A pressure relief nozzle installs on the face of a drill bit, and provides a flow path for drilling fluid. The pressure relief nozzle has a larger internal flow area when flow rates through the drill bit are high, and a smaller flow area when flow rates are low. Upon reduction of the pressure relief nozzle's internal flow area, the pressure drop across the drill bit tends to stabilize due to the reduced flow area through the drill bit.
FIG. 9A

FIG. 9B

FIG. 9C
PRESSURE RELIEF NOZZLE
CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention
[0004] The invention relates generally to drill bits. More particularly, embodiments of the invention relate to fluid nozzles installed on drill bits. Even more particularly, embodiments of the invention are multi-use, self-adjusting pressure relief nozzles.
[0005] 2. Description of the Related Art
[0006] FIG. 1 includes a drilling installation having a drilling rig 10 at the surface 12 of a well, supporting a drill string 14. The drill string 14 is an assembly of cylindrical drill pipe sections which are connected end-to-end through a work platform 16. A drill bit 32 connects to the lower end of the drill string 14. A borehole 18 extends through earth formations 20 and 21.

[0007] As the drill bit 32 rotates, drilling fluid is pumped from a mud pit 34 at the surface through a hose 37, into the drill string 14, and to the drill bit 32. The drill bit 32 ejects drilling fluid through nozzles installed on the face of the drill bit. The drilling fluid cools and lubricates the drill bit 32 and removes cuttings from the borehole 18. The drilling fluid then rises back to the surface through the annular area between the drill string 14 and the walls of the borehole 18. At the surface, the fluid is collected and returned to the mud pit 34 for filtering.

[0008] Two types of drill bits are generally used, roller cone bits and fixed cutter bits. In both types of drill bits, an interior cavity holds the drilling fluid. The drilling fluid arrives to the cavity via the drill string and is ejected through nozzles installed on the face of the drill bit.

[0009] A layout of a three-cone rock bit is shown in FIG. 2. A roller cone bit 32 includes a threaded pin end 14 and is configured with a number of roller cones 16, typically three, at its bottom that are equidistantly spaced around the circumference of the bit. The cone shells 18 are imbedded with inserts 19 (also described as cutting elements or teeth) arranged in annular rows on the cone that penetrate the formation as the drill bit rotates in the hole. Generally, between each pair of cones is a nozzle receptacle 35 with an installed erosion resistant nozzle 30 that directs the fluid from the exit of the nozzle 34 to the hole bottom to move the cuttings from the proximity of the bit and up the annulus to the surface. Additional nozzles may be located elsewhere. The placement and directionality of the nozzle receptacles and nozzles, as well as the nozzle sizing and nozzle extension, significantly affect the rate of penetration for the drill bit and bit life.

[0010] A fixed cutter bit, also referred to as a drag bit, does not have roller cones but instead has rows of cutting elements arranged on its face. An example of a fixed cutter bit is shown in FIG. 3. Bit 32 generally includes a bit body having shank 13. Bit 32 further includes a cutting structure on the face 14 of the drill bit, preferably including various PDC (polycrystalline diamond compacts) cutter elements. Nozzles are placed on the face of the fixed cutter bit in order to distribute and direct drilling fluid to specific regions and or locations of a bit.

[0011] Optimizing the performance and life of a drill bit depends on an enormous number of variables, including variables that change during the drilling program. One variable of particular interest to the invention is the hydraulic pressure of the drilling fluid and the flow of drilling fluid at the drill bit. Controlling the pressure drop across the drill bit may be desirable for a number of different reasons, and under a number of different conditions.

[0012] One difficulty encountered in drilling a borehole, especially for deep wells, is the need to maintain system pressure losses at a value below that of a rig’s pressure rating. In deep wells, system pressure losses increase due to drill string length. System pressure loss is the sum of the pressure losses due to fluid flow through surface equipment, drill string, drill bit and wellbore annulus. In such situations of increased system pressure loss, because a rig has a fixed stand pipe pressure rating, flow rate is decreased, to keep the pressure losses below that of the rig’s constant pressure rating.

[0013] A situation where maintaining a specific pressure drop across a drill bit is desirable is where a drilling tool depends on the pressure drop at the bit. For example, in a long, stepped-out well, the drill string can no longer be pushed along the borehole wall; the friction created by the sliding motion of the drill string against the borehole wall is too great. In such situations, slide mode drilling, needed for wellbore trajectory changes, is almost impossible due to the high wellbore drag values. Rotary steerable tools, which enable constant drill string rotation (no slide mode drilling) even when making wellbore trajectory changes, are much more effective in such instances. Certain types of rotary steerable tools require a specific narrow range of pressure drop values below the tool to make them effective, however. Pressure drop values above and or below the specific value or range lead to tool ineffectiveness or inability to achieve required dog-legs. If the pressure drop is too low, there is not enough energy provided the tool for it to operate properly. If the pressure drop is too great, the seals in the tool are damaged. Consequently, where the pressure drop below the rotary tool does not fall in the required narrow range, the entire drill string must be removed or “tipped” from the well bore, section by section. New nozzles may then be installed on the face of the drill bit to change the pressure drop across the drill bit.

[0014] Increased system pressure losses compromise the efficiencies of rotary steerable tools and bit performance in applications needing specified pressure losses. In the case of rotary steerable drilling when nozzle flow areas are kept constant, and at reduced flow rates, the pressure drop across the bit and the efficiency of the rotary steerable tool are compromised. The pressure drop across the bit makes up the large majority of the pressure drop below the tool. If the pressure drop across the bit can be held to values that permit the operation of the rotary steerable tool, it will be to great
advantage to the success of the drilling program. It would also avoid the need to trip the drill string, which is very time consuming and therefore expensive.

[0015] Another situation where fluid pressure is important is for the cleaning of cutting elements on a drill bit. Cutting elements in plastic shale and other formations tend to suffer from a phenomenon known as “bit balling”. As is known in the art, bit balling describes the packing of formation between components of the drill bit while cutting formation, such as between the cutting elements. When it occurs, cutting elements can become packed off so much that they don’t penetrate into the formation effectively, tending to slow the rate of penetration for the drill bit.

[0016] Fluid directed toward the cones of a roller cone bit, or the blades and or cutters of a PDC or drag bit, can help to clean the cutting elements, thus maintaining or improving the rate of penetration for the bit. A minimum hydraulic horsepower per square inch of borehole area is required, however, in order to clean the cutting elements adequately. A drop in fluid pressure across the drill bit results in a drop in hydraulic horsepower at the bit, leading to poor cleaning of the drill bit’s cutting elements. Similarly, hydraulic horsepower at the bit affects the fluid hydraulics at the bottom of the borehole and may adversely affect the drilling fluid’s ability to remove cuttings from the borehole efficiently.

[0017] There thus is a need for an innovation that can help maintain the required pressure drop across a drill bit, regardless of well depth and or departure, without over compromising the flow rates needed to effectively clean drill bits. Such an innovation, should also apply to any tool or application, where performance is pressure dependent. Ideally, it would be compatible with conventional components used in drilling a wellbore.

SUMMARY OF THE INVENTION

[0018] The invention includes various types of pressure relief nozzles and methods for using them. One or more pressure relief nozzles install on the face of a drill bit, and provide a flow path for drilling fluid. The pressure relief nozzle has a larger internal flow area when flow rates through the drill bit are high, and a smaller flow area when flow rates are low. This response coincides with an increase in the system pressure losses, as flow rate is reduced at greater depths and departures. Upon reduction of the pressure relief nozzle’s internal flow area, the pressure of the drilling fluid tends to stabilize because the total flow area through the drill bit has been reduced. The reduced flow area of the nozzles helps maintain the pressure needed for rotary steerable drilling and in applications that are dependent on high hydraulic horsepower per square inch (HIS) values.

[0019] A pressure relief nozzle according to embodiments of the invention include a hollow nozzle body having an interior passage defining a fluid flow path, and a movable flow control member located in the fluid flow path. The movable flow control member moves between positions, including a fully open position and a fully closed position (although the fully closed position may or may not cut off fluid flow).

[0020] In one embodiment, the movable flow control member may be a plug inserted in the nozzle body. The plug moves linearly with respect to the nozzle body to reduce or increase flow area. The pressure drop across the nozzle or bit, based on flow rates, is affected.

[0021] In another embodiment, the movable flow control member includes a set of one or more sliding ramps that move laterally with respect to the nozzle body to reduce and increase fluid flow through the pressure relief nozzle.

[0022] Other embodiments of the invention include drill bits with at least one pressure relief nozzle that changes its internal flow area in response to changes in flow rate and at least one conventional nozzle that does not change its internal flow area in response to changes in flow rate. Methods for operating such a drill bit are also within the scope of the invention.

[0023] Thus, the invention has a combination of features and advantages that enable it to overcome various problems of prior devices and methods. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

[0025] FIG. 1 is a cut-away view of a wellbore being drilled;

[0026] FIG. 2 is an external view of a rolling cone rock bit;

[0027] FIG. 3 is an external view of a drag bit;

[0028] FIG. 4 is an external view of a base according to a first embodiment of the invention;

[0029] FIG. 5 is an external view of a nozzle body that mates to the base of FIG. 4;

[0030] FIG. 6 is a schematic view of the first embodiment of the invention in a closed position;

[0031] FIG. 7 is a cut away view of a nozzle plug inserted into a nozzle body;

[0032] FIG. 8 is a schematic view of the first embodiment of the invention in an open position;

[0033] FIG. 9A is a schematic view of a second embodiment of the invention;

[0034] FIG. 9B is a top view of a third embodiment of the invention;

[0035] FIG. 9C is a top view of a fourth embodiment of the invention; and

[0036] FIG. 10 is a flow diagram showing a method according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0037] As used herein, the term “closed” refers to and is defined as the pressure relief nozzle in its minimum flow condition even if some fluid is still allowed to flow through the nozzle. The term “fully closed” refers to a no flow, zero flow condition. The term “fully open” refers to and is defined
as the pressure relief nozzle in its maximum flow condition. The term "open" refers to and is defined as the pressure relief nozzle in other than a "closed" or "fully closed" position. It should be noted that these terms should still be viewed in context and may not fully apply when, e.g., using relative terminology such as "more closed" or "more open".

[0038] One of the locations of pressure loss for the drilling system is across the drill bit. A smaller total low area through the drill bit, i.e., for the fluid ejected from the drill bit, results in higher pressure loss across the drill bit, all else being equal. This can be used to affect the pressure drop across the drill bit when fluid flow rates are reduced.

[0039] The pressure relief nozzle of the invention opens to increase flow area, when flow rates are high. The pressure relief nozzle closes, restricting flow area, and establishing the required pressure drop, when flow rates are reduced. The nozzle is capable of repeated opening and closing in response to increases and decreases in flow rate.

[0040] Pressure drops across a drill bit are proportionate to the square of the flow rate, and are inverse to the total flow area (TFA) through the drill bit. When the self-adjusting pressure relief nozzle of the invention closes, either fully or partially, the TFA through the drill bit is reduced. The reduction in TFA partially compensates for the reduced pressure drop that will have occurred if the flow area was kept constant. Thus, the pressure drop across the bit may be kept close to constant, such as within 5% or 10% for a given reduction in flow rate. This maintenance of the pressure drop may require a plurality of pressure relief nozzles installed in the drill bit.

[0041] In operation there may be five nozzles installed on the face of a drill bit, only one or two constructed to be a pressure relief nozzle of the invention. As drilling begins, there may be 1,000 gallons of drilling fluid per minute being pumped through the drill bit, and the TFA may be one square inch. The pressure drop across the bit may be 750 psi. As the drilling proceeds and goes deeper, the pressure losses increase. As fluid flow is reduced in response to increased pressure losses, fluid flow may be cut to 800 gallons per minute. Total flow area may be reduced to 0.7 square inches by the contraction in flow area in the pressure relief nozzles. The pressure drop across the drill bit would be approximately the same as it was before.

[0042] A first embodiment of a self-adjusting pressure relief nozzle includes a nozzle body and a nozzle plug inserted into the nozzle body. Referring to FIG. 4, a plug 404 includes a head 406 and a base 402. Base 402 includes holes 408 at its lower end that facilitate the flow of drilling fluid through the pressure relief nozzle when it is in an open or fully open position. Plug 404 inserts into the nozzle body to form the first embodiment of a pressure relief nozzle.

[0043] An external view of a nozzle body 500 according to the first embodiment is shown in FIG. 5. Nozzle body 500 has an upper end 502 (the body 500 being in an inverted position). Upper end 502 includes threads 504 suitable to engage a standard nozzle receptacle in the face of a drill bit. Other mating structures may of course be used. Body 500 also includes a lower portion 506. Lower portion 506 includes an opening 508 sized to accept nozzle plug 404. Plug 404 locks into opening 508 by any appropriate means, e.g., suitable complementary geometries between the base of the nozzle plug 404 and the opening 508.

[0044] FIG. 6 shows a fully closed position for the first embodiment. Plug 404 having base 402 and head 406 inserts into nozzle body 500. Nozzle body 500 is hollow and includes an internal passage 608 with internal surface 602 that defines a fluid flow path. Head 406 abuts against the internal surface 602 of hollow nozzle body 500 to form a liquid-tight seal against passage 608 when in the fully closed position. Consequently, the minimum diameter of this embodiment's fluid flow path is zero when the nozzle plug is in the low flow condition.

[0045] Referring to FIG. 7, head 406 slides vertically (linearly) relative to base 402 by opposing hydraulic load 702 and spring forces 704. In the absence of a hydraulic load, spring 706 forces the head 406 to a fully extended position relative to base 402. Upon the application of a sufficient hydraulic load to the head 406, the head is compressed toward the base 402, opening the pressure relief valve. In this embodiment, the linear sliding of the head 406 relative to the base 402 opens and closes the pressure relief valve. The amount of hydraulic load necessary to compress head 406 toward base 402 may be adjusted by selection of spring strength.

[0046] FIG. 8 shows a fully open position for the first embodiment. As is appreciated by those of ordinary skill in the art, drilling fluid flows according to a pressure gradient, from a high pressure location to a low pressure location. The magnitude of the hydraulic load is therefore established by the difference in fluid pressures above and below the pressure relief nozzle. Sufficient hydraulic load 702 removes head 406 from the internal surface 602 of hollow nozzle body 500. Drilling fluid 810 then flows through the pressure relief valve. If the head of the nozzle plug is forced an adequate distance from its seating location against the interior passage, the flow area of the nozzle is that of the interior passage of the nozzle when the nozzle plug is in a high flow location.

[0047] A second design of a pressure relief nozzle is shown in FIG. 9A. Nozzle body 902 includes internal passage 911 that forms a fluid flow path 903. Base 904 supports sliding ramps 906. Springs 910 attach between sliding ramps 906 and shoulder 908 formed in nozzle body 902. Low pressure flow diameter 912 and high pressure flow diameter 914 are also shown.

[0048] Low flow diameter 912 is the minimum diameter of the fluid flow path when the pressure relief nozzle is operating under low flow conditions. High flow diameter 914 is the minimum diameter of the fluid flow area when the pressure relief nozzle is operating under high flow conditions. In other words, although greater in area than low flow diameter 912, high flow diameter 914 is smaller than interior passage 911. Diameter 914 is the location of minimum flow area in the pressure relief nozzle when the nozzle is under high flow conditions. Under high flow conditions, the sliding ramps move laterally outward from the inward, closed position of the low fluid flow condition. As the flow rate is reduced, the sliding ramps move laterally inward from an outward, more open position. Thus, in this embodiment, the lateral sliding of the ramps 906 relative to the base 904 opens and closes the pressure relief valve. The amount of fluid pressure (hydraulic, load) necessary to open the valve may be adjusted by selection of spring strength. It will be appreciated that similar results could be obtained even if only a single sliding ramp were employed.
Several ramps of different geometries can be used to achieve the same effects. Referring to FIG. 9B, the flow path may include an opening, for example, at its center that opens from a smaller flow area A at its center under low flow conditions to a larger flow area, B, under high flow conditions. As another example, a "pie slice" area of the flow path may slide open under high flow rate conditions and slide close under low flow rate conditions, as generally shown in FIG. 9C.

A drill bit designed according to the principles of the invention has a smaller TFA at lower flow rates than higher flow rates. The exact relationship between TFA and flow rates, and the layout and number of pressure relief nozzles on the face of the drill bit, may be left to the drill bit designer of ordinary skill and will vary depending on the drilling program and the requirements of, e.g., a given rotary drilling tool. In each case, however, a reduction in TFA in response to a lower flow rate tends to moderate the variation in pressure drop across the drill bit.

From the perspective of an operator, the controllable variable is flow rate of the drilling fluid. A method according to the invention includes the repeated opening and closing of a drill bit nozzle based upon flow rate of drilling fluid through the drill bit. Referring to FIG. 10, at step 1010 a pressure relief nozzle is installed in a drill bit. At step 1015, the flow rate increases and the pressure relief nozzle opens from a smaller minimum diameter to a larger minimum diameter. This may be the initial pumping of drilling fluid through the drill bit. At step 1020, the pressure relief nozzle closes from a larger minimum diameter to a smaller minimum diameter. At step 1025, flow rate again increases and the pressure relief nozzle reopens from the smaller minimum diameter to the larger minimum diameter.

While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims which follow, the scope of which shall include all equivalents of the subject matter of the claims.

What is claimed is:

1. A pressure relief nozzle, comprising:
   a. a hollow nozzle body having an upper end, a lower end, and an interior passage connecting said upper end to said lower end and defining a fluid flow path for fluid flowing through said interior passage;
   b. a flow control member located in said fluid flow path, said flow control member movable between a first position and a second position, dependent upon a difference in fluid pressure of said fluid at said upper end and said lower end of said nozzle body.
2. The pressure relief nozzle of claim 1, said upper end including means for connecting said nozzle body to a nozzle bore in a drill bit body.
3. The pressure relief nozzle of claim 1, said first position being a fully open position and said second position being a fully closed position.
4. The pressure relief nozzle of claim 1, said flow control member being a plug inserted in said nozzle body.
5. The pressure relief nozzle of claim 1, said flow control member moving linearly with respect to said nozzle body to move from said first position to said second position.
6. The pressure relief nozzle of claim 1, said flow control member moving laterally with respect to said nozzle body to move from said first position to said second position.
7. The pressure relief nozzle of claim 6, said flow control member including a ramp.
8. The pressure relief nozzle of claim 6, said flow control member including a sliding ramp.
9. The pressure relief nozzle of claim 6, said flow control member including a first ramp and a second ramp.
10. The pressure relief nozzle of claim 6, said flow control member including a first sliding ramp and a second sliding ramp.
11. The pressure relief nozzle of claim 1, said first position allowing fluid flow through said pressure relief nozzle and said second position not allowing fluid flow through said pressure relief nozzle.
12. The pressure relief nozzle of claim 1, said first position defining a first diameter for said interior passage and said second position defining a second diameter for said interior passage, said first diameter being larger than said second diameter.
13. The pressure relief nozzle of claim 1, said flow control member being repeatedly movable from said first position to said second position, and from said second position to said first position.
14. The pressure relief nozzle of claim 13, said first position defining a first diameter for said interior passage and said second position defining a second diameter for said interior passage, said first diameter being larger than said second diameter.
15. The pressure relief nozzle of claim 1, said flow control member controlling a flow area for said fluid flow path, said first position providing a larger flow area than said second position.
16. A method for operating a pressure relief nozzle, comprising:

   - installing a pressure relief nozzle to a drill bit body, said pressure relief nozzle having a fluid flow passage, said fluid flow passage having a first minimum diameter and a second minimum diameter dependent upon a pressure of fluid in said fluid flow passage, said first diameter being smaller than said second diameter;
   - opening said pressure relief nozzle from said first diameter to said second diameter, and
   - closing said pressure relief nozzle from said second diameter to said first diameter.
17. The method of claim 16, further comprising:

   - re-opening said pressure relief nozzle.
18. The method of claim 17, said pressure having an initial value and staying within ten percent of said initial value throughout said opening, closing, and re-opening steps.
19. The method of claim 17, said pressure having an initial value and staying within five percent of said initial value throughout said opening, closing, and re-opening steps.
20. The method of claim 16, further comprising:
installing a second pressure relief nozzle to said drill bit body; said second pressure relief nozzle having a second fluid flow passage, said second fluid flow passage having a first minimum diameter and a second minimum diameter dependent upon said pressure of fluid in said second fluid flow passage, said first diameter of said second fluid flow passage being smaller than said second diameter of said second fluid flow passage;
opening said second pressure relief nozzle from said first diameter to said second diameter; and
closing said second pressure relief nozzle from said second diameter to said first diameter.
21. The method of claim 16, further comprising:
increasing fluid flow through said fluid flow passage from an initial flow value simultaneous with said opening step;
reducing fluid flow through said fluid flow passage simultaneous with said closing step.
22. A drill bit comprising:
a drill bit body;
a pressure relief nozzle installed into said drill bit body, said pressure relief nozzle comprising
hollow nozzle body having an upper end, a lower end, and an interior passage connecting said upper end to said lower end and defining a fluid flow path for fluid flowing through said interior passage;
a flow control member located in said fluid flow path, said flow control member movable between a first position and a second position, dependent upon a difference in fluid pressure of said fluid at said upper end and said lower end of said nozzle body.
23. The drill bit of claim 22, further comprising:
a second pressure relief nozzle installed into said drill bit body, said second pressure relief nozzle comprising,
hollow nozzle body having an upper end, a lower end, and an interior passage connecting said upper end to said lower end and defining a fluid flow path for fluid flowing through said interior passage;
a flow control member located in said fluid flow path, said flow control member movable between a first position and a second position, dependent upon a difference in fluid pressure of said fluid at said upper end and said lower end of said nozzle body for said second pressure relief nozzle.
24. The drill bit of claim 22, said first position being a fully open position and said second position being a fully closed position.
25. The drill bit of claim 22, said flow control member being a plug inserted in said nozzle body.
26. The drill bit of claim 22, said flow control member moving linearly with respect to said nozzle body to move from said first position to said second position.
27. The drill bit of claim 22, said flow control member moving laterally with respect to said nozzle body to move from said first position to said second position.
28. The drill bit of claim 27, said flow control member including a ramp.
29. The drill bit of claim 27, said flow control member including a sliding ramp.
30. The drill bit of claim 27, said flow control member including a first ramp and a second ramp.
31. The drill bit of claim 27, said flow control member including a first sliding ramp and a second sliding ramp.
32. The drill bit of claim 22, said first position allowing fluid flow through said pressure relief nozzle and said second position not allowing fluid flow through said pressure relief nozzle.
33. The drill bit of claim 22, said first position defining a first diameter for said interior passage and said second position defining a second diameter for said interior passage, said first diameter being larger than said second diameter.
34. The drill bit of claim 22, said flow control member being repeatedly movable from said first position to said second position, and from said second position to said first position.
35. The drill bit of claim 22, said drill bit further comprising a second nozzle, said second nozzle having a hollow nozzle body with an upper end and a lower end connected by a flow path, there being a difference in fluid pressure between said upper end of said second nozzle and said lower end of said second nozzle, said flow path of said second nozzle having a constant flow area regardless of said pressure difference between said upper end of said second nozzle and said lower end of said second nozzle.

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