

[54] DOWNHOLE SAFETY VALVE
[76] Inventor: Frederick Price, 307½ Boles St.,
Houston, Tex. 77011
[22] Filed: Sept. 7, 1972
[21] Appl. No.: 287,101
[52] U.S. Cl. 137/498, 166/224, 251/368
[51] Int. Cl. F21b 33/00, F16k 31/2
[58] Field of Search 137/498, 497, 503,
137/505.38; 166/224; 251/368

[56] References Cited
UNITED STATES PATENTS
2,588,715 3/1952 Garrett 137/498 X
2,655,934 10/1953 Clair 137/498
2,781,775 2/1957 Merrill 137/48

2,799,292 7/1957 Pearce 137/498
Primary Examiner—Henry T. Klinksiek
Assistant Examiner—Robert J. Miller
Attorney—Tom Arnold et al.

[57] ABSTRACT
An abrasion resistant flow control safety valve has a
variably adjustable orifice or port for passage of a de-
sired flow of a well fluid. The annular orifice is defined
by a tapered plug extending through a seat, and the
cross-sectional area of the orifice is varied by moving
the plug relative to the seat. The valve operates respon-
sive to a predetermined flow rate to close and shut in
the well.

18 Claims, 2 Drawing Figures

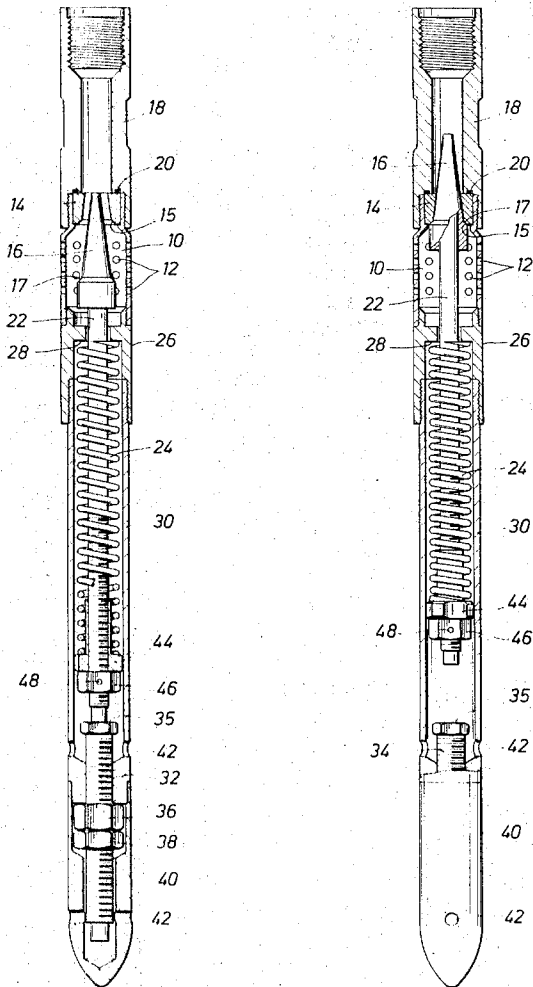


FIG. 1

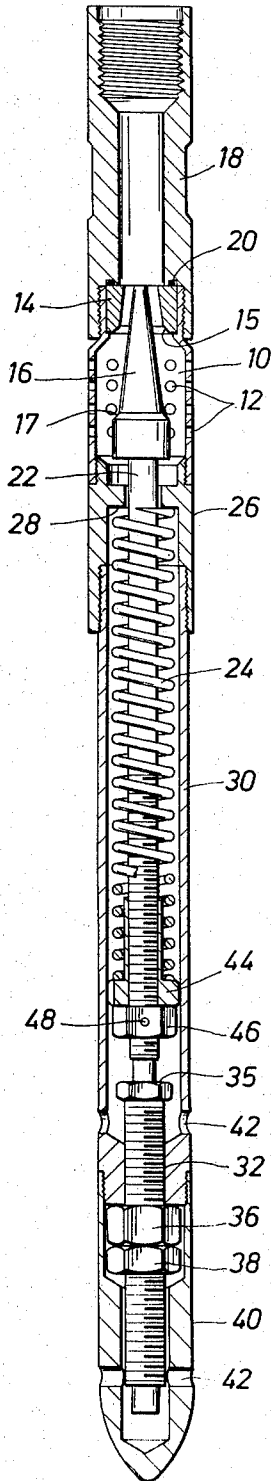
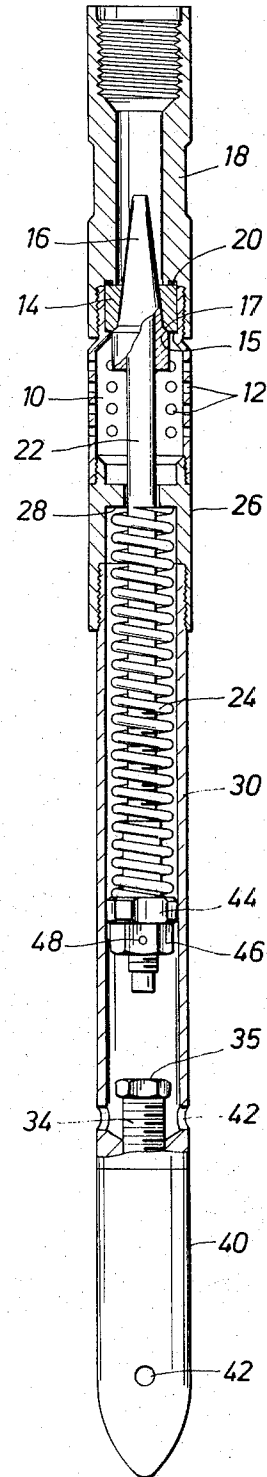


FIG. 2



DOWNHOLE SAFETY VALVE

BACKGROUND OF THE INVENTION

This invention relates to the safety devices for oil and gas wells, and, more particularly, to safety valves for shutting in such wells.

Downhole or tubing safety valves are commonly used in oil and gas wells to prevent environmental damage, product loss, property damage, and personal injury resulting from damage to wellhead equipment, such as being struck by a vehicle or vessel, storm damage, or land or snow slides. In addition, these valves are effective to protect against equipment failures, such as rupture of the well tubing, failure of the production choke, and other equipment malfunctions.

The most commonly used downhole safety valves are those which may be set to close responsive to a predetermined flow rate through the valve. The shut-in rate is set at a level in excess of the normal production flow rate of the well. This type of safety valve is particularly applicable to wells in the United States where production is prorated, as the flow rate of such wells is not limited by casing or tubing size. When the normal flow rate of a producing well is the same as its maximum flow rate, more complex, remote controlled safety valves responsive to remotely sensed conditions at the wellhead, or other like safety devices, must be used.

The reliability of the direct flow controlled downhole safety valves heretofore available has been questionable, in all but applications involving relatively short service intervals. This is especially true in well applications where quantities of sand or other abrasive materials are entrained in the production fluid. Such entrained abrasives can quickly render inoperative or unreliable those downhole safety valves which rely for their operation on packings, bellows, close fitting cylinders, or pistons. Even the common flow bean may be severely abraded under such conditions, increasing its internal diameter so that a flow rate greater than the preset flow rate is required to actuate the device.

If the downhole safety valve is incorporated into the tubing string, its removal from a producing well for inspection or replacement is quite time consuming and expensive. Accordingly, the majority of the downhole safety valves are designed to be hung within the tubing and to be wireline retrievable. But even though such valves can be pulled by wireline for inspection or replacement, the expense is substantial. It is apparent that a reliable, trouble free downhole safety valve is highly desirable to permit longer service intervals between inspections or replacements.

SUMMARY OF THE INVENTION

Downhole safety valves in accordance with the present invention are responsive to increases in production flow rates and operate to shut in a well when the flow rate through the valve exceeds a preestablished limit. These valves include an annular seat and a matching tapered plug or plunger adapted to move axially into the seat to close the valve. The tapered plunger forms one end of a floating stem, which is the only moving part in the valve.

Well fluid flowing through the valve passes through an annulus defined between the tapered plunger and seat, producing a venturi effect tending to draw the plunger into the seat. The valve is biased open to permit flow until the flow rate reaches the preestablished

level, at which point the venturi effect overcomes the open bias of the plunger, permitting the valve to close and to be held in the closed position by the well pressure.

Downhole safety valves in accordance with the present invention are of simple construction, containing no packings, bellows, close fitting cylinders, or pistons, which might be damaged by abrasive action, heat, or chemical reaction with the well products.

Accordingly, it is one object of this invention to provide an improved downhole safety valve.

It is another object of the present invention to provide a downhole safety valve having improved resistance to abrasives entrapped in the well fluid.

It is a further object of the present invention to provide a downhole safety valve having a flow orifice which is readily variable from closed to fully open.

It is still another object of the present invention to provide a downhole safety valve having a longer useful service life than those heretofore available so that the expense of inspecting and replacing such valves may be substantially reduced.

Among the further objects of this invention is to provide a downhole safety valve of extremely simple design, having no packings, bellows, or close fitting cylinders or pistons.

Among the still further objects of the present invention is to provide a downhole safety valve which tends to reduce the abrasive wear on other tubing string elements due to the flow of abrasive well fluids.

Still another of the objects of the present invention is to provide a simple, reliable downhole safety valve which is retrievable by wireline.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical cutaway view of the one embodiment of a downhole safety valve in accordance with the present invention, showing the valve in the open position.

FIG. 2 is a similar view of the downhole safety valve of FIG. 1, showing the valve in the closed position.

DESCRIPTION OF PREFERRED EMBODIMENTS

FIGS. 1 and 2 show one embodiment of a downhole safety valve in accordance with the present invention, including valve body 10 having a number of orifices 12 for passage of well fluid into the valve body. Interior to the valve body are an annular tapered seat 14 and a correspondingly tapered plug or plunger 16. When the valve is open, the plug 16 extends through the seat 14 to define an annular flow orifice or port through which well fluid may pass. The plug 16 is axially movable within the seat to close the valve, bring the tapered surfaces of the two members into mating contact. In addition, seat 14 and plug 16 each include mating shoulders 15 and 17, respectively, defining annular surfaces which contact one another upon full movement of the plug 16 through the seat 14 to provide a second mating, sealing surface between the plug and the seat. Both the plug 16 and the seat 14 are preferably fabricated of an abrasion resistant material, such as, for example, tungsten carbide, and members fabricated of a sintered tungsten carbide, have been found especially effective to resist abrasive wear from entrapped or suspended sand or other abrasives in the well fluid.

An adapter sub 18 is threadedly connected to the valve body 10 and includes a recessed annular groove

containing an O-ring 20 to provide a fluid tight seal between the valve seat 14 and the adapter sub. Conventional apparatus may be connected to the adapter sub, as will be discussed below.

An actuating stem 22 extends axially from the plug 16, and has an externally threaded portion at its end remote from the plug. A coiled spring 24 coaxially surrounds the stem 22. A spring retainer 26 is threadedly connected to the lower end of the valve body 10 and includes a downwardly facing shoulder 28 for retaining the upper end of the spring 24. The stem 22 passes through the retainer 26 and is adapted to slide up and down along its axis through the retainer. Below the spring retainer, a housing 30 is provided to enclose both the spring 24 and the stem 22. The housing 30 is threadedly connected to the spring retainer 26, as shown.

The lower end of the housing 30 includes internal threads 32 into which an orifice adjusting screw 34 is screwed. The head 35 of the orifice adjusting screw defines a stop against which the lower end of the stem 22 rests to variably define the maximum opening of the valve. The spring 24 biases the stem 22 downwardly to maintain the valve in the open position, the stem abutting the orifice adjusting screw head. The orifice adjusting screw 34 extends through the lower end of the housing 30 and is engaged by an orifice adjusting screw nut 36 and a jam nut 38. The head 35 may be raised or lowered as desired by rotation of the screw 34 in the appropriate direction, and the corresponding raising or lowering of the stem 22 adjusts the unobstructed cross section between the seat and the plug when the valve is in the open position. The screw 34 may be rotated as much or as little as desired to adjust the fully open position of the valve, resulting in an almost infinite capability for adjustment from a full closed to a full open position.

A protective cap 40 is screwed to the lower end of the housing 30, to cover the lower end of the orifice adjusting screw and the nuts 36 and 38. Both the housing 30 and the cap 40 include pressure ports 42 communicating between their respective interiors and the well to maintain their interiors at the well fluid pressure.

Near the lower end of the stem 22 are located a spring guide 44 and a spring adjustment nut 46. The spring guide is slideable along the stem and retains the lower end of the spring 24. Portions of the guide 44 are open so that fluid within the housing will not impede operation of the valve. By turning the spring adjustment nut, the compression of the spring may be increased or decreased as desired to control and predetermine the flow rate through the valve necessary to overcome the spring bias and close the valve. Provisions are made in the spring adjustment nut 46 and the lower portion of the stem 22 for engagement of a cotter pin 48 to prevent loosening of the spring adjustment nut.

Downhole safety valves in accordance with the present invention are placed and held in well tubing strings by conventional methods well known to those skilled in the art. For example, the tubing string will usually contain one of a number of types of landing nipples, so that a cooperating mandrel or hanger may be used to hold the safety valve in place in the well. Conventional packers are used to seal the valve in the well so that all well fluid will flow through the valve. Accordingly, such devices need not be discussed in detail.

A pressure equalizing sub is also commonly used in connection with the downhole safety valves of the present invention. The equalizing sub is located above the upper end of the safety valve. Equalizer subs and their operation are also well known in the art, and their use to selectively communicate well fluid pressure to the downstream, or top, side of the closed safety valve to open the valve is a standard practice.

In operation, a downhole safety valve in accordance with the present invention is readied for use by adjusting screw 34 to the desired height to define, through the stem 22, the open position of the valve. The orifice adjusting screw nut 36 and the jam nut 38 are then tightened to hold the orifice adjusting screw in place. The spring adjustment nut 46 is then tightened or loosened on the stem 22 to vary the force biasing the valve in the open position. These adjustments establish the flow rate at which the valve will automatically close, as will be discussed below. The remainder of the valve components are then assembled in preparation for placing the valve in a well.

The valve is then installed in the well tubing by conventional methods, using any type of mandrel or hanger desired, although the use of a landing nipple is preferred. It will be appreciated that the well will usually be brought in, cleaned, and potentialized before the downhole safety valve is set.

The spring 24 biases the valve in the open position. Well fluid flows into the valve body 10 through a number of orifices 12 and out through the annulus defined by the valve seat 14 and the plug 16. As the well fluid flows through this annular orifice or port, a venturi effect is created. This venturi effect lowers the pressure on the downstream side of the plug with respect to the pressure on the upstream side of the plug, urging the plug in the downstream, or upward direction. At the desired production flow rate for the valve, this venturi effect will be insufficient to close the valve against the biasing force of the spring. As the flow increases, the flow produced pressure differential overcomes the biasing effect of the spring, and the plug is drawn toward the seat. As the plug is drawn toward the seat, the annular area through which flow occurs is reduced, heightening the venturi effect to overcome the spring biasing force and close the valve. The well pressure then acts on the upstream side of the plug to maintain the valve in the closed position.

A pressure equalizing sub is commonly used together with downhole safety valves in accordance with the present invention. When the condition that produced the increased flow rate which closed the valve has been relieved, as by repair of a broken line, an appropriate mandrel is run in the well to open one or more valves in the pressure equalizing sub. When the pressure on the downstream side of the valve increases to a value sufficiently close to the upstream pressure, the spring acts to open the valve and well flow may be resumed. Of course, the valve might also be opened by pressurizing the tubing from the wellhead.

It will be appreciated that all portions of the valve below the seat are exposed to the well fluid pressure by ports 42 as shown.

The adjustable flow orifice of valves in accordance with the present invention is particularly advantageous when drops in well pressure become sufficient to adversely affect production. Under such conditions these valves may be quickly retrieved by wireline and reset

to provide a greater flow orifice area to bring production flow to the desired level. Corresponding adjustments in the compression of the biasing spring 24 may similarly be made as desired to control the flow differential at which the valve automatically closes. It will be appreciated that adjustments of the flow orifice and biasing force will be required as well flow conditions change and also as abrasive wear affects the plug and seat surfaces, and that such adjustments may readily be made in the valve of the present invention without replacement of parts, undue loss of time, or substantial difficulty.

Downhole safety valves in accordance with the present invention are particularly well suited to use in wells producing sand or other entrained abrasives in the well fluid. It is widely known that the presently available downhole safety valves have useful lifetimes in abrasive environments which are measured in terms of weeks. These known valves are quickly rendered inoperable by the abrasive action of the well fluid on the flow control surfaces and by the depositing of sand and the like in close filling areas such as sleeves, pistons, and such. After several weeks, such valves are often inoperative at any flow rate or at least unreliable at their preset shut in rates.

The valves of the present invention are exceptionally durable, long lived, and reliable under abrasive flow conditions for several reasons. By simplifying the valve design to incorporate a single moving part and to eliminate the bellows, packing, close fitting cylinders, and pistons which the prior art valves have found necessary, the problems arising from the deposition of particulate matter in the valve have been greatly diminished. In addition, valves in accordance with the present invention have the majority of their areas out of the main well fluid flow path, and are therefore far less likely to experience abrasive wear and be affected by the settling out or depositing of sand and the like.

It will be noted that the fluid flow path through valves according to this invention is such that the fluid enters the valve body and moves toward the annular orifice at a relatively lower velocity than that occurring between the seat and the plug and is substantially parallel to the surfaces of the annular orifice where the more rapid flow occurs. Therefore the impingement of abrasive material on valve elements to produce wear occurs to the greatest extent on the extended plug surface within the valve body and on the opposing plug and seat surfaces defining the narrowest flow restriction in the annular orifice.

The unique arrangement of valve elements in the present invention permits the use of sintered tungsten carbide seats and plugs for resistance to abrasion and resulting long life, but other materials may also be used with some sacrifice in total useful life under abrasive conditions. Particularly effective abrasion resistance is shown by the annular tapered surfaces 15 and 17 due to their locations with respect to the flow within the valve. In these locations the surfaces are not subject to severe impingement of abrasives or high rates of wear, and remain effective as valve seating areas to effectively shut in a well even when the adjoining, extended tapered surfaces are relatively more abraded.

It has been found that the valves of the present invention not only experience surprisingly little internal wear in abrasive flows, but it also appears that their unique tapered plug design reduces abrasive wear on well

equipment downstream of the valves themselves. As the abrasives entrained in the well fluid enter the valve body 10 through the laterally disposed orifices 12, they impinge upon the hardened plug 16. The plug absorbs the abrasive impact, but being of a hardened material is relatively insensitive to such abrasion. The abrasive material entrained in the well fluid is believed to flow along the surface of the plug 16 and through the orifice defined between the plug 16 and the seat 14 without mixing back in the valve body. As a result the seat 14 suffers far less abrasion than would normally be expected. In addition, this concentration of abrasive material toward the center of the tubing string tends to protect equipment and elements downstream from the valve, at least those elements upstream of the first tubing turn or obstruction.

The flow patterns established for abrasive materials entrained in well fluids flowing through valves in accordance with the present invention combine with the dual seat design of the valves to produce outstanding and unexpected results as compared to previously known apparatus, as has been amply demonstrated in one series of tests of a downhole safety valve in accordance with the present invention. In one abrasive well the heretofore available valve had been used and found to have been rendered inoperative or unreliable in as little as six weeks in the well. A valve in accordance with the present invention was run in the well and remained in service for seven weeks. It was then pulled and inspected. No significant wear was noted. The valve was then run back in the same well, where it remained for an additional five months. The valve was then pulled and inspected again. The valve was still completely operable, and, although demonstrating some abrasion, there was no abrasion to critical seating areas 15 and 17 of the valve and the valve still functioned reliably to close and seat at the predetermined and present flow rate.

The test well was a gas well from which a production flow of 1,000,000 cubic feet per day (CFD) was desired. The shut in flow desired was 1,300,000 CFD. A valve in accordance with the present invention was preset for these conditions, placed in the well, and packed off. A flow test was performed and the valve operated to shut in the well at a flow rate of 1,310,000 CFD. After seven weeks and before pulling the valve for inspection a second flow test was performed, and the valve again shut in the well at a flow rate of 1,310,000 CFD. Immediately prior to pulling the valve after a total of more than six months service in the well, still another flow test was performed and the valve operated to shut in the well at a flow rate of 1,310,000 CFD. These tests clearly demonstrate the consistency and reliability of the valves of this invention, as well as the accuracy with which the shut in flow rate can be preset.

The valve used in the above test had a first plug and seat taper over their respective extended surfaces of eight degrees with respect to the valve axis, and a second taper at opposing surfaces 15 and 17 of 45° with respect to the valve axis. It will be appreciated that variations may be made in these respective taper angles, and that variations between the angles of taper of the extended surfaces of the seat and plug may be employed, and that the foregoing angles are illustrative of one embodiment of the present invention.

It will be appreciated by those familiar with flow control safety valves that numerous mechanical and other

details may be modified without departing from the spirit and scope of the present invention as defined by the appended claims. For example, the spring adjustment and orifice adjustment nuts might be set with set screws rather than cotter pins and jam nuts as illustrated. Or biasing means might include a spring in tension rather than in compression. For this reason the embodiments disclosed herein should be regarded as illustrative and not as limiting of the present invention.

I claim:

1. A safety valve for shutting in a well responsive to flow of well fluid exceeding a predetermined rate; comprising:

a valve body having an orifice communicating with the well fluid;

a seat within said valve body downstream of said orifice;

a plug extending through said seat, said plug being axially movable through said seat between a first position defining an annular port in combination with said seat and a second position in contact with said seat to shut in the well;

means resiliently urging said plug toward the first position to maintain said valve open when the flow of well fluid is at a rate not more than the predetermined rate; and

means moving said plug to the second position responsive to flow of well fluid exceeding the predetermined rate to shut in the well.

2. A safety valve as recited in claim 1, including means for variably adjusting the area of the annular port between said seat and said plug when said plug is in the first position.

3. A safety valve as recited in claim 1, wherein said seat and said plug define mating tapered surfaces.

4. A safety valve as recited in claim 3, wherein said seat and said plug have first mating tapered surfaces toward their respective downstream ends and second mating tapered surfaces upstream from said first surfaces and intersecting said first surfaces at an angle with respect thereto to define annular seating surfaces for preventing flow between said plug and said seat when said plug is in the second position.

5. A safety valve as recited in claim 1, wherein said urging means is adjustable to selectively preestablish the flow rate above which the valve operates to shut in the well.

6. A safety valve as recited in claim 1, wherein said urging means comprises a compressed spring.

7. A safety valve as recited in claim 1, wherein said seat and said plug comprise sintered tungsten carbide.

8. A safety valve as recited in claim 1, wherein said valve is wireline retrievable.

9. A downhole safety valve for insertion into a well flowing an abrasive well fluid to shut in the well in response to a flow of well fluid exceeding a predetermined rate, comprising:

a valve body having a plurality of orifices communicating with the well fluid;

a tapered seat in said valve body downstream of said orifices;

a plug extending through said seat and having a taper corresponding to the taper of said seat, said plug being axially movable through said seat between a first position defining an annular port between said seat and said plug and a second position in sealing engagement with said seat to shut in the well, said

plug being exposed to a pressure differential responsive to flow of well fluid through said annular port, the pressure differential urging said plug toward said seat; and

spring means for preventing movement of said plug from the first position to the second position responsive to the pressure differential produced by a well fluid flow rate not greater than the predetermined rate, and permitting said plug to move from the first position to the second position responsive to the pressure differential produced by a well fluid flow rate exceeding the predetermined rate to shut in the well.

10. A downhole safety valve as recited in claim 9, including means for variably adjusting the area of the annular port defined by the first position of said seat and said plug.

11. A downhole safety valve as recited in claim 9, including means for variably adjusting the force of said spring means to predetermine the pressure differential required to move said plug to the second position.

12. A downhole safety valve as recited in claim 9, wherein said seat and said plug comprise sintered tungsten carbide.

13. A downhole safety valve as recited in claim 9, wherein said seat and said plug include first mating tapered surfaces on their respective downstream ends and second mating tapered surfaces upstream from said first surfaces and intersecting said first surfaces at an angle.

14. A downhole safety valve as recited in claim 13, wherein the angle of said first taper with respect to the axis of said plug is less than the angle of said second taper with respect to said axis.

15. A downhole safety valve as recited in claim 13, wherein the angle of said first taper with respect to the axis of said plug is about 8° and the angle of said second taper with respect to the axis of said plug is about 45°.

16. An abrasion-resistant, adjustable downhole safety valve for wireline insertion into and retrieval from a well flowing an abrasive fluid for shutting in the well in response to a flow of well fluid exceeding a predetermined rate, comprising:

a valve body having an interior communicating with the well fluid and having a tapered seat;

a plug extending through said seat and having a corresponding taper, said plug being axially movable between a first position defining an annular port between said seat and said plug and a second position in contact with said seat to shut in the well, said plug being exposed to a pressure differential increasing with flow rate to urge said plug toward said second position to shut in the well;

a stem extending axially upstream from said plug;

a coiled spring coaxially surrounding said stem and having a first end abutting a spring retaining means at a location fixed with respect to said valve body and a second end abutting means variably connected to said stem for adjustably predetermining the force urging said plug toward the first position, said spring force being adjusted to be greater than the pressure differential force responsive to flow rates less than the predetermined rate to maintain said plug in the first position and less than the pressure differential responsive to the predetermined flow rate to permit the pressure differential responsive to the predetermined flow rate to move said

9

plug to the second position to shut in the well; and a stop adjustably located with respect to said seat for limiting the upstream travel of said stem responsive to said spring to predetermine the cross-sectional area of the annular port when said plug is in the first position.

17. A downhole safety valve as recited in claim 16, wherein said seat and said plug include first and second mating tapered surfaces, said second surfaces being up-

10

stream of said first surfaces and disposed at an angle of about 45° to the axis of said plug to define opposed annular seating surfaces for shutting in the well when said plug is in the second position.

18. A downhole safety valve as recited in claim 16, wherein said seat and said plug comprise sintered tungsten carbide.

* * * * *

10

15

20

25

30

35

40

45

50

55

60

65