

[54] SUBSURFACE SAFETY VALVE WELL TOOL OPERABLE BY DIFFERENTIAL ANNULAR PRESSURE

[75] Inventor: James D. Mott, Houston, Tex.
 [73] Assignee: Hydril Company, Houston, Tex.
 [22] Filed: May 14, 1973
 [21] Appl. No.: 359,757

[52] U.S. Cl. 166/224 A, 166/208, 285/18
 [51] Int. Cl. E21b 43/10, E21b 43/12
 [58] Field of Search 166/224, 224 A, 208;
 285/18, DIG. 21

[56] References Cited
UNITED STATES PATENTS

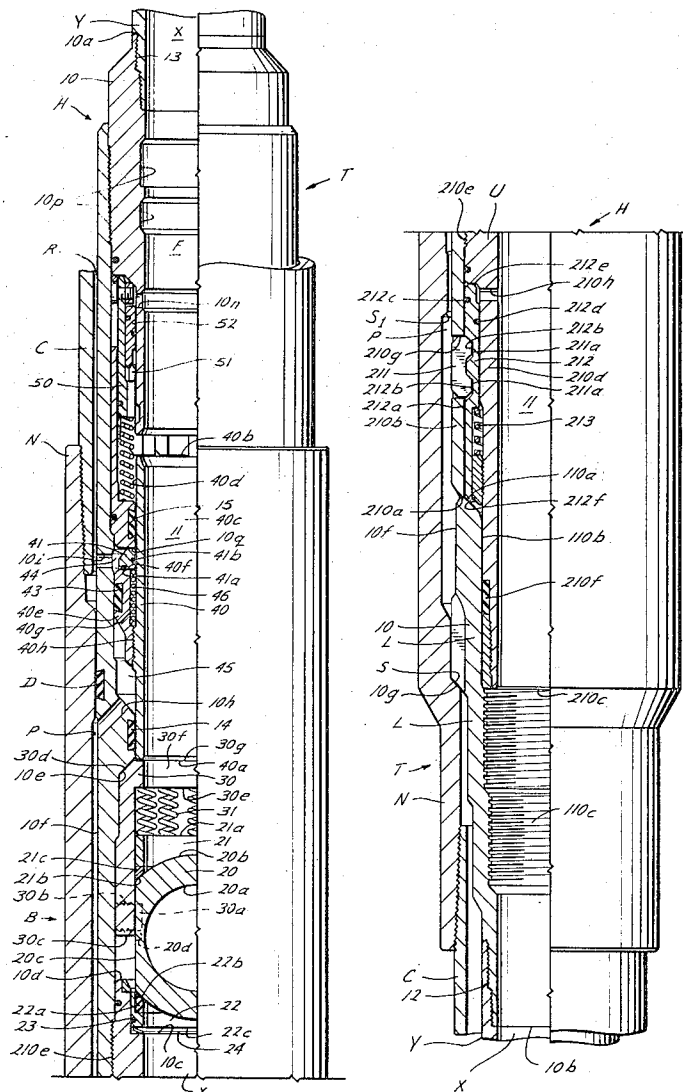
3,098,525	7/1963	Haerber	285/DIG. 21
3,260,309	7/1966	Brown	166/208
3,291,220	12/1966	Mott	166/208
3,543,847	12/1970	Haerber	166/6

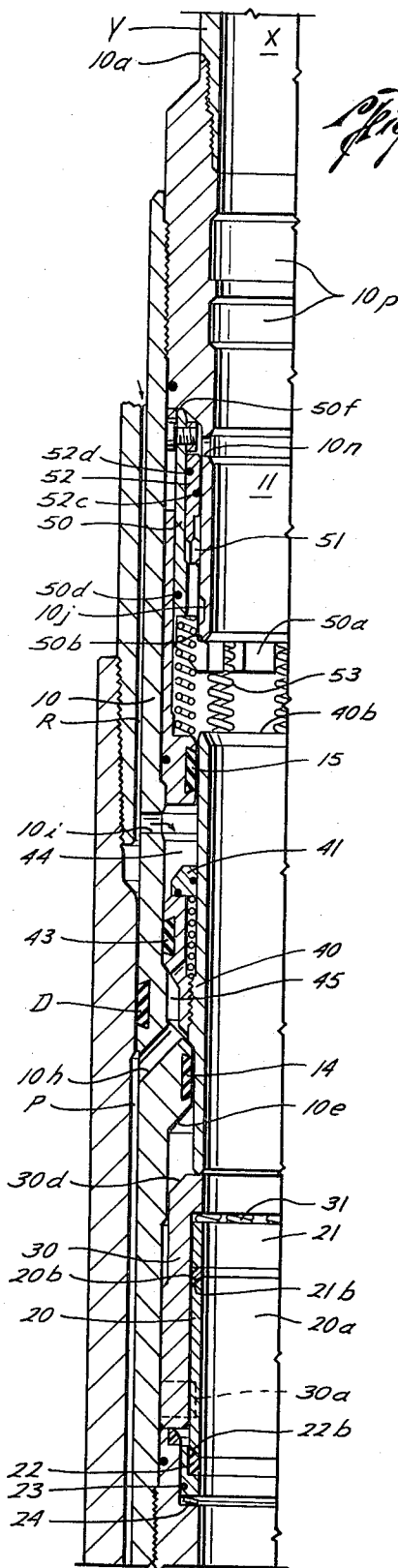
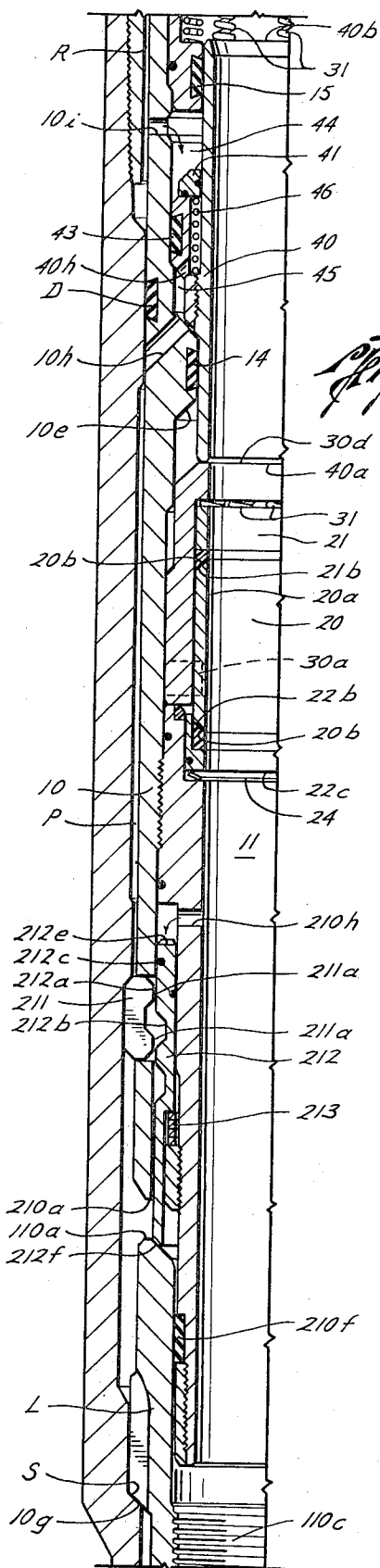
Primary Examiner—James A. Leppink

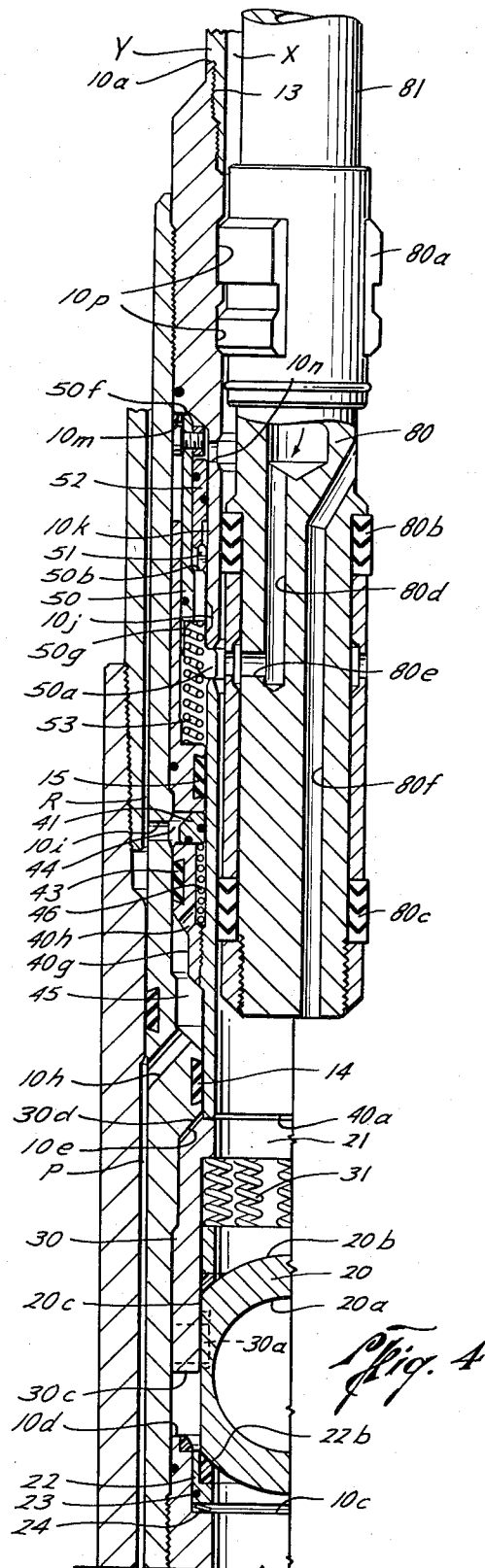
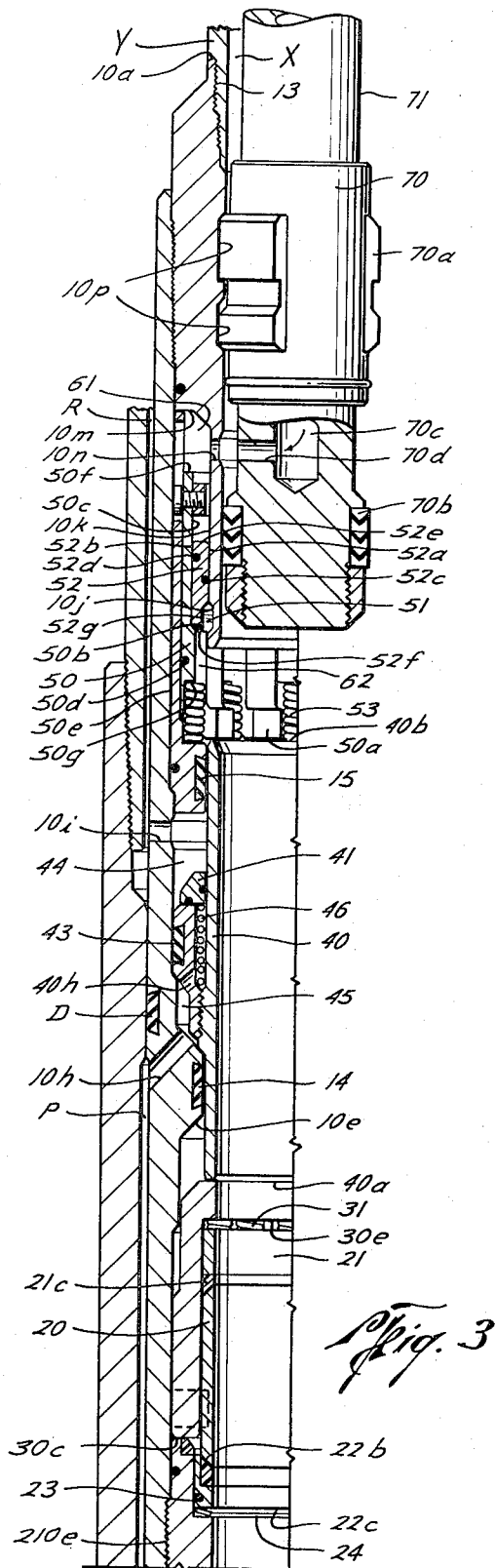
[57] ABSTRACT

A well tool adapted for connection in a production tubing including a separable flow housing having a bore extending therethrough and a rotatable ball bore closure means positioned in said bore which is operable for blocking undesired flow through the production tubing at a subsurface location and a releasable securing means for enabling separation of the flow housing when desired to enable retrieval of the rotatable ball means while leaving a portion of the housing in the well. The well tool includes means for sealing with a well casing adjacent the tool wherein the differential annular pressure urging established across the seal effects rotation of the ball bore closure and a means for mounting the tool with the well casing for supporting the well tool in the well. The rotatable ball may be releasably locked in the open position by the urging of a directional fluid pressure.

18 Claims, 6 Drawing Figures







SUBSURFACE SAFETY VALVE WELL TOOL OPERABLE BY DIFFERENTIAL ANNULAR PRESSURE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to my co-pending application Ser. No. 359,758, filed May 14, 1973, and entitled "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 well tools and more particularly to a pressure responsive subsurface safety valve.

The invention disclosed in my co-pending patent application, identified immediately above, serves a most useful purpose of protecting against costly and dangerous well blowouts. However, that invention had several undesirable features including the inability to retrieve the valve element when desired without pulling the entire string of production tubing and the requirement of rotating the tubing above the valve to connect and disconnect with the tubing above the valve which could result in an inadvertent release of a tubing joint. Furthermore, that invention's operating mechanism made it difficult to determine if a tubing leak into the well annulus was located above or below the annular seal.

SUMMARY OF THE INVENTION

A well tool adapted for connection in a production tubing including a separable housing having a bore extending therethrough with a rotatable ball-type safety valve mounted therein which is operable in response to a fluid pressure differential across an annular seal with a well casing for controlling flow through the production tubing and a means for supporting the well tool in the well casing wherein a portion of the housing mounting the ball valve may be releasably secured to the portion of the housing supporting the well tool to enable retrieval of the ball valve. The ball may also be releasably locked in the open position when desired by a directional pressure communicated thereto for determining the location of tubing leaks.

An object of the present invention is to provide a new and improved well tool having a pressure operated safety valve.

A further object of the present invention is to provide a new and improved well tool having a separating housing releasably secured at a subsurface location in a well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are side views, partially in section, from top to bottom of the well tool of the present invention, positioned within a well casing;

FIG. 2 is a side view, partially in section, illustrating the ball valve of the well tool of the present invention rotated to the open position;

FIG. 3 is a side view, similar to FIG. 2, with the ball valve locked open by directional fluid pressure communicated thereto by a locking plug positioned in the well tool;

FIG. 4 is a view similar to FIG. 3 with the safety valve unlocked by the directional fluid pressure communi-

cated thereto by an unlocking plug positioned in the well tool; and

FIG. 5 is a side view, partially in section, illustrating the securing of the two portions of the housing of the well tool with the ball rotated to the open position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Attention is directed to the FIGS. where the well tool of the present invention, generally designated T, for controlling undesired upwardly flow in a well production tubing Y, is illustrated. The well tool T includes a separable flow housing H having a flow passage or bore F formed therethrough and a valve or bore closure means B disposed in the bore F which is movable to and from an open position for enabling flow of fluids through the bore F of the flow housing H and to and from a closed position for blocking flow of fluid through the bore F of the flow housing H and the production tubing Y.

The bore closure means B is normally operable in response to fluid pressure in an annular area adjacent the flow housing H for controlling the undesired flow in the bore F, but may be releasably locked in the open position when desired by a directional fluid pressure. The well tool T is mountable with a well conduit or casing C, which defines the outer portion of the annular area, for supporting the well tool T therein.

As illustrated in FIGS. 1A and 1B, the flow housing H includes a tubular member 10, which extends downwardly from an upper annular shoulder 10a (FIG. 1A) to a lower annular shoulder 10b (FIG. 1B), having a longitudinally extending bore 11 formed therethrough to serve as the bore F for enabling flow of fluid through the flow housing H. The tubular member 10 further includes a threaded pin connection 12, adjacent the lower shoulder 10b, and a threaded box connection 13, adjacent the upper shoulder 10a or other suitable fastening means for connecting the tubular member 10 at a desired downhole location in the production tubing Y while forming a portion thereof with the bore 11 of the tubular member 10 communicating with a bore X of the production tubing Y above and below the flow housing H.

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. 1A) for blocking flow of fluid through the bore 11 and to and from an open or aligned position (FIG. 5) for enabling flow of fluid through the bore 11 and the aligned flow port 20a. The ball 20 includes a spherical outer surface 20b having two separate portions removed to form a pair of parallel flat portions 20c with each of the circular shaped flats 20c having a radially extending elongated recess 20d formed therein for operably connecting the ball 20 with the flow housing H. Reference is made to my co-pending application, identified above and entitled "METHOD AND APPARATUS FOR A SUBSURFACE SAFETY VALVE OPERATING WITH DIFFERENTIAL ANNULAR PRESSURE" for a more detailed illustration of the recess 20d and the flat 20c.

The bore closure means B further includes an upper seat ring 21 which is concentrically positioned in the bore 11 immediately above the ball 20 and 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 ring 22 concentrically mounts thereon a ring-shaped 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 passage of fluid therebetween. The seat ring 22 also mounts an O-ring 23 thereon 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, which is 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 desired 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. 1A) for rotating the ball 20 closed and a second or lower position (FIG. 2) for rotating the ball 20 to the open position. The pivot member 30 includes a pair of inwardly projecting eccentric pins or fingers 30a which are secured to the pivot member 30 by a suitable fastening means, such as threaded engagement at 30b and which extend into the corresponding 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. The pivot member 30 further includes a lower annular shoulder 30c for engaging an upwardly facing annular shoulder 10d of the tubular member 10 to provide a lower movement limit stop when the ball 20 is rotated open and an upwardly facing tapered annular shoulder 30d for engaging a tapered 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 therethrough communicating with the bore 11 for enabling flow of fluid through the pivot member 11 and a downwardly facing annular shoulder 30e formed thereon above the seat ring 21 in the bore 30f. 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 downward movement of the seat ring 21 into engagement with the spherical surface 20b of the ball 20 and for urging upward movement of the pivot member 30 for normally maintaining the ball 20 rotated closed. The plurality of springs 31 also maintain a downwardly facing arcuate annular sealing surface 21b of a ring-shaped sealing element 21c of the seat ring 21 in annular engagement for effecting an annular fluid seal with the upper portion of the spherical surface 20b of the ball 20.

The tubular operator member 40 is concentrically positioned in the bore 11 immediately above the pivot member 30 and is also longitudinally movable therein between an upper position (FIG. 1A) and a lower position (FIG. 2) for moving the pivot member 30 to rotate the ball 20 to and from the open and closed positions. The operator member 40 extends upwardly from a downwardly facing annular shoulder 40a which en-

gages an adjacent annular shoulder 30g of the pivot member 30 for moving the pivot member 30 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 a movement guiding outer surface 40d. Secured on the surface 40d is an outwardly projecting annular collar 40e having an upwardly facing annular shoulder surface 40f, a downwardly facing annular shoulder surface 40g, and a flow passageway 40h extending through the collar 40e between the annular shoulders 40f and 40g for communicating the area adjacent the shoulders 40f and 40g.

Concentrically mounted with the outer surface 40d of the operator sleeve 40 above the collar 40e and movable relative thereto is a directional flow valve or closure ring 41 which serves as a check valve to enable upwardly flow through the flow passage 40h while blocking downwardly flow through the flow passage 40h by moving into engagement with the surface 40f. The closure ring 41 includes a pair of seal rings 41a and 41b which effect annular fluid seals with the surface 40f and the surface 40d, respectively, of the operator 40 to block leakage of fluid therebetween.

The operator 40 is slidably sealed by seal rings 14 and 15 to the tubular member 10 at spaced locations adjacent the shoulders 40a and 40b, respectively, of the operator 40 to block leakage of fluid therebetween 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 surface 40f between the seal rings 15 and 43 and the closure ring 41 between the seals 41a and 41b form 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 surface 40g between the seal rings 14 and 43 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 to the upper position for enabling the ball 20 to rotate closed.

The tubular member 10 includes an outer surface 10f having a slotted downwardly facing annular support shoulder 10g (FIG. 1B) 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 H at a desired subsurface location with the well casing C to support the flow housing H and connected production tubing Y in the well casing C. While the well tool T of the present invention is described herein as being positioned in the well casing C, it will be immediately appreciated by those skilled in the art that the production tubing T and the well tool T may be positioned in the bore of any well conduit, such as within another production tubing Y, without effecting any change in the operation of the well tool T of the present invention as herein disclosed.

The outer surface 10f of the tubular member 10 mounts a packing or seal ring D thereon above the support shoulder 10g for effecting an annular fluid seal with the well casing C. The fluid passage blocking seal effected by the seal D divides the annular area between

the production tubing Y and the well casing C into an upper chamber or reservoir R above the seal D and a lower chamber or reservoir P below the seal D and above a well packer (not illustrated). The lower reservoir P communicates with the lower annular expansible chamber 45 through a passageway 10h formed in the tubular member 10. The expansible chamber 44 communicates with the reservoir R above the seal 16 through a flow aperture or port 10i 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 while 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 when the ring 41 moves from engagement with the surface 40f. 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 closure ring 41 on the surface 40f to maintain the pressure differential across the collar 40e to hold the sleeve 40 in the lower position.

As illustrated in FIG. 1B, the flow housing H includes a lower or first portion L of the tubular member 10 mounting the support shoulder 10g for supporting the well tool T in the casing C and an upper or second portion U of the tubular member 10, which mounts or carries the rotatable ball 20. The lower housing portion L extends upwardly from the lower annular shoulder 10b to an upwardly facing annular shoulder 110a which engages a downwardly facing annular shoulder 210a to support the upper sleeve housing portion U. The lower portion L includes an inner surface 110b, defining the flow passage bore 11, having a left-hand thread 110c formed thereon to enable connection of the lower portion L with a tubing string for removing the lower portion L from the well casing C when desired.

The upper portion U extends downwardly from the annular shoulder 10a to the outer lower downwardly facing annular support shoulder 210a formed by a sleeve 210b and an inner downwardly facing annular shoulder 210c adjacent the threads 110c provided by a spaced concentric sleeve 210d secured to the sleeve 210b with suitable fastening means such as threaded engagement at 210e. The sleeve 210d mounts a replaceable packing 210f thereon for effecting an annular seal between the lower housing portions L and the upper housing portion U for blocking leakage of fluid therebetween from the bore 11. In this arrangement it is apparent that the sleeve 210d will move to telescope the upper housing portion U into the lower housing portion L until the annular shoulder 210a engages the annular shoulder 110a of the lower portion L.

The flow housing H includes a means for releasably securing the lower portion L and the upper portion U

in response to well pressures for enabling removal of the ball 20 with the upper portion U when desired, comprising a plurality of four latch dogs 211 mounted with the sleeve 210b and a movable locking piston 212 concentrically positioned between the sleeves 210b and 210d. The latch dogs 211 are positioned in a corresponding plurality of circumferentially spaced window openings or apertures 210g formed through the sleeve 210b. The plurality of latch dogs 18 are movable radially to and from a retracted or free position enabling removal of the upper portion U from the lower portion L (FIG. 1B) and to and from an extended or locking position for securing the upper portion U with the lower portion L (FIG. 5) in response to well fluid pressures. The casing adapter N includes a downwardly facing annular shoulder S1 engaging the latch dogs 211 in the locking position for blocking upward movement of the upper portion U relative to the lower portion L. When the plurality of latch dogs 18 are moved radially inwardly, to the free position, the upper portion U may be removed from the lower portion L and withdrawn from the well while the production tubing Y below the lower portion L is supported thereby and remains in the well casing C.

The locking piston 212 is concentrically disposed between the spaced sleeves 210b and 210d and is longitudinally movable to and from a first or upper position (FIG. 1B) for enabling the latch dogs 211 to move to the free position and to and from a lower or second position (FIG. 5) for locking the latch dogs 211 in the locking position. The locking piston 212 is preferably in the form of a sleeve including a constant diameter outer surface 212a adjacent the sleeve 210 having a pair of spaced tapered edged annular recesses 210b formed therein for receiving corresponding inwardly projecting locking collars 211a formed on the latch dogs 211 to enable the latch dogs 211 to move to the free position when the piston 212 moves to the upper position to align the recesses 210b with the collars 211a. Downward movement of the piston 212 from the upper position to the lower position will cam or wedge the latch dogs 211 with the recesses 212b to move radially outwardly to the locking position and in which position the latch dogs 211 are locked by the surface 212a moving adjacent the latch dogs 211a. Thereafter when the locking piston 212 returns to the upper position, engagement of the latch dogs 211 with the tapered annular shoulder S1 will wedge the latch dogs 18 radially inwardly to the free position when the upper portion U is elevated.

The locking piston 212 mounts a pair of O-rings 212c and 212d for effecting a fluid seal with the lower sleeves 210b and 210d respectively, for blocking leakage of fluid about the locking piston 212. Sealed in this manner, the locking piston 212 provides an upwardly facing pressure responsive annular shoulder surface 212e and stepped downwardly facing pressure responsive annular shoulder surface, which for the purposes of this disclosure will be referred to as 212f. The pressure responsive surface 212f communicates with the pressure in the lower reservoir P for urging the locking piston 212 to move to the upper position in response to the fluid pressure in the reservoir P. The pressure responsive surface 212e communicates with the bore 11 through an aperture or port 210h for urging the locking piston 212 to move downwardly for locking the latch dogs 211 in response to the pressure in bore 11

of the tubular member 10. The well fluid pressure differential across the locking piston 212 thus determines the position of the locking piston 212 for releasably securing the lower portion L with the upper portion U. The locking piston 212 is normally maintained in the upper position further by a biasing spring 213 mounted with the sleeve 210d.

As illustrated in FIG. 3, the flow housing H further includes a means for releasably locking the ball 20 in the open position in response to a directional fluid pressure to thereafter block movement of the ball 20 from the open position comprising a lug ring 50, a detent 51 and a piston ring 52, all of which are movably mounted in the bore 11 above the operator 40. 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. 4) and a lower position (FIG. 3) which moves the engaged 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. 4) and a lower position (FIG. 3) where the detent will radially contract to move into an annular recess 10j of a chamber defining surface 10k of the tubular member 10. The piston ring 52 is positioned above the detent 51 and is longitudinally movable along the surface 10k from an upper position (FIG. 4) to a lower position (FIG. 3) in response to a directional pressure urging thereon. The piston ring 52 includes a constant diameter inner surface 52a adjacent the surface 10k for guiding longitudinal movement of the piston ring 52 and a constant diameter 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 10j 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 also effecting desired 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 10m 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 ring 50, is a biasing means or plurality of springs 53 for urging the lug ring 50 to normally remain in the upper position.

The fluid pressure seals effected by the O-rings 50d, 52c and 52d block fluid communication by 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 10n formed in the tubular member 10 adjacent the annular shoulder 10m. The lower annular expandable chamber 62 communicates with the bore 11 through the open 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. 3, the well tool T 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 10p 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 Y 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 10m 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 Y above the plug 70 through the locking plug 70 to the area immediately above the packing ring 70b. Thus, the locking plug 70 enables the 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. 4, the well tool T 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 expandable locking lugs 80a which move radially outwardly into the recesses 10p for securing the plug 80 with the tubular member 10. The unlocking plug 80 includes a pair of pack-

ing or 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 10n for blocking communication of fluid pressure in the bore 11 adjacent the lugs 50a to the port 10n 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 production tubing Y 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 10n 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 then be communicated through the port 10n 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 10n, the pressure in the bore X of the production tubing Y above the plug 80 may be employed to release the ball 20.

Movement of the closure ring 41 enables determination of the location of a production tubing Y leak into either the upper reservoir R or the lower reservoir P by controlling the position of the operator 40. When the operator 40 is in the upper position (FIG. 1A), the closure ring 40 engages a downwardly facing shoulder 10q, adjacent the port 10i for maintaining the closure ring 41 in sealing engagement with the surface 40f for blocking flow in either direction through the passageway 40h and thereby isolating the upper reservoir R from communicating with the lower reservoir P. By venting or bleeding the pressure in the upper reservoir R and then shutting the reservoir R in, the operator may determine if the production tubing Y is leaking above the seal D. If the pressure in the upper reservoir R increases, the production tubing Y is leaking above the seal D. If the reservoir R pressure remains the same, the tubing Y is not leaking above the seal D. When the ball 20 is next locked open, the valve operator 40 is moved to the lower position enabling the spacing of the closure ring 41 from the shoulder 10q by the urging of a spring 46 for enabling fluid communication from the lower reservoir P into the upper reservoir R. With this arrangement, the location of the production tubing Y leaks into the annular area to determine the need to pull all or only a portion of the production tubing Y may be tested for by locking the ball 20 open and then observing if the pressure in the upper reservoir R thereafter increases. By first testing the upper reservoir R for leaks and then locking the ball 20 open to test for leaks, the location of any tubing leaks may be determined with certainty.

In the use and operation of the present invention, the lower portion L is connected with the production tubing Y using the threaded pin 12 and the left-handed thread connection 110c is engaged with a well conduit (not illustrated) for lowering the lower portion L along

with the production tubing Y until the downwardly facing shoulder 10g engages the upwardly facing shoulder S of the casing adapter N which blocks further downward movement of the lower portion L and the production tubing Y and which supports the lower portion L and the production tubing Y in the casing C. Left-hand rotation is then imparted to the well conduit above the lower portion L for disengaging the threaded connection therebetween at threads 110c to enable retrieval of the well conduit from the casing C.

The upper portion U is then connected to the production tubing Y using the box threads 13 and is lowered into the casing C by the addition of joints of tubing Y until the annular shoulder 210a engages the shoulder 110a of the lower portion L with the sleeve 210d telescoped within the lower portion L for effecting a fluid seal with packing 210f. When the upper portion U is seated or supported on the lower portion L, the seal D effects the annular fluid seal between the tubular member 10 and the well casing C to form the upper and lower reservoirs R and P, respectively, in the annular area between the production tubing Y and the well casing C. The well is then completed by any suitable method and hydrocarbons and other well fluids are thus enabled to flow upwardly through the bore X of the production tubing Y and through the bore F of the flow housing H.

In completing the flowing well, the pressure in the bore 11 of the flow housing H will increase to a pressure greater than the pressure in the lower annular reservoir P. The increased pressure in the bore 11 will be communicated through the port 210h for urging the locking piston 211 to move downwardly, but which movement will be blocked by the shoulder 212f engaging the shoulder 110a. The pressure in the bore 11 below the ball 20 will also establish a pressure differential across the closed ball 20 for urging the ball 20 and the upper portion U to move upwardly. As the well pressure commences to move the upper portion upwardly, the same well pressure will also urge the locking piston 212 to move downwardly for maintaining the shoulder 212f in engagement with the shoulder 110a of the lower portion L. The upward movement of the sleeve 210b and the plurality of latch dogs 211 relative to the locking piston 212 will wedge the latch dogs 211 to move radially outwardly into engagement with the downwardly facing locking shoulder S1 of the casing C and in which position they will be locked by the locking piston 212 (FIG. 5). From the foregoing disclosure, it is readily apparent that the natural well fluid pressure developed in completing the well automatically releasably secures the upper portion U with the lower portion L. This same well pressure is sufficient to overcome the urging of the spring 212g to maintain the locking piston 212 in the lower position and the plurality of latch dogs 211 in the locking position.

When it is desired to produce hydrocarbons and the like from the well, the pressure in the upper reservoir R is increased by a pressure generating source or means. This increased pressure is communicated through the port 10i 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. 2).

When it is desired to close in the well at a subsurface location or a catastrophic well failure resulting in a well blowout occurs, pressure in the upper reservoir R is decreased or otherwise vented to reduce 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 D to provide a latent fluid pressure in the reservoir P for closing the ball 20 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 Y.

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 other well fluids.

When it is desired to run various well tools and the like through the bore X of the production tubing Y to a location below the well tool T and in necessary operation for completing the well, 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 Y until the locking lugs 70a are adjacent the annular recesses 10p at which time the locking lugs 70a are expanded or moved radially outwardly into the recesses 10p for securing the locking plug 70 with the tubular member 10. Fluid 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 10j, the detent 51 will radially contract for moving into the recess 10j and enable the piston ring 52 to move downwardly relative to both the detent 51 and the lug ring 50 for locking the detent 51 in the recess 10j. When the detent 51 is locked in the recess 10j, the lug ring 50 is blocked from subsequent upward movement by engagement of the annular 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 is 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 member 10 by inward movement of the lugs 70a and the plug 70 retrieved to enable the running and retrieval of other well tools through the bore X of the production tubing Y below the well tool T.

When it is desired to return the well tool T to pressure responsive operation, the unlocking plug 80 is run through the bore X of the production tubing Y until the locking lugs 80a are aligned with the recesses 10p and which are then radially expanded 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 springs 31 to urge the pivot member 30 and the operator 40 to move upwardly 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 ball 20 restored to the normal pressure responsive operating condition.

Should the valve malfunction for any reason, such as, but not limited to, a second sealing surface, a broken spring or the like, the upper portion U with the ball 20 may be disconnected and retrieved without the need to pull the lower portion L and the entire string of the production tubing Y thus enabling the use of more inexpensive, smaller capacity workover equipment for subsurface safety valve replacement. Preferably, the ball 20 is locked open during the retrieval operation, but that procedure is not required for effecting release from the lower portion of the production tubing Y.

To release the upper portion U from the lower portion L, the pressure in the bore 11 is reduced or otherwise lowered to a level substantially equal to the pressure in the lower reservoir P. This may be accomplished in several ways, such as setting a plug in the production tubing bore X below the well tool T or killing the well with a heavy fluid as is well known. When the combined upwardly urging of the spring 213 and the pressure in the lower reservoir P urging on the shoulder 212f overcomes the downwardly urging on the shoulder 212e to effect movement of the locking piston 212 from the lower to the upper position (FIG. 1B), to align the recesses 212b for enabling the equally spaced latch dogs 212 to move radially inwardly by the wedging engagement with the tapered locking shoulders S1 as the production tubing Y and the well tool T are elevated. The upper portion U with the ball 20 may then be retrieved for enabling desired maintenance work to be performed. Thereafter, the upper portion U

may be lowered back into telescoping engagement with the lower portion L and be releasably secured there-within when desired, by the well fluid pressure as set forth hereinabove.

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 well tool apparatus adapted for connecting in a production tubing to control flow of well fluids through the bore of the production tubing at a subsurface location in a well, including:

a flow housing having a bore formed therethrough and comprising a first housing portion and a second housing portion, said housing 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 mounted with said housing and disposed in said bore for movement to and from an open position for enabling flow of fluid through said bore and a closed position for blocking flow of fluid through said bore;

means mounted with said flow housing for effecting movement of said bore closure means to and from the open and closed position, said means for effecting movement responsive to a controlled application of fluid pressure communicated to said flow housing independently of the fluid flow controlled by said bore closure means; and

means with said flow housing for releasably securing said first portion of said flow housing with said second portion of said flow housing to enable removal of said bore closure means with one of said portions of said flow housing from the well wherein the well tool apparatus is operated.

2. The apparatus as set forth in claim 1, wherein said flow housing includes:

means for mounting said flow housing with the well casing at a subsurface location for supporting said flow housing in the well casing.

3. The apparatus as set forth in claim 1, wherein said means for releasably securing said first housing portion with said second housing portion includes:

a latch dog mounted with said flow housing and movable to and from a locking position for securing said first housing portion with said second housing portion and a free position for releasing said first housing portion from said second housing portion of said flow housing;

a locking piston mounted with said flow housing and movable in response to the urging of well fluid pressures to and from a first position for enabling said latch dogs to move to the free position and a second position for moving said latch dogs to the locking position wherein well fluid pressures effect operation of the well tool.

4. The apparatus as set forth in claim 3, wherein: said latch dog moves radially outwardly relative to a longitudinal axis of said flow housing in moving from the free position to the locking position wherein said first housing portion is secured with said second housing portion.

5. The apparatus as set forth in claim 3, wherein:

said latch dog moves longitudinally relative to said locking piston in moving from the free position to the locking position wherein said first housing portion and said second housing portion are secured.

6. The apparatus set forth in claim 3, wherein:

said latch dog moves into engagement with a downwardly facing shoulder of the well casing when moving to the locking position wherein said first housing portion is secured with said second housing portion.

7. The apparatus as set forth in claim 3, wherein said means for releasably securing said first and said second portion of said flow housing includes:

a plurality of latch dogs mounted about the circumference of said flow housing and movable simultaneously to and from the locking position and the free position in response to the movement of said locking piston wherein said first housing portion and said second housing portion are releasably secured.

8. The apparatus as set forth in claim 1, including: means with said flow housing for effecting an annular fluid seal between said flow housing and a well casing to divide the annular area between the production tubing and the well casing into a lower reservoir below said fluid seal and an upper reservoir above said fluid seal; and

a closure member mounted with said housing for enabling communication from said lower reservoir to said upper reservoir in a first position and movable to a second position in response to the fluid pressure in said upper reservoir to block communications between said lower reservoir and said upper reservoir wherein the fluid pressure in said lower reservoir is determinable.

9. The apparatus as set forth in claim 3, including: means with said first housing portion for mounting said first housing portion with the well casing at a subsurface location for supporting said first housing portion in the well casing; and

said bore closure means mounted with said second portion of said flow housing to enable removal of said bore closure means from the well when said second housing portion is released from said first housing portion.

10. The apparatus as set forth in claim 9, wherein: said bore closure means including a ball member having a flow port formed therethrough which is rotated to and from the open position enabling flow of fluid through said flow port and to and from the closed position where said ball member blocks flow of fluid through said bore of said flow housing; and said means for effecting movement of said bore closure means including a pivot member operably connected with said ball member for imparting rotation to said ball member when there is relative movement between said pivot member and said ball member wherein the well tool is operated to control flow of well fluids.

11. The apparatus as set forth in claim 10, including: means with said flow housing for effecting an annular fluid seal between said flow housing and the well casing to divide an annular area between the production tubing and the well casing into a lower reservoir below said fluid seal and an upper reservoir above said fluid seal with the fluid pressure differ-

15

ential between said upper reservoir and said lower reservoir effecting operating rotation of said ball member wherein fluid pressure in the annular area controls flow through the well tool.

12. The apparatus as set forth in claim 11, wherein said means for effecting movement of said ball member further includes:

an operator movably mounted with said second portion of said flow housing and having a first pressure responsive surface and a second pressure responsive surface and which operably co-acts with said pivot member for effecting rotation of said ball member to and from the open and closed positions; said first pressure responsive surface communicating with said upper reservoir for urging movement of said operator to rotate said ball member to the open position in response to the fluid pressure in said upper reservoir; and said second pressure responsive surface communicating with said lower reservoir for urging movement of said operator to rotate said ball member to the closed position in response to the fluid pressure in said lower reservoir wherein the pressure in said upper reservoir and said lower reservoir controls flow of fluid through the well tool.

13. The apparatus as set forth in claim 12, wherein: said operator member having a flow passageway formed therethrough for communicating said upper reservoir and said lower reservoir;

a closure member mounted with said operator for enabling flow through said flow passageway from said lower reservoir to said upper reservoir when said ball is rotated open and which moves to block flow through said flow passageway from said upper reservoir to said lower reservoir; and

means with said flow housing for releasably locking said ball in the open position for blocking movement of said ball to the closed position in response to the pressure in the annular area between the production tubing and the well casing wherein said ball is locked open for determining the fluid pressure in said lower reservoir.

14. A well tool for connecting in a production tubing including:

a flow housing having a bore formed therethrough and comprising a first housing portion and a second housing portion, said housing 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 a closed position for blocking flow of fluid through said bore;

means with said flow housing for releasably securing said first portion of said flow housing with said second portion of said flow housing in response to the urging of well fluid pressures to enable removal of said bore closure means with a portion of said flow housing from the well, including;

a latch god mounted with said flow housing and movable to and from a locking position for securing said first housing portion with said second housing portion and to and from a free position for releasing said first housing portion from said second housing portion of said flow housing;

16

a locking piston mounted with said flow housing and movable in response to the urging of well fluid pressures to and from a first position for enabling said latch dogs to move to the free position and to and from a second position for moving said latch dogs to the locking position;

means for mounting said first housing portion of said flow housing with the well casing at a subsurface location for supporting the well tool in the well casing;

said bore closure means disposed in said bore of said second portion of said flow housing to enable removal of said bore closure means from the well when said second housing portion is released from said first housing portion;

said bore closure means including a ball member having a flow port formed therethrough which is rotated to and from the open position enabling flow of fluid through said flow port and to and from the closed position where said ball member blocks flow of fluid through said bore of said flow housing; and means for effecting movement of said bore closure means including a pivot member operably connected with said ball member for imparting rotation to said ball member when there is relative movement between said pivot member and said ball member wherein the well tool is operated to control flow of well fluids.

15. The apparatus as set forth in claim 14, including: means with said flow housing for effecting an annular fluid seal between said flow housing and the well casing to divide an annular area between the production tubing and the well casing into a lower reservoir below said fluid seal and an upper reservoir above said fluid seal with the fluid pressure differential between said upper reservoir and said lower reservoir effecting operating rotation of said ball member wherein fluid pressure in the annular area controls flow through the well tool.

16. The apparatus as set forth in claim 14, wherein said means for effecting movement of said ball member further includes:

an operator movably mounted with said second portion of said flow housing and having a first pressure responsive surface and a second pressure responsive surface and which operably co-acts with said pivot member for effecting rotation of said ball member to and from the open and closed positions; said first pressure responsive surface communicating with said upper reservoir for urging movement of said operator to rotate said ball member to the open position in response to the fluid pressure in said upper reservoir; and

said second pressure responsive surface communicating with said lower reservoir for urging movement of said operator to rotate said ball member to the closed position in response to the fluid pressure in said lower reservoir wherein the pressure in said upper reservoir and said lower reservoir controls flow of fluid through the well tool.

17. The apparatus as set forth in claim 16, wherein: said operator member having a flow passageway formed therethrough for communicating said upper reservoir and said lower reservoir;

a closure member mounted with said operator for enabling flow through said flow passageway from said lower reservoir to said upper reservoir when said

17

ball is rotated open and which moves to block flow through said flow passageway from said upper reservoir to said lower reservoir; and

means with said flow housing for releasably locking said ball in the open position for blocking movement of said ball to the closed position in response to the pressure in the annular area between the production tubing and the well casing wherein said ball is locked open for determining the fluid pressure in said lower reservoir.

18. A well tool for connecting in a production tubing including:

a flow housing having a bore formed therethrough and comprising a first housing portion and a second housing portion, said housing 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 a closed position for blocking flow of fluid through said bore; and

18

means with said flow housing for releasably securing said first portion of said flow housing with said second portion of said flow housing in response to the urging of well fluid pressures to enable removal of said bore closure means with a portion of said flow housing from the well, including:

a latch dog mounted with said flow housing and movable to and from a locking position for securing said first housing portion with said second housing portion and to and from a free position for releasing said first housing portion from said second housing portion of said flow housing;

a locking piston mounted with said flow housing and movable in response to the urging of well fluid pressures to and from a first position for enabling said latch dogs to remove to the free position and to and from a second position for moving said latch dogs to the locking position; and

said latch dog moves longitudinally relative to said locking piston in moving from the free position to the locking position wherein said first housing portion and said second housing portion are secured.

* * * * *

25

30

35

40

45

50

55

60

65