SAFETY VALVES FOR WELLS

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ABSTRACT

Well safety valves for shutting off flow in a well tubing string such as a production string or a drilling string responsive to either predetermined low pressures or high pressures and also in response to certain valve malfunctions. The valves include valve operators useful with a ball, poppet, or flapper valve, and biased toward a closed position by a spring and gas pressure on a piston movable in a dome chamber. During normal operations, the valves are each held open by either a tubing-casing annulus pressure or pressure in a control line directed to a chamber applying a control pressure to the piston opposing the dome pressure. Special seals and chambers are included in the valves to effect pressure equalizations causing valve closure when any one or more of the seals leak. Additionally, certain embodiments of the valves include means operative responsive to predetermined high pressures to equalize the pressures in the dome chamber and the tubing-casing annulus effecting valve closure. Some embodiments of the valves include safety piston structure for effecting such valve closure responsive to a predetermined high tubing-casing annulus or control line pressure such as when valve malfunction precludes normal closure. The valves are particularly useful in well systems for both primary and secondary production, for certain subsea well producing systems, and also in well drilling systems for well testing purposes, shutting in wells, and the like.

27 Claims, 11 Drawing Figures
SAFETY VALVES FOR WELLS

This application is a continuation-in-part of our application Ser. No. 238,397 entitled SAFETY VALVES FOR WELLS filed Mar. 27, 1972, now abandoned.

This invention relates to well tools and more particularly relates to safety valves for wells.

In both the drilling and production of oil wells, operating conditions and equipment malfunctions frequently develop which require that fluid flow be quickly shut off through well structure such as production and drill string tubings. In the drilling of wells, it may be desirable to be able to maintain a closed flow passage through a drill string while providing a capability of opening the drill string when certain well tests are to be performed. Alternatively, it may be desired to hold such a valve open and close it when needed. In the drilling of subsea wells, conditions such as storms often make it necessary to shut in a well and temporarily abandon it until sea conditions permit recovery. In such wells, a valve in the drill string may be held open during drilling and thereafter closed while the drill string is left supported in the well by means of special well head apparatus. In the production of subsea wells by secondary means, such as gas lift, and by primary recovery methods involving flow in response to normal formation pressures a well must be protected against the invasion of sea water in the event of a structural failure of the well equipment by a tubing safety valve.

Tubing string valves for use both in producing wells and when drilling wells are well known. Some such valves often are controlled responsive to the tubing casing annulus pressure or the pressure of a control fluid conducted to the valve through a special control line from the surface. Such valves currently available may be operated responsive to a predetermined low pressure while other such valves are responsive to predetermined high pressure levels. Generally, however, the valves are not adapted to react to both a predetermined low and a predetermined high pressure. Additionally, such valves often are not constructed to close when certain valve malfunctions occur. For example, in certain safety valves which include a dome chamber, leaks may occur between the dome chamber and the tubing in which the valve is installed without the valve responding by closing because of the failure of such leak to have any effect upon the tubing-casing annulus pressure. In other available safety valves the casing annulus pressure may rise to a value of sufficient magnitude to effect collapse of the tubing without closing the safety valve.

It is a particularly important object of the invention to provide a new and improved well tool.

It is another especially important object of the invention to provide a new and improved well safety valve useful in both the drilling and the production of wells.

It is another object of the invention to provide a well safety valve which is closable responsive to a predetermined low tubing-casing annulus pressure.

It is another object of the invention to provide a well safety valve which is closable responsive to a predetermined high tubing-casing annulus pressure.

It is another object of the invention to provide a well safety valve which may be included in the drill string used in drilling a well for making drill stem tests on the well during the process of drilling to determine the presence and character of formation fluids.

It is another object of the invention to provide a well safety valve which may be included in the drill string used in drilling a well for shutting in subsea wells during conditions such as storms when the wells must be temporarily abandoned.

It is another object of the invention to provide a well safety valve which is especially useful in the production of subsea wells both by primary and secondary means such as gas lifts to protect the wells against equipment failure causing invasion by sea water.

It is another object of the invention to provide a tubing safety valve responsive to tubing-casing annulus pressure increases to avert tubing damage or collapse effected by well system failures such as tubing leakage at a location which applies tubing pressure to the hydrostatic pressure of liquids in the annulus whereby annulus pressures may build to a value sufficient to collapse the tubing.

It is another object of the invention to provide a well safety valve which closes responsive to a valve malfunction such as a seal failure between the casing and the tubing and between the casing and the dome chamber.

It is another object of the invention to provide a tubing safety valve which may be closed by an increase in casing pressure where a valve malfunction prevents closure by a normal decrease in the annulus pressure.

It is another object of the invention to provide a well safety valve having a dome chamber which functions at a pressure which is chargeable under field conditions from commercially available compressed gas.

It is another object of the invention to provide a well safety valve which is operable by either casing annulus pressure or pressure communicated to the valve through a control line from the surface.

It is another object of the invention to provide a well safety valve having a valve operator biased toward a closed position by dome pressure and a spring and including casing pressure responsive chambers at each end of the valve operator whereby the dome is equalized with the annulus by a seal failure at either end of the dome and the spring closes the valve.

It is another object of the invention to provide well safety valves of the character described wherein valve operating characteristics may be varied by altering the relative sizes or proportions of various pressure responsive elements of the valves.

It is another object of the invention to provide well safety valves of the character described which include sealed chambers adapted to be charged to desired predetermined pressures during valve assembly and preparation.

It is another object of the invention to provide well valves which are operable independently of the tubing-casing annulus pressure to protect such valves against possible debris in the annulus.

It is another object of the invention to provide well safety valves of the character described having control apparatus in which valve operating pressures are communicated to a control piston and to pressure displaceable seals through a control line from the surface extending to the valve independently of the tubing-casing annulus whereby the valve apparatus holds the valve open at a control pressure within a predetermined range and effects valve closure responsive to a control fluid pressure below or in excess of a predetermined value.
It is another object of the invention to provide well safety valves of the character described wherein a control fluid pressure is communicated to an operating piston at one end of a dome chamber through a control line extending to the valve from the surface independently of the tubing-casing annulus and the other end of the dome chamber is closed by a pressure displaceable seal exposed to the tubing-casing annulus pressure for effecting valve closure in response to a high casing pressure.

In accordance with the invention there is provided a well safety valve for use in a tubing string which includes a valve member which may be a ball valve, a poppet valve, or a flapper valve coupled with a tubular valve operator having an external annular piston formed thereon, a valve housing concentrically disposed around the valve and operator member and defining a dome chamber around the operator enclosing the annular piston. A spring is disposed within the dome chamber confined between a flange in the housing and a flange on the operator biasing the valve closed. The dome chamber is adapted to be pressurized to a desired value to provide an additional force biasing the valve closed. In one embodiment of the valve an annular chamber communicating with the casing is provided at opposite ends of the dome chamber so that leakage of seals at either end of the dome chamber causes the dome chamber to reach casing annulus pressure allowing spring valve closure. In a second embodiment of the valve an additional annular chamber at atmospheric pressure is provided between the valve operator and the valve housing at the upper end of the valve for reducing the dome pressure required. In the second and a third embodiment of the valve a lower annular piston is disposed around the valve operator within the valve housing movable responsive to casing pressure to permit the valve to close at a predetermined high casing pressure. In a fourth embodiment of the valve an annular atmospheric chamber is provided at the upper end of the valve to reduce the required dome pressure and a pair of telescopically disposed annular pistons are positioned in an annular chamber between the valve operator and the valve housing below the dome chamber for forcing the valve closed responsive to a predetermined high casing pressure. Each of the several embodiments of the valve is provided with a threaded fitting at each end for connecting the valve in either a drilling string or a production tubing string whereby the valve comprises an integral part of the string. In another embodiment of the valves control fluid pressure is communicated through a single control line to a control piston at one end of a dome chamber and to a displaceable seal at the other end of the dome chamber. In a further embodiment of the valves, control fluid is communicated through a control line to the control piston at one end of the dome chamber and a pressure displaceable seal at the other end of the dome chamber is exposed to the tubing-casing annulus pressure.

In the various embodiments described and claimed the several seals used to close the dome chamber and properly otherwise confine the various pressures involved serve functions including assuring that the control pressures used to hold the valve open are directed to the proper side of the annular piston or pressure responsive means on the valve operator. Such confining means may include seals which are displaced to nonsealing relation by predetermined high pressures as may be applied by a control fluid pressure or a pressure admitted by a tubing rupture. The terms "control fluid" or "control fluid pressure" shall include both fluid pressures directed to a valve for the specific purposes of holding the valve open, of closing the valve, and fluids which enter a ruptured tubing such as sea water in an offshore well. The sea water, for example, serves a control fluid function by emergency closing of the valve to shut-in the well. The various forms of the invention and the foregoing objects and advantages will be apparent from reading the following detailed description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a longitudinal view in section and elevation of a first embodiment of a valve made in accordance with the invention showing the valve open;
FIG. 2 is a longitudinal view in section and elevation of the valve of FIG. 1 closed;
FIG. 3 is a fragmentary view in section of a poppet type valve which may be employed with the valve operating structure;
FIG. 4 is a fragmentary view in section of a flapper type valve which may be employed with the valve operator structure;
FIG. 5 is a fragmentary view in section showing a second form of valve operating structure in accordance with the invention;
FIG. 6 is a fragmentary view in section illustrating a third form of valve operator structure embodying the invention;
FIG. 7 is a fragmentary view in section illustrating a fourth form of valve operator structure embodying the invention, showing the valve open;
FIG. 8 is a fragmentary view in section showing the valve of FIG. 7 closed;
FIG. 9 is a fragmentary view in section illustrating an alternate form of the lower end of the valve structure as shown in FIG. 5;
FIG. 10 is a fragmentary view in section showing an alternate form of the valve operating structure of the valve operating system shown in FIG. 1; and
FIG. 11 is a fragmentary view in section of another alternate form of the valve operating system of FIG. 1.

Referring particularly to FIGS. 1 and 2 of the drawings a safety valve 20 embodying the invention is illustrated for use as an integral part of a tubing string, not shown, which may be either a production string used in either primary or secondary well production or may be a drilling string employed in the drilling of a well. For a better understanding of the valve and one of its applications in a gas lift system of a well, reference may be had to U.S. Letters Pat. No. 3,642,070 issued Feb. 15, 1972, to Frank H. Taylor and Warner M. Kelley. The valve 20 may be substituted in the tubing string 34 of the reference patent for the landing nipple 41 whereby the valve is disposed in the tubing string below the gas lift valve and functions responsive to the pressure applied in the annulus 45 between the casing and the tubing string. The valve 20 is connected in the tubing string by upper and lower tubing couplings 21 and 22 which are threaded, respectively, on upper and lower threaded reduced valve housing portions 23 and 24 of a tubular valve housing 25. A tubular valve operator 30 is movably disposed in concentric relationship within the housing 25 for opening and closing the valve. A ball valve 31 is rotatably secured between the lower end of the valve operator and a tubular lower valve seat 32 bi-
ased upwardly by a spring 33. As discussed in detail hereinafter, the ball valve 31 is rotatable between the open position of FIG. 1 and the closed position of FIG. 2 by the operator 30 responsive to a number of different well conditions and valve malfunctions for shutting off flow through the valve for both safety and other reasons.

The bore of the housing 25 is enlarged along an upper end portion 35 defining a downwardly facing internal annular stop shoulder 40 at the upper end of the housing where the housing connects with the threaded end section 23. The bore of the housing 25 is still further enlarged along a section 41 which is concentrically spaced from the valve operator 30. A ring seal 42 is disposed in an internal annular recess 43 sealing between the upper end portion of the housing and the upper end portion of the valve operator. An annular piston 44 is formed on the valve operator including an upper external annular retainer flange 45. A ring seal 50 is held on the piston portion against the flange 45 by a retainer ring 51 secured to the piston by a shear pin 52. The piston of the valve operator separates the annular space between the housing wall section 41 and the valve operator into an annular dome chamber 53 below the piston portion and an annular casing pressure chamber 54 above the piston. A port 54a in the housing wall opens to the chamber 54 to apply casing pressure above the piston. A coil spring 55 is disposed in the dome chamber between a retainer ring 60 seated against a downwardly facing stop shoulder 61 on the lower end of the valve operator piston 44 and an internal annular flange 62 providing an upwardly facing internal annular stop shoulder 63 in the housing wall. The valve housing is reduced in internal diameter along an intermediate portion 64 which is spaced from the valve operator defining an annular recess 65 at the lower end of the dome chamber. The lower end of the recess 65 is defined by an internal annular stop shoulder 70 which supports a ring seal 71 held in place by a retainer ring 72 secured to the housing wall portion 64 by a shear pin 73. The ring seals 50 and 71 seal the upper and lower ends of the dome chamber 53 which is filled with a suitable gas under pressure through a side port 74 provided in the wall section 41 of the valve housing and sealed by a plug 75. The forces of the gas in the dome chamber and the spring 55 bias the valve operator 30 upwardly toward a valve-closed position.

The valve housing section 64 is provided with a side port 76 which communicates with an internal annular recess 77 within the valve housing around the valve operator below the internal housing shoulder 70. Below the recess 75 a ring seal 80 is positioned around the valve operator within an internal recess 81 of the valve housing to seal between the housing and the valve operator below the recess 75.

At the lower end of the valve housing portion 64 the bore of the housing is enlarged below a downwardly and outwardly sloping stop shoulder 82 and extends at a uniform diameter along a wall portion 83 of the housing to a reduced diameter housing portion 84 defining an upwardly facing stop shoulder 85. The valve operator has an external annular tapered flange 90 above the ball 31 which is engageable, as seen in FIG. 2, with the housing shoulder 82 defining the upper limit of movement of the valve operator at which the ball valve is closed. The lower end portion of the valve operator is provided with an external annular recess 91 which receives a pair of T-shaped ball valve hanger brackets 92 connected between the ball valve 31 and the valve operator 30. The hanger brackets 92 each has an inwardly projecting pin 93 engaging a circular recess, not shown, in the ball valve 31. The brackets are positioned on opposite sides of the valve operator so that the pins 93 engage diametrically opposed recesses of the ball valve rotatably hanging the ball valve from the hanger brackets on an axis of rotation perpendicular to the longitudinal axis of the valve operator 30. Diametrically opposed, inwardly projecting pins 94 are secured within the valve housing wall section 83 extending into slots, not shown, on opposite sides of the ball valve so that the ball valve is raised and lowered by the hanger brackets with the valve operator the co-action of the pins in the slots of the ball valve causes the ball valve to rotate. Further structural details of the ball valve operating mechanism may be found in U.S. Pat. No. 3,273,588 issued to W. W. Dollison Sept. 20, 1966, and U.S. Pat. 3,292,706 issued to George C. Grimmer and Leonard McCasland Dec. 20, 1966. The lower end of the valve operator 30 is provided with a spherical upper valve seat surface 95 with which the ball valve engages in fluid-sealed relationship when the valve is at the closed position of FIG. 2. A relief port 96 is provided in the operator 30 above the seat 95 to prevent a pressure build up along the operator as the seat 90 engages the seat 82 and a suction effect when the seats separate as the operator moves downwardly to open the valve. The ball valve has a bore 100 of substantially the same diameter as the bore through the valve operator and the valve seat.

The lower valve seat 32 is a tubular member having an upper external annular flange 101 for engagement of the upper end of the coil spring 33, which is confined between the housing flange 85 and the flange 101, biasing the valve seat upwardly against the ball valve. The upper end of the lower valve seat is provided with an internal spherical seat surface 103 which engages the ball valve.

In operation the valve 20 may be used in a number of different types of well systems for drilling and in production such as gas lift systems. The valve may be responsive to the tubing casing annulus pressure, or a control line may be connected into the port 54a from a fluid pressure control system at the surface which senses various operating conditions in response to which the valve is closed. For example, a control line may be connected at the surface with an OTIS SURFACE CONTROL MANIFOLD shown and described at page 3,887 of the 1970-1971 edition of the Composite Catalog of Oil Field Equipment and Services. Systems of the nature of FIG. 1 using a separate control line are discussed hereinafter in connection with FIGS. 10 and 11. The valve operation of the FIG. 1 valve system will be described in terms of its functioning responsive to the tubing-casing annulus pressure which can constitute lift gas in a gas lift system, drilling fluid in a well drilling system, or control fluid in a production system where the annulus serves basically the function of a control fluid flow passage. The spring 55 and the pressure in the dome chamber 53 are selected to support the valve operator 30 at an upper end position to hold the ball valve 31 closed, as seen in FIG. 2, during below-normal tubing-casing annulus pressure. The force of the spring and the dome pressure exerted on the piston 44 apply an upward force to the valve opera-
tor which is opposed by the annulus pressure communicated through the port 54a into the chamber 54 applying a downward force to the piston 44 of sufficient magnitude to hold the operator downwardly against the spring and dome pressure for maintaining the ball valve in the open position as in FIG. 1 during normal tubing-casing annulus pressure.

If the annulus pressure is reduced, as by leakage, or by positive action of the control system where the annulus fluid is control fluid, the downward force on the piston 44 in the chamber 54 is reduced permitting the force of the spring and the dome pressure to lift the piston 44 and the operator 30 rotating the ball valve 31 to the closed position of FIG. 2. The operator moves upwardly until the seat 90 on the operator engages the stop shoulder 82 within the valve housing. As the ball valve moves upwardly, it is followed by the upwardly biased lower valve seat 32. Any pressure differential in the tubing upwardly across the ball valve urges the ball valve into a sealed relationship with the operator valve seat 95.

An increase in pressure in the annulus communicated through the port 54a to the chamber 54, when it exceeds a predetermined value sufficient to overcome the dome pressure and spring 55 acting against the piston 44, forces the valve operator 30 downwardly, returning it to the position of FIG. 1 rotating the valve 31 back to the open position.

In accordance with the special features and benefits of the invention, the valve 20 is adapted to close responsive to a number of different valve malfunctions and well system operating condition changes which might endanger such portions of a well system as the tubing string. A leak in the ring seal 43 tends to equalize the pressures in the bore of the valve and the annulus, and when the differential reaches a value below the level required to hold the valve open against the spring and dome pressure, the valve closes. A leak at the ring seal 50 of the operator piston 44 of the valve equalizes the pressures in the dome chamber and the annulus so that the higher annulus pressure is no longer available to hold the valve open and, therefore, the valve operator is moved upwardly by the spring 55 closing the valve. Similarly, a leak at the lower ring seal 71 communicates the dome chamber with annulus 77 equalizing the side port 76 equalizing the pressures in the dome and the annulus so that the spring closes the valve. This particular feature at the lower end of the dome chamber is a distinguishing feature of the present valve as compared with presently available safety valves of a similar type. Generally, available valves use a seal at the lower end of the dome chamber which seals between the dome chamber and the tubing so that a leak in the seal would not necessarily effect valve closure but might in fact create a greater pressure differential across the operator piston as the tubing pressure may be below annulus pressure. Another seal which may leak in the valve 20 is the ring seal 80 which communicates the tubing through the annular space 77 and the port 76 with the annulus so that the tubing and annulus pressures become equalized whereby the annulus pressure is reduced to a sufficient level for the dome pressure and spring to close the valve. Thus, leakage of any one of the seals at the opposite ends of the dome chamber and between the valve operator and the valve housing establishes pressure conditions which effect closure of the valve. Close said valve; a side port and closure means provided in said housing into said lower annular chamber above said forces the ring seal at either or both ends of the dome chamber out of sealing relationship to equalize the annulus and dome pressures. Such a high pressure may force the ring seal 50 against the retainer ring 51 shearing the pin 52 to permit the retainer ring and the ring seal to be forced into the upper end of the dome chamber so that the seal is displaced from a sealing relationship allowing equalization of the annulus and dome pressures. Similarly, the lower ring seal 71 may be forced upwardly against the retainer ring 72 shearing the pin 73 moving the ring seal out of sealing relationship to equalize the annulus and dome chamber pressure at the lower end of the dome chamber. In either situation, the equalization of annulus and dome pressures permits the spring 55 to lift the valve operator, closing it. This, of course, is a safety feature of the valve which would not be employed during normal operations but is available for emergency closing which might be brought about by a number of situations such as a tubing leak which would apply an excessively large pressure into the casing annulus, or, if some other condition developed where an emergency exists causing an excessively high annulus pressure, the valve is closed. It will be apparent that this technique of closing the valve renders the valve inoperative for future normal use due to the effective rupturing of the dome chamber by the displacement of either or both of the seals at the opposite ends of the chamber from their normal positions. The valve would, of course, have to be retrieved from the well and repaired by replacement of the ring seals and shear pins.

It will be apparent that changes in pressure in the tubing string have no effect on the operation of the valve as the effective sealed areas of the valve operator facing both upwardly and downwardly are equal as defined by the ring seals 43 and 81 between the operator and the valve housing. Thus, the only forces which may affect operation of the valve are annulus pressures and changes in pressures between the annulus and the dome chamber.

The valve 20 can be particularly useful during the process of drilling, especially a subsea well, in at least two circumstances. When drilling such a well, it may be necessary to abandon the well during storm conditions. U.S. Pat. No. 3,411,576 issued Nov. 15, 1968, to Donald F. Taylor, Jr. shows a subsea well head which permits temporary abandonment of a drilling well by hanging the drill string in the well and removing certain surface equipment until well re-entry is desired. A valve in accordance with the present invention may be included in the drill string with the valve being allowed to close while the well is temporarily abandoned to shut in the well along the drill string itself. When re-entry is desired, the casing annulus may be pressured up to open the valve. In other uses, both in offshore and in conventional land based wells, the valve may be included in the drill string at a time when a drill stem test is desired. The drill string is run into the well with the valve closed. Obviously, in such a drill string the tubing may be dry above the closed valve. At a time when a test of the formation fluids is desired, the casing annulus around the drill string is pressured up from the surface to a sufficient value to overcome the spring and dome pressure for opening the valve. When the valve opens, the dry drill string above the valve causes the well to come in and flow without the necessity of swabbing the
well. In primary production and in secondary recovery wells located in subsea areas, the possible invasion by sea water presents a continuing hazard. In a gas lift well a leak in the casing will permit sea water to invade the casing, pass through the gas lift valves, and through the string into the formation. A valve constructed in accordance with the present invention would be caused to close by the additional excessive pressure of the sea water, causing a rupture of the shear pins holding the seals in place at the opposite ends of the dome chamber, releasing the pressure of the dome chamber to permit the valve to close. In primary production wells the same events may occur due to the invasion of sea water into the casing.

The principal components of the valve 20 which control operation of the valve may be readily used with poppet and flapper type valve members as represented by FIGS. 3 and 4. In view of the fact that the operating mechanism of the valves represented in FIGS. 3 and 4 is identical to that of the valve 20, only the lower end portions of such valves are shown to clearly identify them as poppet and flapper type valves. Referring to FIG. 3, the poppet type safety valve is represented by the reference numeral 20A. All of the operating structure of the valve 20A is identical to the operating structure of the valve 20 above and including the ring seal 80 sealing between the operator and the valve housing. The lower end of a valve operator 30A is threaded into an enlarged upper end portion of a tubular extension member 110. The valve operator 30A is identical to the valve operator 30 along that major portion of the operator 30 above the bleed port 96. Similarly, it may be considered that the valve housing 25A is identical to the valve housing 25 above the wall portion 83 of the housing 25. The connector 110 has a downwardly and inwardly sloping seat surface 111 which is engageable with a seat or shoulder surface 112 within a housing coupling 113. The engagement of the surface 111 on the operator member extension 110 against the seat surface 112 of the housing member limits the downward movement of the valve operator in the housing. The operator extension 110 is threaded into a poppet valve 114 which has side ports 115 admitting flow from below the valve into the central bore of the valve through the poppet valve 114. The valve 114 has a seat surface 120 which engages a downwardly and outwardly sloping seat surface 121 of the housing member 113 when the valve 114 is at an upper closed position. In FIG. 3 the valve 114 is shown at a lower end position at which the seat surface 120 is spaced below the housing seat surface 121 permitting fluid flow through the ports 115. A tubular plug 122 is threaded on the lower end of the housing member 113 around the valve 114. The operation of the poppet valve 20A is identical in all respects to the operation of the valve 20, the valve 114 being raised and lowered between open and closed positions by the valve operator 30A which is moved responsive to the various change over pressure conditions and the spring 55 as previously described with respect to valve 20.

FIG. 4 shows a flapper type valve 20B which utilizes all of the operating structure of the valve 20 substituting a flapper valve 130 for the ball valve 31. Above the ring seal 80 all of the structure of the valve 20B is identical to the structure of the valve 20. The lower end portion of the valve operator 30B is enlarged providing a downwardly facing valve seat 131 which is engageable by a seat surface 132 on the flapper valve 130 for closing the valve. The valve 130 is mounted on an arm 133 secured on a pin 134 for movement between the horizontal upper closed position of FIG. 4 and a downwardly extending vertical open position, not shown, to which the valve is pivoted from the valve seat 131. A valve operating lug 135 having a shoulder surface 140 is engageable with a valve trip shoulder 141 on the valve operator 30B. When the casing annulus pressure forces the valve operator piston 44 downwardly, the flapper valve is pivoted on the pin 134 to a vertical position into a side recess 142 formed in the valve housing 25B. When pressure conditions return the valve operator back upwardly, the trip shoulder 141 engages the lug face 140, swinging the flapper valve upwardly. Upward flow into the valve completes the movement of the flapper valve to the closed position shown in FIG. 4. A plug 143 is threaded into the lower end of the valve housing 25B. The operating structure and details of the flapper valve assembly are essentially identical to those of U.S. Pat. 3,071,151 issued Jan. 1, 1963, to Phillip S. Sizer. The manner of operation and the conditions under which the valve 20B is operated are identical to those described in relation to the safety valve 20.

Under well conditions where debris is present in the casing which might interfere with the valve operation and which, preferably, is to be excluded from the valve at all times, an alternate form of valve operating apparatus 20F as shown in FIG. 10 may be used. The valve operating mechanism of the valve 20F is identical to that of the valve 20 shown in FIG. 1, and thus all of the common components are identified by the same reference numerals as used in FIG. 1. A small flow conductor or control line 86 extends from a control manifold 87 at the surface. The manifold 87 may be the previously discussed Otis Surface Control Manifold which supplies a fluid under controlled pressure condition to operate various downhole tools such as the present valves. The control line 86 extends downwardly in the tubing-casing annulus of the well in which the valve is installed supported alongside the tubing string in any suitable manner. At the valve 20F the control line 86 connects into a fitting 88 having a side port 88a which communicates with the valve housing side port 54a so that control fluid furnished by the manifold 87 is communicated through the control line into the chamber 54 for biasing the annular piston on the valve operator downwardly to hold the valve at an open position. A short section 86a of the control line extends downwardly from the fitting 88 to another side fitting 89 secured on the valve housing and provided with a port 89a communicating with the valve housing side port 76 so that the control fluid pressure from the manifold is also communicated inwardly around the valve operator between the seals 71 and 80 above and below the port 76.

The operation of the valve 20F is identical to the operation of the valve 20 other than the fact that the valve 20F is controlled by fluid communicated through the control line 86 as distinguished from fluid being communicated to the valve through the tubing-casing annulus. In the event of a failure of the seal 50, the pressure as communicated to the valve through the control line is equalized between the dome chamber 53 and the chamber 54 permitting the spring 55 to lift the valve operator 30 to close the valve. Similarly, a failure at the lower end of the valve at the seal 71, also equalizes the
pressure across the piston so that control line pressure exists in the dome chamber as communicated through the side port 76 past the seal 71 and in the chamber 54 which permits the spring to lift the valve operator to close the valve. The pressure may be increased in the control line to a value sufficient to shear either or both of the pins 52 and 73 allowing the seals 50 and 71 to be displaced so that pressure is equalized across the piston between the chambers 54 and 53 allowing the valve to be closed by the spring. This safety feature of the valve is, of course, also operative in the event of destruction of the control line and an increase in the tubing-casing annulus pressure for any reason above the level required to displace the seals.

A still further form of valve control apparatus is illustrated in the valve 20G of FIG. 11 which utilizes a valve control system identical to that of the valves of FIGS. 1 and 10. More specifically, the valve 20G is identical to the valve 20 of FIG. 1 except that control fluid pressure is communicated to the valve through the line 86 into only the upper side port 54a. As seen in FIG. 11, the control line 86 extends from a surface control manifold 87 to the side fitting 89 connected on the housing. The side port 89c of the fitting is in communication with the valve side port 54a so that control fluid from the manifold communicates into the chamber 54 for biasing the valve operator piston downward to hold the valve open. The side port 76 is in communication with the tubing-casing annulus at all times. Thus, the valve 20G remains sensitive to the casing pressure exterior of the safety valve so that an excessive casing pressure will shear the pin 73 to effectively deactivate the dome chamber. The form of the valve 20G presents a limitation which is not inherent in the valve 20 which communicates through both the side ports 76 and 54a with the tubing-casing annulus. In the valve 20G the control fluid pressure in the line 86 from the manifold may somewhat exceed the normal casing pressure but must never exceed the casing pressure sufficiently to produce a condition under which the pressure in the chamber 54 above the operating piston would remain in excess of the casing pressure and the spring force to hold the operating piston downward and the valve open even if the lower seal 71 failed.

It will be recognized in connection with the configuration of the valve shown in FIGS. 5 and 6 that the variations of the valve structure as illustrated in FIGS. 10 and 11 may also be used with operation of such valves being affected in the same manner as described in connection with the valves 20F and 20G.

FIGS. 5–8 illustrate modified forms of safety valve operating mechanisms which may be employed with ball, poppet, or flapper type valves. The structure of the valve housing for these embodiments above and below that shown in the drawings is identical to the valve housing structure shown in FIG. 1.

Referring to FIG. 5, a well safety valve 20C has a tubular valve operator 150 which is longitudinally movable within a valve housing 151 having opposite end portions connectible into a tubing string, as seen in FIG. 1. The valve operator has a thin-walled upper end portion 152 slidable in a bore portion 153 of the housing. A ring seal 154 in an internal recess 155 of the housing seals between the housing and the operator upper end portion 152. A bore portion 160 of the housing provides an annular space 161 within the housing around the operator upper end portion 152. The housing has a port 162 closed by a removable plug 163 opening into the chamber 161. During assembly of the valve, the chamber 161 is sealed at atmospheric pressure. The wall thickness of the valve operator is increased along a portion 164 the outer surface of which is spaced from the bore wall surface of a valve housing portion 165 defining an annular chamber 170 which communicates with the casing annulus through a side port 171. A “V” packing assembly 172 is disposed in the annular space 170 above the port 171 between the housing and the valve operator against an internal housing flange 173. The outside diameter of the operator wall portion 164 is substantially greater than the diameter of the operator wall portion 152 so that the difference in the sealed areas of the valve operator defined by the seal 172 and by the seal 154 provides a substantial annular area of the valve operator which is exposed to the atmospheric pressure in the annular chamber 161, which, in effect, reduces the amount of force which must be supplied by a spring and the pressure in the dome chamber of the valve when the valve is at operating depth within a well.

The valve operator 150 of the valve 20C is enlarged along a piston portion 174 which is sealed with the wall section 165 of the valve housing by a ring seal 180 in an external recess 180 of the piston. The piston 174 defines the upper end of a dome chamber 181 comprising the annular space between the valve housing and the valve operator below the piston 174. The valve housing has an internal annular flange 182 spaced from the wall portion of the valve operator below the piston and supporting the lower end of a valve operator spring 183. The upper end of the spring engages a downwardly facing annular shoulder 184 on the lower end of the piston 174. The spring biases the valve operator upwardly. The dome chamber 181 is charged through a port 185 closed by removable plug 190. Due to the presence of the atmospheric chamber 161 above the seal 172, it is not necessary to charge the dome chamber to a high pressure as would be required under the same operating conditions in a well for a safety valve such as the valve 20. A substantial portion of the valve operator is working against atmospheric pressure in the chamber 161 while another portion of the operator above the piston 174 is subjected to the casing annulus pressure in the chamber 170 through the port 171. Thus, in a valve which may be used deep in a well under high operating pressures, a dome chamber pressure still may be used of a value which permits it to be charged from available facilities, such as bottled gas in the field.

The valve housing 151 of the valve 20C is increased slightly in internal diameter along a wall portion 191 defining a slightly larger lower end portion 192 of the dome chamber. The valve housing is reduced slightly in internal diameter along a wall portion 193 and still further reduced in diameter along a wall portion 194 defining an upwardly facing shoulder surface 195. The valve housing is still further reduced in internal diameter along a wall portion 200. An annular piston 201 having a lower skirt portion 202 is disposed for movement between the valve housing and the operator member at the lower end of the dome chamber. The piston has internal and external ring seals 203 and 204, respectively, sealing between the piston and the operator member and housing along the housing wall portion 193. The space along the piston skirt portion 202 at the
valve housing wall portion 194 defines an annular chamber 205 which is at atmospheric pressure so long as the piston is in the lower end position shown in FIG. 5 inasmuch as the valve is assembled under atmospheric pressure when the piston is put in place in the housing around the valve operator. A ring seal 210 in a recess of the valve housing below the annular space 203 seals between the housing and the piston skirt portion 202. An annular space 192 between the valve operator and the valve housing wall portion 200 is communicated with the casing annulus through a side port 213 in the valve housing. Below the port 213 the valve housing is reduced in diameter along a wall section 214 provided with an internal recess 215 in which a ring seal 220 is disposed around the valve operator. The seal 220 corresponds functionally with the seal 80 in the valve 20.

The valve 20C generally operates in a similar manner and to perform the same functions as the valve 20. The principal distinguishing features of the valve 20C compared to the valve 20 are the atmospheric chamber 161 reducing the required dome pressure and the annular piston 201 which is a safety feature for effecting closure of the valve in response to an excessively high annulus pressure. The sealed areas of the valve operator at the seals 154 and 220 are the same size and, thus, the tubing pressure has no effect upon the movement of the valve operator. During normal operation, the forces biasing the valve operator upward and, thus, the valve to an open position comprise the upward force of the spring 183 and the pressure in the dome chamber 181, while the forces biasing the valve downwardly to an open position are the forces of the atmospheric pressure in the chamber 161 and the casing annulus pressure in the chamber 170. The casing annulus may be used to control the valve with the force of the casing pressure in the chamber 171 downwardly on the piston 174 holding the valve operator at a lower end position for maintaining the valve open. When such casing pressure is bled off, the spring and dome chamber pressure lift the valve operator to close the valve in the manner previously described. In the event of leakage of the ring seal 175, the dome and annulus pressures are equalized, and the spring 183 lifts the valve operator to close the valve. Similarly, leakage along the seals associated with the annular piston 201 will effect the same pressure equalization to cause closure of the valve by the spring. Leakage along the seal 220 between the annulus and the tubing through the valve communicating through the annulus 212 and the port 213 may equalize tubing and annulus pressure, bleeding off the annulus pressure to a level sufficient for the spring and dome chamber pressure to close the valve.

In accordance with a special feature of the valve 20C, the annular safety piston 201 may be forced upwardly by predetermined high casing pressure to equalize the dome chamber and casing annulus pressures for permitting the spring to lift the valve operator and close the valve. Such a high annulus pressure is applied through the port 213 and the annular space 212 to the piston 201 in the skirt 202 over an effective area of the piston defined by seals 203 and 210. When this annulus pressure acting upwardly on the piston and skirt is sufficiently high to overcome the dome chamber pressure downwardly on the piston 201 over the area sealed by the ring seals 203 and 204, the annular piston is moved upwardly. When the annular piston moves upwardly into the larger annular space 192, the ring seals 203 and 204 no longer can effectively seal between the valve operator and the valve housing, thereby permitting an equalization of pressure past the annular piston between the valve operator and piston and housing. At this upper position of the piston and skirt, the lower end of the skirt is above the ring seal 210. The equalization of the annulus and dome chamber pressures permits the spring 183 to lift the valve operator to close the valve. The larger area of the piston 201, as compared with the skirt 202, permits the dome chamber pressure under normal valve operating conditions to hold the safety piston at a lower end position without the necessity of utilizing a biasing spring bearing on the piston.

It is readily apparent from the drawing and foregoing description of the valve 20C in FIG. 5 that the upper end of the piston 201 must be larger than the lower end of the piston so that the piston will remain in the sealing position as illustrated when the casing pressure acting upwardly against the lower end of the skirt exceeds by even a small amount the charge pressure within the dome chamber 181. It will be obvious that as the lower end of the pistons 201 moves outwardly, the casing pressure required to lift and unseat the piston will be increased. Similarly, if the lower end of the piston is enlarged, the casing pressure to which the piston responds is decreased. Thus, the sensitivity of this particular feature of the safety valve is readily adjusted by varying the ratio between the effective sealed areas of the piston and skirt portions exposed to the pressure in the chamber 192 and in the annular space 212.

Another feature of the valve 20C in FIG. 5 which permits variations in the operating characteristics of the valve is the small annular chamber 205 below the piston 201 around the piston skirt 202. Ordinarily this chamber contains atmospheric pressure as the valve is usually assembled in an environment of air, atmospheric or ordinary room pressure. Quite obviously, such pressure may vary with location, altitude, and weather conditions, and the particular environment of the space in which the valve is assembled may be changed as desired. For example, the valve may be assembled in a special chamber in which the pressure is either reduced substantially by vacuum means or substantially increased for the purpose of providing a desired pressure in the chamber 205.

A structural alteration which may be made in the valve 20C is represented in FIG. 9 which shows that portion of the valve apparatus in the vicinity of the annular piston. All structural features of the portion of the valve shown in FIG. 9 are identical to those of FIG. 5 with the exception of the provision of a side charge port 205a leading to the chamber 205 so that the chamber may be charged with gas to any desired pressure and sealed by a suitable plug inserted into the port 205a. Inasmuch as the pressure within the chamber 205 tends to lift the annular piston in a direction which unseals the piston, variations in the pressure within the chamber vary the sensitivity of this particular element of the valve.

FIG. 6 shows another embodiment 20D of a well safety valve which includes a valve operator 230 movable in a valve housing 231 for opening and closing a ball, a poppet, or a flapper type valve. The operator member structure of the valve 20D is essentially identical to those of the previously described valves depend-
ing upon which type flow control member is used. The upper end portion of the valve operator has a thick wall section 232 which slides within an enlarged bore portion of the valve housing along a housing section 233. A ring seal 234 in an internal annular recess 235 seals between the valve operator section 232 and the housing wall section 233. Below the housing wall section 233 the valve housing bore is increased along a wall portion 240 which is spaced from the valve operator section 232 defining an annular space 241 which communicates with the annulus through a side port 242 in the valve housing wall section 240. The valve operator has a piston 243 provided with a ring seal 244 in a recess 245 for sealing between the piston and the valve housing wall portion 240. The piston defines the upper end of a dome gas chamber 250 comprising an annular space between the valve housing wall and the valve operator below the piston. An internal annular flange 251 is formed within the valve housing supporting the lower end of a spring 252. The upper end 253 of the spring engages a downwardly facing shoulder surface 254 on the bottom of the valve operator piston. The spring biases the valve operator upwardly toward a valve closed position. The dome chamber 250 is charged through a side port 255 closed by a threaded plug 260. Below the internal flange 251 the bore of the valve housing is slightly enlarged in diameter along a wall portion 261. Below the wall portion 261 the valve housing is slightly reduced in diameter along a section 262 to an internal shoulder surface 263 defined between the wall section 262 and a further reduced diameter portion along a wall section 264. The wall section 264 is provided with a threaded lateral port which has a reduced smooth internal end port opening into the bore of the housing for a shear pin 271 held in position by a threaded plug 272 in the port 270. An annular piston 273 having a thin-walled lower skirt portion 274 is slidably disposed around the valve operator wall section 275 within the valve housing along the housing wall sections 261, 262, and 264. The lower end portion of the valve operator wall 275 and the valve housing wall portion 264 are concentrically spaced apart defining an annular space 276 which is sealed at atmospheric or some other desired pressure during assembly of the valve. A lower outer end portion of the piston 273 at the upper end of the skirt 274 has circumferentially spaced slots 277 which open outwardly and downwardly. The spaces provided by the slots 277 are at the pressure of the annulus 276 so that the entire piston 273 over the lower end portions is at the pressure of the annulus 276 while the upper end of the piston is at the dome chamber pressure. It will be recognized that the exposure of the outer portion of the lower end of the piston 273 to the annulus 276 pressure also could be effected by internal slots, not shown, along the lower end of the interior of the housing wall portion 262 instead of by the use of the piston slots 277. Such an alternative would, however, be more expensive to machine in the housing interior than in the piston exterior. The function of the use of a lower pressure in the annulus 276 and around the piston skirt in the slots 277 is so that the dome gas pressure above the piston biases the piston downwardly without the use of a spring. An internal V-packing assembly 280 seals within the piston 273 around the valve operator wall portion 275. An external ring seal 281 carried by the piston seals between the piston and the valve housing wall portion 262, thereby sealing off the lower end of the charge chamber 250 when the piston is at the lower end position shown in FIG. 6. The shear pin 271 projects into the bore 282 through the piston skirt portion. The bore 282 is larger than the shear pin so that pressure is readily communicated through the piston skirt. The space around the shear pin, together with the longitudinal slots 277 on the piston 273 and along the piston upper skirt portion freely communicates the pressure in the annulus 276 over the entire area of the piston sealed by the V-packing 280 and the external ring seal 281. A second wall portion 283 of the valve operator is spaced within the housing wall portion 264 defining an annular chamber 284 in which the piston skirt portion slides. The chamber 284 communicates with the annulus through a side port 285. A V-packing 290 is positioned in the annular space at the lower end of the piston skirt 274 for sealing at the lower end of the skirt between the valve operator and the valve housing. A ring seal 291 in an external recess on the valve operator below the port 285 seals between the valve operator and the valve housing defining the lower end of the annular space 284.

The valve housing wall portion 263 below the port 285 is increased in thickness while the valve operator similarly is increased in thickness along the portion 294 at the seal 291 so that the downwardly facing areas of the operator member exposed to tubing pressure as defined by the line of sealing engagement between the ring seal 291 and the inner housing wall 293 are the same as the upwardly facing areas of the operator member as defined by the line of sealing engagement between the ring seal 234 and the operator member wall 232. Equalizing the upwardly and downwardly facing areas of the operator member exposed to tubing pressure neutralizes any effect of tubing pressure upon the valve operation. Additionally, the outward movement of the sealing line between the ring seal 234 and the operator member relative to the line of sealing between the ring seal 244 and the inner wall of the housing, as contrasted with the first and second embodiments of the valve, reduces the effective area of the operator member subject to casing annulus pressure in the chamber 241. By so reducing such effective area the required dome pressure in the chamber 250 for biasing the valve toward a closed position is proportionately reduced so that the valve is more readily serviceable in the field at lower pressures.

The operation of the valve 20D is essentially identical to the operation of the valve 20C with the exception of the fact that the valve 20D does not include an atmospheric chamber at the upper end of the valve operator. The valve operator is biased upwardly by the spring 252 and the dome gas pressure while being held downwardly in an open position by casing annulus pressure applied through the port 242 in the annular chamber 241 against the piston 243. Any conditions which reduce the annulus pressure below a predetermined level permit the spring and dome pressure to move the valve operator upwardly closing the valve. Also, seal failures as discussed with respect to the valve 20 also affect the operation of the valve 20D causing it to close. Excessive annulus pressures above a predetermined value apply an upward force in the annular chamber 284 to the annular piston skirt 274 at the seal 290. When the force is sufficient on the piston to shear the pin 271, the piston 273 is forced upwardly into the enlarged wall portion 261 of the valve housing. When the piston 273
moves into the enlarged annular space, the seals on the piston are no longer effective, and the skirt 274 with the seal 290 are moved upwardly from the annular space 284 into the enlarged annular chamber 276. The casing annulus pressure is then exerted past the piston and skirt into the dome gas chamber equalizing the pressure in the chamber with the annulus pressure so that the spring 252 lifts the valve operator to close the valve. It will be recognized that without the movement of the annular safety piston and skirt, the downward force on the valve operator piston 243 from the pressure in the annular chamber 241 tends only to hold the valve more firmly in the open position. It will also be recognized that the atmospheric pressure sealed in the valve at the surface during assembly in the annular chamber 276 is communicated over the entire area of the piston 273 sealed by the seals 280 and 281, thus rendering the downward force of the dome gas pressure more effective on the piston so that a biasing spring against the piston is not necessary, and the piston tends to remain firmly in position in the absence of the excessive pressures required to dislodge it for closing the valve under emergency conditions. Also, it will be recognized that once closed in this manner, the valve may not be reopened without removing the valve to the surface, disassembling it, replacing the shear pin 271 to hold the annular piston skirt in the lower end sealed position, and reassembling the valve.

A still further form of well safety valve 20E is illustrated in FIGS. 7 and 8. The principal distinguishing feature of the valve 20E as compared with the other valves disclosed herein is a capability of being pumped closed in the event of a valve malfunction which renders the biasing spring ineffective. Such a malfunction may include several conditions, such as the lodging of some obstruction along the valve structure which would require more force than the spring is capable of delivering to close the valve. The lower end portions of the valve 20E including the ball valve structure, the housing, and the operator member below the seal 80 are identical to that shown and described with respect to the valve 20 in FIGS. 1 and 2. Those identical structural features of the valve 20 shall be referred to by the same reference numerals as used in FIGS. 1 and 2. The valve has a tubular operator 300 slidably disposed in concentric relationship within a valve housing 301. An O-ring seal 302 is positioned in an internal recess 303 of the upper end portion of the valve housing sealing around the upper end of the valve operator in the housing. The valve housing bore is enlarged in diameter along a thin wall portion 304 spaced in concentric relationship from the valve operator which has an external annular dome chamber piston 305 dividing the annular space between the operator and valve housing into an upper atmospheric chamber 310 and a dome gas chamber 311. A side port 312 closed by a threaded plug 313 communicates with the atmospheric chamber 310. The dome gas chamber 311 is charged through a side port 314 closed by threaded plug 315.

A coil spring 320 is confined in the dome chamber between the lower shoulder face 321 on the piston 305 and an upwardly facing stop shoulder surface 322 on the upper end of an internal flange 323 within the valve housing below the wall section 304. The flange 323 has an internal recess 324 for a V-packing assembly 325 held in place by an internal snap ring 330. The packing seals the lower end of the dome gas chamber 311. Below the flange 323 the concentric spaced positioning of the valve operator and the valve housing defines an annular atmospheric chamber 331 communicating with a side port 332 closed by a threaded plug 333. The valve operator 300 of the valve 20E has an external annular operating flange 334 positioned in the annular chamber 331 above an upper annular operating piston 335 having a head portion 340 and a skirt portion 341. The piston is releasably locked in place by a shear pin 342 held between the valve housing and the annular piston by a threaded plug 343. The upper end of the piston 340 is engageable with the operating flange 334 on the valve operator for emergency lifting of the valve operator to close the valve as discussed hereinafter. A lower concentric valve operator piston 344 is telescoped into the skirt 341 of the upper piston between the valve operator and the valve housing. The piston 344 has an upper skirt portion 345 and a lower piston or head portion 350. A V-packing assembly 351 seals between the lower piston skirt 345 and the upper piston skirt 341 above a side port 352 leading to an annular space 353 between the valve housing and the lower skirt 345 extending from the upper end of the piston head 350 to the lower end of the V-packing 351 for applying the force of casing annulus pressure to both the upper and lower operator pistons. A ring seal 354 within an annular recess 355 in the lower piston head seals between the piston and the valve operator member 300. An external ring seal 360 in a recess 361 of the piston head 350 seals around the piston head within the valve housing. The space between the valve operator and the valve housing below the lower piston head 350 communicates with a side port 362 sealed by a threaded plug 363 at the surface after assembly under atmospheric conditions so that the lower end of the piston 350 operates at atmospheric pressure. A shear ring 364 interconnects the piston head 350 with the valve operator 300, permitting the lower operating piston to hold the valve operator downwardly when the annulus pressure is sufficient, allowing the operator to lift the lower operating piston when the valve is closed under normal operating conditions, and permitting excessive annulus pressures to release the operator 300 from the lower operating piston under emergency conditions.

During normal operation of the valve 20E, which may function in the same types of well systems as discussed with respect to the other valves disclosed herein, the valve is biased closed by the spring 320 and the pressure of dome gas in the chamber 311 acting upwardly on the piston 305. The valve is biased open by annulus pressure applied through the port 352 into the annular space 353 acting over an area defined by the sealing engagement between the V-packing 351 and the outer wall of the piston skirt 345 and the inner wall of the valve housing at the annular chamber 353. So long as this annulus pressure within the chamber 353 is sufficiently high, the valve is held open against the spring 320 and the dome chamber pressure. The annulus pressure holds the piston 344 at the lower end posi-
tion of FIG. 7 at which the head of the piston engages the top surface of the internal flange portion 370 of the valve housing. The piston holds the valve operator down by means of the shear ring 364. The upper end of the piston 305 is subjected to atmospheric pressure in the chamber 310 while, similarly, the pistons 344 and 335 are exposed to the atmospheric pressure within the annular chamber 331. When the annulus pressure drops below a level sufficient to hold the valve open, the dome chamber pressure in the chamber 311 and the spring 320 lift the valve operator rotating the ball valve 31 closed. As the valve operator is raised, the shear pin 364 lifts the piston 344 which travels upwardly with the valve operator, the skirt 345 of the lower operating piston moving upwardly in the space around the valve operator within the upper piston skirt 341 below the upper piston head 340. An increase in the annulus pressure applied through the side port 352 acts on the lower operating piston head 350 to force the valve operator member 300 back downwardly to return the ball valve 31 to the open position.

When an emergency develops, such as a casing rupture in an offshore well allowing sea water invasion into the annulus, the valve 20E is closed if the pressure rises to a predetermined dangerous high level. When a valve malfunction occurs which prevents the valve closing under normal reduction of pressure in the annulus, a controlled annulus pressure increase may be applied from the surface for the purpose of closing the valve. The increased annulus pressure applied through the side port 352 into the annular space 353 acts upwardly on the upper operating piston 335 and downwardly on the lower operating piston 344. The downward pressure on the lower operating piston holds it against the flange 370, while the upward force of the high annulus pressure on the upper operating piston 335 shears the pin 342, forcing the upper piston upwardly against the operating shoulder 334 of the valve operator 300. The upper operating piston lifts the valve operator to force the valve closed. The lifting force of the upper piston on the valve operator, while the lower operating piston 344 is held down by the high annulus pressure, shears the ring 364, releasing the valve operator for upward movement. The upper operating piston then lifts the valve operator to the position of FIG. 8 closing the ball valve. The relative positions of the upper and lower operating pistons after the shear pin 342 and the shear ring 364 are both severed and the valve is fully closed are shown in FIG. 8. Thus, the valve may be positively closed by means of the controlled increase in annulus pressure to overcome an obstruction or other valve malfunction impairing the normal closing of the valve responsive to the several conditions discussed with respect to the other valves.

It will be evident that the various forms of well tubing safety valves illustrated and described are useful in a multiplicity of well production and drilling systems for shutting off fluid flow in response to changes in well operating conditions, the occurrence of dangerous situations, and valve malfunctions. Also, it will be evident that each of the valve forms includes features for emergency valve closure to avert tubing collapse when excessive annulus pressures are developed. Additionally, at least one form of the valve includes features which are used for pumping the valve closed when obstructions or other structural problems preclude normal closing of the valve in response to the dome chamber and/or spring.

The various forms of flow control devices embodying the invention are described herein in terms of the valve housing being an integral part of a well tubing string. It is to be understood, however, that the device may be installed in a tubing string at a suitable conventional landing nipple having side ports and seal means to provide communication from either a control line or the casing annulus into the side ports for pressure control of the device. Additionally, the device may be installed in tubing strings at landing nipples provided with a sliding sleeve valve which is closed when the device is not present within the landing nipple. In accordance with known procedures, such a sleeve valve may be opened when a device in accordance with the invention is installed in the tubing string and closed when the device is removed from the tubing string in order to preclude invasion of the tubing string by the fluids in the casing annulus.

What is claimed is:

1. A device for controlling fluid flow in a flow conductor of a well comprising: a valve housing having a longitudinal bore defining a flow passage therethrough; means for communicating control fluid pressure to said device; valve means supported in said housing adapted to be opened and closed to control fluid flow through said housing; valve operator means supported for longitudinal movement in said housing and operatively connected with said valve means for opening and closing said valve means, said operator means having a longitudinal flow passage communicating with said flow passage through said housing; means for applying a force to said operator means for biasing said operator means in a direction to close said valve means; pressure responsive valve opening and holding means operatively connected with said operator means for biasing said operator means toward a position to hold said valve means open responsive to a first control fluid pressure level; and means between said housing and said operator means operative responsive to a second higher control fluid pressure level for deactivating said valve opening and holding means whereby said valve means is closed when control fluid pressure applied to said device exceeds said second higher pressure level.

2. A device in accordance with claim 1 including a control fluid conduit connected with said device for directing control fluid pressure from a surface positioned fluid control system to said pressure responsive means for operating said device from the surface end of a well.

3. A device in accordance with claim 1 wherein said means for biasing said operator means in a direction to hold said valve means closed includes means defining a dome gas chamber adapted to be charged to a predetermined pressure to apply a gas pressure to said operator means and a spring engaged between said housing and said operator means for applying a force to said operator means.

4. A device in accordance with claim 3 including first chamber means provided at a first end of said dome chamber on the opposite side of said pressure responsive means from said dome chamber adapted to be sealed at a predetermined pressure lower than the pressure in said dome chamber; said pressure responsive means being exposed to the pressure in said first chamber means; second chamber means provided at the other end of said dome chamber; a slideable safety pise-
ton disposed in said second chamber means; seal means between said piston and said operator means and said housing, said piston and said second chamber means being sized to permit sealing said second end of said dome chamber by said piston at a first position of said piston and providing communication around said piston into said second end of said dome chamber at a second position of said piston; and said housing having means communicating with said second chamber means on the opposite side of said piston from said dome chamber whereby said piston is exposed to pressure for displacing said piston toward said dome chamber responsive to a predetermined pressure differential between a pressure applied exterior of and the pressure within said dome chamber.

5. A device in accordance with claim 3 including piston means on said operator means defining a first end of said dome gas chamber; means defining a first control chamber at said first end of said dome gas chamber on the opposite side of said piston means from said dome gas chamber, said first control chamber being sealed at a pressure below the pressure in said dome gas chamber; seal means between said housing and said operator means sealing an opposite second end of said dome gas chamber; means defining a second control chamber between said operator means and said housing at said second end of and separate from said dome gas chamber; a pair of coengaged first and second pistons in said second control chamber, said first piston being movable toward said second end of said dome chamber; an operating flange on said operator means within said second control chamber and engageable by said first piston for moving said operator means to close said valve responsive to movement of said first piston toward said dome gas chamber; said second piston being movable away from said dome gas chamber and being engageable with said operator means for moving said operator means in a direction to open said valve; releasable coupling means between said second piston and said operator means for releasing said operator means from said second piston to permit said operator means to move in a direction to close said valve independently of said second piston; said housing having flow passage means into said second control chamber between said first and second pistons for applying a control pressure against said second piston to bias said valve toward an open position at a pressure above a predetermined minimum and for urging said first piston in a direction away from said second piston for moving said operator means in a direction to close said valve responsive to a control pressure in excess of a predetermined maximum.

6. A device in accordance with claim 3 wherein a portion of said pressure responsive means exposed to said control fluid pressure at a first end of said dome chamber is smaller in area than another portion of said pressure responsive means exposed to the pressure in said dome chamber whereby the pressure in said dome chamber may be maintained at a minimum; chamber means defined at a second end of said dome chamber between said operator means and said housing; said housing being provided with passage means into said chamber means; and piston means movably disposed in said chamber means for sealing said chamber means at a first position of said piston means and for communicating said second end of said dome gas chamber through said chamber means to said passage means at a second position of said piston means when said piston means is disposed to said second position by pressure applied through passage means.

7. A device in accordance with claim 6 including releasable means between said piston means and said housing for holding said piston means at said first sealing position until the pressure applied through said flow passage means exceeds a predetermined level.

8. A device in accordance with claim 6 including means defining a pressure chargeable chamber around said annular piston between a head portion and a skirt portion of said piston defined between a sealed area of said head portion and a sealed area of said skirt portion whereby the operating characteristics of said piston are varied by changes in the pressure within said chamber.

9. A device in accordance with claim 3 wherein said operator means includes a piston forming a movable closure at a first end of said dome gas chamber and the second end of said dome gas chamber is closed by seal means exposed on one side to the pressure of gas in said dome chamber; said housing is provided with passage means communicating with the other side of said seal means at said second end of said dome chamber; and at least one of said piston and said seal means includes said deactivating means for effecting closure of said valve means responsive to said second higher control pressure.

10. A device in accordance with claim 3 wherein said deactivating means comprises means responsive to a predetermined high pressure for displacing seal means to non-sealing portions on at least one of said piston and said seal means at said second end of said dome chamber for equalizing the pressures on opposite sides of said piston to permit said spring to move said operator means to close said valve when said pressure is applied to said one of said seal means.

11. A device in accordance with claim 10 including seal means between said valve operator means and said housing on the opposite side of said piston from said dome chamber and seal means between said valve operator means and said housing on the opposite side from said dome chamber of said passage means communicating with said seal means at said second end of said dome gas chamber.

12. A device in accordance with claim 9 wherein a side of said piston opposite said dome chamber and said passage means at said second end of said dome chamber are adapted to communicate directly with the tubing-casing annulus of a well when said device is in operating position in said well.

13. A device in accordance with claim 9 including conduit means connected with said device communicating with a side of said piston opposite said dome chamber and said passage means at said second end of said dome chamber for conducting control fluid under pressure from a surface system independently of the tubing-casing annulus of a well when said device is in operating position in said well.

14. A device in accordance with claim 9 including conduit means connected with said device communicating with a side of said piston opposite said dome chamber for conducting control fluid under pressure from a surface control system to said piston when said device is in operating position in said well and said passage means at said second end of said dome chamber communicates directly with the tubing-casing annulus
of said well when said device is in said operating position in said well.

15. A safety valve for a well tubing string comprising: a tubular outer housing member adapted to be operatively connected with said tubing string, said housing member having a longitudinal flow passage disposed coincident with the flow passage through said tubing string when said valve is operatively connected with said tubing string; a tubular valve operator longitudinally movably mounted in said housing member; a valve in said housing member operatively connected with said valve operator to be opened and closed responsive to longitudinal movement of said valve operator for controlling flow along said longitudinal passage of said housing member; means in said housing member biasing said valve operator longitudinally to close said valve comprising a chamber for a fixed predetermined charge of gas under pressure acting upon said valve operator; spring means between said housing member and said valve operator to move said valve operator to close said valve upon occurrence of a predetermined low pressure condition communicated to said valve housing member, said pressure condition opposing the force of said spring and said charge of gaseous pressure; and deactivating means between said valve operator and said housing member for rendering inoperative said pressure condition opposing the forces of said spring and said charge of gaseous pressure whereby said opposing pressure condition is ineffective to bias said valve open whereby said valve is closed responsive to a predetermined high pressure condition communicated to said valve.

16. A well valve in accordance with claim 15 wherein said means for closing said valve responsive to said predetermined high pressure include a pair of telescopically coengaged annular pistons between said valve operator and said housing member, a first of said annular pistons releasably engaging said valve operator for holding said valve operator at a position at which said valve is open responsive to control pressure communicated to said valve, said first piston opposing the force of said spring means and said fixed predetermined charge of gas, and said second annular piston being engageable with said valve operator for releasing said valve operator from said first annular piston to deactivate said first piston and forcing said valve operator in a direction to close said valve independently of said spring and said charge of gaseous responsive to said predetermined high pressure.

17. A well valve in accordance with claim 15 wherein said deactivating means for closing said valve responsive to said predetermined high pressure comprises displaceable seal means confining said charge of gas in said chamber and adapted to be moved in a non-sealing relation for equalizing the pressure in said chamber with the pressure communicated to said valve from exterior of said housing member to permit said spring to move said valve operator to a position to close said valve.

18. A well valve in accordance with claim 17 wherein said deactivating means for closing said valve responsive to said high predetermined pressure includes an annular piston between said valve operator and said housing member at one end of said chamber for said charge of gas, said annular piston being responsive to said pressure communicated to said valve from exterior of said tubular housing and being movable from a first sealing relationship between said housing member and said valve operator to a second non-sealing relationship between said valve operator and said housing member at which said chamber is communicated with said pressure exterior of said housing member.

19. A flow control device for a well tubing string comprising: a tubular housing adapted to be operatively connected with said tubing string and having a longitudinal flow passage disposed coincident with a flow passage through said tubing string when said housing is so associated with said tubing string; a tubular valve operator concentrically positioned within said housing for movement between a valve-open position and a valve-closed position, said valve operator having a longitudinal flow passage coincident with said flow passage through said housing; valve means within said housing movable between open and closed positions for controlling fluid flow in said housing into said valve operator; said valve operator being concentrically spaced within said housing; said valve operator and said housing having means dividing the annular space between said housing and said valve operator along the length of said operator into a first upper annular chamber, a second intermediate annular chamber, and a third lower annular chamber; a seal between said housing and an upper end portion of said valve operator sealing at a location between said upper chamber and said flow passage through said housing; said housing having a port communicating with said first upper annular chamber; said valve operator having an annular piston dividing said upper and said second intermediate annular chamber for biasing said operator downwardly responsive to a fluid pressure communicated to said first side port into said upper chamber and biasing said operator upwardly responsive to pressure in said second chamber; side port and port closure means in said housing into said second intermediate chamber for injecting gas into said chamber to pressurize said chamber to a predetermined value for biasing said valve operator upwardly; a spring between said housing and said valve operator biasing said valve operator upwardly; seal means between said housing and said valve operator at the lower end of said second chamber separating said second chamber from said third chamber; said housing being provided with a second side port communicating with said third lower annular chamber; seal means between said valve operator and said housing below said second lateral port sealing between said housing and said valve operator at a location between said longitudinal passage through said housing and said third lower annular chamber; and means between said valve operator and said housing for effecting pressure equalization across said annular piston on said valve operator for closure of said valve responsive to a predetermined high pressure around said tubular housing.

20. A valve for controlling flow through a tubing string of a well comprising: a tubular housing having a longitudinal flow passage therethrough and adapted to be operatively associated with said tubing string, said flow passage being coincident with the flow passage along said tubing string when said housing is so associated; a tubular valve operator having a longitudinal flow passage therethrough operatively associated in concentric relationship within said housing, said flow passage of said operator being coincident with said flow passage of said housing, said operator being movable between valve-open and valve-closed positions; a valve...
supported in said housing and operatively connected with said valve operator for controlling flow through said flow passages of said housing and said valve operator, said valve being opened and closed by said valve operator, said valve operator in said housing being concentrically arranged to define therebetween a first upper annular chamber, a second intermediate annular chamber, and a third lower annular chamber; seal means between an upper end portion of said valve operator and said housing above said first upper annular chamber sealing between said valve operator and said housing at a location between said flow passages through said housing and said first upper annular chamber, means providing a side port and a closure member for said port in a wall portion of said housing leading to said first upper annular chamber whereby said chamber may be sealed at a pressure less than the pressure in said second intermediate annular chamber; a seal between said housing and said valve operator sealing between said housing and said valve operator between said first and second annular chambers; said housing having a lateral port leading to said second annular chamber below said seal between said first and second annular chambers; said operator having an annular piston separating said second annular chamber and said third annular chamber, said piston having a seal for sealing between said piston and said housing; a stop shoulder provided within said third annular chamber on said housing spaced below said operator piston; a spring confined in said third annular chamber between said stop shoulder and said annular piston on said valve operator for biasing said valve operator in a direction to close said valve; said housing having a side port and closure means leading to said third annular chamber for charging said chamber with a gas to provide a pressure therein of a predetermined value for applying a gas pressure force to said operator piston for biasing said valve operator in a direction to close said valve; an annular piston disposed in said third annular chamber below said stop shoulder therein, said piston having a head portion and a reduced skirt portion; seal means sealing between said annular piston and said valve operator and housing whereby the lower end portion of said third annular chamber is sealed at a first position of said annular piston and said seal means are moved with said piston into a larger portion of said third annular chamber at a second position of said annular piston for communicating said third annular chamber below said piston with said chamber above said piston; said housing having a lateral port communicating with said reduced portion of said third annular chamber below said annular piston for applying a pressure to said annular piston from exterior of said housing for forcing said piston upwardly to permit communication past said piston into said third annular chamber above said piston to permit said valve to close under predetermined high pressure conditions around said valve; and a seal within said housing around said valve operator below said side port into said third annular chamber for sealing between said housing and said valve operator at a location between said third annular chamber and said longitudinal flow passage through said housing, said latter seal engaging said valve operator around a line of sealing engagement with said valve operator of the same diameter as a chambering between said seal at the upper end of said first upper annular chamber with said valve operator at the upper end thereof whereby said valve operator is non-responsive to pressure conditions through said longitudinal flow passage of said housing.

21. A valve for flow control through a tubing string of a well comprising: a tubular valve housing adapted to be operatively associated with said tubing string and having a longitudinal flow passage coincident with a flow passage through said tubing string when said housing is so associated; a tubular valve operator having a longitudinal flow passage disposed for longitudinal movement within said housing; a valve operatively connected in said housing and coupled with said valve operator, said valve being opened and closed by longitudinal movement of said valve operator; said valve operator and said housing being concentrically spaced to define upper and lower annular chambers therebetween; a seal between said housing and an upper end portion of said valve operator at the upper end of said upper chamber for sealing between said valve operator and said housing at a location between said longitudinal flow passage through said housing and said upper chamber; said valve operator having an external annular operator piston dividing said upper annular chamber into said lower annular chamber; said housing having an internal stop flange along said lower annular chamber spaced from said operator piston; a spring disposed within said lower annular chamber between said operator piston and said stop flange for biasing said valve operator in a direction to close said valve; a lower portion of said lower annular chamber being incrementally reduced in radial thickness by variations in wall thickness of said valve operator and said housing along said lower portion of said lower annular chamber, an annular relief piston disposed within said lower portion of said lower annular chamber and having seals around inner and outer wall portions of a head portion thereof for sealing with said valve housing and said valve operator to close said lower annular chamber along said lower portion thereof for defining within said chamber between said piston and said operator piston a dome chamber for containing a gas under predetermined pressure for applying a force to said operator piston to bias said valve operator in a direction to close said valve; a side port and closure means provided in said housing into said lower annular chamber above said annular piston for charging said dome chamber to a predetermined gas pressure, said upper annular chamber having a cross-sectional area less than the cross-sectional area of said dome chamber for reducing the value of the pressure to which said dome chamber is charged under predetermined well conditions; said annular relief piston having a lower reduced skirt portion extending into a reduced lower end portion of said lower annular chamber; seal means within said lower reduced portion of said lower annular chamber sealing within said chamber portion below a lower end of said relief piston skirt portion; said annular relief piston being movable upwardly from lower reduced portions of said lower annular chamber to a position out of sealing engagement between said valve operator and said housing to communicate past said piston into the lower end of said portion of said lower annular chamber defining said dome chamber; said housing having a side port communicating with said lower end portion of said lower annular chamber below said packing at the lower end of said relief piston skirt portion for communication with a
pressure source exterior of said valve housing; and a seal between said valve operator and said housing at the lower end of said lower annular chamber below said port in said housing leading to said chamber for sealing between said valve operator and said housing at a location between the longitudinal flow passage through said housing and the lower end of said lower annular chamber, said latter seal effecting a seal between said operator and said housing around a line of sealing engagement equal to a line of sealing engagement between said operator at the upper end thereof in said housing by said seal at the upper end of said upper first annular chamber whereby said valve operator is nonresponsive to pressure conditions within said longitudinal flow passage of said housing.

22. A well flow control valve in accordance with claim 21 wherein said valve operator and said valve housing are shaped along a portion of the lower end portion of said lower annular chamber at a first lower position of said annular piston to provide annular space between the piston head of said relief piston and the sealed lower reduced skirt portion of said piston, which space is sealed during assembly of said valve at a pressure below the pressure in said dome chamber during normal operation of said valve, and side port and shear pin means disposed laterally through said valve housing into said reduced skirt portion of said relief piston for sealing said lower portion of said lower annular chamber along said reduced piston skirt portion at a desired pressure and said shear pin being adapted to hold said piston against upward movement until a predetermined pressure is applied through said side port below said skirt portion.

23. A valve for controlling fluid flow through a tubing string of a well comprising: a tubular housing adapted to be operatively associated with said tubing string and having a longitudinal flow passage coincident with the flow passage through said tubing string when so associated; a tubular valve operator concentrically disposed within said valve housing and having a longitudinal flow passage coincident with said flow passage of said housing and longitudinally movable for opening and closing said valve; a valve within said housing coupled with said valve operator and adapted to be opened and closed responsive to longitudinal movement of said valve operator; said valve operator being concentrically spaced within said housing and said housing and said valve operator being shaped to define upper, intermediate, and lower annular chambers between said operator and said housing; a seal between said valve operator along an upper end thereof and said housing at the upper end of said first upper annular chamber for sealing between said housing and said operator at a location between said first chamber and said flow passage through said housing; a side port and closure means in said housing opening to said first annular chamber for sealing said chamber at a desired pressure; said operator having an annular piston thereon and having seal means therein for sealing between said piston and said housing separating said first annular chamber and said second annular chamber, said second annular chamber comprising a dome chamber adapted to be pressurized to a predetermined level for providing a gas pressure within said dome chamber for applying a force to said operator piston for biasing said valve operator in a direction to close said valve; said housing having an internal flange and seal means thereon between said valve operator and said housing defining a lower end of said dome chamber; a spring within said dome chamber confined between said operator piston and said internal flange of said housing for biasing said valve operator in a direction to close said valve; said port means having closure means in said housing opening into said dome chamber to permit said chamber to be pressured with a gaseous medium to a desired level; said housing having an internal flange and seal means engaging said valve operator defining a lower end of said lower annular chamber between said valve operator and said housing; a pair of telescopically related annular pistons slidably disposed in said lower annular chamber, each of said pistons having a had portion and reduced skirt portion, the skirt portions of said pistons being intermeshed in telescopie relationship; said housing having a side port opening into said lower annular chamber between said annular pistons, whereby said annular pistons are urged in opposite directions responsive to pressure communicated into said chamber through said side port; said valve operator having an external annular operating flange disposed in said lower annular chamber above said upper annular piston whereby upward movement of said upper piston lifts said valve operator to close said valve; shear means releasably securing said upper piston with said valve housing at a first lower position at which said valve operator is permitted to move longitudinally between upper and lower end positions; shearable means releasably coupling said lower piston with said valve operator whereby said lower piston is adapted to hold said valve operator at a lower end position for holding said valve open responsive to a pressure applied from exterior of said housing through side port into said lower annular chamber between said annular pistons when said pressure is of a value sufficient to overcome the pressure in said dome chamber and the force of said spring against said annular operator piston; an internal annular flange in said housing defining a lower end of said lower annular chamber and providing a lower stop shoulder for said lower annular piston positioning said piston at a lower end position for holding said valve operator at a position at which said valve is open; and a seal in said flange at the lower end of said lower annular chamber sealing between said flange and said valve operator for sealing between said housing and said valve operator at a location between said longitudinal flow passage through said housing and a lower end of said lower annular chamber, said seals in said lower housing flange and at the end of said upper annular chamber sealing along lines of engagement with said valve operator of equal diameter whereby said valve operator is non-responsive to pressure conditions in said longitudinal flow passage through said housing.

24. A device for controlling flow in a flow conductor comprising: a valve housing having a longitudinal bore defining a flow passage therethrough; valve means supported in said housing adapted to be opened and closed to control fluid flow through said housing; valve operator means movable longitudinally in said housing and operatively connected with said valve means for opening and closing said valve means; said valve operator means having a flow passage communicating with said...
flow passage through said housing; means applying a force to said valve operator means to bias said valve operator means in a direction to close said valve means; pressure-responsive actuating means having an operative connection with said valve operator means for biasing said valve operator means in a direction to open said valve means when a pressure is applied to said actuating means; means for conducting a control pressure fluid to said pressure-responsive actuating means to apply said pressure to said actuating means and thereby hold said valve means in open position; and means operatively connected with said operator means and also responsive to the pressure being applied to said actuating means for deactivating said pressure-responsive actuating means for effecting closure of said valve means when said applied pressure exceeds a predetermined value.

25. A device as set forth in claim 24, wherein: the means for conducting pressure to said pressure-responsive actuating means is at least one lateral port extending through the wall of the valve housing.

26. A device for controlling flow in a flow conductor comprising: a valve housing having a longitudinal bore therethrough; valve means supported in said housing adapted to be opened and closed to control fluid flow through said housing; valve operator means movable longitudinally in said housing and operatively connected with said valve means for opening and closing said valve means; said valve operator means having a flow passage communicating with said flow passage through said housing; means applying a force to said valve operator means to bias said valve operator means in a direction to close said valve means; pressure-responsive actuating means having an operative connection with said valve operator means for biasing said valve operator means in a direction to open said valve means when control pressure is applied to said actuating means; means for conducting control pressure to said pressure-responsive actuating means; means for confining the pressure applied to said actuating means in a manner to assure that said pressure is applied to said means in a direction holding the valve means open, said confining means displaceable to a non pressure confining relationship for effecting an equalization of pressure across the pressure-responsive actuating means to effect closing of said valve means when said pressure confining means is subjected to a control pressure above a predetermined value.

27. A device as set forth in claim 26, wherein: said confining means is at least one sealing means rendered inoperative responsive to said control pressure above a predetermined value and positioned with respect to the pressure-responsive actuating means to effect an equalization of pressure across the actuating means when said sealing means is rendered inoperative.

* * * * *
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,860,066 Dated January 14, 1975

Inventor(s) Joseph L. Pearce, Phillip S. Sizer, Donald F. Taylor

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 7, line 67, cancel "close said valve; a side port and"; and insert as a new paragraph -- Another particularly novel feature of the valve 20 effects pressure equalization between the annulus and dome chamber in response to a predetermined high pressure. --

Column 8, lines 1 and 2, cancel "closure means provided in said housing into said lower annular chamber above said" and insert -- Such a high pressure --.

Column 22, line 28, cancel "3" and insert -- 9 --.

Column 23, line 54, cancel "ina" and insert -- to --.

Column 28, line 14, cancel "had" and insert -- head --.

Signed and Sealed this twenty-ninth Day of June 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks