating fittings normally positioned substantial distances below the surface of the ground, merely by the manipulation of certain valves at the well head and without the necessity for using fishing tools or like instrumentalities, or for withdrawing the tubing from the well in order to obtain access to the fittings. The method and apparatus herein disclosed are further characterized by the fact that repressuring fluid may be injected into a plurality of different strata, or oil and gas may be drawn from a plurality of different levels in a well, in an easily regulated manner by the use of a single string of tubing, a result not hitherto attainable. Not only do the new method and apparatus effect substantial savings in time and labor, but there is also very little wastage of fluid in the operations involved. The importance of such savings will be readily appreciated when it is considered that in repressuring operations, in particular, it is necessary to vary the pressure of the fluid which is injected into the different strata of the oil producing sand at relatively frequent intervals in order to avoid too rapid depletion of the more permeable strata and to maintain the desired rate of recovery of the producing wells. These and other features, all of which will be apparent from the disclosure herein, endow the present invention with substantial advantages over the methods and apparatus of the same generic character hitherto known to the art.

Although two specific forms of apparatus embodying the invention have been described and illustrated in the accompanying drawings, it will be obvious that the invention is not limited to the particular structures shown, but is capable of a variety of mechanical embodiments. For example, the fittings which are connected to the tubing strings may vary in their details of construction from those specifically illustrated in the drawings, and may be detachably connected to

the tubing in other ways than by the threaded connections shown. Similarly, the particular arrangement of valves and connections at the well head which enable the port plugs to be raised by fluid pressure alone may be varied somewhat from the embodiment illustrated. It should also be clearly understood that it is not necessary that plugs be used with all of the ported fittings at all times, since, when unrestricted flow through any particular port or ports is desired, that fitting may be used without a plug without in any way interfering with the herein described method by which whatever plugs are used may be raised and lowered from and to their respective seats. Various other changes, which will now suggest themselves to those skilled in the art, may be made in the procedural steps of the method, and in the form, details of construction and arrangement of the parts of the apparatus, without departing from the spirit of the invention. Reference is therefore to be had to the appended claims for a definition of the limits of the invention.

What is claimed is:

1. In gas or oil well apparatus of the character described, the combination of a string of tubing through which fluid may be injected into or removed from the well, means connected to said tubing at a plurality of vertically spaced points below the surface of the ground providing ports of fixed size through which fluid may pass from or to the interior of said tubing, means including plug members associated with said ports for restricting the flow of fluid through the latter, and means for producing an upward flow of fluid from said well of sufficient force to raise said plug members from their flow restricting positions to the well head by fluid pressure alone.

2. In gas or oil well apparatus of the character described, the combination of a string of tubing through which fluid may be injected into or removed from the well, means connected to said tubing at a plurality of vertically spaced points below the surface of the ground providing ports of fixed size through which fluid may pass from or to the interior of said tubing, a tapered seat associated with each of said ports, a plug having a tapered lower end adapted to engage each of said seats and to obstruct the flow of fluid through the associated port, the maximum external diameter of each of said plugs being less than the minimum internal diameter of each of said tapered seats above that with which said plug is adapted to cooperate, and means for producing an upward flow of fluid from said well of sufficient force to unseat said plugs and raise them to the well head by fluid pressure alone.

3. In gas or oil well apparatus of the character described, the combination of a single string of tubing having therein a plurality of vertically spaced ports of fixed size through which fluid may be injected into or removed from the well at a plurality of different levels, and means for controlling the flow of fluid through said ports comprising a tapered seat associated with each of said ports and a plurality of plug members having tapered lower ends adapted to engage said seats, said plug members being so constructed and arranged as to offer resistance to the flow of fluid through said ports when in engagement with said seats, the minimum internal diameters of said seats decreasing in order toward the bottom of the tubing string and each of said plug members having a maximum external diameter which is smaller than the minimum internal diameter of

each of the seats located above that with which said plug member is adapted to cooperate.

4. The combination according to claim 3 wherein said tapered seats are coaxial with the tubing string and each of said plug members has an axial bore therethrough of a diameter which is smaller than the minimum internal diameter of the tapered seat with which it is adapted to cooperate.

5. The combination according to claim 3 wherein said tapered seats are coaxial with the tubing string and each of said plug members has an axial bore therethrough of a diameter which is smaller than the minimum internal diameter of the tapered seat with which it is adapted to cooperate, and including means for producing a flow of fluid upwardly through said tubing string of sufficient force to raise said plug members from their seats to the upper end of said tubing by fluid pressure alone.

6. The combination according to claim 3 wherein said tapered seats are coaxial with the tubing string and each of said plug members has an axial bore therethrough of a diameter which is smaller than the minimum internal diameter of the tapered seat with which it is adapted to cooperate, the bore of each plug member except that adapted to cooperate with the lowermost seat in the tubing string being sufficiently large to offer no substantial resistance to the flow of fluid downwardly to those ports which are located below that with which said plug member is adapted to cooperate.

7. The combination according to claim 3 wherein said tapered seats are coaxial with the tubing string and each of said plug members has an axial bore therethrough of a diameter which is smaller than the minimum internal diameter of the tapered seat with which it is adapted to cooperate, the lowermost port in said tubing string being located below its associated tapered seat and having a greater cross sectional area than the bore of the plug member adapted to cooperate with said seat, whereby the flow through said port is controlled by the size of the bore in said plug member, each of the other ports in said string intersecting the tapered inner surface of the associated seat in such position as to be obstructed by the tapered lower end of the plug cooperating with the latter.

8. In gas or oil well apparatus of the character described, the combination of a single main string of tubing having therein a plurality of vertically spaced ports of fixed size through which fluid may flow into or out of said tubing at a plurality of different levels, and means for controlling the flow of fluid through said ports comprising an auxiliary string of tubing paralleling said main string and into which said ports lead, a tapered seat formed in said auxiliary tubing string adjacent each of said ports, a secondary port associated with each of said seats providing communication between said auxiliary tubing string and the well, and a plurality of plug members having tapered lower ends adapted to engage said seats and to obstruct the flow of fluid through said first named ports, the minimum internal diameters of said seats decreasing in order toward the bottom of the auxiliary tubing string and each of said plug members having a maximum external diameter which is smaller than the minimum internal diameter of each of the seats located above that with which said plug member is adapted to cooperate.

9. The combination according to claim 8 in-

cluding means for producing a flow of fluid upwardly through said auxiliary tubing of sufficient force to raise said plug members from their flow obstructing positions to the upper end of said auxiliary tubing string by fluid pressure alone.

10. The combination according to claim 8 wherein at least the lowermost one of said plug members is imperforate longitudinally and the lowermost secondary port in said auxiliary tubing string is positioned below its associated tapered seat in such position that the bottom end of said lowermost plug member may always be subjected to the fluid pressure existing in the well adjacent said secondary port.

11. In gas or oil well apparatus of the character described, the combination of a string of tubing through which fluid may be injected into or removed from the well, a fitting connected to said tubing forming a tapered seat therein and having a port intersecting the tapered surface of said seat through which fluid may pass from or to the interior of said tubing, and a plug having a tapered lower end adapted to engage said seat and to obstruct at least a portion of said port so as to restrict the flow of fluid therethrough, said plug also having a vertical bore therethrough of smaller diameter than the minimum internal diameter of said tapered seat.

12. In gas or oil well apparatus of the character described, the combination of a main string of tubing through which fluid may be injected into or removed from the well, an auxiliary tubing string associated with said main string, means connected to said tubing strings at a point a substantial distance below the well head forming a tapered seat in said auxiliary string and providing a port intersecting the tapered surface of said seat through which fluid may pass between the interiors of said main and auxiliary strings, a secondary port associated with said seat providing communication between said auxiliary string and the well, and a longitudinally

imperforate plug member having a tapered lower end adapted to engage said seat and to obstruct at least a portion of said first named port so as to restrict the flow of fluid therethrough.

13. In a pressure well, the combination of a single string of tubing through which a repressuring fluid may be injected into the well, a connection to the upper end of said string for supplying repressuring fluid thereto, a plurality of fittings connected to said string at vertically spaced points below the well head each having a port through which the repressuring fluid may flow from said string into the well, means for selectively regulating the flow of fluid through said ports including a removable plug member associated with each of said ports and at least partially restricting the flow therethrough, and means for producing a back flow of fluid from the well into and upwardly through said tubing string of sufficient force to raise said plug members from their flow restricting positions to the well head by fluid pressure alone.

14. In a producing well, the combination of a main string of tubing through which the fluid to be recovered from the well may be raised to the well head, an auxiliary tubing string associated with said main string and having a plurality of vertically spaced openings in the wall thereof through which fluid may flow from the well, means providing communication between the interiors of said main and auxiliary strings including a port positioned at substantially the same level as each of said openings in the auxiliary string, means including a removable plug member associated with each of said ports for restricting the flow of fluid through the latter, and means for producing a flow of fluid upwardly through said auxiliary string of sufficient force to raise said plug members from their flow restricting positions to the top of said auxiliary string by fluid pressure alone.

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