

May 9, 1967

H. U. GARRETT ETAL

3,318,386

WELL FLUID FLOW REGULATOR

Original Filed Jan. 26, 1955

2 Sheets-Sheet 1

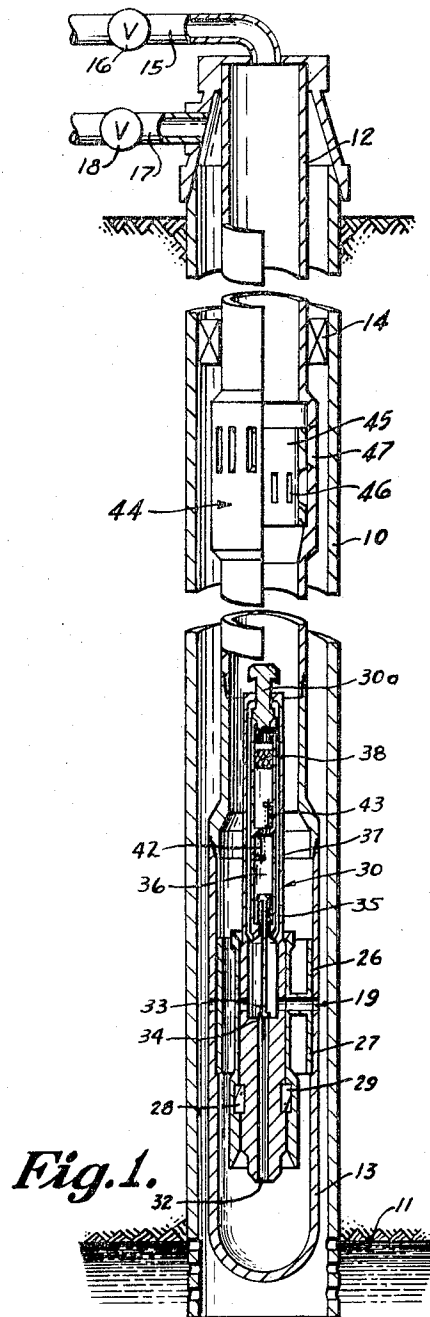


Fig. 1.

HENRY U. GARRETT INVENTORS.

CLIFFORD M. PETERS

ROBERT W. DINNING

BY

ATTORNEYS

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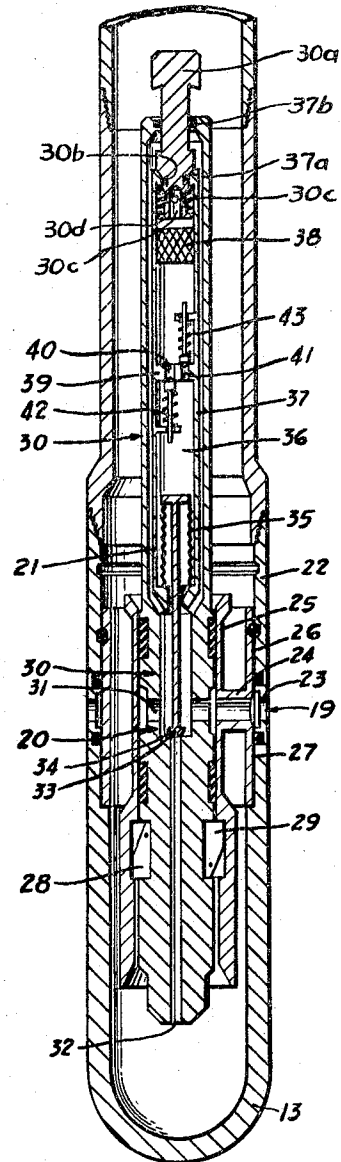


Fig. 2.

HENRY U. GARRETT
CLIFFORD M. PETERS INVENTORS.

ROBERT W. DINNING

BY *J. Vincent Martini*
for E. Edwards
W. H. Gay
ATTORNEYS.

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3,318,386

WELL FLUID FLOW REGULATOR

Henry U. Garrett and Clifford M. Peters, Longview, and Robert W. Dinning, Kilgore, Tex., assignors, by mesne assignments, to said Garrett

Original application Jan. 26, 1955, Ser. No. 484,164, now Patent No. 3,045,759, dated Aug. 24, 1962. Divided and this application Apr. 16, 1962, Ser. No. 187,904
16 Claims. (Cl. 166—224)

This application is a division of application Ser. No. 484,164, filed Jan. 26, 1955, now Patent No. 3,045,759.

This invention relates to apparatus employed in controlling flow of fluid into or out of a conduit in a well. In one of its aspects, it relates to a system and improved apparatus adapted to be employed in such a system for regulating the production of fluid from an earthen formation so as to maintain and control the pressure maintained on the formation. In another aspect, the invention relates to improved apparatus particularly useful in producing a well by gas lifting techniques and to improved apparatus for completing and producing wells.

In many petroleum producing wells, it is desired to control flow of fluid produced from a formation into the production conduit or tubing string so as to maintain a substantial back pressure on the formation while fluid is being produced from the same. There are several reasons for such desire, any one or all of which may be existent with respect to any given well. Thus, the maintenance of a production flow rate to be such as to yield a substantially constant back pressure on the formation has been found to limit the gas-to-oil ratio of the production from the well. It also prevents "coning" of water from a lower water-bearing zone into the oil sands and into the bore hole. By maintaining at least a minimum back pressure on the formation, the "sand-face" differential (i.e. the pressure drop between a point in the formation and a point in the bore hole) does not become great enough that water underlying the producing sands will be lifted up sufficiently from its normal level so as to flow into the well. Still another reason may lie in the fact that some wells cannot be produced at their maximum rate without injury to the productivity of the well. For example, a high pressure well may not be capable of successfully producing at a maximum sand-face differential such as would exist if flow from the formation was substantially unrestricted. In fact, permitting such maximum differential to be applied to some wells will ruin them. Accordingly, it is necessary to maintain a back pressure on the formation at all times. It would therefore be desirable, for these and other reasons known to those skilled in the art, to maintain the back pressure on the formation to be as high as possible consistent with the volume of fluid to be produced.

Heretofore, it has been one practice to locate a choke, which is a structure containing a small fixed-size orifice, in the tubing to limit flow from the formation therinto. While such a choke will tend to so limit the flow and thereby maintain a back pressure on the formation, it has the disadvantage of being fixed in size so that once it is situated in the well, it is not possible to change the size thereof short of pulling the tubing or otherwise removing the choke from the well. Also, the back pressure it maintains fluctuates with flow rates, tubing pressure, formation pressure, the physical characteristics of the formation fluid and other factors. Accordingly, variations in these factors, changes in the gas-to-oil ratio, and other fluctuations dictating a change in back pressure to be maintained on the formation cannot be readily accommodated.

Bottom hole pressure regulators have also been sug-

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gested for regulating the flow of a formation fluid into a tubing. Such regulators operate by maintaining a predetermined differential across themselves so that by adjusting the pressure maintained on the tubing at the well head, the back pressure maintained on the formation can also be adjusted. However, with such regulators, there is the disadvantage of not being able to adjust the differential they maintain across themselves while situated in the well and, more important, adjustment of the tubing pressure at the well head to supposedly fix a selected back pressure on the formation involves several disadvantages. One is that it presupposes a knowledge of the pressure exerted on the regulator by the head of fluid in the tubing and that such head will be substantially constant. Since such knowledge cannot be ascertained with any degree of certainty, particularly under practical field operations and since the head will fluctuate in many wells, the maintenance or application of a selected back pressure on a formation with any degree of accuracy is not only well nigh impossible to attain but frequently cannot be attained at all. Also, failure of surface choke or other equipment so that they no longer maintain the desired tubing pressure at the well head will cause the back pressure on the formation to drop. In such event, the flow from the well will be increased since the regulator will open to accommodate the volume of flow necessary to yield the pressure differential for which the regulator is set.

It is accordingly an object of this invention to provide a system for regulating the flow of fluid from a producing formation of a well into a flow conduit in the well to maintain a selected back pressure on the formation, the flow regulation being controlled by and responsive to pressure of fluid flowing from the formation so that an accurate and reliable control of back pressure on the formation is obtained despite fluctuations in well conditions.

Another object is to provide such a system in which a pressure responsive valve means is employed to control flow from the formation into a well conduit, the valve means being opened and closed in response to variations in pressure of fluid flowing from the formation upstream of the valve means so that when such pressure rises or falls to be above or below a predetermined amount, the valve means is respectively opened and closed substantially irrespective of pressure of fluid downstream of the valve means or of the flow rate through the valve means.

Another object is to provide such a system in which the back pressure to be maintained on the formation can be regulated from the surface of the earth without withdrawing a flow regulating means from the well.

Another object is to provide such a system in which the back pressure maintained on the formation by the valve means can be selected by operation of an instrumentality controlled from the earth's surface, such as by manipulating the pressure in a tubing or casing or both or by a wire line operation, thereby permitting periodically changing the back pressure to be maintained on the formation to be at a value consistent with the then desired volume of production from the well or with other factors, such as the gas-to-oil ratio, determined by such back pressure, all without removing the valve means from the well.

Another object is to provide a system for producing a well in which flow of fluid from a producing formation is controlled by the pressure of such fluid to maintain a selected back pressure on the formation and in which the pressure of such fluid is also employed to change the value of the back pressure to be so maintained.

Another object is to provide such a system in which a valve for controlling flow of fluid from the formation into a well conduit can be landed in or removed from its operating position in a well by a wire line operation, the

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arrangement being such that pressure of formation fluid controls opening and closing of the valve in operation and also can be employed to periodically and selectively adjust the operating characteristics of such valve to thereby determine the magnitude of the pressure of the formation fluid required to control opening and closing of the valve in operation.

Another object is to provide such a system having a valve arrangement as aforesaid and also having a packer or sealing means in the conduit-well bore annulus confining the formation fluid to the lower portion of such annulus, means also being provided for variably controlling from the earth's surface the pressure of formation fluid in such lower annulus portion in order to thereby permit selection of the charge pressure of a valve from a wide range of pressures.

It is another object of this invention to provide an apparatus and system in which valve means are provided to regulate fluid flow through a well conduit to yield a substantially constant pressure downstream thereof, irrespective of pressure fluctuations upstream of the valve means whereby fluid can be delivered to the earth's surface at a preselected pressure independently of bottom hole pressure.

Another object is to provide a system for maintaining a selected back pressure on a producing formation substantially independently of conditions existing in a production tubing and for regulating the flow of production fluids through the tubing to decrease their pressure therein and to deliver them to the surface of the earth at a preselected pressure substantially independently of bottom hole pressure.

Another object is to provide such a system wherein the valve means controlling flow through the tubing are adapted to have their operating characteristics changed while disposed in the well whereby the pressure downstream thereof can be changed as desired.

In accordance with one feature of the system to which this invention pertains as above indicated and as will be more fully described hereinafter, the force required to be exerted by a control pressure to operate a pressure responsive valve is changed while the valve remains in the well by an instrumentality manipulated from the earth's surface. For example, the concept of the system of this invention includes the use of a valve of the pressure charged type to control fluid flow from a producing formation into a tubing and varying the pressure charge in the valve while it is in the well to adjust the force exerted by the charge in urging the valve toward closed position in opposition to the force exerted by a control (i.e. formation) fluid urging the valve toward open position. By thus varying the charge pressure, the pressure of the control fluid necessary to open a valve is likewise varied. While valves capable of having their operating characteristics changed in this or other manners can be employed in accordance with the above noted feature of the system of this invention, there is provided new and improved valves for use in such system and also for use in accordance with gas lifting and other techniques employed in producing wells.

Thus gas lifting of a well usually involves an installation of a plurality of dumping valves and one or more working valves spaced along a well conduit or tubing to control flow of a lifting fluid between such conduit and another conduit. These valves are usually of the type employing a resilient means, such as a pressure charge, urging the valves toward closed position against the force of a control fluid, which may be either casing or tubing fluid, urging the valves toward open position. The operating characteristics of such type valves thus are at least in part determined by the magnitude of the resilient means or charge pressure. It would be highly desirable to possess a valve which can have the magnitude of its resilient means or charge pressure accurately changed while the valve remains in the well with such a change

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being under positive control from the earth's surface and accomplished in an improved manner. Such valve could be useful not only in gas lifting a well but also in the system of this invention and in other well operations.

It is therefore an object of this invention to provide an improved pressure responsive valve wherein the effective force exerted by a resilient means urging the valve toward one of its open and closed positions can be selectively changed under the control of a tool insertable through a conduit in a well and manipulatable therein from the earth's surface so that the initiation and prevention of any such change is positively controllable from the earth's surface independently of well pressures whereby the latter can be varied over a wide range without effecting an undesirable change in the force exerted by the resilient means.

Another object is to provide such a valve which when installed on a well conduit in a well can have the pressure of the fluid exteriorly of the well conduit applied to change the force of the resilient means by a wire line manipulation occurring in the conduit controlling such application of pressure exterior of the conduit.

Another object is to provide an improved pressure responsive valve means of the pressure charged type adaptable not only for use in such system but also for other uses in a well such as gas lifting in which the pressure charge can be adjusted by manipulating a tool into the well without removing the valve from the well to cause the application of pressure exterior of the valve means to that of the charge to raise and lower the latter whereby the application of such exterior pressure can be positively controlled independently of the magnitude of fluctuations in magnitude of the exterior pressure.

Another object is to provide a pressure responsive valve of the pressure charged type wherein the magnitude of the pressure charge can be changed while the valve is in the well through manipulation of well pressures to open and close pressure responsive valve means controlling flow of fluid through a port into and out of the charge chamber of the valve to thereby vary the pressure in such chamber, the arrangement of the pressure responsive valve means being such that they respond to the difference in pressure between that in the charge chamber and that of a control fluid substantially independently of flow through said port whereby any change in charge pressure can be very closely controlled.

Another object is to provide such a valve in which the fluid in a charge chamber acts as a charge pressure not only in controlling opening and closing of the valve itself, but also in opening and closing valve means for changing the magnitude of such charge pressure.

Other objects, advantages and features of this invention will be apparent to one skilled in the art upon a consideration of the written specification, the appended claims, and the attached drawings wherein:

FIG. 1 is a diagrammatic illustration of a well installation showing an embodiment of the system of this invention arranged for controlling flow from a formation into tubing, in which a packer has been set between the tubing and well casing; and

FIG. 2 is an enlarged view of the lower portion of FIG. 1 to better illustrate the details thereof.

Like characters of reference are used throughout the several views to indicate like parts.

In accordance with the system of this invention, a pressure responsive valve is disposed in a well to control flow of formation fluid from a producing formation into a well conduit or tubing in such a manner that the valve will regulate flow into the conduit so as to maintain a selected back pressure on the formation. Stated in another manner, the valve desirably maintains a substantially constant "sand-face differential." The valve means is so arranged that the pressure of the formation fluid between the formation and the valve means is the control variable which exerts a dominating influence upon the opening

and closing of the valve means and pressures of fluids in other portions of the well, while they may exert some relatively minor influence, are for all practical purposes dominated in this respect by the action of the pressure of the formation fluid. Thus, for example, if the valve means is set to maintain 800 pounds per square inch back pressure, any increase or decrease in formation pressure will result in a corresponding increase or decrease in the flow rate into the tubing so that the back pressure remains at 800 pounds. Also, any change in tubing pressure or well head pressure downstream of the valve means as by fluctuation in separator pressures, fluid head in the tubing, gas lifting, etc., will not effect a change in the 800 pounds per square inch back pressure being maintained by the valve.

In accordance with one aspect of the system of this invention, means are provided for changing, by manipulation controlled from the earth's surface, the back pressure maintained by the valve means on the formation. With such arrangement, it is possible to adjust the back pressure maintained on the formation to be a maximum consistent with the production of the desired volume of well fluid irrespective of tubing pressure and other factors. This means that the gas-to-oil ratio can be maintained at a minimum and also that the bottom hole pressure of the well maintained over longer periods of time instead of being depleted by excessive withdrawal of gases due to not maintaining sufficient back pressure on the formation. Also, water coning, excessive flow rates due to failure or improper operation of surface equipment, etc., are prevented.

The foregoing concept of the system of this invention is exemplified by the apparatus shown in FIG. 1; it being understood that other arrangements of apparatus are possible in accordance with the concept of the system and several of these will be described in detail hereafter. Thus, referring to FIG. 1, there is shown a producing well having a casing 10 extending to a producing formation 11 to receive formation fluids therefrom. Also extending into the well is a tubing 12 which, in this instance, is closed at its lower end as at 13 and provided with a packer 14 sealing the annulus between the tubing and casing. A well head is provided with the usual structure including a flow line 15 receiving fluid from the tubing 12 and controlled by a valve 16 or other suitable means. Another conduit 17, including a valve 18, communicates with a tubing-casing annulus and can be used to supply gas to the annulus in the event the well is to be equipped with gas lift valves above packer 14.

The tubing is provided with a passage, designated generally by the numeral 19, disposed to provide fluid communication between formation 11 and a point interior of tubing 12. The valve means, designated generally by the numeral 20, are provided substantially adjacent formation 11 to control flow through the passage. Opening and closing of the valve means is controlled by a pressure responsive means 21 connected thereto and urging the valve means toward closed position but controlling opening and closing of the valve means in response to the pressure of formation 11 existing upstream of the valve means.

Referring more specifically to the apparatus shown in FIGS. 1 and 2, a mandrel 22 can be provided with an inlet port 23 communicating through a web 24 with a port in an inner sleeve 25. An outer sleeve 26 is disposed in mandrel 22 to be shiftable between two positions therein so as to move the passage in web 24 into and out of register with port 23. When the passage is moved out of register with port 23, an imperforate portion 27 of the outer sleeve 26 is positioned across port 23 to prevent flow therethrough. In this manner, valve means are provided to block and permit flow into or out of the tubing independently of valve means 20.

The pressure responsive valve means 20 for maintaining a selected back pressure on formation 11 are arranged in this embodiment so as to be landable in inner sleeve

25 by a wire line operation and secured therein upon release of dogs 28 and 29 to abut opposing shoulders in an extension of inner sleeve 25 which comprises a receiver. Accordingly, manipulation of the valve means 20 permits sleeve 26 to open and close port 23 and the arrangement is such that upon pulling upwardly on valve means 20 to remove the same, dog 29 is not released until sleeve 26 has been moved to closed position thereby assuring that fluid cannot pass into the tubing except under the control of valve means 20.

The valve means generally comprises a housing 30 having an inlet port 31 and an outlet port 32. A seat 33 and valve member 34 are provided to control flow between these ports and hence through port or opening 23 which is a portion of passage 19. The valve member is connected to a pressure responsive means, here illustrated as a bellows 35, which is exposed on its inner side to the pressure of fluid from port 31 and its outer side to the pressure of fluid in a charge chamber 36. With this construction, it will be noted that the pressure responsive member urges valve member 34 toward closed or seated position due to the pressure in chamber 36 acting across the effective area of bellows 35. On the other hand, the pressure of formation fluid acting through passageway 19 upstream of seat 33 acts on bellows 35 to thereby urge valve member 34 toward open position.

It will be noted that chamber 36 is illustrated as being defined by an inner housing 37 which has its lower end sealed to the fixed end of bellows 35 and arranged to permit fluid communication between passage 19 and the annulus between inner housing 37 and housing 30. The upper end of the inner housing is arranged so that fluid can flow through a straining element, such as plastic member 38, into or from charge chamber 36 so that pressure from the formation fluid acting through passage 19 can be applied to that in charge chamber 36 to vary the operating characteristics of the valve means without removing the same from the well. It will be understood that the above-mentioned annulus will act as a reservoir to contain a resilient fluid and that formation fluid must move all of the reservoir fluid through element 38 before the formation fluid can flow therethrough.

In order to prevent an increased formation pressure from pressuring up the charge chamber each time the well is shut in, valve means are provided preventing flow from the formation to the charge chamber except when such valve means are opened by a control exercised from the earth's surface, as by wire line. Thus, wire line head 30a can be constructed as a reciprocable valve member seating across a seat 37a at the upper end of inner housing 37. Seat 37a can be formed as a cylinder to receive a piston-like portion of head 30a bearing a seal, such as O-ring 30b. A similar seal 37b can be provided in an inturned portion at the upper end of housing 30 to form a sliding seal with head 30a. Also, means are provided urging the head toward seated position and can comprise a spring 30c acting between the inturned portion of housing 30 and a guide extension 30d on head 30a. The guide extension should have a fairly close fit within inner housing 37 in order that it can, with seal 37b, maintain the head in seating alignment with seat 37a. To facilitate flow across the seat and head when unseated, guide extension 30d can be provided with an inner bore 30c having ports at its upper end communicating with the exterior of the head just below seal ring 30b.

In accordance with one aspect of this invention means are provided which are selectively operable to apply the pressure of fluid exteriorly of charge chamber 36 to the interior thereof to raise and lower the pressure in the chamber by a predetermined amount where the pressure of the fluid exteriorly of the chamber is respectively higher and lower than that in the chamber and also operable to prevent the application of pressure of the exterior fluid to that in the chamber despite substantial variation in the pressure of the exterior fluid from that in the chamber. As shown in FIG. 2, such means takes the

form of a partition 39 disposed in inner housing 37 to define the upper end of charge chamber 36. Partition 39 has ports 40 and 41 therethrough along with oppositely disposed spring loaded check valves 42 and 43 controlling flow through the ports. The springs on these check valves can be set or selected to exert a predetermined force holding the check valves in seated position. The springs will thus maintain the respective check valves closed until the formation pressure exceeds or falls below that in charge chamber 36 by a predetermined amount. The amount which the formation pressure must exceed the charge pressure in order to open check valve 42 can be the same as or different from the amount it must fall below the charge pressure in order to open check valve 43. The springs can be made strong or weak to determine the range through which the formation pressure can vary without affecting the charge pressure. In any event, the check valves will always maintain the charge pressure so that the difference between itself and the pressure of the formation fluid from port 23 will always be less than a predetermined amount.

Means are also provided which are manipulatable from the surface of the earth for controlling the selectively operable means described above to cause the latter to apply and prevent the application of the formation pressure to that in the charge chamber. In the embodiment of FIG. 1, such means includes not only valve 16 in line 15 but also a means for establishing communication between the earth's surface and the tubing-casing annulus below packer 14. This latter means can include a valve 44 comprising a sleeve 45 shiftable in the tubing to place ports 46 in the sleeve in and out of register with ports 47 in the tubing. The sleeve 45 is shiftable in this instance by a wire line tool between open and closed positions.

In operation of the system embodied in FIG. 1, let it be assumed that tubing 12 has been positioned in the well with packer 14 in place and with sleeves 26 and 45 in closed position. The pressure responsive valve means can then be lowered into the well by a wire line tool releasably connected to head 30a and latched in position in inner sleeve 25 and the landing extension thereof. In so landing the valve, sleeve 26 is moved to open position thereby permitting formation fluid to flow through passage 19 and to act against bellows 35. At the same time, the formation fluid exerts its pressure on fluid in the annulus between housings 30 and 37 and hence upon check valves 42 and 43, head 30a being held in open position by an upward pull exerted thereon by the wire line tool.

For the construction shown in FIGS. 1 and 2, charge chamber 36 will be substantially at atmospheric pressure when valve 20 is inserted in the tubing and the pressure of this chamber will increase upon landing valve 20 in sleeve 25 and establishing communication between check valves 42 and 43 and formation 11 via passage 19, the annulus between housings 30 and 37 and the unseated head 30a. The pressure in the charge chamber will thus be less than that of the formation by an amount determined by the strength of the spring on check valve 42. The strength of this spring and that of check valve 43 are preferably great enough, particularly when the seating arrangement of head 30a is not employed and the upper end of housing 37 left open, to afford a range of pressures through which the formation fluid can vary without opening either of the check valves and yet permitting opening and closing of valve 20 at a pressure within such range. Stated in another manner, the pressure required to be exerted by the formation fluid to open valve 20 against the opposing force of the pressure in the charge chamber acting across bellows 35 is less than that required to open either of check valves 42 and 43. Such an arrangement permits valve 20 to open and close to control flow into the tubing and hence maintain a selected back pressure on the formation without having its own characteristics incidentally changed during its normal operation by the formation fluid opening one of check valves 42 and 43.

However, when head 30a is made to seat across the upper end of housing 37, a substantial increase in formation pressure over that in the charge chamber merely urges the head toward seated position while a decrease in such pressure will eventually cause the pressure interiorly of housing 37 to overcome spring 30c and unseat the head. Therefore, the range of pressures through which the formation fluid can vary without changing the charge pressure has only a lower limit. In this connection, check valves 42 and 43 can be eliminated and spring 30c made strong enough to provide a known differential between a lower formation pressure and a higher charge pressure in much the same manner as check valve 43 so that the pressure in the charge chamber can be lowered by lowering the formation pressure, in a manner described below, to a value equal to the desired charge pressure minus the differential maintained by spring 30c. On the other hand, the charge pressure can be raised by raising the formation pressure to a value equal to the desired charge pressure and unseating head 30a by a wire line tool. Also, spring 30c can be made strong enough to hold the head seated against well pressure at all times and a wire line tool employed to unseat the head when the charge pressure is to be either increased or decreased.

Upon landing of valve 20 and moving sleeve 26 to open position, the pressure in the charge chamber may be less than or greater than that necessary to maintain a selected back pressure on formation 11. In some cases, the resulting back pressure maintained on the formation will be too high to achieve the desired rate of production of the well. In such event, sleeve 45 can be moved to open position, if it had not been moved to such position prior to landing of valve 20, and valve 16 opened to permit a more rapid flow from the well and thereby decrease the pressure in the tubing-casing annulus below packer 14. In this connection, ports 46 and 47 of valve 44 can be sized to provide an area substantially equivalent to that in the flow tubing so that opening of the valve 44 permits the bleed down of the formation at the full capacity of the tubing. As the bottom hole pressure drops, the pressure in charge chamber 36 will also decrease (head 30a being held open by either the wire line tool or by the pressure differential thereacross) but a predetermined differential will always be maintained between the charge pressure and the bottom hole pressure by the spring on check valve 43. Since this differential is known or can be determined before the valve is inserted in the well, it is possible to regulate valve 16 to obtain a selected charge pressure in chamber 36. When valve 43 is not employed and spring 30c made strong, the bottom hole pressure can be lowered to a value equal to the selected charge pressure and then head 30a seated or, where spring 30c maintains a known differential, the bottom hole pressure lowered to a value equal to the charge pressure minus the differential maintained by spring 30c to give the selected charge pressure. This selection of the charge pressure will determine the back pressure maintained on the formation and it will be so maintained because should the formation pressure increase, valve member 34 will be moved to a more open position to increase flow through the valve and thereby decrease the back pressure and vice versa. After the desired charge pressure has been obtained, valve 44 is, of course, moved to closed position. Valve 16 can then be opened and valve 20 will control production from the well.

On the other hand, if the charge pressure in chamber 36 is too low so that the back pressure on the formation is likewise too low, valve 16 can be partially or completely closed to raise the pressure in the tubing and hence that of the formation fluid flowing through passage 19. Then upon unseating head 30a, the rise in pressure will eventually cause check valve 42 to open and permit the charge pressure to be increased. When check valve 42 is not employed, head 30a is seated when the formation pressure rises to a value equal to the desired charge pressure.

The exact mode of use of the apparatus shown in FIG. 1 will be somewhat dependent upon the characteristics of the individual well. In some wells, it will be possible to land valve 20, open valve 44 and then adjust valve 16 to give the desired rate of production after which valve 44 is closed and valve 16 opened. Such manipulation automatically charges valve 20 (head 30a being held open) to a value substantially such as to maintain the desired rate of production and yet maintain the maximum back pressure on the formation consistent with such rate. Such a back pressure maintains a minimum gas-to-oil ratio because the pressure on the formation fluid is not excessively reduced before it flows into the tubing to permit excessive quantities of gas to break therefrom. On the other hand, when the rate of production is to be adjusted so that the gas-to-oil ratio is either at a desired value or as low as possible, valve 20 is landed in the well as before and valves 44 and 16 opened to substantially reduce the bottom hole pressure and hence the charge pressure of valve 20. The production rate and gas-to-oil ratio can then be measured and if a higher back pressure is desired on the formation, valve 16 partially closed to increase the bottom hole pressure of the well and hence the charge pressure in chamber 36. Valve 16 can then be opened and the production rate and gas-to-oil ratio measured again. By gradual increase in the charge pressure in chamber 36, the desired back pressure on the formation can be obtained. After the desired charge pressure has been attained, the wire line tool can be released from head 30a and thereafter, even if the well is closed in, increasing formation pressure cannot alter the charge pressure. This saves re-adjusting the charge pressure each time the well is placed in production after having been closed in.

The construction of valve 44, the receiver and valve means comprising sleeves 25 and 26 and that of dogs 28 and 29 has been shown somewhat schematically and for a more detailed description thereof, reference is made to copending applications Ser. No. 330,294, filed Jan. 8, 1953, now United States Patent No. 2,804,830, and Ser. No. 414,924, filed Mar. 9, 1954, now United States Patent No. 2,790,395.

Reference is made to Patent No. 3,045,759, issued to H. U. Garrett et al. on July 24, 1962. The disclosure of this patent is here included by reference.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the apparatus.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A system for regulating the flow of fluid from a producing formation of a well and maintaining a selected back pressure on the formation which comprises, in combination,

a flow conduit disposed in the well and pressure-responsive valve means disposed in the well and controlling flow of well fluid from the formation through said conduit, said valve means including,
a housing having an inlet and an outlet interconnected by a passageway, a valve seat across said passageway,
a valve member cooperable with said valve seat to control flow therethrough,
pressure-responsive means controlling movement of said valve member,

means providing fluid communication between a pressure-responsive surface of said pressure-responsive means and said inlet,
pressure fluid in said inlet urging the pressure-responsive means toward valve-opening position,
a closed charge chamber, another pressure-actuable surface on said pressure-responsive means forming a part of said closed charge chamber,
resilient fluid under super atmospheric pressure in said charge chamber urging the pressure-responsive means toward valve-closing position, and
means operably controlled from the earth's surface for selectively changing the pressure of said resilient fluid in said chamber to thereby change the back pressure maintained on said formation by said valve means.

2. A system for regulating the flow of fluid from a producing formation of a well and maintaining a selected back pressure on the formation which comprises, in combination,

a flow conduit disposed in the well to conduct fluids from said formation to the surface of the earth,
valve means in the well disposed to control flow from the formation through said conduit comprising,
a housing having an inlet and an outlet interconnected by a passageway, a valve seat across said passageway,
a valve member cooperable with said seat to control flow therethrough,
a normally closed pressure chamber including a pressure-responsive means having a pressure-actuable surface,
a charge of fluid under pressure in said chamber, said pressure-responsive means connected to said valve member and urging the valve member toward closed position under the force of pressure in said chamber,
means exposing another pressure-actuable surface of said pressure-responsive means to pressure of upstream fluid in said inlet,
the force of upstream pressure urging the pressure-responsive means against pressure of fluid in said chamber and toward valve-opening position,
said pressure-responsive means being responsive to an increase of said formation fluid pressure above a predetermined value to open the valve means and upon decrease of formation fluid pressure below a predetermined value to close the valve means, thereby maintaining a selected back pressure on said formation,
means selectively operable to apply pressure of fluid exteriorly of said pressure chamber to the interior thereof to raise and lower the pressure in said chamber by a predetermined amount where the pressure of fluid exteriorly of said chamber is respectively higher and lower than that in said chamber and also operable to prevent the application of pressure of said exterior fluid to that in said chamber despite substantial variation in the pressure of said exterior fluid from that in said chamber, and
means manipulatable from the surface of the earth for controlling said selectively operable means to cause the latter to apply and prevent the application of said pressure of said exterior fluid to that in said chamber whereby the back pressure maintained on said formation can be adjusted from time to time through a manipulation controlled at the earth's surface.

3. The system of claim 2 wherein said selectively operable means includes

a passageway communicating between the interior of said chamber and the exterior of said conduit and
a valve controlling flow through said passageway,
said valve having a part adapted to be engaged by a

tool within said conduit and manipulated thereby to open and close the valve.

4. The system of claim 3 wherein said means manipulatable from the surface of the earth includes

a wire line tool movable through said conduit and having a portion releasably engageable with said valve part to open and close the valve upon manipulation of the wire line tool.

5. A system for regulating the flow of fluid from a producing formation of a well through a flow conduit in the well to maintain a selected back pressure on the formation which comprises, in combination,

a flow tubing extending into said well and having an opening permitting fluid from said formation to flow into the tubing and thence to the earth's surface, valve means in the portion of said flow tubing in said well controlling flow through said opening and including pressure-responsive means controlling the opening and closing of the valve means and urging the latter to closed position,

said pressure-responsive means being exposed to fluid from said formation upstream of the valve means and urged thereby to open the valve means, and

means controllable from the earth's surface for selectively increasing and decreasing the force exerted by the pressure-responsive means in urging the valve means to closed position thereby increasing and decreasing the pressure required to be exerted by said fluid upstream of the valve means to open the latter whereby the back pressure maintained on said formation is changed.

6. The system of claim 5 wherein said means for increasing and decreasing the force exerted by the pressure-responsive means includes

a normally closed pressure chamber, and a passageway communicating between the exterior of the tubing and said chamber,

said pressure-responsive means having a part exposed to the pressure of a fluid within said chamber to cause it to urge the valve means toward closed position, and

a valve controlling flow through said passageway, said valve having a part adapted to be engaged by a tool within said conduit and manipulated thereby to open and close the valve.

7. The system of claim 6 wherein said valve includes a sleeve positioned within the tubing and shiftable therein to open and close said passageway.

8. In a well system,

a flow tubing disposed in a well bore and having an opening to receive fluid from a producing formation;

seal means in the well above said opening and sealing across the tubing-well bore annulus above said formation;

fluid pressure-responsive valve means in the well controlling flow through said opening and including a fluid pressure-charge chamber and pressure-responsive means urging the valve means to closed position under the influence of pressure in said chamber,

said pressure-responsive means having a part exposed to pressure of fluid from the formation upstream of the valve and urged thereby to open the valve means; means for applying the pressure of fluid from said formation upstream of said valve means to the interior of said chamber to selectively increase and decrease the pressure in said chamber by a predetermined amount where the pressure of said upstream fluid is higher and lower than that in said chamber; and

means including a valve for establishing fluid communication between the earth's surface and the tubing-well bore annulus below said seal means so that fluid can be bled from the annulus below said seal

to decrease the pressure of fluid upstream of said valve means whereby the pressure in said chamber can be changed to a desired low pressure.

9. The system of claim 8 wherein

said pressure responsive valve means includes a wire line head adapted to be engaged by a wire line apparatus, said pressure-responsive valve means being adapted to be lowered into the tubing by a wire line apparatus and

wherein there is provided means in the tubing for receiving and releasably retaining said pressure-responsive valve means when landed therein by said wire line apparatus.

10. The system of claim 9 in combination with valve means separate from said pressure-responsive valve means and movable to selectively block and permit flow through said opening and having a part engageable by a wire line tool to be moved thereby so that flow through said opening can be blocked upon removal of said pressure-responsive valve means from said tubing.

11. In a well system,

a flow conduit disposed in a well and having an opening to receive fluid from a producing formation;

valve means insertable into said conduit to control flow through said opening and including a fluid pressure charge chamber and fluid pressure-responsive means urging the valve means toward closed position under the influence of pressure in said chamber;

said pressure responsive means having a part exposed to pressure of fluid from the formation and upstream of the valve means and urged thereby to open the valve means;

means for applying the pressure of fluid from said formation upstream of said valve means to the interior of said chamber to selectively increase and decrease the pressure in said chamber by a predetermined amount where the pressure of said upstream fluid is higher and lower than that in said chamber;

means connected to said valve means and adapted to be lowered therewith through the conduit by a wire line apparatus and including means for releasably locking the valve means at a selected depth in the conduit, and

means constraining flow through the conduit to be through said valve means.

12. A valve for controlling flow of fluid into or out of a conduit in a well and adapted to have its operating characteristics changed while it is disposed in the well by a manipulation controlled from the earth's surface which comprises, in combination,

a housing, a passage in said housing for flow of fluid between the interior and exterior of said conduit,

a charge chamber in said housing having a movable wall,

a valve member connected to said movable wall and controlling flow through said passage and urged to one of its passage-opening and passage-closing positions by fluid pressure in said charge chamber,

a passageway communicating between the interior of said charge chamber and the exterior of said housing for permitting the pressure of well fluid exterior of the housing to be applied to that in said chamber, valve means controlling flow through said passageway and including a part movable to open and close said valve means, and

means movable through said conduit to move said part and being controllable from the earth's surface.

13. The valve of claim 12 wherein

said movable means is a wire line tool having a portion releasably engageable with said part of said valve means to open and close the latter whereby the wire line tool can be lowered through the con-

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duit to open and close said part and then removed from the conduit.

14. The valve of claim 12 wherein

said valve means includes a valve element reciprocally mounted for movement into a portion of said passageway to block flow through the same and for movement out of said passageway portion to open the passageway,

a wire line head carried by said valve element and adapted to extend into the bore of said conduit to be engaged by said means movable through the conduit and moved thereby to position said valve element in passage-opening position.

15. The valve of claim 12 wherein

said valve means includes a valve element movable to open and close said passageway,

said part including a sleeve adapted to be mounted interiorly of the conduit to be shifted therein by said means movable through the conduit, and

a force transmitting connection between said sleeve and said valve element for movement of the element responsive to shifting of the sleeve.

16. The valve of claim 12 wherein

said valve means includes a sleeve adapted to be mounted interiorly of the conduit to be shifted by said means movable through the conduit,

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a portion of said passageway being situated in said sleeve so that upon shifting of the sleeve said passageway portion is moved into and out of register with a remaining portion of said passageway to permit and block flow through the same.

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CHARLES E. O'CONNELL, *Primary Examiner.*

JACOB L. NACKENOFF, *Examiner.*

C. D. JOHNSON, J. A. LEPPINK, *Assistant Examiners.*