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The present invention relates to methods for controlling the flow of oil and gas wells, and particularly to well flow regulating means adapted to be located in the bottom of the well.

To preserve the formation gas pressure which, in flowing wells, forces the oil to the surface through an eduction tube, valves, or chokes have been installed in the bottom of the well. These chokes or bottom hole regulators cause the gas dissolved in the oil to be expanded and liberated at the bottom of the well, and thus permit the lifting of the oil to the well surface at lower gas-oil ratios. Further, these regulators hold the gas in solution in the oil during its flow through the formation, whereby the viscosity and surface tension of the oil are reduced and the resistance to the flow of the oil through the formation is decreased.

It is highly desirable to flow a well at a constant rate and to maintain a steady pressure at the inlet and outlet ends of the eduction tube, since it is under these conditions that most efficient and economical well production is obtained.

The use of most bottom hole regulators is however subject to difficulties of installation, adjustment and removal. Some bottom hole regulators, such as the fixed orifice type, being dependent upon constant pressures on either side of the orifice, require constant flow, usually require a second control point at the surface to exert sufficient back pressure for controlling the volume to a desired amount, since it is costly and impractical to remove bottom hole chokes for frequent adjustment. The back pressure at the surface has a marked effect on flow efficiency or heading, since a comparatively small surface back pressure increase reduces the volume of the rising fluid, slows its travel, and accentuates surging or heading in the tubing, thus largely or completely nullifying the beneficial effects of the bottom hole choke. In other regulators, a constant pressure drop is maintained at the inlet or bottom end of the eduction tube by means of a spring-loaded choke or valve, while secondary control is obtained at or near the surface with an additional orifice or choke. These regulators, since no compensation is obtainable for variations in bottom hole pressure without removing and readjusting the bottom hole choke, likewise fail to fulfill the requisite conditions for most efficient operation.

It is therefore an object of the present invention to provide an improved bottom hole regulator for oil wells, which is remotely controlled from the surface of the well.

It is a further object to provide an improved bottom hole regulator for oil wells, which is substantially independent of variations in bottom hole pressure.

It is likewise an object of this invention to provide means including an improved bottom hole regulator for extending the flowing life of oil wells.

Other objects will be apparent from the following description, taken in reference to the drawings, wherein:

Figure I is a longitudinal cross-sectional view of the upper portion of an embodiment of the bottom hole regulator of the present invention.

Figure II is a longitudinal cross-sectional view of the lower portion of an embodiment shown in Figure I.

Figure III is a longitudinal cross-sectional view of a modification of the upper portion of the embodiment shown in Figure I.

Figure IV is a diagrammatic view of a well showing the control equipment and the present bottom hole regulator installed in the tubing of a well.

Figure V is another diagrammatic view of a well showing the regulator installed without the casing of a well.

Briefly, the bottom hole regulator of the present invention comprises conduit means, such as a tubing string, extending down into the well together with an orifice associated with the lower portion thereof through which the well fluid must flow, valve means for regulating the fluid flow through said orifice, resilient means for urging said valve means into open position, hydraulic means extending to the well surface for adjusting the position of said valve from the surface, and means for neutralizing and eliminating the effects of bottom hole pressure variations on the position of the valve, whereby the downward force of the hydraulic means which tends to close the valve is balanced against the upward force of the resilient means together with that of the pressure on the outlet or downstream side of the valve, which tends to open said valve.

Figure IV of the drawings diagrammatically illustrates the position of the bottom hole regulator of the present invention in a casing of a well. The casing extends from a point above the ground level down to the bottom of the well, the top of the casing being closed by a casing head. A tubing string extends down through the casing and terminates in a perforated plug.
4, screen, or other suitable strainer. The annular space \(10\) between the tubing string \(3\) and the casing \(1\) is closed by means of a suitable packer \(5\) carried on the lower portion of said tubing string \(3\). The present bottom hole regulator, generally designated as \(6\), is positioned within the lower portion of said tubing string \(3\) by means of a suitable packer \(7\) carried by a depending coaxial tubular extension \(9\) of the regulator \(6\). Fluid flow passes from the oil sand \(2, 3, 51, 822\) and rod \(3\) by the spring \(35\) and rod \(31\) by the spring \(43\) is regulated by hollow adjusting nut \(35\), after which the adjusting nut \(35\) is locked in the desired position by locknut \(47\).

The upper end of the rod \(31\) is highly polished and forms a piston \(31b\) which fits slidingly into a sleeve cylinder \(81\) extending into the chamber \(52\) of the plug member \(26\). The position of the piston \(31b\) and therefore of the valve \(32\) is regulated by adjusting the pressure within the chamber \(52\), which communicates with the surface. This communication may be obtained through channel \(56\) extending from the chamber \(52\) upwardly to the annular space \(56\) between the flow string or eduction tubing \(9\) and the outer tubing \(3\). A perforated plug \(81\) is preferably attached to the end of the channel \(56\) in the plug member \(26\) to prevent debris from falling into and plugging channel \(56\). Likewise, a tubular element \(85\) forming an upwardly opening cup, is attached to the upper end of the plug member \(26\), in order to prevent sediment from lodging between the regulator \(6\) and the outer tubing \(3\) and preventing the removal of the regulator.

As shown in Figure IV, the eduction tube or flow string \(9\) extends from the regulator \(6\) through the top of the casing head \(2\) and is thereabove fitted with a back-pressure valve \(80\), which keeps a constant pressure on the top of the flow string \(9\). The annular space \(56\) between the flow string \(9\) and the outer tubing \(3\) is filled with a control fluid and is connected at the surface by means of a pipe \(81\) to a control fluid reservoir tank \(82\).

Preferably, the control means comprises a control fluid consisting of liquid, such as oil, water or the like, filling the control chamber \(56\), channel \(56\), annular space \(56\), and the lower portion of the tank \(82\) and gas filling the space above the liquid in the tank \(82\). The liquid is kept at approximately constant level, for which purpose a sight glass or gauge \(53\) is provided on the tank \(82\). Gas is pumped into the tank under pressure by means of a valve \(34\) to exert the controlling force on the regulator piston \(31b\), the combined liquid and gas pressure being required to balance the force of the spring \(43\) below the regulator valve \(32\).

The mode of operation of the regulator may be best described algebraically; therefore, let

\[ A1 = \text{Area of control cylinder} \]  
\[ A2 = \text{Area of valve orifice} \]  
\[ A3 = \text{Area of valve rod} \]  
\[ P1 = \text{Gas pressure in control tank} \]  
\[ P2 = \text{Hydrostatic liquid pressure in control chamber} \]  
\[ P3 = \text{Pressure in chamber} \]  
\[ P4 = \text{Bottom hole or well pressure in chambers} \]  
\[ P5 = \text{Pressure of spring} \]  

With the valve \(32\) partially open, the forces acting on the valve are as follows:

(a) Downwards

\[ (P1 + P3) A1 + P3 (A2 - A3) \]

(b) Upwards

\[ P3 (A1 - A3) + P2 A4 + P3 \]

For balance

\[ (P1 + P3) A1 + P3 (A1 - A3) = P3 (A1 - A3) + P2 A4 + P3 \]
Since $P_3$, $A_1$, $P_4$, are fixed and $A_2 - A_3$ is small but larger than $A_4$, a reduction of pressure $P_3$ in chamber 27 will cause the valve to open or an increase in pressure will cause the valve to close, thus tending to create substantially constant pressure in chamber 27, the magnitude of which is set by the main variable control pressure $P_1$ at the surface. The equation is for stable conditions in chamber 27 regardless of well conditions, since the effect of well pressure below valve 32, i.e. in chamber 16 and 16a, has little effect on the valve.

In order to make the regulator applicable over a fairly wide range of depths, the gas pressure $P_2$ is kept fairly large with respect to the hydrostatic pressure $P_3$, and the volume of the tank 32 is made large so that leakage of fluid or adsorption of gas does not cause appreciable differences in control pressures and, therefore, of flow. Also, expansion of the fluid in the control column or surface as temperature changes should then not cause appreciable recompression in gas pressure $P_2$ after well fluid flow has settled down to steady conditions.

Changes in the operating range of the regulator can be made by simple changes in the size of parts 31a, 31b, 36, 42, and 51 as required to suit conditions.

It will be readily apparent from the above description that various modifications may be made without departing from the spirit of the present invention as defined by the appended claims. For example, it is shown in Figure III, passages 36a provide fluid communication between the valve chamber 37 and the annular space 56 between the outer tubing 3 and a small control tubing string 9a, whereby well fluids flow upwards through the regulator 8 and the annular space 56 instead of a central education tube 5, as in Figure I.

The lower end of the control string 9a is preferably fitted with an annular sealing ring 80 and thereby engages tightly within the coaxial counterbore 82 which communicates with the control chamber 32 through a debris-catching screen 86. Likewise, if desired, as shown in Figure V, the valve 8 may be fitted directly within the casing string 1 whereby the outer tubing 3 and the tubing packer 7 may be omitted and the casing packer 8 and perforated plug 8 or screen carried by the regulator tubular extension 89.

In wells which have declined to the point where they will no longer flow naturally, the bottom hole regulator of the present invention is particularly effective and advantageous when used in conjunction with a flow string having a small diameter bore, as illustrated in Figures 1 and 11, so as to permit passage of fluid to the surface at suitable velocities and to prevent or greatly minimize "heading" or "surging." The use of a flow tubing with the proper small diameter bore, depending on the range of flow rates, will permit the raising of a given volume of fluid to the surface at the minimum expense of bottom hole energy. Intermittent flow absorbs considerably more energy per unit of fluid delivered at the surface than steady flow, which is the most desirable method of producing oil wells.

With this arrangement of a small bore flow string, together with the present bottom hole regulator which is largely independent of variations in bottom hole pressures, the natural flowing life of a well can be considerably increased, for example, under certain conditions for an additional period of three to eight years, and the pumping period may be reduced as much as 80 per cent. By using a small bore flow string, which is preferably suitably insulated, such as with a lining of cement or the like, heat loss by heat exchange will be minimized and the velocity of flow will be sufficiently high to assure that the temperature of the crude oil produced will be above the temperature at which any paraffin present accumulates.

For example, many wells with present size of tubing and production methods, will not flow naturally after having been shut in if the bottom hole pressure drops below 600 lbs. per sq. in. However, the wells will continue flowing with a small sized tubing with as low as 400 lbs. per sq. in. bottom hole pressure. The steady flow characteristics resulting through the use of small diameter insulated tubing would have the additional advantage of decreasing the rate of water encroachment in contrast to the presently used stop-cocking or high rate intermittent flow, which is necessary to reduce paraffin accumulation in the tubing, but which hastens production of water from the well and increases the rate of water production after it first appears.

The present combination thus postpones and sometimes eliminates the need and expense of salt water disposal facilities.

For this purpose, tubing strings having diameters of 1 1/2 to 2 inches may be used, depending on the flow rate. For example, under certain fluid conditions a suitably insulated, e.g. cement-lined, flow tubing having a one-half inch bore will produce oil continuously at the rate of one barrel an hour, while maintaining the tubing inlet pressure at 500 lbs. per sq. in. by means of the present bottom hole regulator and the surface exit pressure at 30 lbs. per sq. in. by means of a back pressure valve, whereby there is obtained efficient continuous flow over a long period of time. In such small tubing strings and at such small flow rates, it is essential that the inlet pressure to the tubing string be maintained very closely to a predetermined pressure, which condition for efficient flow can be obtained by the use of the present bottom hole regulator.

I claim as my invention:

1. In a bottom hole regulator for oil wells having an eduction tubing and casing string depending therefrom, said regulator being adapted to be positioned in the lower portion of the well, passage means longitudinally through said regulator, said passage means comprising a valve port, a reciprocable stem carried within said housing, the lower portion of said stem having a thickened cross-section substantially equal in diameter to that of said valve port, a valve carried by said stem and adapted to seat in said valve port for regulating the flow of well fluids through said passage means, adjustable resilient means for urging said valve into open position, hydraulic means for urging said valve into closed position, said hydraulic means comprising an upper cylinder adapted to receive slidable the upper portion of said valve stem, a passageway communicating with the surface, and means for imparting fluid pressure to said valve stem in said cylinder through said passageway, a lower cylinder adapted to receive slidable the lower thickened portion of said stem and including passage means to provide pressure communication between the lower cylinder and the housing space directly above the valve, whereby the position of the valve is regulated from the surface and is substantially unaffected by varying pressures below the regulator.
2. In a pressure regulator adapted to be positioned in the bottom portion of a well, means forming a flow passage through said regulator for the well fluid to the surface, a valve seat in said flow passage means, a pressure-responsive valve element adapted to cooperate with said valve seat for controlling the flow of fluid through said regulator, a reciprocable stem carrying said valve element, resilient means for urging said valve element into open position, hydraulic means acting upon said stem and extending from the upper end of said stem to the well surface for maintaining a substantially constant pressure on said valve element counter to the pressure of said resilient means, and equalizing passage means extending from the lower end of the valve stem to the space on the outlet side of the valve, whereby the effects of fluctuations in pressure below the pressure regulator on the operation of the valve are substantially eliminated.

3. In a pressure regulator for oil wells, a passage for the flow of well fluid to the surface, a valve seat in said flow passage, a reciprocable valve element adapted to cooperate with said valve seat for controlling the flow of fluid through said flow passage, a reciprocable stem rigidly carrying said valve element, resilient means adapted to urge said valve element into open position, hydraulic means extending to the surface for applying a fluid control pressure to one end of said stem in opposition to the effect of said resilient means on said valve, and equalizing passage means extending from the other end of said valve stem to said flow passage on the outlet side of the valve for applying to the other end of said valve stem the pressure at said outlet side of the valve.

4. In a pressure regulator for oil wells, a passage for the flow of well fluid to the surface, a valve seat in said flow passage, a valve element adapted to cooperate with said valve seat for controlling the flow of fluid through said flow passage, a reciprocable stem rigidly carrying said valve element, cylinders slidingly fitted about the ends of said stem, said stem ends forming pistons in said cylinders, resilient means adapted to urge said valve element into open position, hydraulic means extending to the surface and opening to one of said cylinders for applying to a first piston formed by the first end of said stem, a fluid control pressure in opposition to the effect of said resilient means on said valve, and equalizing passage means in communication between the other cylinder and said flow passage on the outlet side of the valve for applying to said second piston formed by the second end of said stem the pressure on said outlet side of the valve.

5. A well pressure system for naturally flowing wells comprising the combination of an education string and a control fluid string concentrically extending into the well from the surface, a packer within the lower portion of the well sealing the annular space between said strings, a bottom hole regulator forming a passage through said packer, a valve seat in said passage, a valve element adapted to cooperate with said valve seat for controlling the fluid flow through said passage, resilient means for urging said valve element into open position, first piston means attached to said valve, said means being responsive to pressure in the control fluid string for urging said valve into closed position, second piston means attached to said valve, said second piston means being responsive to rising pressure in said flow passage on the inlet side of the valve for closing said valve and to rising pressure in said flow passage on the outlet side of the valve for opening said valve, and control means at the surface for regulating the pressure in said strings.

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