ABSTRACT

A tool and method for automatic subsurface closure of a well to prevent the uncontrolled flow of high-pressure formation fluids upward to the atmosphere while a well is being drilled or completed. The tool includes at least two main parts: A movable sealing means and a fluid flow control means positioned above the sealing means. The movable sealing means is used to shut in the well in response to a subsurface pressure condition. The fluid flow control means automatically provides an opening between the interior and exterior walls of the tool, when the pressure below the sealed off area is greater than the pressure above the sealed off area. The tool's functions are automatic, reversible and repetitive.

21 Claims, 8 Drawing Figures
AUTOMATIC SUBSURFACE BLOWOUT PREVENTION

REFERENCE TO PRIOR APPLICATION

This application is a continuation of application Ser. No. 12,823 filed Feb. 19, 1970, and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to the field of pressure control in the drilling of oil and gas wells or other type wells. More particularly it relates to the automatic subsurface closure of a drilled hole to prevent the upward flow of high-pressure formation fluids when the pressure of the formation's fluid exceeds the hydrostatic pressure of the drilling fluid adjacent to the formation. It also provides an automatic fluid flow control means to allow for the circulation of higher weight drilling fluid, thereby containing the formation's pressure.

2. Description of the Prior Art

A well blowout condition refers to the uncontrolled flow of fluids from a well to the atmosphere. The outward manifestations of a blowout condition can be very damaging both to property and life. Great efforts have been made to solve the blowout problem.

One common method involves the use of a surface blowout preventer around the drill string. Such a surface preventer can cause a subsurface blowout condition. More recently, a subsurface blowout preventer was proposed which consists of a fluid-operated packer to shut in the well, and a valve means to allow for the circulation of drilling fluid above the sealed off area. Such an apparatus is described in U.S. Pat. No. 3,427,651. In the patented apparatus, (using the reference characters of the patent) when a high-pressure formation 12 is penetrated by a drill bit 11 and it is desired to inflate the packer 16, drilling is halted and the hydraulic pressure of the drilling fluid is increased to a predetermined pressure above the normal circulation pressure. Then the hydraulic pressure is further increased to shear pin 33 and to move plug 30. Fluid pressure then expands packer 16 and seals the annulus 45 between tubular member 15 and the wall of borehole 10. Hydraulic pressure within the drill string is then decreased to prevent fluid pressure from escaping from packer 16. A circulation port 17 is opened by means of a wire line. The weight of the drilling fluid is increased to compensate for the high-pressure formation fluid. To deflate packer 16, circulation port 17 is closed by means of a wire line and the hydraulic pressure in the drill string is increased to a predetermined pressure level above the pressure required to inflate packer 16. This increased hydraulic pressure causes shear pin 39 to shear and the packer to deflate.

Among the main shortcomings encountered with known devices are: the parts forming the subsurface blowout preventer require human effort to become operative; precious time is wasted in manually carrying out the required manipulations; educated guesses must be made concerning the relation between the subsurface pressure conditions existing inside and outside the portion of the drill string adjacent the high-pressure formation; the fluid-inflatable packer can carry out only one cycle of operation; and after one cycle of operation the apparatus must be reconditioned and at least the shear pins restored.

Accordingly, it is a main object of this invention to overcome the above and other shortcomings of known devices. In accordance with this invention, a well can be controlled automatically in response to the occurrence of a sudden change in the pressure of a subsurface formation. A sealing wall will automatically expand in response to such changed pressure condition, and automatically contract after the pressure of the drilling fluid is properly compensated. The operation is therefore automatic, reversible, and repetitive.

SUMMARY OF THE INVENTION

An automatic tool and method for shutting in a well when a subsurface formation pressure becomes excessive, thereby preventing the lifting of the drilling fluid in the portion of the borehole above the tool. The tool includes at least two distinct and cooperating parts. The first is a fluid-inflatable packer and the second a fluid flow control valve positioned above the packer. After the packer provides a seal and effectively shuts in the well, the valve automatically opens to provide a flow channel for the circulation of drilling fluid. When the pressure of the drilling fluid above the sealed off area exceeds the pressure below the sealed off area, the packer will automatically deflate and return to its deactivated condition. Thereafter, normal drilling operations can be resumed. When another high-pressure formation is encountered, the packer will again inflate to shut in the well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view in perspective of a preferred embodiment of the present invention;
FIGS. 2A, 2B, and 2C are more detailed views partly in section of the embodiment shown in FIG. 1;
FIGS. 3A, 3B, and 3C are similar to FIGS. 2A, 2B, and 2C but with the movable parts arranged in activated positions, and
FIG. 4 is a cross-section on line 4—4 in FIG. 2C.

Referring to the drawings there is shown a subsurface apparatus 10 for controlling wells during drilling operations. Apparatus 10 is herein, generally, called a tool and, particularly, a subsurface blowout preventer. Normally, tool 10 forms part of and is positioned at a selected, desired elevation along a drill string assembly, generally designated as 11. String 11 includes drill pipes 12, collars 14, and a bit 16.

Experience indicates that if one tool is used, the preferred location is near the top drill collar 14. Several vertically-spaced tools 10 can be inserted within string 11 for greater protection. Drill string 11 has an inner wall 15 and an outer wall 17 and extends into a borehole 13 which may or may not have a casing. Borehole 13 traverses a formation 18 whose wall 19 is typically made up of distinct, vertically-spaced zones, each zone being characterized by an internal fluid (water, oil, or gas) pressure $P_i$.

Under normal drilling operations, a drilling fluid (liquid or gas) is pumped from the surface down string 11, through restricted orifices (not shown) in bit 16, and up through an annular area or annulus 20 between walls 17 and 19. After circulation of the drilling fluid is established, for the same elevation, the hydraulic pressure inside string 11 on the inner wall 15 is greater than the pressure on the outer wall 17. Conversely,
with no fluid circulation, the interior and exterior hydrostatic fluid pressure, at any level, is substantially the same.

As bit 16 continues to drill, a formation may be encountered whose pressure \( P_f \) is greater than the pressure of the circulating fluid in the adjacent annulus 20. This condition may cause the well to "blow out" unless preventive measures are immediately taken, preferably automatically. The outward manifestations of a blow-out condition are well-known and need not be described. A check valve 21 positioned at the lowermost end of tool 10 will prevent the formation's pressure \( P_f \) from fluidly communicating with the interior of drill string 11.

Referring more specifically to the construction of tool 10, it includes a preferably tubular member or mandrel 34 which extends throughout the entire length of tool 10. The mandrel's lower end is threaded and connected to a bottom connector 22, and its upper end is threaded connected to a top connector 23. Mandrel 34 has an inner wall 24 and an outer wall 25. Mounted on wall 25 are fixed and movable members which can be grouped into two main parts: a valve 26, and a fluid-inflatable sealing means or packer 28 which includes a packer setting mechanism 30.

**THE PACKER SETTING MECHANISM 30**

Guide pins 36 of mechanism 30 extend into spaced, longitudinal slots 38 to allow for the up-and-down movement of mechanism 30. A locking sleeve 40 is threadedly connected to a cylinder 42, which in turn is threadedly connected to a packer piston 44. Sleeve 40 is releasably secured by a snap ring 46 and a fixed, splined, retainer ring 48. Ring 48 defines several (six) openings 50. Through each opening 50 vertically extends a finger 52 of a movable expander ring 54. The tip 56 of each finger 52 is in contact with a power piston 58. Piston 58 is slidably mounted between wall 25 and the cylindrical inner wall 60 of cylinder 42. Piston 58 can move between a shoulder 62 of sleeve 40 and a shoulder 64 of cylinder 42. Between the internal wall 60 of cylinder 42 and the external wall 25 of mandrel 34 is formed a long chamber 66 which communicates with the internal pressure in mandrel 34, through a port 68. Below piston 58 is a chamber 70 which fluidly communicates with the pressure in the annular area 20, through ports 71. Above piston 58 is the chamber 66.

A sleeve 80 is fixedly secured on wall 25 by rings 82 and 84. Wall 60 of cylinder 42 slides on a seal 86 in the outer wall of sleeve 80. A port 88 communicates the annulus pressure to a chamber 90. This pressure is exerted on the lower surface 92 of the packer piston 44. The outer cylindrical wall portion 94 of cylinder 44 defines the previously-mentioned, vertically-extending, spaced slots 38. The top surface 96 of packer piston 44 is exposed to the pressure of an enclosed fluid within packer chamber 98. The packer fluid is typically a heavy oil having a low vapor pressure.

**THE PACKER 28**

Chamber 98 is formed between the outer wall 25 of mandrel 34 and the inner wall 100 of a cylinder 102. Pins 36 of cylinder 102 extend into slots 38. Cylinder 102 forms integral part with a movable flexible member, or fluid-expandable packer wall 104. Wall 104, in turn, forms integral part with a sleeve 106 which is threadedly connected to a sleeve 108. Sleeve 108 defines a stop shoulder 110 for arresting the further movement of the bottom surface 112 of a piston 114. A fluid passageway 116 establishes fluid communication between chambers 98 and 118.

**THE VALVE 26**

A valve cylinder 120 is threadedly connected to piston 114. The top surface 122 of cylinder 120, when in its raised position, will abuttingly engage the bottom surface 124 of top connector 23. When valve 26 is open, a chamber 126 is in fluid communication with the mandrel's interior pressure through openings 128 and with the annulus pressure through ports 130. A cylinder 132 is fixedly mounted on the outer wall 25 by two retaining rings 134 and 136. Cylinder 132 defines an inclined valve surface 138 which snugly engages surface 140 of cylinder 120. A seal 139 is provided on surface 138. A floating piston 142 provides a shoulder 144 for engaging a coiled spring 146 which also rests on the top surface 148 of piston 114. Ports 150 fluidly communicate with a chamber 152 formed between wall 25 and the inner wall 154 of cylinder 120.

**GENERAL DESCRIPTION OF OPERATION**

To facilitate the understanding of the operation of tool 10, and with particular reference to FIGS. 3A, 3B and 3C, let \( P_1 \) = pressure inside mandrel 34, \( P_2 \) = pressure outside tool 10 and below packer seal 104, \( P_3 \) = pressure outside tool 10 and above packer seal 104, \( P_4 \) = pressure inside packer seal and in chamber 98, \( A_1 \) = cross-sectional area of chamber 66, \( A_2 \) = cross-sectional area of piston surface \( 96 = A_1 \), \( A_3 \) = cross-sectional area of piston surface \( 112 = 0.54A_1 \), \( A_4 \) = cross-sectional area of sliding piston \( 142 = A_1 \), \( A_5 = A_4 = A_3 \), \( A_6 = A_5 = 0.74A_1 \). For simplicity assume that, \( A_1 = A_2 = A_4 = 1 \) (unit area), and \( A_5 = A_6 = 0.5 \).

In operation, tool 10 is connected to a drill collar 14 and to a drill pipe 12 by connectors 22 and 23, respectively. As the drill string 11 is being lowered into the annular area 20, tool 10 is in its deactivated and locked condition. Check valve 21 prevents the drilling fluid which is in borehole 13 from entering into mandrel 34. Accordingly, before fluid circulation begins, the exterior hydrostatic pressure is greater than the interior pressure and an upward force becomes exerted on the power piston 58. The movement of piston 58 is arrested by shoulder 64 of cylinder 42. Snap ring 46 locks sleeve 40 and hence cylinder 42.

Thereafter, in conventional manner, the drill pipe 12 is filled with a drilling fluid and circulation is established through the drill string 11, bit 16, and up the annular area 20. The interior pressure then becomes greater than the exterior pressure. A downwardly directed force now becomes exerted on power piston 58. Piston 58 pushes against the tips 56 of fingers 52, causing ring 54 to move downwardly against connector 22. Snap ring 46 reduces its diameter and frees sleeve 40.
and hence cylinder 42, for upward movement. The packer setting mechanism 30 is now in its deactivated and unlocked condition, and cylinder 42 does not move upward, since piston 58 now exerts a downward force against shoulder 62 of sleeve 40.

OPERATION OF PACKER SETTING MECHANISM 30

When the drill bit 16 encounters a high-pressure formation sufficient to cause a blowout condition, the formation’s fluid pressure \( P_f \) will communicate through ports 71 with chamber 70. The check valve 21 will prevent the formation’s pressure from lifting the drilling fluid inside mandrel 34. \( P_f \) is then greater than \( P_1 \), and is applied against the top surface and \( P_f \) against the bottom surface of power piston 58, and power piston 58 will move upwardly. An upward force also becomes exerted by \( P_f \) on the lower surface 92 of packer piston 44. Since piston 58 pushes cylinder 42 upwardly and an upward force is also exerted on the packer piston 44, the packer 28 will now become inflated.

OPERATION OF PACKER 28

As the packer piston 44 moves up into chamber 98, the constant volume fluid in chamber 98 moves up through passageway 116 and causes the flexible wall 104 to move radially outwardly. If possible, a seal will be established between packer wall 104 and wall 19 of borehole 13. If packer wall 104 does not effectuate a seal, cylinder 120 will not move up and valve 26 will remain closed. Conversely, if a wall is encountered and a seal established, valve 26 can open.

OPERATION OF THE CIRCULATING VALVE 26

Surface 112 of piston 114 is exposed to the pressure \( P_a \). Therefore, when \( P_a \) is greater than \( P_f \), the upward force \( F_a \) on threadedly connected members 114 and 120 is,

\[
F_a = P_a A_3 + P_a A_4 + P_a A_5
\]

and the downward force \( F_d \) on members 114 and 120 is,

\[
F_d = P_f A_1 + P_f A_5
\]

A balanced condition of the valve 26 exists, and valve 26 is closed, when the upward forces equal the downward forces, i.e., \( F_a = F_d \).

By substituting the above numbers for \( A_3, A_4, A_5 \), and \( A_6 \), and since,

\[
P_a = 2P_f - P_1
\]

then one obtains

\[
P_a = 5P_f + P_f/6 = Q_1
\]

Thus for all conditions when \( P_a \) is greater than \( Q_1 \), valve 26 will be closed, and for all conditions where \( P_a \) is less than \( Q_1 \), valve 26 will be open.

It follows then that for valve 26 to open \( P_f \) must be less than \( P_2 \). This condition is met only when packer 28 has sealingly engaged wall 19 of borehole 13, and a differential pressure is established across the packer 28.

Under normal drilling operations when the interior pressure \( P_1 \) is greater than the exterior pressure \( P_2 \), the floating piston 142 is at its upper position and engages stop ring 136. The forces involved are \( P_2 A_4 \) acting downwardly through port 150 against piston 114 and \( P_1 A_4 \) acting upwardly through port 128 on cylinder 120. Since \( P_2 A_4 \) is greater than \( P_1 A_4 \), cylinder 120 is forced downwardly and its shoulder 140 tightly engages seal 139 to prevent fluid from communicating between the valve’s internal port 128 and its external port 130.

Upon the occurrence of a blowout condition, \( P_a \) becomes greater than \( P_f \), and an upward force is exerted on cylinder 42 and hence on packer piston 44, as previously described. The packer’s fluid in chamber 98 becomes compressed and its wall 104 inflated. For valve 26 to open, \( P_a \) must be less than \( P_2 \), hence either \( P_2 \) must increase or \( P_f \) must decrease. \( P_2 \) may become greater than \( P_f \) when an effective seal is established between wall 104 and wall 19 of borehole 13. It may be possible from the surface to decrease \( P_f \).

In any event, when \( P_a \) is greater than \( P_f \), \( P_f \) exerts a downward force \( P_2 A_4 \) through port 130 on the top surface of floating piston 142 moving it downwardly, compressing spring 146, and pushing against surface 148 of piston 114. A downward force is thus exerted on cylinder 120. On cylinder 120 are also exerted a downward force \( P_2 A_4 \) and an upward force \( P_2 A_4 \). The net force is however a downward force. Valve 26 will remain effectively closed and will not accidentally open.

Now, under all conditions the packer fluid in chamber 98 fluidly communicates with chamber 118 through passageway 116. Hence, either a low or relatively high upwardly directed force \( P_2 A_4 \) is exerted on surface 112 of piston 114. When pressure conditions in and around tool 10 are such that \( P_a \) is less than \( Q_1 \), (see Equation 1), valve 26 will open.

To open valve 26, piston 114 and cylinder 120 must move upwardly until surface 122 of cylinder 120 is stopped by surface 124 of top connector 23. Fluid communication is now established between the valves internal port 128 and external port 130, i.e., between the inside and outside of drill string 11 above the sealed off area. Moving up with piston 114 is piston 142 thereby carrying compressed spring 146.

After valve 26 opens, the circulation of drilling fluid can be re-established and the weight of the fluid increased so that the internal pressure \( P_2 \) is greater than the external pressure \( P_2 \) below packer 28. Again a downwardly directed force is exerted on piston 58 through port 68. Piston 58 pushes locking sleeve 40 and piston 44 downwardly to their lowermost deactivated position. The fluid pressure in chambers 98 and 118 becomes reduced and wall 104 deflated. Valve 26 closes thereby breaking fluid communication between the valve’s ports 128 and 130.

Tool 10 has now completed a full cycle: Packer 28 was activated and reversibly deactivated. Tool 10 is now ready to repeat another full cycle in response to another high-pressure formation fluid.

Thus, it will be evident from the above description that the various movable parts of tool 10 become automatically actuated without human intervention. Also, the function of each part is executed without having to guess at the subsurface pressure values in and around tool 10. Since no human effort is required, little precious time is wasted and serious damage to both life and property can be averted.

It will be appreciated that while a preferred embodiment of this invention has been described in great detail and with reference to certain illustrative values, the invention is not limited thereto and modifications will readily suggest themselves to those skilled in the art,
and all such modifications are intended to fall within
the scope of the following claims.

What is claimed is:

1. A well tool for controlling a well having a borehole
filled with a drilling fluid, said borehole extending
through a geological structure which is susceptible of
containing a formation fluid, the tool being adapted for
insertion within a very long drill string which is lowered
into the well bore, said tool comprising:
a tubular member having an inner and an outer wall; 10

a fluid-inflatable sleeve means mounted on said outer
wall and being adapted to radially expand and to
close off the annular area between the drill string
and the borehole wall;

fluid pressure control means mounted on said tubular
member for controlling the expansion and contraction
of said sleeve means, said control means defining:
(1) a first fluid chamber fluidly communicating
with said sleeve means, said first chamber being
filled with a constant volume fluid, and (2) a sec-
ond chamber fluidly communicating with the inte-
or of said sleeve means and with said first cham-
ber, said second chamber being positioned on said
outer wall above said sleeve means;
said control means including: a first piston movably
mounted in said first chamber and a second piston
mounted on said outer wall for moving said first
piston in and out of said first chamber; and
said sleeve means radially expanding when said first
piston moves into said first chamber and radially
contracting when said first piston moves out of said
first chamber.

2. The tool of claim 1 and further including:
locking means mounted on said outer wall for releas-
ably securing said first piston to said tubular mem-
ber; and
said second piston unlocking said locking means
when the pressure of the fluid inside said tubular
member is greater than the pressure of the fluid
within said annular area.

3. The tool of claim 2 and further including:
a first fluid passageway between said inner wall and
said annular area above said sleeve means; and
valve means for automatically controlling fluid flow
through said first passageway.

4. The tool of claim 3 and further including:
a third piston movably mounted in said second cham-
ber, one surface of said third piston being respons-
ive to the pressure inside said sleeve means and
another surface being responsive to the pressure
inside said tubular member; and
said third piston moving out of said second chamber
after said annular area below said sleeve means be-
comes effectively sealed off.

5. The tool of claim 4 and further including:
second sleeve means connected to said third piston;
and
said second sleeve means defining a valve surface
which controls the fluid flow through said first pas-
sageway.

6. The tool of claim 5 and further including:
a spring-biased floating piston mounted on said outer
wall; and
said floating piston assisting in moving said third pis-
ton downwardly into said second chamber when

fluid communication through said passageway be-
comes cut off.

7. The tool of claim 6 and further defining:
a second fluid passageway between said annular area
and a surface of said second piston;
a third fluid passageway between said annular area
and said first piston;
a fourth fluid passageway between said tubular mem-
ber and a surface of said floating piston; and
an opposite face of said floating piston being respon-
sive to the fluid pressure in said annular area above
said inflatable sleeve means.

8. The tool of claim 7 and further including:
a shoulder securely mounted on said outer wall;
a seal on said shoulder; and
said seal snugly engaging said valve surface when said
valve means is closed.

9. A method for controlling a well having a borehole
filled with a drilling fluid, said borehole extending
through a geological structure which is susceptible of
containing a formation of high-pressure fluid, and a
very long drill string extending through said borehole,
said method comprising:
sealing off a portion of the annular area between said
drill string and the borehole wall in response to
subsurface differential pressures existing between
the interior and exterior of said drill string;
opening a fluid passageway between the interior of
said drill string and said annular area above said
sealed off portion in response to said differential
pressures;
circulating drilling fluid down said drill string through
said passageway and up said annular area above
said sealed off portion;
increasing the weight of said drilling fluid;
closing said fluid passageway in response to said dif-
ferential pressures; and
unsealing said previously sealed off portion when the
weight of said drilling fluid reaches a sufficient
level, thereby allowing drilling fluid to circulate
down said drill string and up through said annular
area.

10. An elongated tool connectable to a string of liq-
uid conducting hollow members for insertion into a
well bore, said tool comprising:
a hollow mandrel;
radially expandable sealing means carried by said
mandrel, said sealing means defining a first cham-
ber and a liquid filling said chamber;
pressure-responsive control means operatively cou-
piled to said sealing means for normally maintaining
said sealing means contracted, and
said control means controlling the pressure of the liq-
uid in said first chamber and including a differenti-
al-pressure sensing element responsive to a change
in the well bore pressure external to said
tool relative to the pressure in said hollow mandrel.

11. The tool of claim 10 including,
disabling means coupled to said pressure control
means adapted to disable said control means when
said tool is initially inserted into said well bore, and
said disabling means changing to enabling means
after said tool becomes functional in said well bore.

12. The tool of claim 10 including,
normally-closed first fluid communication means disposed above said sealing means, and said communication means being adapted to open for establishing fluid communication between the inside and outside of said tool.

13. The tool of claim 10 wherein, said first sensing element is a piston mounted on said mandrel for longitudinal movement.

14. The tool of claim 13 wherein, said control means include a movable mechanism controlled by said first sensing element; and said mechanism pressurizing or depressurizing the liquid in said first chamber.

15. The tool of claim 14 including, locking means for initially securing said mechanism to said mandrel, and said locking means releasing said mechanism after said tool becomes functional in said well bore.

16. The tool of claim 15 wherein the movement of said first sensing element exerts a downward force against said locking means to release said locking means.

17. The tool of claim 16 wherein said mechanism includes a piston adapted to move in or out of said first chamber.

18. The tool of claim 17 wherein said first communication means includes a circulating valve having a body portion coupled to said sealing means.

19. The tool of claim 18 wherein the first communication means includes a second differential-pressure sensing element movably mounted on said mandrel, and said second sensing element assisting in maintaining said circulating valve normally closed.

20. The tool of claim 19 wherein: said second sensing element is a piston movably mounted on said mandrel; and said sealing means includes an expandable element adapted to seal off said well bore when said first chamber becomes pressurized.

21. The tool of claim 20 including a check valve positioned near the bottom end of said mandrel to prevent fluid from entering said mandrel.

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