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JET SUB FOR DRILLING WELL BORES

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Fig. 1

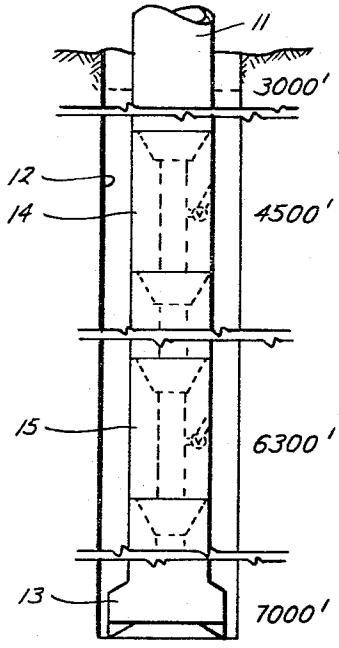


Fig. 2

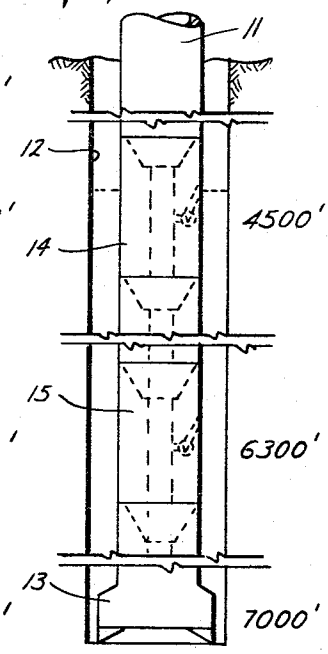


Fig. 3

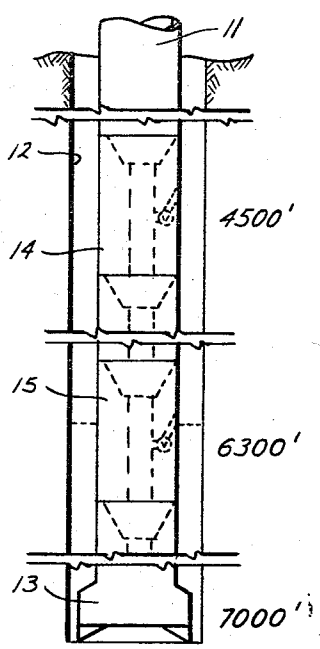
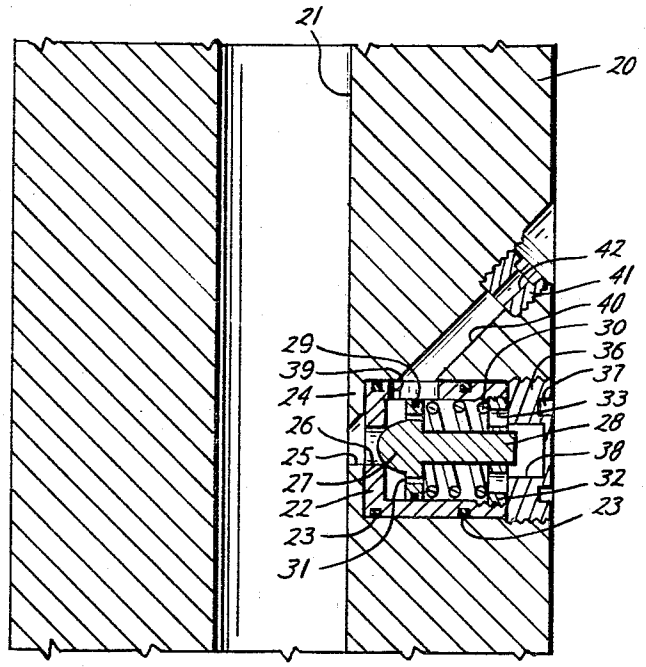


Fig. 4



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JET SUB FOR DRILLING WELL BORES

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ABSTRACT OF THE DISCLOSURE

A pressure responsive jet sub for including in a drill string wherein gas is used as a circulating fluid. The sub is adapted for evacuating slugs of liquid that may accumulate in the annulus during drilling operations.

This invention relates to a pressure responsive jet sub for including in a string of drill pipe. More particularly, the invention relates to an automatic pressure responsive jet sub for including in a string of drill pipe for removing liquid slugs from the well bore during rotary drilling operations. It has particular application in rotary drilling operations wherein a gas, such as air, or an inert gas, is used as the circulating fluid to remove the cuttings from the well bore.

When performing a rotary drilling operation utilizing air as the circulating fluid, quite often the drilling operation is greatly impeded by the influx into the bore hole of water from the earth formations traversed. The collection of water or other fluids in the bore hole causes at least two major problems. One of these problems relates to the condition which results when water or other liquid flows into the hole following a trip of the drill pipe out of the hole to change bits or during the addition of a length of pipe to the drill string. When this occurs, a higher or greater amount of air pressure is required to effect circulation of the air down through the drill pipe, past the drilling bit and out the annulus, to thereby remove the liquid from the well bore, than is required during normal drilling operations where there is no liquid or water collected in the bore hole. The amount of air pressure required is a function of the amount of water or fluid collected in the bore hole, but nevertheless is considerably above the normal air circulating pressure. Once the water or liquid is pushed from the drill pipe, the air or gas being used as the circulating fluid goes around the bit and into the annulus and the water or other liquid is thereby blown upwardly and unloaded. Hence, the amount of pressure necessary to accomplish this unloading will be greater than that required for normal drilling operations and quite often will be so much greater that a static condition will exist in the pipe which will thereby block the circulation of the gas used as the circulating fluid, and hence, stop drilling operations.

A second and related problem arises when water or other fluid flows into the bore hole during the actual drilling phase of the drilling operations, i.e. when the drill bit is being rotated. In this instance, water or other liquids accumulate in the annulus, causing pressure surges at the pressure discharge and in the bore hole. Hence, it is desirable to have a tool and method which will eliminate both of the aforesaid problems.

One prior art attempt at solving these problems was by the use of a device commonly referred to as a jet sub. This sub was run in the drill string above the bit and had a fixed orifice for discharging from the inside of the drill pipe to the annulus. A portion of the air was diverted continuously during the unloading and drilling phase. This method partially alleviated the foregoing problems, but had a serious disadvantage in that a portion of the air or circulating fluid was continuously diverted whether or not it was needed. Hence, the full flow of the circulating fluid was not through the bit. This tended to slow penetration rate of the bit in relation to the quantity of air or other drilling fluids which was diverted. A further problem was the difficulty of selecting a size for the orifice which would be proper under all circumstances that might arise.

Another prior art attempt at solving the foregoing problems was the use of sleeve type valve carried in a jet sub such that by increasing the velocity of the circulating fluid, which in this instance was a liquid, a valve would thereby be actuated. This method had the serious disadvantage that the sleeve members caused an obstruction in the pipe bore thereby reducing the quantity of fluid which would flow therethrough. In addition, these particular sleeves did not prove satisfactory, particularly where the drilling fluid was a gas such as air. Hence, it is an object of the present invention to provide an improved automatic jet sub overcoming the foregoing shortcomings of the prior art and providing solutions to the above described problems.

Briefly stated, the pressure responsive sub of this invention is adapted for including in a string of drill pipe during rotary drilling operations and has threaded upper and lower ends for threadably engaging with adjoining lengths of pipe. The jet sub has a cylindrical body member, preferably tubular in shape, having a generally unobstructed axial bore therethrough. The body member is also provided with a jet opening extending through the wall of the body member, which jet opening communicates between the axial bore of the body member to the outside surface thereof. A pressure responsive valve means is also mounted in the wall of the body member and is adapted for controlling the passage of fluid through the jet opening. Preferably, the jet opening extends upwardly and outwardly from a point in the axial bore to the outside of the body member, although this is not absolutely necessary in all instances. The pressure responsive valve means is preferably a resiliently biased pressure responsive valve mounted in the wall of the body member so as not to obstruct the axial bore of the sub. This valve will normally be in the closed position and will open at a predetermined pressure level. This pressure level is a differential pressure between the outside of the valve and the inside of the valve, i.e. the pressure inside the pipe bore and the pressure in the annulus. This valve means can have adjusting means for setting the valve to open at a predetermined pressure differential. The valve may also be constructed to be demountable so that valves of different pressure sensitivity may be substituted therefor.

This invention is adapted for removing unwanted liquid, such as liquid slugs, from a well bore during drilling operations wherein gas is used as the circulating fluid. This is carried out by forcing gas downwardly through the bore of the drill pipe through the drill bit. A portion of this gas is diverted out an opening spaced above the drill bit when the liquid builds up in the well bore above the point of the diversion. This diversion is accomplished without increasing the velocity of gas in the pipe, and is terminated when the liquid has been removed from above the opening.

Reference to the drawings will further explain the invention.

FIG. 1 is a side elevation view of a well bore having centrally positioned therein a string of drill pipe carrying two automatic jet subs of the instant invention, and showing the liquid level that may be present upon initial resumption of the drilling operations.

FIG. 2 is a view similar to FIG. 1 showing the liquid level after the upper jet sub has performed an unloading operation.

FIG. 3 is a view similar to FIGS. 1 and 2, showing the level of the liquid slug after the lower jet sub has performed an unloading operation.

FIG. 4 is a fragmentary central vertical sectional view of one of the jet subs shown in FIGS. 1, 2, and 3, and shows the details of one embodiment of the instant invention.

Referring now to FIGS. 1, 2, and 3, it will be observed that a string of drill pipe **11** is inserted in bore hole **12**. Drill pipe **11** has suspended on the lower end thereof drill bit **13**. Spaced upwardly from drill bit **13** and below the well head are two jet subs of the instant invention indicated as upper jet sub **14** and lower jet sub **15**. The space between drill pipe **11** and bore hole **12** will be referred to as the annulus. It is to be understood that upper jet sub **14** and lower jet sub **15** are axially spaced apart from each other with a length or more of drill pipe therebetween. Hence, subs **14** and **15** each have threaded ends for threadably engaging adjacent lengths of drill pipe.

Referring now to FIG. 4, it will be observed that the sub is provided with body member **20** which is generally cylindrical in shape or tubular and has axial bore **21** extending axially therethrough. Bore **21** is unobstructed and is generally of uniform size throughout, and transmits the circulating fluid downwardly through the drill pipe.

Body member **20** is provided with a valve opening extending radially inwardly from the outside surface to the axial bore and communicating with the axial bore. This valve opening is shown having inserted therein cylindrical shaped valve body **22**, having a pair of spaced apart O-ring seals **23** positioned thereabout. It will be observed that the base of the valve opening terminates short of the axial bore **21** whereby a partition wall **24** is provided therebetween. However, partition wall **24** is provided with a small annular central opening **25** which communicates with the valve opening and may be considered a part thereof.

The forward end of valve body **22** is provided with a small valve opening **26** which matches the central opening **25**. A resiliently biased valve is carried in valve body **22**, which valve has an annular valve head **27** attached to the fore end of valve stem **28**.

Valve head **27** is annular in shape and supports O-ring seal **29** thereabout which engages the inside surface of valve body **22**. The fore end of valve head **27** is dome shaped for seating in valve opening **26** and thereby controlling the flow of fluids through central opening **25** from axial bore **21**.

Valve head **27** is normally biased to the closed position as shown in FIG. 4 by operation of compression spring **30**, which surrounds the valve stem **28**. Valve head **27** is also provided with a plurality of pressure relief openings **31** which communicate with the spaces on each side of the valve head **27**.

Valve body **22** is also provided with adjusting means whereby the tension on spring **30** may be adjusted to permit the opening of the valve at a specified pressure differential. This means takes the form of adjusting plate **32** which threadably engages the rear or outward end of valve body **22**. Adjusting plate **32** is provided with appropriate relief ports **33**, which ports may also serve as wrench fittings for screwing or turning adjusting plate **32** relative to valve body **22**. Hence, by adjusting the extent to which adjusting plate **32** is threaded into valve body **22**, control is exercised over the amount of pressure required to actuate the valve by compression of spring **30**.

The valve assembly, including valve body **22**, is held in the valve opening by means of valve cover **36** which threadably engages body member **20** and abutts against valve body **22**. The outside surface of cover **36** is provided with a plurality of wrench fitting openings **37** which permit the turning of valve cover **36** and thereby threadably engaging body member **20**. The inside surface of valve cover **36** is depressed in the form of valve recess **38** which

permits valve stem **28** to move freely outwardly or rearwardly.

Valve body **22** is also provided with connecting opening **39** which is positioned near the base of the valve opening and which communicates with jet opening **40**, which extends upwardly and outwardly from axial bore **21** to the outside surface of body member **20**. The upper end of jet opening **40** is reduced, which reduction is accomplished by plug **41**, which threadably engages body member **20**, and has a reduced orifice **42** therethrough. Orifice **42** may be fitted with an enlarged exterior end so as to admit of a wrench for threading plug **41** into body member **20**.

It will be observed that not only may the valve means be adjusted to be actuated at different pressure levels, but the whole valve assembly or valve body member **22** can be removed and a different valve inserted therein which will be responsive to a different pressure level.

In operation, when the gas pressure in axial bore **21** exceeds the pressure level set on the valve assembly, then valve head **27** moves radially outward, thereby permitting the escape of the gas out central opening **25**, through connecting opening **39**, out jet opening **40**, and out orifice **42** to the annulus surrounding the pipe. When the water or liquid level in the annulus is above orifice **42**, the water will be percolated or forced upwardly in the annulus and thereby removed from the well bore. While jet opening **40** has been described as extending upwardly and outwardly, in some embodiments it can be horizontal, although the upwardly and outwardly extending jet opening is preferred because of the more direct force exerted on the water or liquid.

Referring now to FIGS. 1, 2, and 3, the operation of a drill string with two valve subs of the instant invention will be described. During the initiation or resumption of drilling operations after a shut down, it may be assumed that the liquid slug in the drill pipe **11** is at the 3,000 foot level as shown. It is further assumed that the well bore is 7,000 feet deep, that the maximum well head pressure available is 1,000 p.s.i., that the drill pipe has a 3½" I.D. and 4½" O.D., that the bore hole is 12½" in diameter, that the gas pressure in the drill pipe is not sufficient to evacuate the fluid slug from the well bore without resorting to the instant invention, and that drilling operations could not proceed.

Depending upon the specific gravity of the liquid slug, the amount of liquid lost through the formation during pressure up, and other variables, it will be assumed that with a maximum well head pressure of 1,000 p.s.i., a static condition would be reached when the level of the liquid slug in the axial bore of the drill pipe reaches 5,410 feet, for example, and the liquid slug level in the annulus reached 2,650 feet for example. Hence, it is necessary to place one of the valves of the instant invention above the 5,410 foot level and below the 2,650 foot level. By diverting a portion of the gas in this depth range, the liquid slug above the diversion point will be removed from the well bore. Hence, upper sub **14** might be placed at the 4,500 foot level, for example. Upper jet sub **14** could, for example, have a valve which would be activated at 300 p.s.i. differential between the axial bore and the annulus. When the well head or surface pressure in drill pipe **11** reaches 1000 p.s.i., the valve of upper jet sub **14** will open and unload water from above the 4500 foot level to the surface, as shown in FIG. 2.

I.D. gas pressure in the bore of the drill pipe will then cause the liquid level to drop to a new lower level such as 6800 feet, for example. As the liquid level in the drill pipe drops, the liquid level in the annulus rises, but is unloaded by gas emitting from upper jet sub **14**, with another static condition occurring at the aforesaid 6800 foot level.

Thus, another jet opening, such as lower jet sub **15**, is inserted in the drill string at the 6300 foot level, which again is above the fluid level in the pipe at the new static

condition but below the liquid level in the annulus. The pressure differential on the valve in lower jet sub **15** would be set for any convenient pressure differential, but the lower the pressure differential setting, the deeper the valve can be placed and the fewer number of valves required. For example, the valve in lower jet sub **15** might be set to actuate at a pressure differential of 200 p.s.i. Hence, by placing it at the 6300 foot level, the liquid slug thereabove can be removed from the well bore when the well head pressure reaches 1000 p.s.i., as shown in FIG. 3. Then pressure in the bore of the drill pipe will force the fluid slug therein downwardly and put the circulating fluid or gas around the bit to complete the unloading process.

When the liquid slug is unloaded and air is flowing through the bit, the surface pressure and drill pipe pressure at a given air flow rate will drop to a low value determined by the area of the jets in the bit. When this pressure drops below the setting of the jet sub valves, they will close and all of the air will be directed around the bit.

If a slug of water or the liquid builds up after the actual rotation of the drill pipe resumes, and after the foregoing unloading has been accomplished, the pressure effect of this slug will be transmitted inside the drill pipe and the pressure therein will rise above the opening pressure for the lowest valve and this valve will open, pushing some air into the annulus to help unload the slug. If this inflow of liquid into the annulus is greater than can be satisfied or removed by the lower most valve, then the pressure inside the drill pipe will continue to increase and as a result thereof the upper valve opens.

It is to be understood that any number of such valves could be used and axially spaced along the drill pipe string. Also, the foregoing specific figures are given as examples only and the various levels at which the valves are utilized will depend, of course, upon maximum compressor output, maximum compressor volume, depth of the well bore, height of the water level or fluid slug, density of the water or liquid slug to be removed, and the differential pressure across the drill bit required for normal dry hole drilling. The foregoing variables will thereby determine the differential pressure to set on the valves controlling the jet openings, the choke size or orifice size in the jet openings, and the spacing of the valves.

Referring now to FIG. 4, it will be observed that plug **41** may be removed and a different plug with a different size orifice **42** substituted therefor. While such a discharge orifice is not essential to the operation of the automatic jet sub valve, the use of such a discharge orifice as orifice **42** provides flexibility of operation. It is to be understood that the size of valve opening **26** and of orifice **42** determine both the pressure that builds up in the drill pipe at a given volume of gas flowing through the valve, and the volume of gas flowing through the valve at a given pressure. Because it is not convenient to change the size of valve opening **26**, greater flexibility is acquired by having the size of orifice **42** changeable by changing plug **41**.

During down hole drilling operations when the drill bit is actually being rotated, it is important that the volume of gas flowing through the valves in upper jet sub **14** and lower jet sub **15** be such that the bit will never be completely starved of gas circulation. In other words, it is necessary that not all of the gas circulation be diverted by the jet subs. Thus, when the valves open, the volume of gas flowing through the sum of the valves must be less than the total volume of gas flowing into the drill pipe.

It is generally not convenient to change the size of valve openings **26**. If there were no orifice **42** positioned on the end of jet opening **40**, the volume of gas flowing through the valve would be controlled only by the size of valve opening **26** which might be ¼" diameter, for example, at pressures greater than the bias of the valve.

If two valves were utilized which had a bias or were set to operate at a pressure of 300 p.s.i., for example, and assuming that the drill pipe pressure was 400 p.s.i., the flow rate through one valve would be about 300 c.f.m., or with two valves, 600 c.f.m. If it should occur that this rate of flow through the valves would starve the bit of gas circulation, it is desirable to reduce the volume of gas that would flow through the valves. This is done by placing an orifice, such as orifice **42**, in the end of jet opening **40**. Orifice **42** may, of course, be less than ¼" in diameter.

If, for example, orifice **42** were ¼" in diameter, then the volume of gas flowing through the valve at 400 p.s.i. drill pipe pressure would be that volume of gas which would lead to a pressure in jet opening **40** that is equal to the drill pipe pressure (400 p.s.i.) minus the setting of the valve (300 p.s.i.) or 100 p.s.i. Valve head **27** would then chatter by rapid opening and closing to limit the volume of gas flowing through the valve, the rate equivalent to 100 p.s.i. across a ¼" orifice **42** which would be equivalent to about 80 c.f.m.

In summary, the discharge orifice **42** exerts control over the volume of gas that will flow through the valve at a given drill pipe pressure. Hence, the valve with orifice **42** in operation has a metering action whereby the amount of gas discharged therefrom is that volume that will give a pressure in jet opening **40** that is less than drill pipe pressure by the pressure bias of the valve.

By placing a discharge orifice such as orifice **42** in jet opening **40**, the number of valves required in any particular drill string is reduced.

Thus, the diverting of a portion of the gas out of the jet openings is accomplished without increasing the velocity of the gas in the pipe. To state it another way, the blow out or removal of the liquid slug is accomplished by opening of the valves while maintaining the velocity of the gas in the pipe at a rate no greater than the rate obtaining prior to initiation of the diverting. It will also be observed that the diversion of the gas is terminated when the liquid slug has been removed, thereby permitting the full flow of gas to be around the drill bit. Full advantage can be taken of the cleansing effect of the full gas flow to the bottom of the well bore to remove cuttings therefrom.

It will be observed that the operation of the valves and the jet subs of this invention are not dependent upon an increase in velocity of the circulating fluid in the drill pipe bore in order to be actuated. Moreover, the unobstructed design of the bore of the jet sub permits the free flowing of the circulating fluid therethrough and is not hindered by any obstructions therein such as a venturi type sleeve or the like. By use of this invention, it is now possible to utilize an air compressor at the well head, which compressor has a lower output and hence permits the operation over a wider range of conditions for a given size compressor. Not only that, but the instant invention also permits the full flow of the circulating fluid to be directed through the bit during times when no water or liquid slug is present in the well bore. This greatly enhances and speeds the drilling operation.

Further modifications may be made in the invention as particularly described without departing from the scope of the invention. Accordingly, the foregoing description is to be construed illustratively only and is not to be construed as a limitation upon the invention as defined in the following claims.

What is claimed is:

1. A pressure responsive jet sub for including in a string of drill pipe for removing liquid slugs from the well bore during drilling operations in which gas is used as the circulating fluid, comprising:

a generally tubular body member having a generally unobstructed axial bore therethrough of generally uniform size throughout,

said body member having a jet opening extending upwardly and outwardly through the wall thereof and

which opening has a reduced orifice at the upper end thereof,

a resiliently biased pressure responsive valve mounted entirely within the wall of said body member and controlling the passage of gas through said jet opening, and

adjusting means for setting said valve to open only when the pressure differential between said axial bore and the annulus around said pipe exceeds a predetermined level.

2. The apparatus as claimed in claim **1** wherein:

said valve is demountable from said body member, whereby valves of different pressure sensitivity may be substituted therefor.

3. A pressure responsive jet sub for including in a string of drill pipe for removing liquid slugs from the well bore during rotary drilling operations in which gas is used as the circulating fluid, comprising:

a generally tubular body member having a generally unobstructed axial bore therethrough, and generally uniform size throughout,

said body member having a jet opening extending upwardly and outwardly through the wall thereof,

replaceable plug means mounted in said body member and in said jet opening and having a reduced orifice therethrough for controlling the rate of gas flow out said jet opening,

a resiliently biased pressure responsive replaceable valve mounted entirely within the wall of said body member and controlling the passage of gas through said jet opening, and

adjusting means connected to said valve for setting said valve to open only when the pressure differential between said axial bore and the annulus around said pipe exceeds a predetermined level.

4. A pressure responsive jet sub for including in a string of drill pipe for removing liquid slugs from the well bore during rotary drilling operations in which gas is used as the circulating fluid, comprising:

a generally tubular body member having a generally

unobstructed axial bore therethrough and generally uniform size throughout,

said body having a valve opening extending radially inwardly from the outside surface to said axial bore and communicating with said axial bore, and

a jet opening extending upwardly and outwardly from a point near the base of said valve opening to the outside surface of said body member, whereby said jet opening communicates with said axial bore through said valve opening,

replaceable means mounted in said body member and in said jet opening and having a reduced orifice therethrough for controlling the rate of gas flow out said jet opening,

pressure responsive valve means mounted in said valve opening and entirely within the wall of said sub for controlling the passage of fluid through said jet opening, said valve means being adapted for insertion in said valve opening from the outside surface of said body member,

said valve means being adapted to normally be in the closed position, and to open when the pressure differential between said axial bore and the annulus around said pipe exceeds a predetermined level.

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