

[54] METHOD AND APPARATUS FOR A
SUBSURFACE SAFETY VALVE OPERATING
WITH DIFFERENTIAL ANNULAR
PRESSURE

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[58] Field of Search 166/224, 224 S

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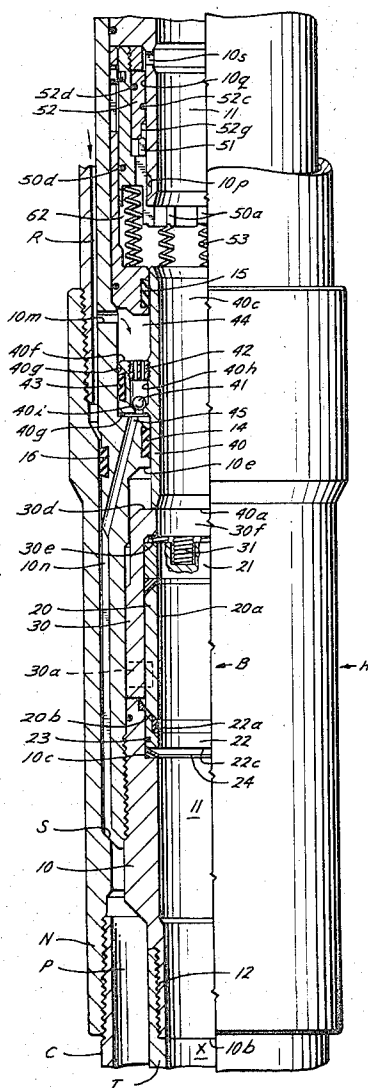
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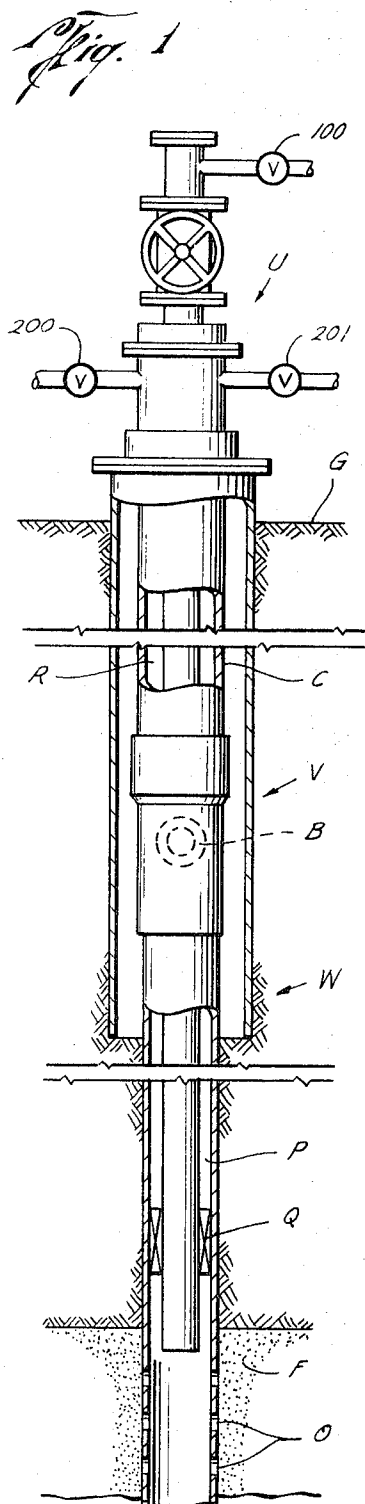
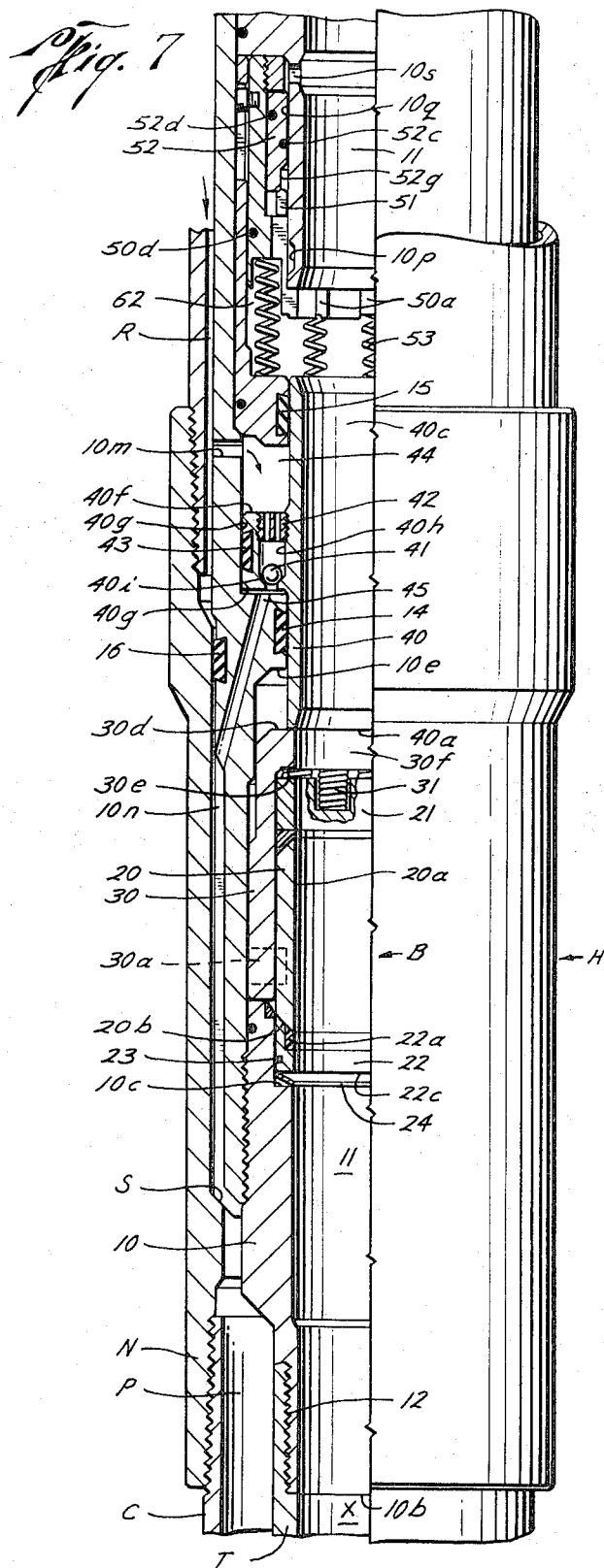
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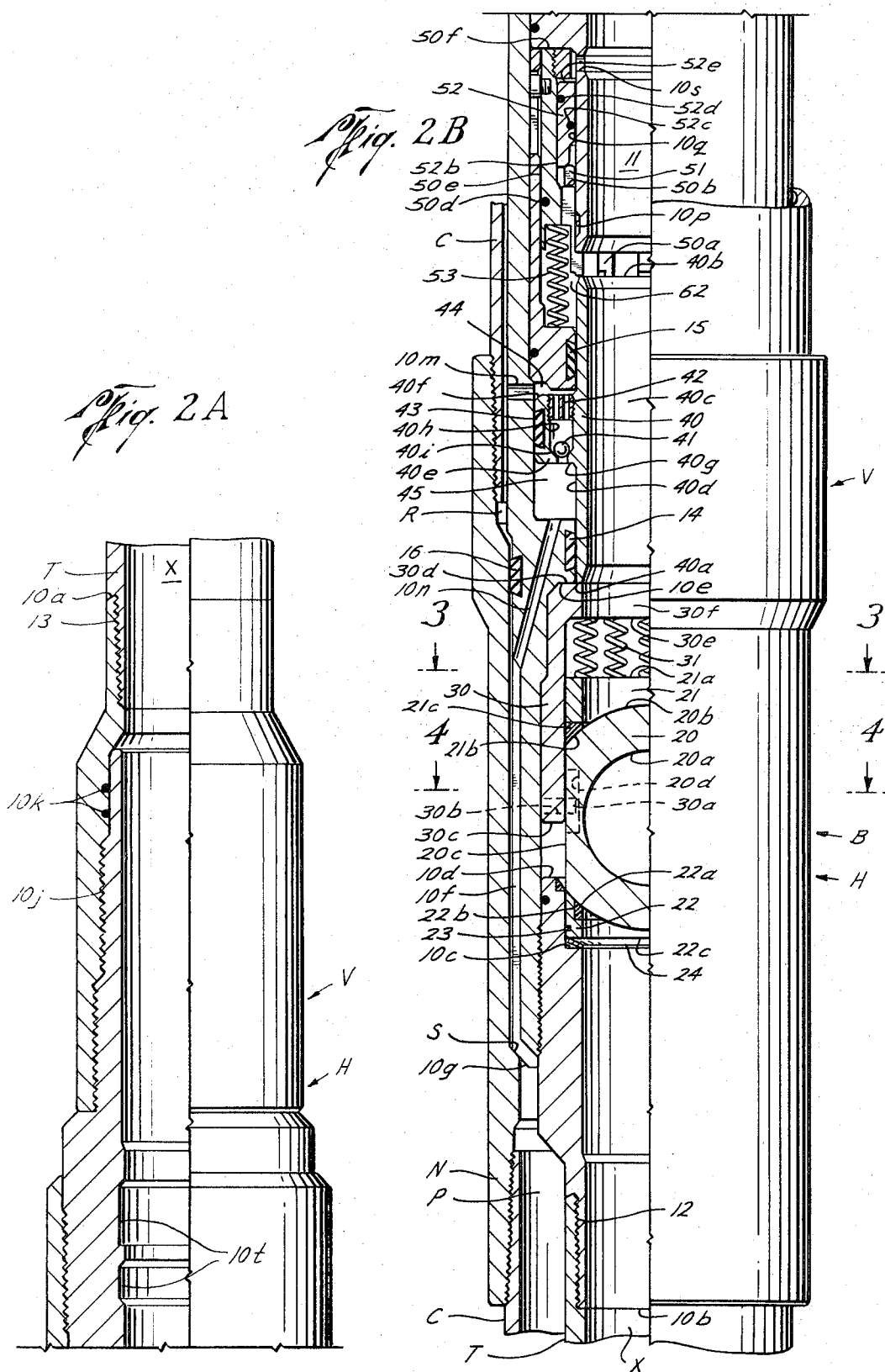
[57] ABSTRACT

A method and apparatus for a production tubing safety valve having a rotatable ball closure means for shutting in a well at a subsurface location which is operable in response to fluid pressure in an annular area between the production tubing and the well casing. The valve mounts means for sealing the annular area adjacent the valve wherein the differential pressure urging established across said seal communicated to the valve effects operation thereof and means for mounting the valve with the well casing for supporting the valve in the well. The safety valve may be releasably locked in the open position when a directional pressure is communicated thereto through the production tubing.

19 Claims, 10 Drawing Figures







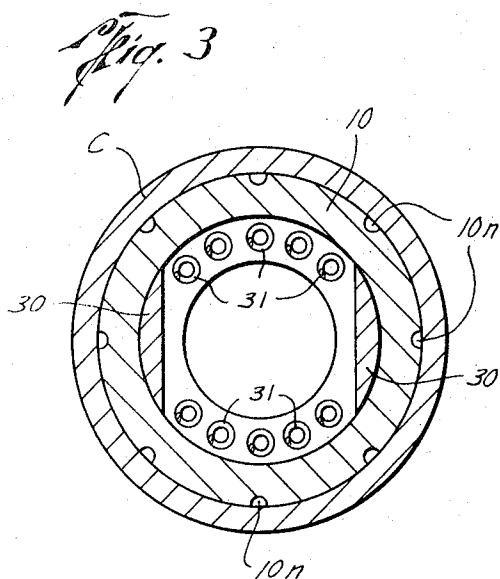
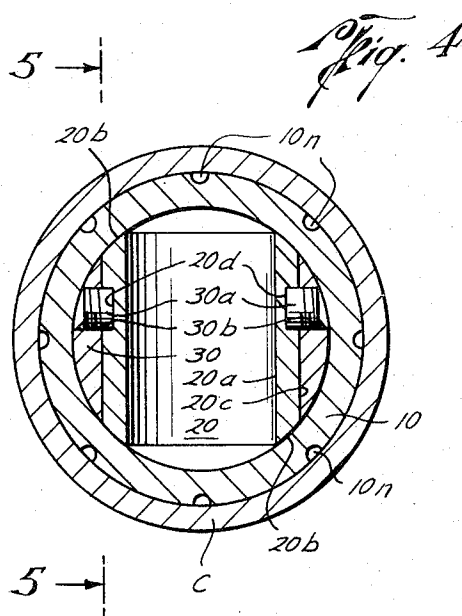
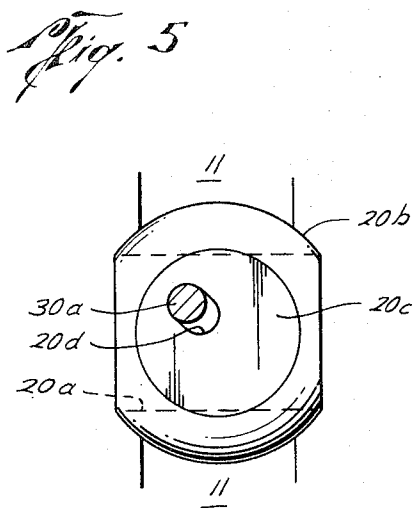
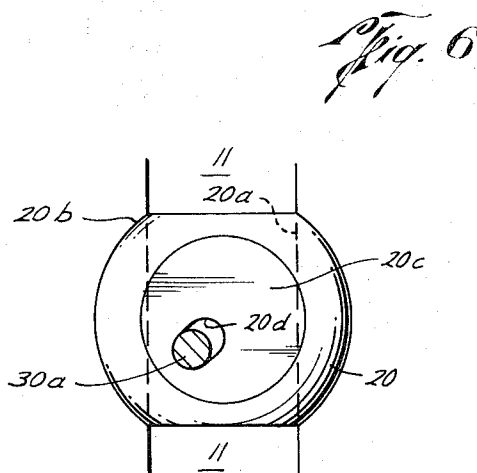


Fig. 8

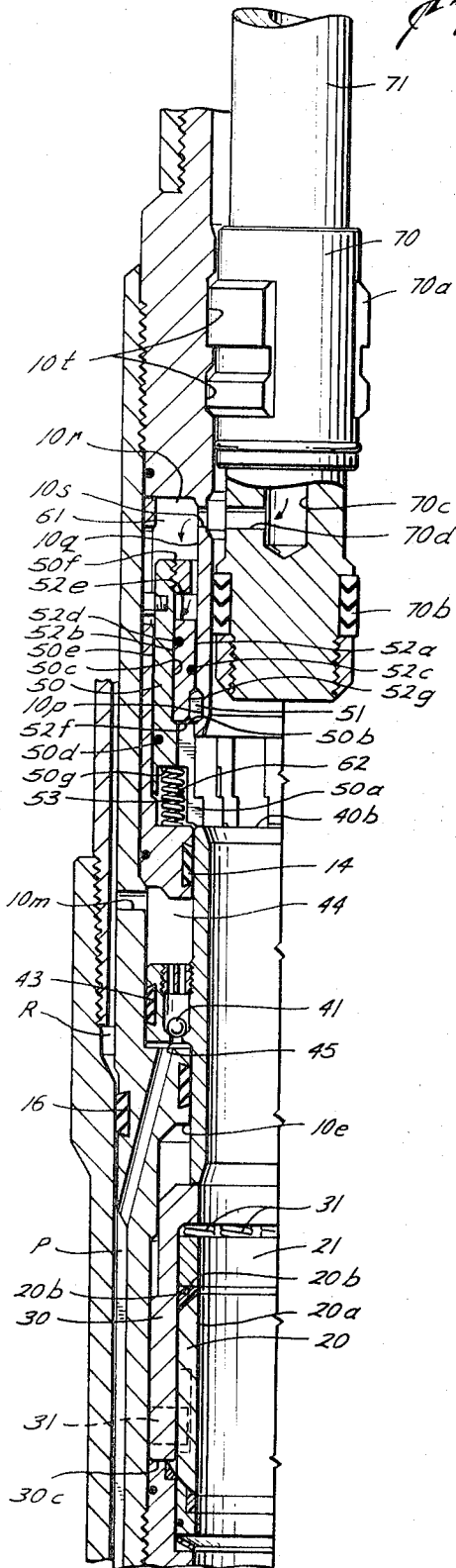
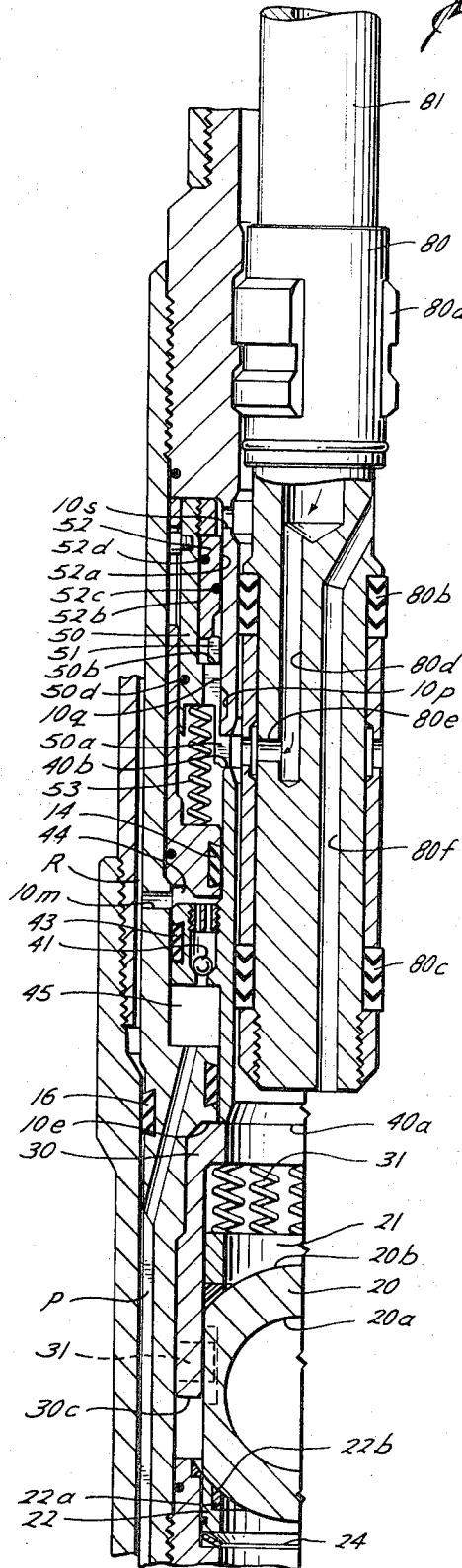


Fig. 9



METHOD AND APPARATUS FOR A SUBSURFACE SAFETY VALVE OPERATING WITH DIFFERENTIAL ANNULAR PRESSURE

BACKGROUND OF THE INVENTION

This invention pertains generally to the field of safety valves and more particularly to pressure responsive subsurface safety valves.

Subsurface production tubing safety valves which operate in response to the fluid pressure in an annular area between the production tubing and a well casing or a concentric tubing string to control well blow-outs and other undesired well flow, have been known and used for some time. Generally, these valves have relied on increased pressure in the annular area to overcome a normal closing bias to open the valve to enable production of hydrocarbons and other fluids from the well through the production tubing. Fluid leakage through the production tubing joints often effected a sufficient pressure change in the annular area to interfere with the valve operation and often rendered the safety valve uncontrollable. It was necessary to kill the well and pull the entire string of production tubing to tighten the leaking joints which was both a costly and hazardous operation.

SUMMARY OF THE INVENTION

A method and apparatus for a subsurface production tubing safety valve mounting an annular seal to seal with a well casing for operating the safety valve in response to the differential pressure in an annular area across the seal. The valve also includes means for supporting the valve in the well wherein the production tubing above the valve may be pulled independently of the valve. The valve may also be releasably locked in the open position when desired by a directional pressure communicated thereto.

An object of the present invention is to provide a new and improved apparatus for a pressure operated safety valve.

A further object of the present invention is to provide a new and improved method for operating a subsurface safety valve.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view, partially in section, of the safety valve of the present invention positioned in a producing well;

FIGS. 2A and 2B are side views, partially in section, from top to bottom of the safety valve of the present invention in the closed position;

FIGS. 3 and 4 are views taken along lines 3—3 and 4—4 respectively, of FIG. 2B;

FIGS. 5 and 6 are views taken along line 5—5 of FIG. 4, illustrating the relationship of the ball and pivot pins in the open and closed positions, respectively;

FIG. 7 is a side view, partially in section, illustrating the safety valve of the present invention in the open position;

FIG. 8 is a side view, similar to FIG. 7, with the safety valve locked open by directional fluid pressure communicated thereto by the locking plug positioned in the safety valve; and

FIG. 9 is a view similar to FIG. 8 with the safety valve unlocked by the directional fluid pressure communi-

cated thereto by the unlocking plug positioned in the safety valve.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Attention is directed to the Figs. where the safety valve of the present invention, generally designated V, for controlling undesired flow from a well W, is illustrated. The safety valve V includes a flow housing H having a bore formed therethrough and a bore closure means B disposed in the bore which is movable to and from an open position for enabling flow of fluid through the flow housing H and to and from a closed position for blocking flow of fluid through the flow housing H.

The bore closure means B is normally operable in response to fluid pressure in an annular area for controlling the undesired flow, but may be releasably locked in the open position when desired by a directional pressure. The valve V is also mountable with the conduit defining a portion of the annular area for supporting the valve V therein.

As illustrated in FIGS. 2A and 2B, the flow housing H includes a tubular member 10 which extends downwardly from an upper annular shoulder 10a (FIG. 2A) to longitudinally lower annular shoulder 10b (FIG. 2B) and having a longitudinally extending bore 11 formed therethrough for enabling flow of fluid through the flow housing H. The tubular 10 includes a threaded pin connection 13, adjacent the upper shoulder 10a, for connecting the flow housing H at a desired downhole location in the production tubing T to form a portion thereof with a bore X of the production tubing T communicating with the bore 11 of the tubular member 10 above and below the flow housing H.

As illustrated in FIG. 2B, the bore closure means B includes a ball member 20 having a bore or flow port 20a formed therethrough which is rotatable to and from a closed or transverse position (FIG. 2B) blocking flow of fluid through the bore 11 and to and from an open or aligned position (FIG. 7) for enabling flow of fluid through the bore 11 and the flow port 20b. As illustrated in FIGS. 5 and 6, two separate portions of the spherical surface 20b of the ball 20 are removed to form a pair of parallel flat portions 20c (FIG. 4) with each of the circular flats 20c having a radially extending elongated recess 20d formed therein for operably connecting the ball 20 with the flow housing H. The bore closure means B further includes a seal ring 21 which is concentrically positioned in the bore 11 immediately above the ball 20 in engagement therewith and a lower seat ring 22 which is concentrically positioned in the bore 11 immediately below the ball 20 and also in engagement therewith. The lower seat rings 22 mounts thereon a sealing element 22a having an arcuate upwardly facing annular surface 22b for effecting an annular fluid seal with the spherical surface 20b of the ball 20 for blocking leakage of fluid therebetween. The seat ring 22 also mounts an O-ring 23 for effecting an annular seal between the seat ring 22 and the tubular member 10 to block passage of fluid therebetween. The bore closure means B further includes a biasing means or seal spring 24 located between a downwardly facing annular shoulder 22c and an upwardly facing annular shoulder 10c for biasing the seat ring 22 to move upwardly for maintaining the sealing surface 22b in

sealing contact with the spherical surface 20b of the ball 20.

The flow housing H includes an operator member 40 and a pivot member 30 for effecting rotational movement of the ball 20 to and from the open and closed positions. The pivot sleeve member 30 is concentrically mounted in the bore 11 between the ball 20 and the tubular member 10 and is longitudinally movable between a first or upper position (FIG. 2B) for rotating the ball 20 closed and a second or lower position (FIG. 7) for rotating the ball 20 to the open position. As illustrated in FIG. 4, the pivot member 30 includes a pair of inwardly projecting pins or fingers 30a which extend into the recesses 20d of the ball 20 for rotating the ball 20 when there is relative longitudinal movement between the ball 20 and the pivot member 30. Preferably, for ease of assembly, the pins 30a are secured to the pivot member 30 by a suitable fastening means, such as threaded engagement at 30b. The pivot member 30 further includes a lower annular shoulder 30c, below the pins 30a, for engaging an upwardly facing annular shoulder 10d of the tubular member 10 to provide a lower movement limit stop and an upwardly facing annular shoulder 30d for engaging a downwardly facing annular shoulder 10e of the tubular member 10 to provide an upper movement limit stop for the pivot member 30. The pivot member 30 includes a longitudinally extending bore 30f formed through the pivot member communicating with the bore 11 for enabling flow of fluid through the pivot member 11 and having a downwardly facing annular shoulder 30e formed thereon above the seat ring 21. The flow control housing H includes an urging means or plurality of springs 31 positioned between the annular shoulder 30e and an upwardly facing annular shoulder 21a of the seat ring 21 for urging movement thereof into engagement with the ball 20 and for urging movement of the pivot member 30 to the upper position for normally maintaining the ball 20 rotated closed. The springs 31 maintain a downwardly facing arcuate annular sealing surface 21b of a ring-shaped sealing element 21c of the seat ring 21 in engagement with the spherical surface 20b of the ball 20, for effecting an annular fluid seal therebetween.

The operator member 40 is concentrically positioned in the bore 11 immediately above the pivot member 30 and is longitudinally movable therein between an upper position (FIG. 2B) and a lower position (FIG. 7) for moving the pivot member 30 to rotate the ball 20 open and closed. The operator member 40 extends upwardly from a downwardly facing annular shoulder 40a which engages the shoulder 30d of the pivot member 30 for moving the pivot member 30 along with the operator member 40 to the lower position to an upwardly facing annular shoulder 40b. The operator member 40 further includes a longitudinally extending bore 40c formed therethrough communicating with the bore 11 for enabling flow of fluid through the operator 40 and an outer surface 40d. Formed on the movement guiding outer surface 40d is an outwardly projecting annular collar 40e having an upwardly facing annular shoulder 40f, a downwardly facing annular shoulder 40g, and a flow passageway 40h extending therethrough between the annular shoulder 40f and 40g for communicating the area adjacent the shoulders 40f and 40g. The flow passage 40h includes an upwardly facing annular sealing shoulder 40i adjacent the shoulder 40g for effecting

an annular seal with a ball 41 which is moveably disposed in the flow passage 40h. The ball 41 and the sealing surface 40i thus co-act to provide a check valve blocking downwardly flow through the flow passage 40h by moving the ball 41 into engagement with the sealing surface 40i. The ball 41 is maintained in the flow passage 40 h by a cage member 42 which is threadably secured with the operator 40 adjacent the shoulder 40f.

The operator 40 is slidably sealed to the tubular member 10 at spaced locations to block leakage of fluid therebetween by seal rings 14 and 15 mounted with the tubular member 10 adjacent the shoulders 40a and 40b, respectively, of the operator 40 and by a seal ring 43 mounted on the collar 40e of the operator member 40. The three annular seals so effected form a pair of annular expansible chambers 44 and 45 located above and below the annular collar 40e, respectively. The upwardly facing annular shoulder 40f forms a portion of the chamber 44 for enabling the fluid pressure in the chamber 44 to urge thereon for urging movement of the operator member 40 downward to the lower position for rotating the ball 20 open. The downwardly facing annular shoulder 40g forms a portion of the chamber 45 for enabling the fluid pressure in the chamber 45 to urge thereon for urging movement of the operator member 40 upward to the upper position for enabling the ball 20 to rotate closed.

The tubular member 10 includes an outer surface 10f having a downwardly facing annular support shoulder 10g formed thereon for engaging an upwardly facing shoulder S formed on a casing reducer or adapter N forming a portion of a well casing C for mounting the flow housing F at a desired subsurface location with the well casing C to support the flow housing H and connected production tubing T in the well casing C. While the safety valve V of the present invention is described herein as being positioned in the well casing C, it will be immediately appreciated that the production tubing T and the safety valve V may be positioned in the bore of any well conduit, such as another production tubing, without changing the operation of the safety valve V as herein disclosed.

The outer surface 10f of the tubular member 10 mounts a packing or seal ring 16 thereon above the support shoulder 10g for effecting an annular seal with the well casing C. The fluid passage blocking seal effected by the seal 16 divides the annular area between the production tubing T and the well casing C into an upper chamber or reservoir R above the seal 16 and a lower chamber or reservoir P below the seal 16. The lower reservoir P communicates with the lower annular expansible chamber 45 through a plurality of passageways 10m formed in the outer surface 10f of the tubular member 10. The expansible chamber 44 communicates with the reservoir R above the seal 16 through a flow port 10n formed through the tubular member 10. Thus, the pressure differential between the upper reservoir R and the lower reservoir P will be sensed across the collar 40e of the operator 40 for operating the ball 20 to and from the open and closed positions. A greater pressure in the upper reservoir R urging downwardly on the annular shoulder 40f will move the operator 40 to the lower position to rotate the ball 20 open. Likewise, a greater pressure in the lower reservoir P will urge upwardly on the annular shoulder 40g for moving the operator 40 upwardly to rotate the ball 20 closed.

The flow passageway 40h formed through the collar 40e is of such small flow area in comparison with the volumes of the reservoirs R and P that the differential pressure urging upwardly from the reservoir P will move the operator 40 to the upper position prior to being equalized with the pressure in the upper reservoir R. The urging of the plurality of the springs 31 is sufficient to maintain the pivot member 30 and the operator 40 in the upper position when the pressure in the reservoirs R and P are substantially equal. Increasing the pressure in the upper reservoir R will seat the ball 41 on the seating surface 40i to maintain the pressure differential across the collar 40e to hold the sleeve 40 in the lower position.

Since the flow housing F is supported in the casing C by the shoulder 10g, the flow housing H is provided with a means for releasing the portion of the production tubing T connected thereto above the flow housing H to enable removal of that portion of the production tubing T for tightening leaking joints and performing other work thereon without the need to pull the entire production tubing T. As illustrated in the FIG. 2A, the tubular member 10 includes a left-hand threaded connection 10j for securing separate portions of the tubular member 10 together as a unit. Left-hand rotation of the production tubing T above the flow housing H will disengage the threads 10j for releasing the production tubing T from the safety valve V. Leakage of fluid along the engaged threads 10j is blocked by a pair of O-rings 10k effecting seals above the threads 10j.

The flow housing H further includes a means for releasably locking the ball 20 in the open position in response to a directional pressure to thereafter block movement of the ball from the open position comprising a lug ring 50, a detent 51 and a piston ring 52, all of which are movably mounted above the operator 40 in the bore 11 of the tubular member 10. As illustrated in greater detail in FIG. 8, the lug ring 50 includes a plurality of downwardly extending fingers or lugs 50a for engaging the upper annular shoulder 40b of the operator 40 while enabling fluid communication between the lugs 50a. The lug ring 50 is longitudinally movable between an upper position (FIG. 9) and a lower position (FIG. 8) which moves the operator 40 downwardly for rotating the ball 20 to the open position. The detent 51 is a gapped radially expandable ring positioned above and in engagement with an upwardly facing annular shoulder 50b formed on the lug ring 50 above the lugs 50a. The detent 51 is also longitudinally movable between an upper expanded position (FIG. 9) and a lower position (FIG. 8) where the detent will radially contract to move into an annular recess 10p of a chamber defining surface 10q of the tubular member 10. The piston ring 52 is positioned above the detent 51 and is longitudinally movable along the surface 10q from an upper position (FIG. 9) to a lower position (FIG. 8) in response to a directional pressure urging thereon. The piston ring 52 includes an inner surface 52a adjacent the surface 10q for guiding longitudinal movement of the piston ring 52 and an outer surface 52b engaging a constant diameter surface 50c of the lug ring 50 for guiding relative movement therebetween. The inner and outer surfaces 52a and 52b mount O-rings 52c and 52d, respectively, for effecting sliding seals with the tubular member 10 and the lug ring 50 to block flow of fluid about the piston ring 52. By sealing the piston ring 52 in this manner, an upwardly facing annular shoulder

52e and a downwardly facing annular shoulder 52f are provided for fluid pressure to urge thereon to effect longitudinal movement of the piston ring 52. The inner surface 52a includes an annular locking recess 52g adjacent the lower annular shoulder 52f for blocking radial expansion of the detent 51 out of the recess 10p when the piston ring 52 is in the lower position.

The lug ring 50 mounts an O-ring 50d on an outer surface 50e thereof for slidably sealing the lug ring 50 with the tubular member 10. By sealing the lug ring at this location, the lug ring 50 is provided with a pressure responsive annular effective surface area between the seals effected by the O-rings 52d and 50d. The differential pressure urging on the piston ring 52 will also urge on this effective surface area for effecting longitudinal movement of the lug ring 50. The lug ring 50 includes an upwardly facing upper annular shoulder 50f, which will be referred to as the upwardly facing pressure responsive effective surface area, for purposes of this disclosure, and which also engages a downwardly facing annular shoulder 10r of the tubular member 10 to provide a movement upper limit stop to the lug ring 50. The lug ring 50 further includes a downwardly facing annular shoulder 50g, which will also be referred to as the downwardly facing pressure responsive effective surface area for purposes of this disclosure, for urging upwardly movement of the lug ring 50 in response to the fluid pressure urging thereon. Mounted in the bore 11 below the lug means 50, is a biasing means or plurality of springs 53 for urging the lug ring 50 to move to the upper position.

The fluid pressure seals effected by the O-rings 50d, 52c and 52d block fluid communication between the annular area above and below the lug ring 50 and the piston ring 52 for forming an upper or first chamber 61 above the lug ring 50 and a second or lower chamber 62, below the annular shoulder 52f of the piston ring 52. The upper annular expandable chamber 61 communicates with the bore 11 of the tubular member 10 through a port 10s formed in the tubular member 10 adjacent the annular shoulder 10r. The lower annular expandable chamber 62 communicates with the bore 11 through the area between the lugs 50a and which are spaced from the port 10s to enable the establishment of a fluid seal in the bore 11 therebetween. Normally, the fluid pressure in the bore 11 is communicated into both the chamber 61 and the chamber 62 to provide equal and offsetting urging on the lug ring 50 and the piston ring 52, wherein the spring 53 will maintain the lug ring 50, the piston ring 52 and the detent 51 in the upper position.

As illustrated in FIG. 8, the safety valve V includes a means for communicating a predetermined directional pressure or locking plug 70 for releasably locking the ball 20 in the open position. The locking plug 70, which is well known in the art, includes a plurality of movable locking lugs 70a mounted therewith for moving radially outwardly into a pair of spaced locking annular recesses 10t formed in the tubular member 10 for securing the locking plug 70 therewith and with the lugs 70a moving radially inwardly to release the plug 70 and enable the locking plug 70 to move through the bore X of the production tubing T and the bore 11 of the tubular member 10. The locking plug 70 includes a seal or packing ring 70b mounted thereon for effecting an annular seal between the tubular member 10 and the locking plug 70 at a location between the port 10s

and the lugs 50a for blocking communication of fluid pressure therebetween and a longitudinally extending flow passage 70c communicating with a horizontal flow port 70d for communicating the pressure in a tubing 71 connected above the locking plug 70 or the bore X of the production tubing T above the plug 70 through the locking plug 70 to the area immediately above the packing 70b. Thus, the locking plug 70 enables communication of fluid pressure in the tubing 71 or the bore X above the plug 70 to the upper chamber 61 while blocking communication of the same pressure into the lower chamber 62 for thus establishing a movement urging pressure differential or directional pressure across the lug ring 50 and the piston ring 52.

As illustrated in FIG. 9, the safety valve V further includes a means for communicating a predetermined directional pressure or unlocking plug 80 for releasing the ball 20 from the locked open position. The well known cross-over or unlocking plug 80 includes means for releasably securing the plug 80 in the bore 11 of the tubular member 10 such as radially expansible locking lugs 80a which move radially outwardly into the recesses 10r for securing the plug 80 with the tubular member 10. The unlocking plug 80 includes a pair of packing seal rings 80b and 80c mounted thereon for effecting spaced annular seals between the plug 80 and the tubular member 10 for blocking communication of fluid pressure with the upper chevron packing 80b, effecting a seal therebetween below the port 10s, for blocking communication of fluid pressure in the bore 11 adjacent the lugs 50a to the port 10s and into the chamber 61. The unlocking plug 80 includes a longitudinally extending flow passage 80d formed therein which communicates a tubing 81 positioned in the bore X of the tubular member 10 and a horizontal flow port or passage 80e adjacent the lugs 50a for communicating therebetween a pressure into the lower annular chamber 62 while blocking its communication into the annular chamber 61. The lower chevron packing or seal ring 80c effects a seal below the port 10s for blocking communication of fluid pressure communicated to the chamber 62 from being communicated around the bottom of the unlocking plug 80 and upwardly through a vent passage 80f where it would be communicated through the port 10s into the chamber 61. Fluid pressure introduced through the tubing 81 will thus be communicated into the chamber 62 for urging upwardly on the lug ring 50 and the piston ring 52 for moving the lug ring 50, the detent 51 and the piston ring 52 to the upper position. By using a third annular seal ring (not illustrated) on the plug 80 for effecting a seal above the port 10s, the pressure in the bore X above the plug 80 may be employed to release the ball 20.

In the use and operation of the present invention, the safety valve V is connected in the production tubing T using threaded pin 12 and box 13 connections with the bore 11 communicating with the bore X of the production tubing T above and below the safety valve V. The safety valve V is lowered along with the production tubing T until the downwardly facing shoulder 10g engages the upwardly facing shoulder S of the casing adapter N which blocks further downward movement of the safety valve V and which supports the safety valve V and the production tubing T in the casing C. When the shoulder 10g of the tubular member 10 is seated on the shoulder S of the adapter N, the seal 16 effects the annular fluid seal between the tubular mem-

ber 10 and the well casing C to form the upper and lower reservoirs R and P in the annular area between the production tubing T and the well casing C. The lower reservoir P is further defined by a well packer Q which effects a fluid seal between the well casing C and the production tubing T at a location below the safety valve V and above a producing formation F. Hydrocarbons and other well fluids in the producing formation F are thus enabled to flow through the perforations O in the well casing C and up the bore X of the production tubing T to a christmas tree U located at the earth surface G. Normally, production of hydrocarbons from the well W is controlled by operation of a valve, indicated at 100, mounted on the christmas tree U.

While the safety valve V may be run into the well W in any condition, for purposes of this disclosure, it will be assumed that the valve will be installed in the closed position, as illustrated in FIGS. 2A and 2B. When it is desired to produce hydrocarbons and the like from the well, the pressure in the upper reservoir R is increased by opening the valve located on the christmas tree U, indicated at 200, which is connected with a pressure generating source or means, while closing or shutting in the reservoir R vent valve, indicated at 201. This increased pressure is communicated through the port 10m into the chamber 44 for urging the operator 40 to move downwardly. When the fluid pressure in the chamber 44 is increased sufficiently to overcome the combined upwardly urging of the fluid pressure in the chamber 45 and the springs 31, the operator 40 will move downwardly for moving the engaged pivot member 30 downwardly to rotate the ball 20 to the open position (FIG. 7). Operation of the valve, indicated at 100, will then control the production of hydrocarbons from the formation F through the well W.

When it is desired to close in the well W at a subsurface location or a catastrophic well failure resulting in a well blow-out occurs, pressure in the upper reservoir R is decreased or otherwise reduced by venting to the atmosphere through the valve 201 while shutting the valve 200. This reduces the pressure in the chamber 44 to a pressure less than the pressure in the chamber 45 for moving the operator 40 to the upper position. The pressure in the lower reservoir P when the ball 20 is rotated open will expand the casing C below the seal 16 to provide a latent fluid pressure in the reservoir P for closing the valve V when the pressure in the upper reservoir R is vented. The flow passage 40h is of such a small size when compared to the volume of reservoirs P and R, that the pressure equalization therebetween will not occur until after the operator 40 is moved to the upper position. When the operator 40 is in the upper position, the spring 31 will insure that the pivot member 30 moves to the upper position for rotating the ball 20 to the closed position. When rotated closed, the ball 20 co-acts with the sealing element 22a and the O-ring 23 to block flow of fluid in an upwardly direction through the bore 11 of the tubular member 10 and the bore X of the production tubing T.

A subsequent increase in pressure in the reservoir R above the pressure in the lower reservoir P will again rotate the ball 20 to the open position for enabling production of hydrocarbons and the like from the well W.

When it is desired to run various well tools and the like through the bore X of the production tubing T to a location below the safety valve V, the ball 20 may be

releasably locked in the open position by the use of the locking plug 70. The locking plug 70 is lowered down the bore X of the production tubing T until the locking lugs 70a are adjacent the annular recesses 10t at which time the locking lugs 70a are expanded or moved radially outwardly into the recesses 10t for securing the locking plug 70 with the tubular member 10. Pressure in the locking plug tubing 71 is then increased which is communicated through the flow passage 70c and the flow port 70d of the plug 70 into the expansible chamber 61. The packing ring 70b blocks communication of this increased fluid pressure into the expansible chamber 62.

The pressure in the chamber 61 will urge downwardly on the upwardly facing annular shoulder 52e and 50f of the piston ring 52 and the lug ring 50, respectively, for moving the lug ring 50, the detent 51, and the piston ring 52 downwardly from the upper position, as a single engaged unit relative to the tubular member 10. When the detent 51 is adjacent the annular recess 10p, the detent 51 will radially contract for moving into the recess 10p and enable the piston ring 52 to move downwardly relative to both the tubular member 10 and the lug ring 50 for locking the detent 51 in the recess 10p. When the detent 51 is locked in the recess 10p, the lug ring 50 is blocked from subsequent upward movement relative to the tubular member 10 from the lower position by engagement of the shoulder 50b with the detent 51.

The downward movement of the lug ring 50 overcomes the upwardly urging of the springs 53 and moves the operator member 40 downwardly along with the lug ring 50 by engagement of the lugs 50a with the upper annular shoulder 40b of the operator member 40. Thus, the downward movement of the lug ring 50 in response to the pressure in the chamber 61, moves the pivot member 30 downward for rotating the ball 20 open and in which position it is locked by engagement of the lug ring 50 with the detent 51. Thereafter, differential fluid pressure in the reservoirs R and P are ineffective to operate the safety valve V from the open position. The locking plug 70 may thereafter be released from the bore 11 of the tubular 10 by inward movement of the lugs 70a and the plug 70 retrieved to the surface G to enable the running and retrieval of other well tools through the bore X of the production tubing T below the valve V.

When it is desired to return the safety valve V to pressure responsive operation, the unlocking plug 80 is run through the bore X of the production tubing T until the locking lugs 80a are adjacent the annular recesses 10t at which time the lugs 80a are radially expanded into the recesses 10t for securing the unlocking plug 80 in the bore 11 of the tubular member 10. The pressure in the tubing 81 is then increased which is communicated to the lower annular expansible chamber 62 through passage 80d and port 80e and which is blocked from communication into the upper annular expansible chamber 61 by chevron packings 80b and 80c. The pressure differential established across the lug ring 50 and the piston ring 52 will initially move the piston ring 52 upwardly relative to the detent 51 and the lug ring 50 for releasing the detent 51 from the annular recess 10p. Thereafter, the differential pressure urging on the lug ring 50 and the piston ring 52 will move the lug ring 50, the detent 51 and the piston ring 52 upwardly, as a unit relative to the tubular member 10, to the upper

position. This movement enables the spring 31 to urge the pivot member 30 and the operator 40 upward relative to the ball 20 for rotating the ball 20 to the closed position. Thereafter, the lugs 80a may be released, and the unlocking plug 80 retrieved to the surface with the valve V restored to the normal pressure responsive operating condition.

Should the valve malfunction for any reason, such as but not limited to, scored sealing surface or production tubing joint leaks above the valve V, the production tubing T above the valve V may be disconnected and removed from the well W without the need to pull the entire string of the production tubing T thus enabling the use of more inexpensive, small capacity workover equipment. Preferably, the ball 20 is locked open, as set forth hereinabove, using the locking plug 70 during this operation, but this operation is not required for disconnecting the tubing T. Right-hand rotation is then imparted to the production tubing T above the safety valve V which disengages the left-hand thread 10j of the tubular member 10 for releasing the production tubing T above the flow housing H for enabling removal of that portion of the production tubing T from the well W. The annular shoulder 10g of the tubular member 10 supports the portion of the tubular member 10 and the lower portion of the production tubing T remaining in the well W. After the desired work-over operations are complete, the production tubing T may be reconnected by engaging the threads 10j and imparting a left-hand rotation to the production tubing T above the safety valve V.

The foregoing disclosure and description of the invention are illustrative and explanatory thereof, and various changes in the size, shape and materials as well as in the details of the illustrated construction may be made without departing from the spirit of the invention.

What is claimed is:

1. A subsurface safety valve apparatus for connecting in a production tubing positioned in a well casing and sealed to the well casing by a packer for directing the flows of fluids produced by a well through a flow passage of the production tubing including:

a flow housing having a bore therethrough adapted for connection in the production tubing to form a portion thereof with said bore in communication with a flow passage of the production tubing for enabling flow of fluid through said bore;

bore closure means disposed in said bore for movement to and from an open position for enabling flow of fluid through said bore and to and from a closed position blocking flow of fluid through said bore;

means with said flow housing for effecting a fluid seal between said flow housing and the well casing to divide the annular area between the production tubing and the well casing above the packer into a lower reservoir below the fluid seal and an upper reservoir above the fluid seal; and

means with said flow housing for effecting movement of said bore closure means to and from the open and closed position in response to the fluid pressure differential between said upper reservoir and said lower reservoir wherein the safety valve is operated.

2. The apparatus as set forth in claim 1, wherein:

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greater fluid pressure in the upper reservoir moves said bore closure means to the open position for enabling flow of fluid through said bore wherein the safety valve is operated open.

3. The apparatus as set forth in claim 1, wherein: 5
greater fluid pressure in the lower reservoir moves said bore closure means to the closed position for blocking flow of fluid through said bore wherein the safety valve is operated closed.

4. The apparatus as set forth in claim 1, wherein said 10
bore closure means includes:

a ball member having a flow part formed there-
through which is rotatable to and from the open
position for enabling flow of fluid through said flow
port and the closed position where said ball mem- 15
ber blocks flow of fluid through said bore of said
housing wherein the flow is controlled by rotation of
said ball member.

5. The apparatus as set forth in claim 1, including: 20
means with said flow housing for mounting said flow
housing with the well casing for supporting said
flow housing in the well casing.

6. The apparatus as set forth in claim 5, wherein said
flow housing further includes: 25
means for releasing the connected production tubing
above said flow housing to enable removal of the
portion of the production tubing above the flow
housing from the well while supporting said flow
housing in the well casing.

7. The apparatus as set forth in claim 1, wherein: 30
the fluid pressure in said lower reservoir effects
movement of the said bore closure means to the
closed position when the fluid pressure in said
lower reservoir exceeds the fluid pressure in said
upper reservoir wherein the safety valve is oper- 35
ated closed.

8. The apparatus as set forth in claim 1, wherein: 40
the fluid pressure in said upper reservoir effects
movement of said bore closure means to the open
position when the fluid pressure in said upper re-
servoir exceeds the fluid pressure in the said lower
reservoir by a predetermined pressure wherein the
safety valve is operated open.

9. The apparatus as set forth in claim 1, wherein said 45
means for effecting movement of said bore closure
means includes:

a. an operator member movably mounted with said
flow housing having a first pressure responsive sur-
face and a second pressure responsive surface and
which is operably connected with said bore closure 50
means for effecting movement thereof;

b. said first pressure responsive surface communicat-
ing with said upper reservoir for urging movement
of said operator in response to the fluid pressure in
said upper reservoir to move said bore closure 55
means to the open position; and

c. said second pressure responsive surface communi-
cating with said lower reservoir for urging move-
ment of said operator in response to the fluid pres-
sure in said lower reservoir to move said bore clo- 60
sure means to the closed position wherein differ-
ential fluid pressure in said first and said second re-
servoir operate the safety valve.

10. The apparatus as set forth in claim 9, wherein: 65
said bore closure means including a ball member hav-
ing a flow port formed therethrough which is ro-
tated to the open position enabling flow of fluid

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through said flow port and to the closed position
where said ball member blocks flow of fluid
through said bore of said housing; and

said means for effecting movement of said bore clo-
sure means including pivot means for coaxing with
said operator member for imparting rotation to
said ball member when there is relative movement
between said pivot means and said ball wherein the
safety valve is operated by rotation of the ball
member.

11. The apparatus as set forth in claim 10, wherein:

said operator member moves said pivot means rela-
tive to said ball member for rotating said ball mem-
ber to and from the open and closed positions
wherein the safety valve is operated.

12. The apparatus as set forth in claim 1, including:

means for releasably locking said bore closure means
in the open position to thereafter block movement
of said bore closure means to the closed position in
response to fluid pressure changes in the upper and
lower reservoir wherein the safety valve is rendered
inoperative.

13. The apparatus as set forth in claim 12, wherein:

said means for releasably locking said bore closure
means is operated by a predetermined directional
pressure in said bore of said flow housing wherein
the directional pressure controls operation of the
safety valve.

14. the apparatus as set forth in claim 13, wherein
said means for releasably locking said bore closure
means includes:

a. a locking sleeve movably disposed in said bore of
said flow housing operably connected with said
bore closure means for moving said bore closure
means to the open position when the predeter-
mined directional pressure urges on said locking
sleeve;

b. a detent disposed in said bore of said tubular mem-
ber and movable with said locking sleeve;

c. a recess formed in a surface of said flow housing
into which said detent moves when said locking
sleeve moves said bore closure means to the open
position; and

d. a locking piston disposed in said bore of said hous-
ing and movable in response to the predetermined
directional pressure urging thereon to lock said de-
tent in said recess wherein said detent blocks
movement of said locking sleeve and said bore clo-
sure means from the open position.

15. A subsurface safety valve for connecting in a pro-
duction tubing positioned in a well casting, including:

a flow housing having a bore therethrough adapted
for connection in the production tubing to form a
portion thereof with said bore in communication
with a flow passage of the production tubing for en-
abling flow of fluid through said bore;

bore closure means disposed in said bore for move-
ment to and from an open position for enabling
flow of fluid through said and a closed position
blocking flow of fluid through said bore;

means with said flow housing for effecting movement
of said bore closure means to and from the open
and closed position in response to a fluid pressure

change in an annular area between the production tubing and the well casing above the flow housing;

means for releasably locking said bore closure means in the open position to thereafter block movement of said bore closure means to the closed position in response to the fluid pressure change in the annular area between the production tubing and the well casing, said means for releasably locking said bore closure means is operated by a predetermined directional pressure in said bore of said flow housing and includes;

a locking sleeve movably disposed in said bore of said flow housing operably connected with said bore closure means for moving said bore closure means to the open position when the predetermined directional pressure urges on said locking sleeve;

a detent disposed in said bore of said tubular member and movable with said locking sleeve;

a recess formed in a surface of said flow housing into which said detent moves when said locking sleeve moves said bore closure means to the open position; and

a locking piston disposed in said bore of said housing and movable in response to the predetermined directional pressure urging thereon to lock said detent in said recess wherein said detent blocks movement of said locking sleeve and said bore closure means from the open position.

16. A method of operating a subsurface safety valve connected in a production tubing positioned in a well casing and having a packer sealing between the production tubing and the well casing for directing flow of well fluids through the production tubing, including the steps of:

effecting a fluid pressure seal in the area between the production tubing and the well casing to form a lower reservoir and an upper reservoir between the production tubing and the well casing above the packer;

increasing the fluid pressure in the upper reservoir;

communicating the increased pressure in the upper reservoir to the safety valve;

communicating the fluid pressure in the lower reservoir to the safety valve.

opening the safety valve in response to the increased fluid pressure communicated thereto from the upper reservoir exceeding the fluid pressure communicated to the valve from the lower reservoir for enabling flow of fluid through the production tubing wherein the safety valve is operated open.

17. The method as set forth in claim 16, including the steps of:

a. decreasing the pressure in the upper reservoir communicated to the safety valve for opening the safety valve; and

b. closing the safety valve to block flow of fluid through the production tubing in response to the fluid pressure in the lower reservoir exceeding the fluid pressure in the upper reservoir wherein the safety valve is closed.

18. The method as set forth in claim 16, wherein the steps of opening the safety valve include the steps of:

moving an operator member of the safety valve in response to the urging of the increased fluid pressure in the upper reservoir;

rotating the flow blocking member to an open position for enabling flow through the production tubing when the operator member moves in response to the urging of the increased fluid pressure in the upper reservoir;

19. The method as set forth in claim 18, including the steps of:

moving the operator member of the safety valve in response to the urging of the fluid pressure in the lower reservoir exceeding the urging of the fluid pressure in the upper reservoir; and

rotating the flow blocking member to a closed position for blocking flow of fluid through the production tubing when the operator member moves in response to the urging of the fluid pressure in the lower reservoir exceeding the urging of the fluid pressure in the upper reservoir, wherein the safety valve is closed.

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