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Young

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[54] **LOW FLOW SAFETY VALVE WITH PRESSURE LOCK**

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[73] Assignee: **Schlumberger Technology Corporation,** New York, N.Y.

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[52] **U.S. Cl.** **137/459,** 137/464, 137/466

[51] **Int. Cl.** **F16k 17/64**

[58] **Field of Search** .... 137/459, 464, 466; 166/224, 224 S

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Primary Examiner—Harold W. Weakley
Attorney, Agent, or Firm—David L. Moseley; William R. Sherman; Stewart F. Moore

[57] **ABSTRACT**

A safety valve for installation down hole in the production string of an oil well includes a housing having a valve head disposed in fixed relation thereto. An actuator sleeve is disposed within the housing and cooperates with the housing structure to define a flow passage through the valve mechanism. The actuator sleeve is moveable linearly within the housing between open and closed positions and carries a valve face that is engageable with the valve head in the closed position thereof to interrupt the flow of fluid through the flow passage of the valve.

The actuator sleeve is moveable to the closed position thereof upon reduction of the rate of flow through the valve below a predetermined minimum and, once closed, is maintained in the closed position by pressure upstream of the valve. The safety valve includes selectively actuatable means for modifying the pressure responsive means and thereby allow formation pressure to move the actuator sleeve to the open position thereof.

25 Claims, 10 Drawing Figures

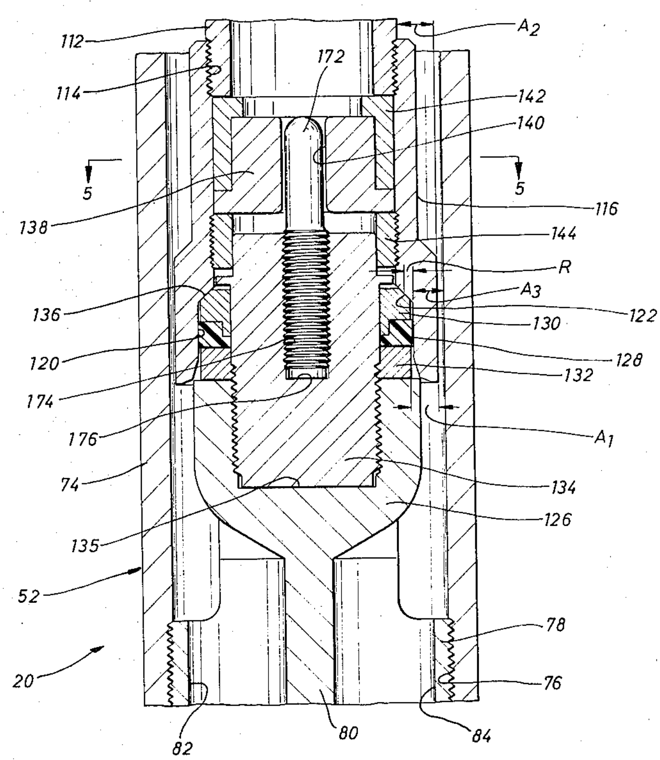
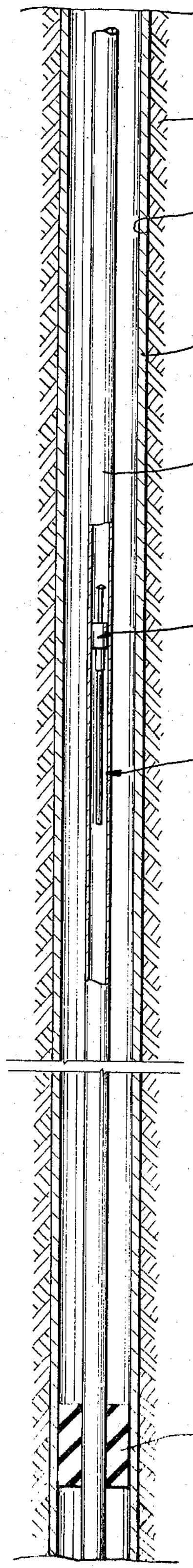


FIG. 1


10
12
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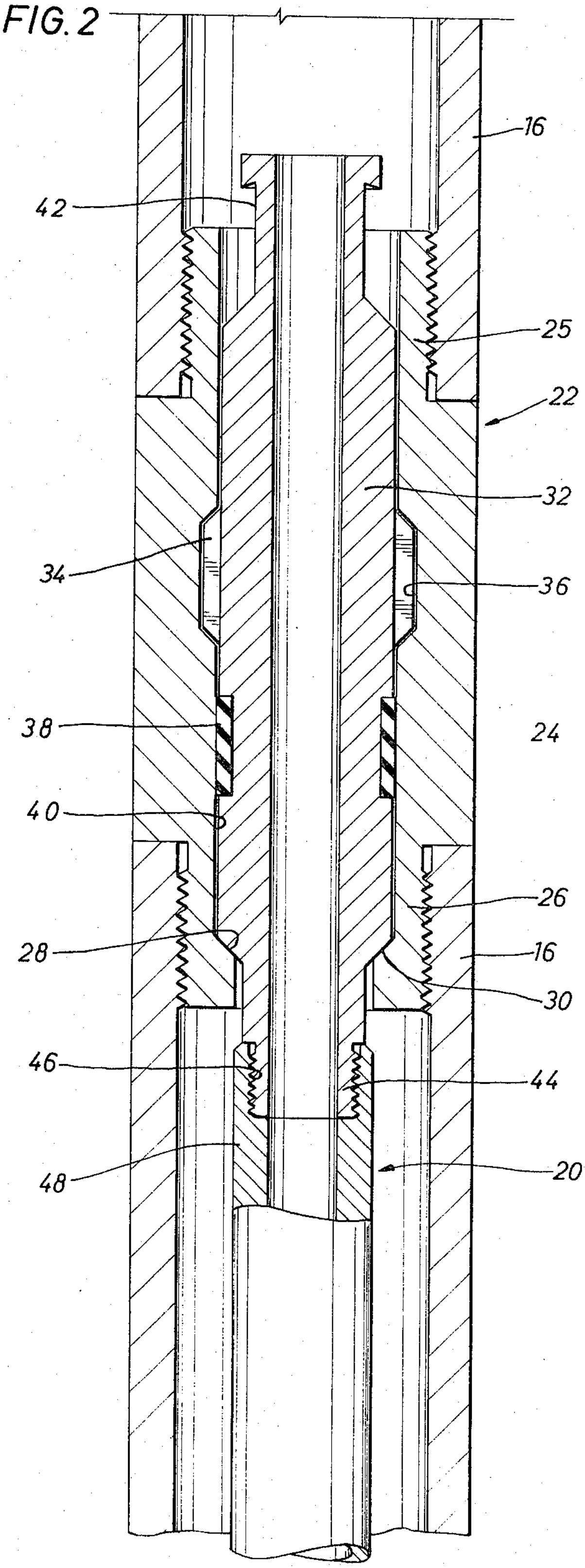
16
22
20
18

FIG. 2


16
42
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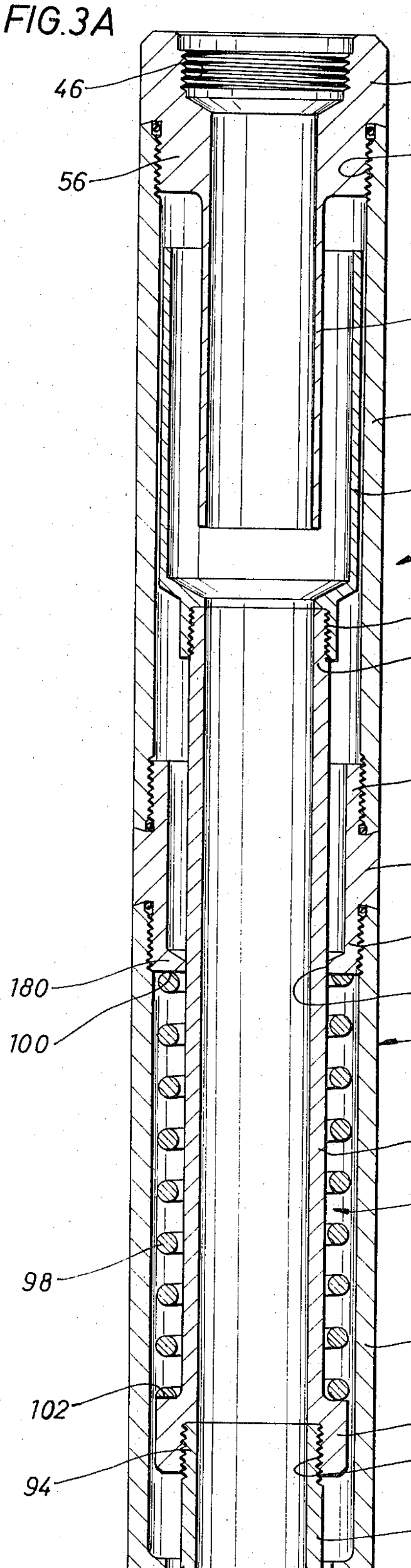
44
48
20

FIG. 3A


46
58
56
54
110
60
104
20
106
108
66
64
68
180
178
100
52
88
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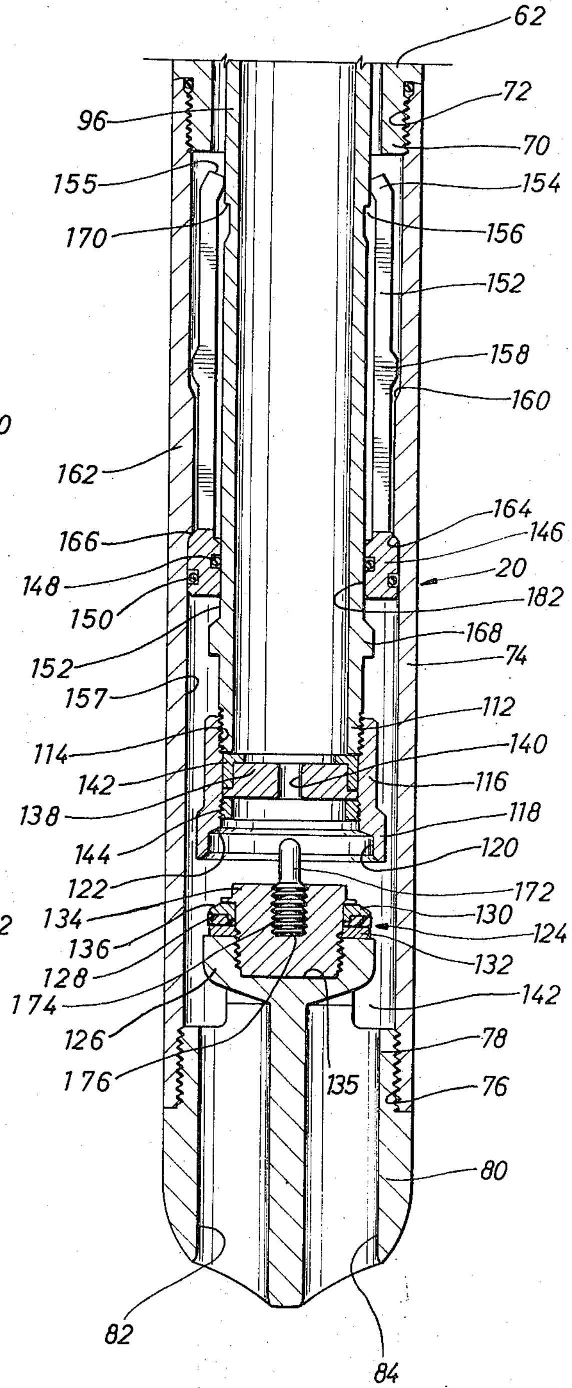
98
62
102
90
94
92
96

FIG. 3B


62
96
72
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155
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170
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146
148
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74
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112
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142
116
138
118
144
120
122
172
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132
174
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78
176
135
76
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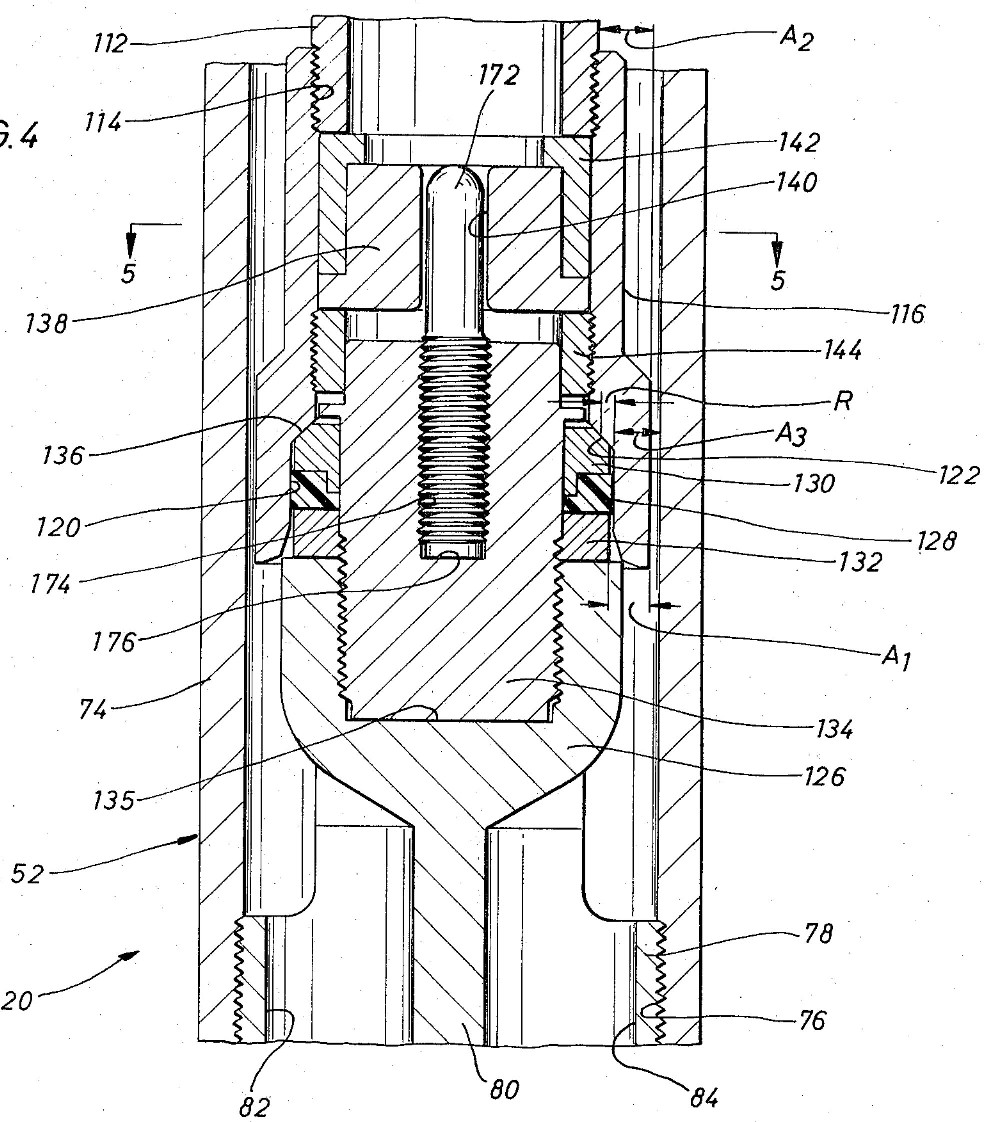
82
84

FIG. 4


112
A2
172
114
142
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5
5
138
116
144
R
136
A3
122
130
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A1
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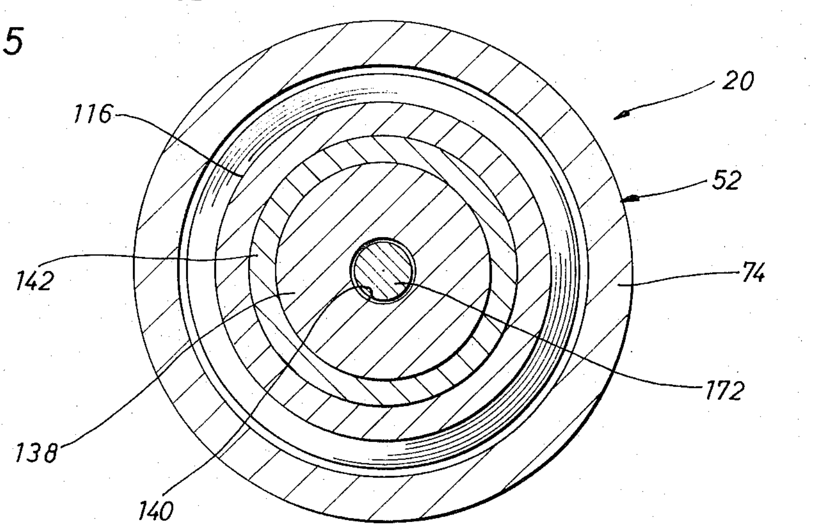
FIG. 5


20
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142
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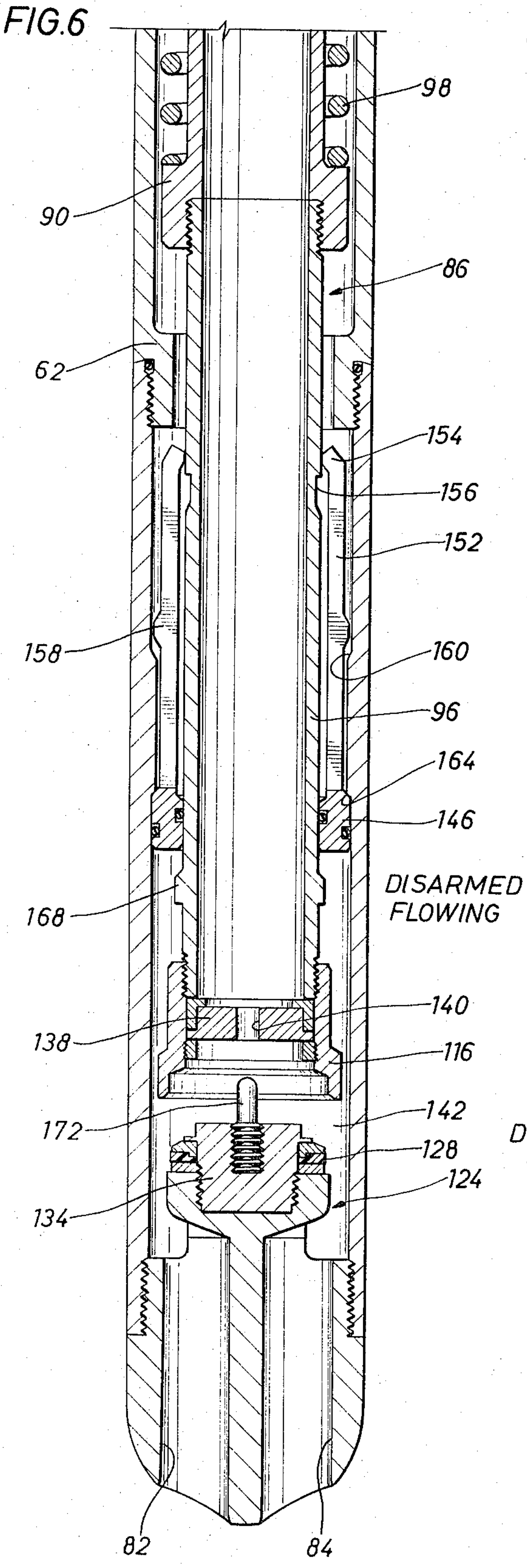
140

FIG.6


98
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86
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154
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152
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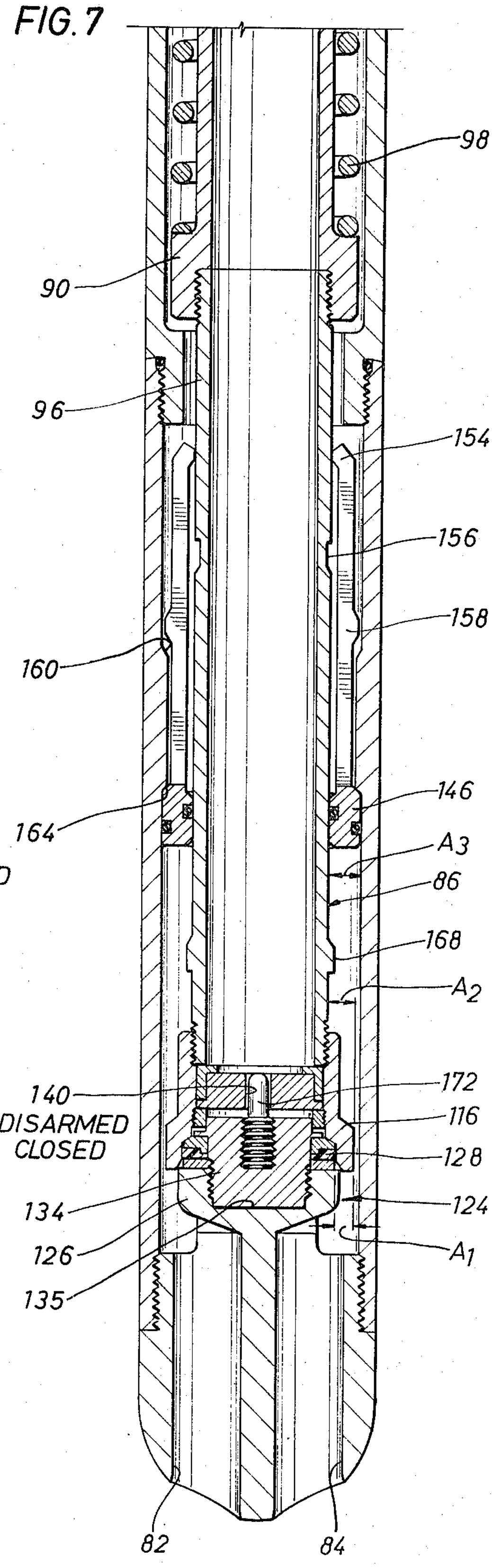
164
146
168
DISARMED
FLOWING
138
140
116
172
142
128
134
124
82
84

FIG.7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A3
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124
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A1
135
82
84

FIG. 8

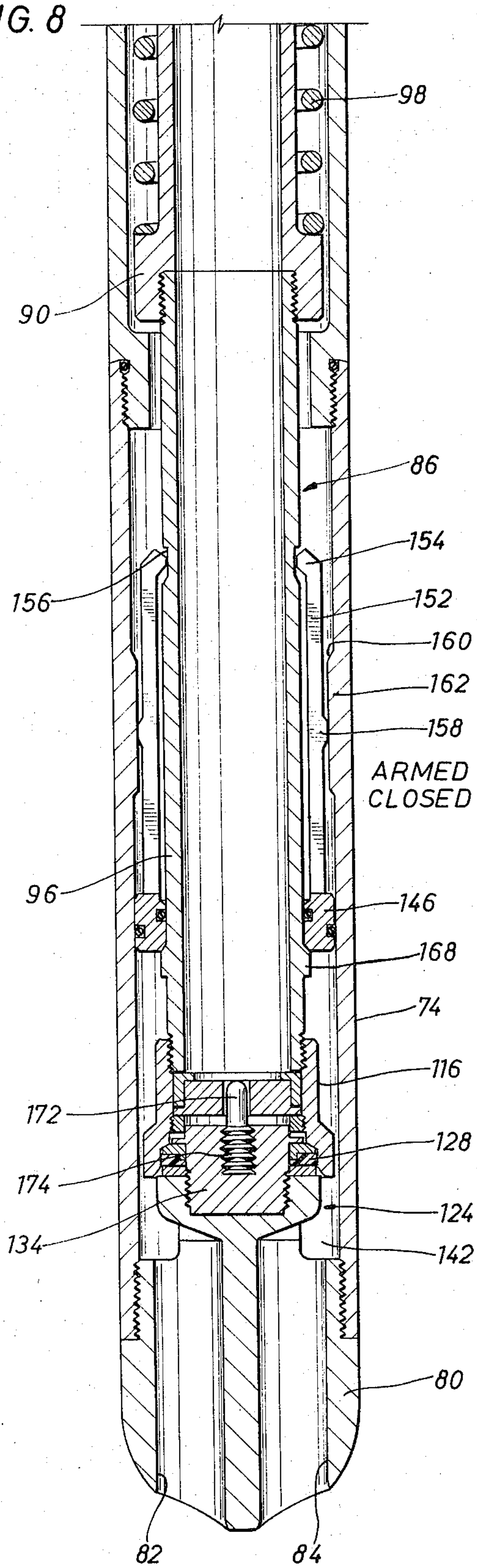
98
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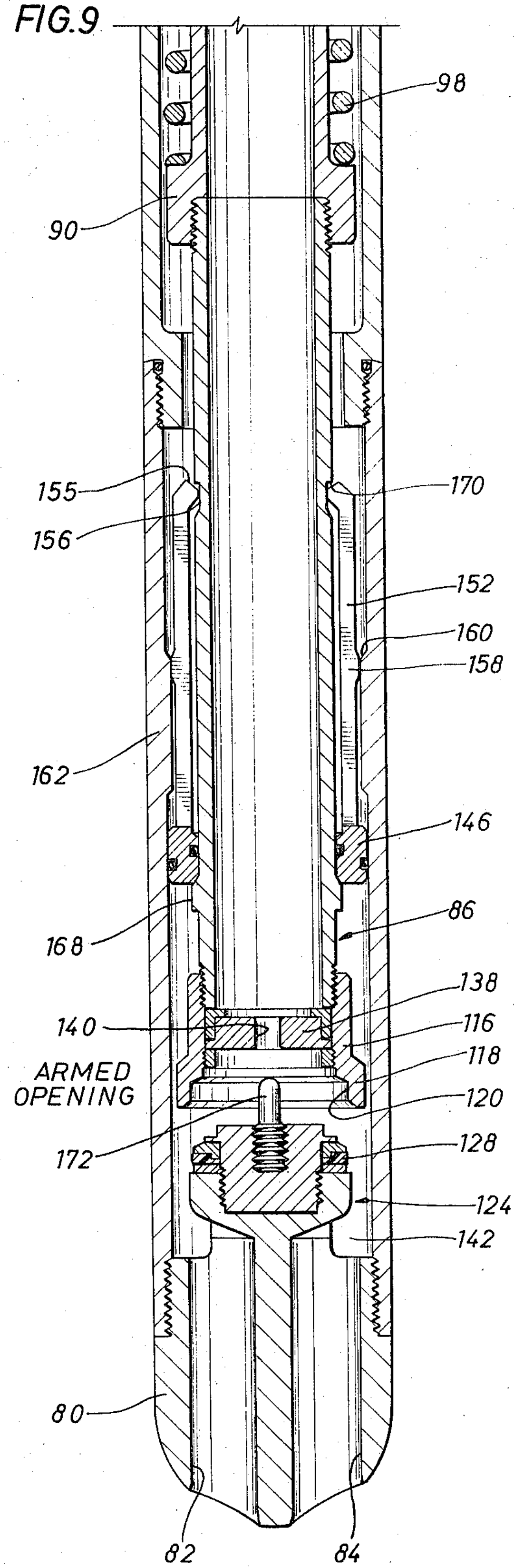
FIG. 9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ARMED
OPENING
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128
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LOW FLOW SAFETY VALVE WITH PRESSURE LOCK

FIELD OF THE INVENTION

This invention relates generally to control valves used in well installations, and more particularly to a down hole safety valve mechanism having a facility for interrupting the flow of production fluid in the event the rate of fluid flow falls below a predetermined minimum and for preventing automatic reopening of the valve mechanism in the event formation pressure conditions should subsequently increase to a level that would again establish a normal rate of flow.

BACKGROUND OF THE INVENTION

In order to provide maximum protection to the environment and to insure against loss of lives and damage to property in connection with the development of offshore oil fields, it is necessary to install a down hole safety valve in the well that is capable of closing off the production string of the well in the event well operating conditions should become undesirable or dangerous.

Most wells drilled at the present time incorporate velocity sensitive safety valve mechanisms capable of shutting in the well in the event velocity should exceed a predetermined maximum. This condition of course may occur in the event of failure of surface valves of the production system of the well, in the event of rupture of a production flow line or in the event of any other failure that might allow a relatively unrestricted flow of fluid through the tubing string.

It is desirable to provide a safety valve mechanism that will stop the flow of production fluid through a well production system in the event the velocity of flow should fall below a predetermined minimum rate. A decrease in velocity may represent the development of an undesirable condition in the formation produced by the well or might indicate the existance of an abnormal condition in the down hole production equipment of the well. It is desirable, therefore, to cause production of fluid to cease in the event any abnormal condition is sensed and to maintain the well production equipment in a safe closed position, even though operating conditions may be restored, in order that tests may be performed to determine the cause of the abnormal flow condition.

If a velocity sensitive safety valve should automatically close, even for an instant, responsive to the development of excessive flow in a well production system, it may be desirable to provide a secondary safety valve mechanism that is sensitive to the decrease in flow caused by closure of the velocity sensitive system. This feature would, of course, allow a safety valve mechanism to shut in the well, even though the velocity sensitive valve might not be sufficient, acting alone, to completely shut in the well and maintain the well system under a safe closed condition until the well production system may be repaired or otherwise restored to the proper operating condition thereof.

It is therefore a primary object of the present invention to provide a novel safety valve mechanism for a down hole well environment which is effective to close, thereby completely shutting in a production system of the well, in the event the rate of flow of production fluid through the valve mechanism should fall below a predetermined minimum level.

It is also an object of the present invention to provide a novel safety valve mechanism for a down hole well environment which includes a pressure sensitive mechanism that effectively retains the valve mechanism in the closed position thereof after being closed responsive to the development of a condition of abnormally low fluid velocity.

It is an even further object of the present invention to provide a novel safety valve mechanism for a down hole well environment that includes a selectively actuatable mechanism for conditioning the safety valve mechanism for pressure sensitive reopening movement.

Among the several objects of the present invention is noted the contemplation of a novel safety valve mechanism for a down hole well environment including means for insuring positive, but selective reopening of the valve mechanism after closure thereof.

It is an even further object of the present invention to provide a novel safety valve mechanism for a down hole well environment that effectively prevents reclosing of the valve mechanism after being selectively reopened.

It is another object of the present invention to provide a novel safety valve mechanism for a down hole well environment that causes pressure differential across a flow restriction to be automatically modified to prevent automatic closure of the valve mechanism as a reopening procedure is being conducted.

It is also an important object of the present invention to provide a novel down hole safety valve mechanism that is of simple nature, reliable in use and low in cost.

Other and further objects, advantages and features of the invention will become obvious to one skilled in the art upon an understanding of the illustrative embodiment about to be described and various advantages, not referred to herein, will occur to one skilled in the art, upon employment of the invention in practice.

SUMMARY OF THE INVENTION

The present invention is directed to the provision of a down hole safety valve mechanism that is maintained in an open or flowing condition thereof by a resultant force developed by pressure differential caused by the flow of fluid across a choke bean, which resultant force is greater than the force developed by a compression spring urging the valve mechanism toward the closed position thereof. The valving mechanism of the safety valve may comprise a valve head, maintained in stationary relation to the housing structure, and a valve face, carried at the lower extremity of an actuator sleeve assembly or mandrel and being disposed for engagement with the stationary valve head to interrupt the flow of fluid through the valve mechanism. The actuator sleeve assembly may be urged by a compression spring toward the closed position thereof and may be maintained in the open position by a resultant force developed by the flow of production fluid across a choke element carried within the mandrel. Upon the development of an abnormally low flow rate, the actuator sleeve assembly or mandrel will be moved to the closed position thereof by the compression spring.

In the closed position of the valve mechanism, the actuator sleeve assembly becomes pressure sensitive in a manner causing the valve mechanism to be maintained in the closed position thereof responsive to the development of a net closing force developed by formation pressure down-stream of the valve mechanism and acting against differential surface areas. Means may be provided for selectively modifying the pressure sensitive nature of the actuator sleeve by balancing the pressure responsive surface areas and thereby conditioning the valve mechanism for reopening responsive to formation pressure.

A mechanism may also be provided to prevent the valve assembly from moving immediately to a reclosed position, subsequent to opening, if the rate of flow across the choke bean is insufficient to produce a force of a magnitude necessary to overcome the force of a valve closing compression spring that urges the valve mechanism toward the closed position thereof at all times.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the manner in which the above recited advantages and objects of the invention are attained, as well as others, which will become apparent, and can be understood in detail, more particular description of the invention, briefly summarized above, may be had by reference to the specific embodiment thereof which is illustrated in the appended drawings, which drawings form a part of this specification. It is to be understood, however, that the appended drawings illustrate only typical embodiments of the invention and therefore are not to be considered to be limiting of its scope, for the invention may admit to other equally effective embodiments.

In the Drawings:

FIG. **1** is a pictorial representation illustrated partially in section of a subsurface earth formation having a well bore extended therethrough and being lined with a well casing including a production tubing containing a down hole safety valve mechanism constructed in accordance with the present invention.

FIG. **2** is a fragmentary sectional view of the well casing structure of FIG. **1**, illustrating a typical landing nipple and showing wire line emplacement and retrieval apparatus having a safety valve mechanism constructed in accordance with the present invention connected to the lower extremity thereof.

FIGS. **3**A and **3**B are sectional views of the upper and lower portions, respectively, if the safety valve mechanism of the present invention, illustrating the moving parts in the normal fluid producing positions thereof.

FIG. **4** is a fragmentary sectional view of the valve mechanism of FIGS. **3**A and **3**B, illustrating the valving mechanism thereof in the fully closed position.

FIG. **5** is a sectional view taken along line **5—5** in FIG. **4.**

FIG. **6** is a sectional view of the lower portion of the safety valve mechanism of the present invention illustrating the moveable parts of the valve mechanism in the disarmed and flowing condition thereof.

FIG. **7** is a sectional view of the lower portion of the valve mechanism of the present invention showing the condition of the moveable parts of the valve mechanism in the disarmed and closed position thereof.

FIG. **8** is a sectional view of the lower portion of the safety valve mechanism of the present invention illustrating the moving parts thereof in the armed and closed position thereof immediately preceeding opening movement of the valve mechanism.

FIG. **9** is also a sectional view of the lower portion of the valve mechanism of this invention illustrating the moveable parts thereof in the armed and opening condition.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Now referring to the drawings and first to FIG. **1,** an earth formation is illustrated at **10** having a well bore **12** drilled therein which is lined with a well conduit **14** that may be cemented in place in conventional manner. Production tubing **16,** typically referred to in the industry as a tubing string, extends through the well casing **14** and is sealed with respect to the well casing by a packer **18** located a convenient distance above the production zone of the earth formation. The tubular conduit **16** is open at its lower extremity to production fluid flowing through perforations in the casing **14** and conducts the production fluid upwardly through the tubing string in conventional manner.

For the purpose of shutting off the flow of production fluid through the tubing **16** in the event production flow in the tubing should increase or decrease abnormally, it will be desirable to provide a safety valve mechanism that is responsive to predetermined decrease in the flow of production fluid to close and effectively shut off the flow of fluid. According to the present invention, such safety valve mechanism may conveniently take the form illustrated in the drawings where a safety valve mechanism is depicted generally at **20** that may be installed and removed by conventional wire-line equipment, illustrated generally at **22.** It will be convenient to install the safety valve within the tubing string at a level where the temperature is high enough to prevent solidification of paraffin which might otherwise cause fouling of the moveable valve parts.

With reference now to FIG. **2,** the wire-line apparatus **22** is shown to include a landing nipple **24** that may be provided with externally threaded extensions **25** and **26** that receive internally threaded extremities of the production tubing **16.** An annular landing shoulder **28** may be defined within the lower extension **26** of landing nipple **24** for engagement by an annular shoulder **30** formed on a wire-line tool **32,** thereby preventing the wire-line tool from descending below the level established by annular shoulder **28.** Wire-line tool **32** may be provided with locking detents **34** adapted to be received within an annular locking groove **36** defined within landing nipple **24.** Wire-line tool **32** may also be provided with a packing **38** of annular configuration for engagement with the cylindrical surface **40,** defining a portion of the receptacle for the wire-line tool. As is typically the case, wire-line tool **32** may also be provided with a fishing neck **42** at the upper extremity thereof that may be engaged by appropriate installation and retrieval apparatus of conventional nature.

While the particular wire-line installation and retrieval apparatus **32** is illustrated in FIG. **2,** it is to be understood that the particular configuration illustrated is not intended to limit the present invention. It is intended to be obvious that any suitable wire-line tool of conventional nature may be employed within the spirit and scope of the present invention. The wire-line tool **32** may be provided with a lower externally threaded extremity **44** adapted for threaded connection to internal threads **46** formed within the upper sub **58** of an upper housing section **60** of the safety valve mechanism **20**, thereby effectively supporting the safety valve in depending relation from the wire-line tool **32**.

Referring now to FIGS. **3A** and **3B** which depict the upper and lower portions of the valve mechanism of the present invention, respectively, the safety valve mechanism, illustrated generally at **20** may comprise an outer housing, illustrated generally at **52**, that is of generally tubular configuration. The internal threads **46** of the upper sub may establish threaded connection to a wire line tool such as illustrated at **32** in FIG. **2**, generally referred to as a setting mandrel, or may establish connection of the safety valve mechanism to a section of tubing carried by the wire line tool or setting mandrel depending upon design parameters of the production system of the well.

The housing structure **52** may be defined by an upper housing section **60** and an intermediate housing section **62** that are joined by a coupling element **64** having an intermediate thickened wall section and having upper and lower threaded extremities **66** and **68** for threaded engagement with the upper and intermediate housing sections, respectively.

The intermediate housing section **62** may be provided with an externally threaded lower extremity **70** that may be threadedly received by internal threads **72** defined within a lower housing section **74.** The lower housing section may likewise be provided with internal threads **76** adapted to receive an externally threaded extension **78** of a lower sub **80**, defining the lower extremity of the valve mechanism. A plurality of passages, such as shown at **82** and **84** in FIG. 3B, may be bored or otherwise formed in the lower sub **80** and may communicate pressurized production fluid from the formation into the tubular valve housing **52.**

It will be desirable to provide a valving mechanism that is capable of interrupting the flow of fluid through the safety valve structure in the event the rate of flow of production fluid through the valve assembly should decrease below a predetermined minimum rate. One suitable means for accomplishing closure of the valve mechanism, responsive to predetermined decrease in the rate of production fluid flow, may conveniently take the form illustrated in FIGS. 3A and 3B, where a valve actuator assembly, also referred to as a "mandrel", illustrated generally at **86**, may be disposed for reciprocal movement within the housing structure **52** and may carry a valve face element at the lower extremity thereof for valving engagement with a valve head carried in fixed relation to the valve housing. The valve face element and the head portion of the valve structure are described in detail hereinbelow. The valve actuator assembly **86** may comprise an upper tubular section **88** having an enlarged flange portion **90**, disposed at the lower extremity thereof and provided with internal threads **92**, for engagement with the externally threaded portion **94** of a lower tubular section **96**.

An urging means for imparting a force to the valve actuator assembly **86** and urging the same towards a position causing the valving assembly to close, may comprise a compression spring **98** disposed about the upper tubular section **88** and interposed between shoulders **100** and **102** defined, respectively, by the lower extremity of the coupling element **74** and the upper annular surface of the enlarged flange portion **90** of the upper tubular section **88.**

It is well known that most wells produce a quantity of particulate matter such as sand gains or other abrasive matter along with the production of both gaseous and liquid production fluids. It is, therefore, appropriate to provide a mechanism for preventing the sand or other abrasive material from causing erosion of any sealing surfaces and to prevent sand and other foreign matter from settling on top of sealing elements and interfering with the sealing function thereof. One suitable means for protecting the valve mechanism from the abrasive or interference problems created by production of sand along with the well fluid, may conveniently take the form of a thin walled tubular element **104** provided with a lower internally threaded extremity **106** and being received by an externally threaded upper extremity **108** of the upper tubular section **88** of the valve actuator assembly. The thin walled tubular element **104** may be adapted to receive a smler thin walled sleeve **110** which may depend from the upper sub **58** and may be disposed concentrically and in spaced relation within the outer thin walled section **104.** This arrangement provides a substantial dead fluid space or gravity barrier to prevent sand gains or other abrasives in production fluids from contacting any sealing surfaces of the valve mechanism or settling on top of a piston, to be described hereinbelow, and interfering with the sealing ability of sealing elements carried by the piston. This particular arrangement has been found to provide a substantial protection against surface galling and seal failure.

For the purpose of interrupting the flow of production fluid in response to a decrease in the rate of flow below a predetermined minimum, the lower tubular section **96** of the valve actuator assembly or mandrel **86** may be provided with a lower externally threaded extremity **112** disposed in threaded engagement with internal threads **114** provided on a valve face element **116** having an enlarged or flared lower portion **118** defining an internal annular sealing surface **120** and a tapered seat shoulder **122.**

A stationary valve head portion of the valving mechanism, illustrated generally at **124** in FIG. 3B, may comprise a valve head base structure **126** formed integrally with or disposed in fixed relation to the structure of the lower sub **80.** The valve head portion **124** may be provided with an annular resilient seal element **128** that may be sandwiched between upper and lower retainer rings **130** and **132** to form a seal assembly. The seal assembly may be retained in assembly with the base portion **126** of the valve head by a retainer post element **134** having external threads received by internal threads defined within a blind bore **135** of the post. The annular seal element **128**, along with the retainer ring **130** and **132**, may be disposed relative to the valve face portion **116** as to be received in sealing engagement within the annular generally cylindrical seal surface **120** to the extent that an annular tapered surface **136** defined on the upper retainer ring **130** may move into abutting relation with the tapered annular surface **122**, thereby defining a secondary or metal-to-metal seal. Moreover, it should be noted that the annular sealing element **128**, which, for example, may be composed of a wear resistant material, such as polytetrafluoroethylene, may be compressed slightly as a force is applied by the head portion **116** of the actuator sleeve through the tapered surfaces **122** and **136**, thereby causing the outer periphery of the sealing element to expand slightly and develop tighter sealing contact with the surface **120.** As the mechanical force urging the face portion into engagement with the head portion relaxes, the elastic memory of the seal material will contract the outer periphery of the seal element back to the original slight interference fit with the cylindrical surface **120.**

As indicated above, the valve actuator assembly or mandrel **86** is normally urged downwardly by the compression spring **98** to a position closing the valving assembly. It is desirable, therefore, that velocity sensitive means be provided to maintain the mandrel in an upper position thereof against the force developed by the compression spring in order to maintain the valving mechanism in the open position thereof to allow normal flow of fluid through the safety valve. In accordance with the present invention, such means may conveniently take the form of a choke bean **138** having a restricted flow orifice **140** defined therein. In the open position of the valving mechanism, fluid flows upwardly from the formation through the flow passages **82** and **84** into a valve chamber **142** and, if the valving mechanism is open, production fluid will flow through the restricted orifice **140** in the choke bean **138,** thereby developing a pressure differential across the choke bean, which develops a resultant force of sufficient magnitude to overcome the force developed by the compression spring **98.** The resultant force urges the mandrel **86** upwardly to the open position thereof, illustrated in FIG. 3B.

The choke bean **138,** although typically composed of an extremely hard and wear resistant material, will become worn after a period of time, because of the abrasive action of sand and other foreign matter being carried along with production fluid flowing through the orifice **140.** It is desirable, therefore, to provide a choke bean structure that may be readily replaced without difficulty. An upper choke retainer element **142** may be received in abutment with the lower annular surface of the lower tubular section **96** of the mandrel and may provide downstream support for the choke bean. A threaded retainer element **144** may be received by internal threads formed within the face portion **116** and may provide upstream support for the choke bean. The choke bean may be removed from the face portion **116** simply by unthreading the retainer element **44** and extracting the choke bean from engagement with the upper retainer element **42.** Access may be gained to the threaded retainer **144** and choke bean **138** simply by unthreading the lower sub **80** from the lower housing section **74.** Replacement or repair of other portions of the valving assembly can logically be accomplished in similar manner without complete disassembly of the safety valve mechanism.

As explained above, if the rate of flow of production fluid through the valving mechanism should decrease below a predetermined minimum level, determined by the magnitude of the force necessary to compress the spring **98,** the force developed by pressure differential across the choke bean **138** will be insufficient to overcome the compression of the spring **98** and the spring will drive the mandrel **86** downwardly, causing the face portion **116** of the valving mechanism to move the seal surface **120** into receiving relation with the annular sealing element **128,** as shown in FIG. **4,** and the flow of production fluid through the valving mechanism will be effectively interrupted.

It will be desirable, upon closure of the valving mechanism, to cause the valving mechanism to remain in the closed position thereof to prevent further flow of production fluid even though conditions may be effectively restored for establishment of normal flow. For example, formation pressure may decrease momentarily due to development of some unusual well condition and the valve may close. If the valve mechanism were capable of being opened responsive to restoration of normal operating pressure, the valve would reopen and production flow would begin without allowing production personnel to detect the abnormal pressure condition and a dangerous well condition could develop. It is, therefore, desirable to construct the valving mechanism in such manner that it will remain open responsive to fluid flowing above a predetermined minimum velocity and, after becoming closed, responsive to decrease in velocity below a predetermined minimum rate of flow, the valve mechanism will be maintained in the closed position thereof responsive to formation pressure. In other words, the valve mechanism is desired to be velocity sensitive in the open condition thereof and is desired to be pressure sensitive in its closed position.

As illustrated in FIG. **4,** the area of the mandrel that is acted upon by formation pressure and develops a force tending to move the valving mechanism to the open position thereof is illustrated by dimension Al. The area of the valving mechanism acted upon by formation pressure and developing a force tending to close the valve mechanism is illustrated by dimension **A2.** As shown in FIG. **4,** the area A2 is substantially larger than the area A1 defining a resultant area R, which, when acted upon by the formation pressure, will produce a net or resultant force acting downwardly upon the mandrel and tending to maintain the valving mechanism closed. As long as the formation pressure is greater than pressure within the tubing downstream of the valve element, the valve mechanism, after becoming closed, will not reopen even though formation pressure should subsequently increase to a normal pressure or to a pressure greatly exceeding normal pressure.

In wells that are produced by formation pressure, it is obvious that the formation pressure will always exceed pressure downstream of the valve mechanism, because the well would require pumping for production if pressure conditions were otherwise. After the valving mechanism has become closed, it will not be possible for pressure conditions to develop that will automatically open the valve and allow production to be resumed.

Once the valve mechanism has become closed, therefore, it will be necessary to institute a particular reopening procedure for opening the valve and placing the production system of the well back on flow. This feature allows production personnel to detect unusual well conditions and conduct tests to determine the reason for the abnormal flow condition.

After the valving mechanism has closed, thereby shutting in the well, and after tests conducted by production personnel indicate that normal production can be resumed, it will be desirable to institute a reopening procedure to open the valving mechanism and place the production system back in operation. One suitable means of accomplishing the valve reopening procedure can effectively be accomplished by selective alteration of the pressure responsive areas of the valve actuator assembly or mandrel **86**, to allow formation pressure to open the valve and allow resumption of flow across the choke bean **138**. One suitable means for selectively altering the pressure responsive areas of the mandrel may conveniently take the form of a piston **146** the annular area A3 of which is larger than the area R (difference in areas A1 and A2), illustrated in FIG. **4**, thereby changing the net of the pressure responsive areas of the mandrel and allowing formation pressure, acting upon the piston, to develop a resultant force on the mandrel **86** acting upwardly and opposing the force developed by the compression spring **98**. If the resultant force, developed by pressure acting upon the piston **146**, is sufficient to overcome the force developed by the spring **98**, the spring will be compressed and the mandrel **86** will be moved upwardly, thereby causing the valve face portion **116** to move upwardly relative to the head portion **124**, breaking the seal and allowing the flow of production fluid to be resumed through the orifice **140**. The piston element **146** may be provided with inner and outer annular sealing elements **148** and **150** respectively, which may conveniently take the form of O-rings or any other suitable sealing devices, for engagement with sealing surfaces **152** and **154** defined on the lower tubular section **96** and lower housing section **74**, respectively.

It will be necessary for the piston element **146** to be physically connected to the lower tubular section **96** of the mandrel in order to add the surface area of the piston to the mandrel. A means for achieving interlocking of the piston with the mandrel may conveniently take the form of a plurality of spring fingers that may, if desired, be formed integrally with the piston **146**. Each of the spring fingers may include locking portions **154** thereof disposed for locking engagement within an annular groove **156** defined in the lower tubular section of the mandrel. The spring fingers **152** will ordinarily be urged radially outwardly away from locking engagement within the annular groove **156**, but may be cammed inwardly to establish such locking engagement by a plurality of cam elements **158** defined on the finger elements, which cam elements may engage an annular cam surface **160** defined by a reduced diameter portion **162** defined within the lower housing section **74**.

Upward movement of the piston element **146**, relative to the lower housing section **74** of the safety valve mechanism, may be limited by a tapered annular surface **164**, also defined by the reduced diameter portion **162** of the housing, which may be engaged by an annular tapered surface **166** defined on the upper surface of the piston element. Downward movement of the piston element relative to the moveable lower tubular section of the mandrel **96** may be limited by an annular enlargement **168** defined on the mandrel, which enlargement is engaged by the piston as the piston is urged downwardly by application of pressure upstream of the valving mechanism. As the piston element is caused to move downwardly, relative to the lower tubular portion of the mandrel, assuming the valve mechanism to be disposed in the closed position thereof, the cam portion **158** of the spring fingers **152** will be caused to engage the annular cam surface **160**, defined by the annular restricted portion **162** of the lower housing section. This causes the spring fingers to be urged from the normally outward position thereof to a position urging the locking portions **154** of the spring fingers radially inwardly. As the piston moves downwardly, relative to the mandrel, slightly before the lower extremity of the piston reaches engaging relation with the annular enlargement **168** on the lower tubular portion **96** of the mandrel, the locking portions **154** of the spring fingers will be urged into the annular groove **156**. The piston will continue to move downwardly thereafter, until its downward movement is stopped by the annular enlargement **168**.

As fluid pressure conditions are then reversed by bleeding pressure from above the valve mechanism, formation pressure, acting across the piston, will develop a resultant force of sufficient magnitude to overcome the force developed by the compression spring **98**. When this occurs, the mandrel **86** will be urged upwardly, thereby causing the valve mechanism to open and allow flow to again be resumed through the restricted orifice **140** of the flow bean. As the mandrel is moved upwardly, a sufficient distance to allow the cam portion **158** of the spring fingers to clear the cam surface **160**, the spring fingers **152** will move radially outwardly, thereby releasing the locking portion **154** of the spring fingers from the annular shoulder **170** defined by the groove **156**, thereby releasing the piston from the mandrel. The unlocking movement of the spring fingers is caused partly by the inherent spring nature thereof and partly by outward forces on the fingers that are caused by interaction between an annular shoulder **170**, defined by the locking groove **156** and tapered cam surfaces **155**, defining the upper extremities of each of the spring fingers. If a condition of normal flow has resumed thorugh the orifice **140** at the time the piston **146** is released from the mandrel, a force developed by pressure differential across the flow bean will be of sufficient magnitude to overcome the compression of spring **98** and will thereby maintain the mandrel in its upper or normal flow position. Normal flow will continue through the safety valve mechanism until such time as flow is again reduced below the predetermined minimum rate, whereupon the compression spring **98** will again urge the valve mechanism to its closed position and the valve mechanism will remain closed thereafter because of its pressure sensitive nature until such time as the reopening procedure is selectively instituted.

It is obvious that if a condition of normal flow has not developed across the flow bean **138** at the time the piston **146** is released from its locked engagement with the lower tubular section **96** of the mandrel, the mandrel will automatically move again to its closed position and the reopening procedure must again be reinstituted to open the valve mechanism and put the flow system of the well back in normal operation. One suitable means for preventing reclosing of the valve mechanism, immediately following release of the piston **146** from the mandrel, may conveniently take the form of a restriction modifying pin **172** that may be provided with a threaded portion **174** adapted to be received within an internally threaded blind bore **176** defined in the retainer post element **134**. The pin **172** may be disposed centrally of the retainer post **134** and may be adapted to be received within the restricted orifice **140** of the choke bean **138** upon movement of the valve face element into closing engagement with the valve head **124**. The restricted orifice **140** of the choke bean is likewise maintained in accurate alignment with the pin **172** by an upper guide surface **178** defined by an internal annular flange **180** on the coupling element **64** and by an internal guide surface **182** defined by the piston **146.** The guide surfaces **178** and **182** effectively center the mandrel **86,** relative to the housing **52** of the valve **20,** and accurately guide the mandrel as it reciprocates within the valve housing responsive to pressure and flow conditions.

As indicated above, after the piston element **146** has been released from its connection with the mandrel, the compression spring **98** will tend to force the mandrel downwardly causing reclosure of the valve mechanism, because conditions of fluid flow across the choke bean **138** will not at this time have reached a sufficient velocity to develop a pressure differential across the choke of sufficient magnitude to develop a resultant force that is capable of stopping spring urged downward movement of the mandrel before it moves to its completely closed position. During downward movement of the mandrel by the compression spring, after having been released from the piston **146,** as the valve face portion **116** nears valve closing engagement with the head portion **124,** the choke modifying pin **172** will enter the restricted orifice **140** of the choke bean, thereby restricting the flow of fluid through the orifice. The pin **172** is of such size, relative to the orifice, that flow of fluid is allowed to continue through the orifice, but such flow will be substantially restricted, as compared with the unrestricted dimension of the orifice. The restricted flow condition caused by insertion of the pin into the orifice logically develops a condition of extremely high differential pressure across the choke bean **138** and thereby develops a resultant force of large mangitude acting through the choke bean **138** on the mandrel structure **86.** Before the face portion of the valve can reach a sealed and closed relationship with the head portion of the valve mechanism, the mandrel will be suddenly subjected to an upward force that stops the downward movement of the mandrel and thrusts it upwardly against the compression of the spring **98.** As the mandrel is thrust or kicked upwardly by the large upward force developed when the orifice **140** is restricted by the pin **172,** a condition of flow will again be developed across the choke bean **138** and a resultant force will again be induced through the choke bean structure to the mandrel which force opposes the bias of the compression spring **98.** The compression spring, after the mandrel has been kicked upwardly a short distance from the upper extremity of the pin **172,** will tend to return the face portion of the valve mechanism to the closed position, but, because of the now expanded condition of the spring, will not cause the mandrel to accelerate downwardly as rapidly as when the mandrel is first released from the piston **146** and the spring **98** is compressed to its maximum extent.

During the period of time the mandrel is thrust upwardly by the large magnitude force developed by severe restriction of the choke bean by the pin **172** and then reverses direction and again starts moving downwardly responsive to the force of the compression spring **98,** toward the closed position thereof, a condition of flow from the formation through the flow passages **82** and **84** and through the restriction **140** of the choke bean will develop that will generally be sufficient to develop a pressure differential across the choke bean of sufficient magnitude to overcome the spring **98** and urge the mandrel upwardly to normal operating position thereof.

The choke bean **138** may be oscillated a few cycles by the mandrel relative to the choke restricting pin **172,** with less rebounding of the mandrel during each succeeding cycle, responsive to a lower rate of acceleration of the mandrel as it starts moving downwardly under the force developed by the spring **98.** After a few cycles of oscillation, a normal flow condition will be developed across the choke bean which produces a pressure differential developing a resultant force of sufficient magnitude to compress the spring **98** and urge the mandrel upwardly to its normal operating position.

OPERATION

Referring now to FIGS. **6, 7, 8** and **9** various operating conditions of the safety valve mechanism of this invention are depicted. In FIG. **6** the valve mechanism is illustrated in the normal operating position thereof, which is referred to as the "disarmed-flowing" position. In this condition the valving mechanism is maintained in its open position and the valve opening piston is disconnected from the mandrel.

In FIG. **7,** the valving mechanism is depicted in the closed position that it achieves, after having been closed by the compression spring **96,** responsive to the development of a flow condition of insufficient velocity. This position is referred to as the "disarmed-closed" position; the mechanism being disarmed because the valve opening piston is disconnected from the mandrel.

In FIG. **8,** the safety valve mechanism of this invention is depicted in the "armed-closed" position with the valving mechanism being maintained in the closed position thereof while the piston mechanism has moved downwardly into latched position with the mandrel, thereby substituting the surface area of the piston for the differential areas of the mandrel for subsequent pressure sensitive opening movement of the valve mechanism.

In FIG. **9,** the safety valve mechanism is depicted in the "armed-opening" position with the valving mechanism in the open position thereof and the piston element disposed in latched or assembled relation with the mandrel. In this particular position the mandrel has not been moved to the uppermost position thereof by the piston and the reduced dismeter portion of the lower housing section maintains the spring fingers in latched engagement with the latching groove of the mandrel, causing the upper tapered cam surfaces **155** of the locking portion **154** of spring fingers to engage the annular shoulders **170** defined by the annular **156,** thereby causing the mandrel to be urged upwardly. As the cam portions **158** of the spring fingers **152** move to a position clearing the annular restricted portion **162** of the lower housing section, the spring fingers will be caused to move radially outwardly partly by the inherent spring nature of the fingers and partly by the outward force developed on the fingers by interaction between the annular shoulder **170** and the tapered cam surfaces **155** defining the upper extremities of the spring fingers, whereupon the spring fingers, and the piston **146** formed integrally therewith, will be released from connection with the mandrel.

For a more detailed description of the operational concepts of the present invention and with reference particularly to FIG. **6,** where the valving mechanism is disposed in the "disarmed-flowing" condition, a condition of normal flow exists and fluid flowing from the production zone of the well will enter the valve chamber portion **142** of the housing through a plurality of flow passages **82** and **84.** The production fluid then flows from the valve chamber and into the tubular conduit defined by the valve actuator assembly or mandrel **86,** through the restricted orifice **140** in the choke bean **138.** The restriction to flow caused by the orifice **140** develops a pressure differential across the choke bean that induces a resultant force, acting upwardly on the choke bean and mandrel, that compresses the spring **98** and maintains the face portion **116** of the valving mechanism in the open position thereof relative to the stationary valve head portion **124.**

The same pressure differential, acting across the choke bean **138,** also acts across the piston element **146** and develops a resultant force acting upwardly on the piston and retaining it in engagement with the annular stop surface **164.** The spring fingers, connected to or formed integrally with the piston **146,** will be disposed with the latching portions **154** thereof above the annular latching groove **156** of the mandrel. The piston element, with its spring fingers and the mandrel, in this particular condition will be freely moveable elements that are completely disconnected from one another and will be moveable relative to one another. The piston is pressure sensitive while the mandrel is velocity sensitive when the valve mechanism is in the disarmed-flowing position.

With reference now to FIG. **7,** the valving mechanism and the mandrel of the safety valve of this invention is depicted in the closed position thereof, but disarmed because the piston, and the spring fingers carried by the piston, are in disconnected relation with the mandrel. Assuming that the velocity of fluid flowing through the valve mechanism and through the restricted orifice of the choke bean should become decreased below a predetermined operating rate for any condition whatever, the resultant force produced by the pressure differential across the choke bean **138** will become insufficient to overcome the pressure of the spring **98** and the spring will expand, thereby urging the mandrel downwardly and causing the face portion **116** of the valving mechanism to move into sealed relationship with the sealing element **128,** carried by the stationary portion **124** of the valving mechanism, thereby completely interrupting the flow of fluid and ceasing production of the well. As explained above, in connection with FIG. **4,** in the closed position, the valve mechanism becomes pressure sensitve and the area **A1,** subjected to formation pressure, being smaller than area A2, also subjected to formation pressure, will cause a resultant force to be induced to the face portion **116** of the valve mechanism and to the mandrel, which resultant force causes the face portion and the mandrel to be urged toward the closed position thereof. The valving mechanism, in the disarmed and closed position thereof, as illustrated in FIG. **7,** will be pressure sensitve and will be urged to the closed position by formation pressure. Regardless of how high formation pressure should become, the valve mechanism will not reopen, but, rather will be more tightly closed.

In the disarmed and closed position, the piston element **146,** also being pressure sensitive, will be urged upwardly by the same pressure differential that exists across the valve mechanism, thereby causing it to engage and be restrained against further upward movement by the tapered stop surface **164.** Again, as in FIG. **6,** the spring fingers **152** will be disengaged from the annular locking groove **156,** thereby allowing movement of either the mandrel or the piston independently of one another. Of course, in this particular position the mandrel will not be capable of upward movement responsive to formation pressure because of the net downward or closing force induced thereto by formation pressure acting upon the annular areas A1 and A2 as described above.

With reference now to FIG. **8,** the valving mechanism of the safety valve is depicted in the armed and closed position thereof with the piston **146** interlocked with the mandrel **86,** because of the locking portions **154** of the spring fingers **152** being urged, by interaction between the cam portion **158** of the spring fingers and the internal restricted portion **162** of the lower housing section, into latching engagement within the annular groove **156.**

When it is desired to reopen the valving mechanism to again reestablish production through the tubing string to which the safety valve is associates, pressure may be injected into the tubing string above the valve mechanism to the extent that formation pressure is overcome. When this condition occurs, the pressure sensitive piston **146** will be driven downwardly by the downward resultant force developed across the piston by the difference between the tubing pressure above the valve mechanism and formation pressure below the valve mechanism. As the piston is shifted downwardly the cam portions **158** of the spring fingers **152** will engage the tapered cam surface **160** of the internal restricted portion **162** of the lower housing section **74** and will cause the spring fingers **152** to be urged radially inwardly. As the piston element **146** nears its lowermost position of movement, relative to the lower tubular portion **96** of the mandrel, the locking portions **154** will snap into the annular groove **156.** The piston element **146** will continue to be driven downwardly until it shoulders against the annular enlargement **168** defined on the lower tubular portion **96** of the mandrel. The mandrel and the piston element **146** will remain in the position illustrated in FIG. **8** until such time as pressure above the valve mechanism is reduced below the level of formation pressure.

As fluid pressure above the valving mechanism is bled off to a level below formation pressure, the annular area of the piston **146,** now interconnected with the mandrel by virtue of the latching engagement of the spring fingers **152** with the latching groove **156,** becomes added to the mandrel. In other words, the area of the piston provides a new resultant area which is the difference between the areas A3 and R and thereby causes the development of a net upward force acting upon the mandrel due to formation pressure. If pressure is balanced across the piston element **146,** the mandrel will be subject only to the downward force produced by the compression spring **98** and tending to move the mandrel toward the closed position. The piston element therefore modifiers the pressure sensitive nature of the valving mechanism when the piston is connected to the mandrel by the spring fingers **152.**

After pressure above the valve mechanism has been reduced to a level below formation pressure, a pressure differential will exist across the piston **146,** tending to urge the piston, and the mandrel connected thereto, upwardly against the bias of the compression spring **98.** When the resultant force acting upon the piston **146** becomes sufficiently great to overcome the compression of the spring **98,** the spring will be compressed and the mandrel will begin to move upwardly. As bleeding of fluid pressure above the valve mechanism is continued, the mandrel continues to be moved upwardly by the resultant force produced by increasing pressure differential across the piston **146,** until the piston and the mandrel move slightly above the position illustrated in FIG. **9.** After upward movement of the mandrel has occurred, sufficiently to cause the cam portions **158** of the spring fingers to clear the tapered cam surface **160,** the spring fingers will be urged radially outwardly, partially by the inherent spring nature thereof and partially by a resultant force developed by interaction between the cam surfaces **155** and the annular shoulder **170** defined by the annular groove **156** on the lower tubular section of the mandrel.

After the locking portions **154** of the spring fingers have disengaged from the annular locking groove **156,** the mandrel **86** will be subjected only to the downward force of the compression spring, which will be offset to some extent at this time by a condition of flow that is developing through the restricted orifice **140** of the choke bean **138** and which develops a resultant force, acting upwardly and opposing the force of the compression spring. As explained above, the resultant force acting upwardly through the choke bean on the mandrel will be insufficient to overcome the compression **98** because the spring, as the mandrel is released from its connection with piston **146,** will compressed to its maximum extent. The mandrel therefore will be accelerated downwardly at a very rapid rate and will tend to urge the face portion **116** of the valving mechanism into closed relation with the annular sealing element **128** carried by the stationary head portion **124.**

The valving mechanism will not be allowed to fully close, however, because the pressure differential modifying pin **172** will enter the restricted orifice **140,** thereby further restricting the orifice to the flow of fluid and greatly increasing the magnitude of differential pressure across the choke bean **138.** This substantially increases the upward resultant force, acting upon the mandrel **82,** which results in the mandrel being suddenly subjected to an upward thrust that drives the mandrel upwardly against the compression of the spring **98.** As this occurs, a condition of flow will again exist through the orifice **140** of the choke bean and, if the rate of flow across the choke becomes sufficient to produce a pressure differential of sufficient magnitude to develop the necessary resultant force to overcome the bias of the spring **98,** the spring will be compressed by the resultant force and the mandrel will be driven upwardly to its normal operating position, as illustrated in FIG. **1.**

If the condition of flow existing across the flow bean is insufficient at this time to fully overcome the compression of the spring **98,** the mandrel, with the valve face portion **116** connected thereto, will be urged downwardly at a lower rate of accelleration toward its closed position, where the pin **172** will again enter the orifice **140** and develop a pressure differential across the choke bean that again thrusts the mandrel against the compression of spring **98.** The mandrel may oscillate a few cycles until a rate of flow is developed thorugh the orifice **140** that is of sufficient magnitude to develop a resultant force that overcomes the compression of the spring. When this occurs the mandrel will be urged by the resultant force to its fully open position as illustrated in FIG. **6.**

The piston **146,** after becoming released from the mandrel and being sensitive to pressure, will be moved upwardly by a resultant force developed by pressure drop across the choke bean **138** until it shoulders out against the annular stop surface **164** in the manner shown in FIG. **6.** After the reopening procedure has been fully accomplished, the valve mechanism will disposed in the disarmed-flowing condition, illustrated in FIG. **6** and the piston **146** will be disposed in its disarmed condition, also illustrated in FIG. **6.** The safety valve mechanism of this invention will remain in the disarmed and flowing condition until such time as the velocity of fluid flowing through the restricted orifice **140** again decreases to an unacceptable minimum level which allows the force induced by the compression spring **98** to overcome the resultant force acting upon the flow bean **138** and cause downward movement of the mandrel to the disarmed and closed position, illustrated in FIG. **7,** where it will remain until such time as a reopening procedure is instituted in the manner explained above.

In view of the foregoing, it is apparent that I have provided a novel safety valve mechanism that will serve effectively to stop the flow of production fluid through a well production system in the event the velocity of flow should fall below a predetermined minimum rate. The valve mechanism of my invention, after being closed, will not be opened even though well conditions may be resumed that would otherwise result in normal production flow. The valve mechanism will remain closed until such time as a specific reopening procedure is instituted to cause selective opening of the valve mechanism. This particular feature allows production personnel to be aware that a condition of undesirable flow rate has developed causing the well to shut in.

After the valve mechanism of my invention has become closed, responsive to conditions of abnormally low rate of flow, the valve mechanism is pressure sensitive, but is urged to closed position thereof by a resultant force produced by formation pressure acting upon differential areas of the valve actuating mechanism. Regardless how high pressure upstream of the valve mechanism may increase, the valve mechanism will always be subjected to a net downward resultant force tending to maintain the valve mechanism in the closed position thereof. Automatic resumption of production of the well will be effectively prevented after the valve mechanism has closed.

When it is desired to reopen the valve mechanism and again place the production system of the well on stream, I have provided a mechanism that effectively changes the pressure sensitive nature of the valve mechanism by modifying the areas that are subjected to differential pressure existing across the valve mechanism. After the pressure sensitive nature of the valve mechanism has been selectively modified, the valve mechanism may be selectively opened, responsive to formation pressure, and production through the tubing string, with which the safety valve mechanism is associated, may be resumed under conditions responsive solely to the velocity of fluid flowing through the valve mechanism.

Safety valves manufactured in accordance with the present invention are extremely safe and reliable and are capable of operating over extremely long periods of time without the development of any discernable wear.

It is therefore apparent that the present invention is one well adapted to attain all of the objects and advantages, hereinabove set forth, together with other advantages, which will become obvious and inherent from a description of the apparatus itself. It will be understood that certain combinations and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the present invention.

As many possible embodiments may be made of this invention without departing from the spirit or scope thereof, it is to be understood that all matters, hereinabove set forth or shown in the accompanying drawings, are to be interrupted as illustrative and not in any limiting sense.

What is claimed is:

1. A safety valve apparatus comprising:

an inner member movable between longintudinally spaced positions within an outer member, said members defining a flow passage;

valve means for closing said flow passage in one position of said inner member; said flow passage being open in the other position of said inner member;

means operable under normal flow conditions for maintaining said inner member in said other position;

means for shifting said inner member to said one position when the flow of fluids falls below a predetermined minimum rate;

pressure sensitive means operable upon closure of said valve means and being responsive to upstream pressure for retaining said inner member in said one position; and

second pressure sensitive means normally being disposed in inoperative relation to said pressure sensitive means and being selectively operable to combine with said pressure sensitive means and allow upstream pressure acting thereupon to develop a resultant force urging said inner member toward said other position.

2. A safety valve apparatus as recited in claim 1:

wherein said pressure sensitive means comprises surface areas surrounding said flow passage and subject to the difference in the pressures of fluids upstream and down stream of said valve means.

3. A safety valve apparatus as recited in claim 1, wherein said pressure sensitive means comprises:

hydraulically operable means responsive to a greater fluid pressure upstream of said valve means for overcoming said shifting means of said pressure sensitive means and for moving said inner member toward said other position to open said alve means.

4. A safety valve apparatus as recited in claim 1, wherein:

said second pressure sensitive means selectively modifies the physical dimension of said pressure sensitive means and cooperates with said pressure sensitive means to develop said resultant force and causes said valve means to be urged away from said one position thereof responsive to pressure differential of greater magnitude upstream of said valve means than downstream thereof.

5. A safety valve apparatus comprising:

an inner member movable longitudinally within an outer member between spaced positions, said members defining a flow passage and having coengageable means for closing said flow passage in one of said positions, said flow passage being open in the other of said positions;

means operable under normal conditions of fluid flow for maintaining said inner member in said other position;

means for shifting said inner member to said one position when the flow of fluid falls below a predetermined minimum rate;

means providing an upwardly facing transverse surface on said inner member subject to the pressure of fluids upstream of said coengageable means;

means providing a resultant downwardly facing transverse surface on said inner member subject to the pressure of fluids downstream of said coengageable means, so that when said inner member is in said one position an excess of upstream pressure over downstream pressure develops force to retain said coengageable means engaged; and

means normally disposed in inoperative relation to said resultant surface providing means and being selectively operable to increase the physical dimension of said downwardly facing surface means, thereby allowing an excess of upstream pressure over downstream pressure acting upon said inner member to develop a force urging said inner member toward said other position.

6. A safety valve apparatus as recited in claim 5, wherein said last mentioned means comprises:

piston means movable relatively along said inner member between an active position and an inactive position;

selectively operable means for connecting said piston means in force-transmitting relationship to said inner member in said active position; and

said piston means having a transverse pressure area of larger size than said resultant surface subject to the difference in pressures of fluids upstream and downstream of said coengageable means, so that when said piston means is connected to said inner member an excess of upstream pressure over downstream pressure forces said piston means and said inner member toward said other position to disengage said coengageable means.

7. A safety valve apparatus as recited in claim 6, including:

means for disconnecting said piston means from said inner member in said inactive position.

8. A safety valve apparatus as recited in claim 7, including:

means for transmitting force on said piston means to said outer member in said inactive position.

9. A safety valve apparatus as recited in claim 8, including:

means for locking said connecting means during movement between said active and inactive positions.

10. A safety valve apparatus as recited in claim 5, including:

means for preventing return movement of said inner member to said one position after said inner member has been urged away from said one position by said excess of upstream pressure.

11. A safety valve apparatus as recited in claim **5**, wherein:

said means for preventing return movement of said inner member to said one position comprises means for increasing pressure differential acting across said inner member sufficiently to develop a resultant force of sufficient magnitude to oppose said return movement.

12. A safety valve mechanism comprising:

valve elements being movable between an open position where fluid is allowed to flow and a closed position where the flow of fluid is blocked;

flow responsive means for maintaining said valve elements in the open position thereof responsive to normal rate of flow through said valve mechanism;

means for shifting valve element toward the closed position thereof when the flow of fluid falls below a predetermined minimum rate;

pressure responsive means operable upon closure of said valve elements for inducing a resultant force that maintains said valve elements in the closed position thereof; and

means for selectively reversing the pressure responsive nature of said pressure responsive means for causing pressure responsive movement of at least one of said valve elements toward the open position thereof.

13. A safety valve mehanism as recited in claim **12** wherein said valve elements define first and second pressure responsive areas, said first pressure responsive area being greater than said second pressure responsive area and being responsive to upstream pressure to develop a resultant force urging said valve elements toward the closed position thereof.

14. A safety valve mechanism as recited in claim **12** wherein said means for selectively reversing the pressure responsive nature of said pressure responsive means comprises:

third pressure responsive area means being disposed in disconnected relation with said second pressure responsive means during conditions of normal operation and being selectively connectable to said second pressure responsive means whereby the conbined areas of said second and third pressure responsive area means is greater than the area defined by said first pressure responsive area means and upstream pressure acting upon said pressure responsive areas develops a resultant force urging said valve elements toward the open position thereof.

15. A safety valve mechanism as recited in claim **12** wherein said third pressure responsive area means comprises:

a pressure responsive piston element being movable responsive to said valve elements; and

locking means for selectively locking said piston element to at least one of said valve elements.

16. A safety valve mechanism as recited in claim **12** wherein one of said valve elements is stationary and the other of said valve elements is movable between said open and closed positions:

said movable valve element having first and second pressure responsive areas defined thereon in the closed position of said valve elements and being responsive to upstream pressure for developing a resultant force acting upon said movable valve element and urging said movable valve element toward the closed position thereof; and

said means for selectively reversing the pressure responsive nature of said pressure responsive means being third pressure responsive area means being normally disposed in inoperative relation to said first and second pressure responsive area means and being selectively operable to combine said third pressure responsive area means with said second pressure responsive area means and thereby cause upstream pressure acting upon said pressure responsive areas to develop a resultant force urging said movable valve element toward the open position thereof.

17. A safety valve mechanism as recited in claim **16**:

said means for selectively reversing the pressure responsive nature of said pressure responsive means being a pressure responsive piston element normally disposed in movable relation to said valve elements;

locking means for selectively connecting said piston element to said movable valve element; and

said piston element being movable by pressure downstream of said valve elements to a position causing locking actuation of said locking means.

18. A safety valve mechanism as recited in claim **12**:

one of said valve elements being stationary;

valve actuator means being disposed for movement between open and closed positions thereof and defining flow passage means;

the other of said valve elements being carried by said valve actuator means; and

means restricting said flow passage means and being responsive to a predetermined rate of flow through said flow passage for maintaining said valve actuator means and said other valve element in the open positions thereof.

19. A safety valve mechanism as recited in claim **12**:

means for causing said flow responsive means to develop a pressure differential inducing a force acting upon said valve elements that prevents full closure of said valve elements subsequent to being opened.

20. A safety valve mechanism as recited in claim **12**, including:

means for preventing return movement of said valve elements to the closed position thereof subsequent to being moved toward the open position thereof by said pressure responsive means.

21. A safety valve mechanism as recited in claim **12**, including:

means for automatically increasing pressure differential across said valve elements upon movement of said valve elements toward the closed position subsequent to being moved toward the open position thereof by said pressure responsive means and thereby inducing a resultant force to said valve elements to stop said closing movement and urge said valve elements toward the open position thereof.

22. A valve mechanism, comprising:

a valve housing;

an actuator element being movably disposed within said housing and cooperating with said housing to define flow passage means through said valve mechanism;

a first valve element being disposed in stationary relation with said housing;

a second valve element being carried by said actuator element and being movable to a closed position thereof by said actuator element for sealed relation with said first valve element to interrupt the flow of fluid through said flow passage means;

means urging said actuator means toward said closed position thereof;

means restricting said flow passage means and being responsive to a predetermined rate of flow through said flow passage means for overcoming said urging means and maintaining said second valve element in an open position thereof, said urging means urging said second valve element to the closed position thereof at flow rates below said predetermined rate of flow;

pressure responsive means, responsive to excess of upstream pressure over downstream pressure for maintaining said second valve element in the closed position thereof; and

means for selectively reversing the pressure responsive nature of said pressure responsive means to facilitate movement of said second valve element away from said closed position responsive to excess of upstream pressure over downstream pressure.

23. A valve mechanism as recited in claim **22,** including:

means for preventing reclosing movement of said second valve element subsequent to movement of said second valve element away from sealing relation with said first valve element.

24. A valve mechanism as recited in claim **22**; including

means for automatically increasing the restriction of said restriction means upon movement of said second valve element toward the closed position thereof and developing sufficient differential pressure across said restriction means to overcome said urging means and prevent reclosing movement of said second valve element.

25. A valve mechanism as recited in claim **24** wherein

said restriction means comprises a choke element having a restricted orifice; and

said means for automatically modifying the restriction means carried by said valve mechanism and being operative to enter said restricted orifice and further restrict the same.

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