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APPARATUS FOR TREATMENT OF HYDRAULIC JET DRILLING LIQUID

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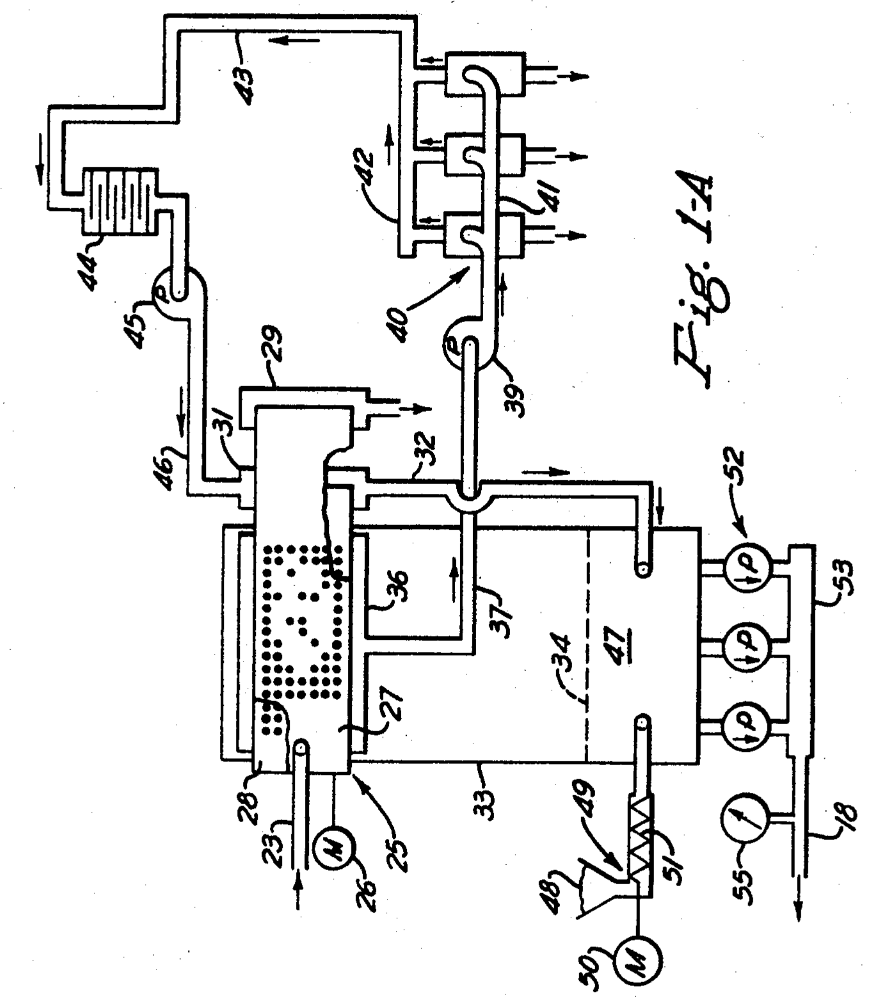

Fig. 1-A

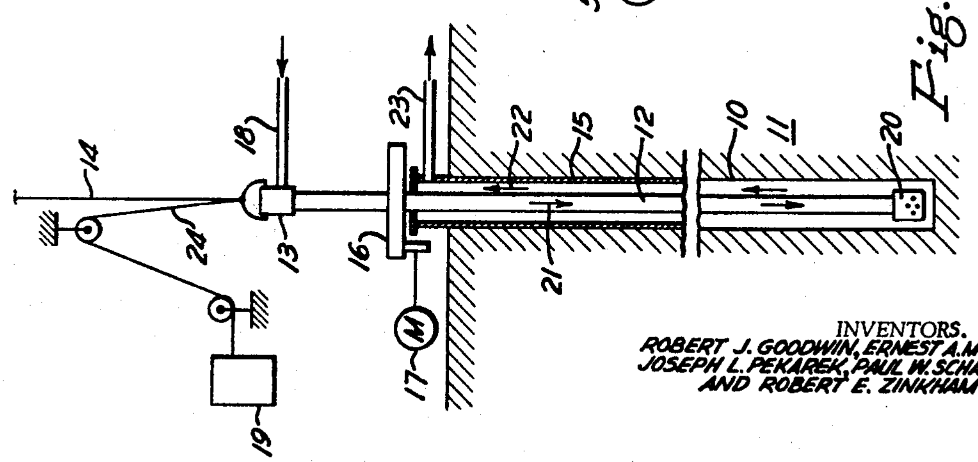

Fig. 1

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3,399,739

APPARATUS FOR TREATMENT OF HYDRAULIC JET DRILLING LIQUID

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5 Claims. (Cl. 175—206)

ABSTRACT OF THE DISCLOSURE

Apparatus for treating an abrasive-laden liquid used in hydraulic jet drilling of wells. The apparatus includes a first separator for removing from the drilling liquid solid particles larger than the abrasive particles, a second separator for removing the abrasive particles, and a third separator for removing the particles smaller than the abrasive particles. The liquid from the third separator is mixed with abrasive particles and returned, without admixture with a liquid containing any appreciable concentration of particles other than the abrasive particles, to the well for further drilling.

This application is a division of application Ser. No. 311,035, filed Sept. 24, 1963.

This invention relates to the drilling of boreholes in the earth and in particular concerns an apparatus for treating the drilling fluid employed with a hydraulic jet drill.

Conventional devices for drilling deep boreholes function by making physical contact of the cutting surfaces of a metal drill bit with the rock formation at the bottom of the hole to mechanically cut the rock away. Such drill bits as the well known fish-tail bit, drag bit, core bit, roller bit, cone bit, disk bit, etc., all operate to make hole by mechanically breaking up the rock at the bottom of the hole whence the cuttings are removed to the surface of the earth by means of a circulating fluid medium such as air, foam, or drilling mud. In mechanically breaking up the rock it is inevitable that a substantial amount of wear and breakage also occurs to the cutting elements of such a drill bit, so that eventually the bit wears out and can no longer make hole. The drill stem must then be withdrawn from the hole, the bit replaced, and the bit stem with the new bit reinserted in the borehole. In drilling hard formations in a deep hole the time spent replacing conventional drill bits may exceed the actual drilling time on bottom, and this results in a loss of efficiency and very substantially increases the expense of the drilling operation.

Hydraulic jets have heretofore been included with conventional drill bits, but these jets have been for the purpose of keeping the cutting edges of the drill bit, or the rock surface being cut, free from mud and chips produced by the bit and thereby increase the efficiency of the mechanical cutters on the bit. However, such ancillary jets as have been employed with conventional rock bits have no effective cutting action when operated with the pressures normally employed for fluid circulation in conventional mechanical drilling operations.

We have found that when hydraulic jets are operated at very high pressure so that extremely high velocities are attained by the emerging jet stream, the fluid jet is very effective in making hole in hard rock. By omitting substantially all mechanical cutters from the drill bit there is obtained a bit that is substantially free of mechanical

wear or breakdown. Accordingly when such a bit is used in the hole, it will remain effective to make hole for a much longer period of time than a bit that includes mechanical cutting elements. Also due to the fact that the jets tear up the rock into very small fragments, the cuttings are more easily removed by the circulating fluid than are the larger cuttings made by conventional mechanical drill bits. Furthermore, because of the mechanical simplicity of such an all-jet bit, such bits are very sturdy and are also relatively inexpensive, thus resulting in a further saving of drilling expense. In addition when such bits are operated in accordance with this invention they are found to make hole at a much faster rate than conventional mechanical bits.

We have found that when a plurality of hydraulic jet streams of extremely high velocity are rotated in a borehole, very effective cutting action is obtained even in hard rock. In accordance with this invention, the velocity of said streams exceeds the critical minimum cutting velocity for the earth material being penetrated. It is to be noted that in contrast to prior-art drilling devices, there is substantially no physical contact of the tool employed to produce said hydraulic jets with the surfaces of the earth formation being drilled or bored. Thus, the tool or "bit" used in hydraulic jet drilling is substantially free of the wear or breakdown occasioned by the physical contact of prior-art bit surfaces with the rock formation being drilled.

Although we have for convenience herein used the term "bit" to describe the drilling tool of the present invention, from the foregoing and the detailed description which follows it will be apparent to those skilled in the art that the process and apparatus of the present invention are entirely different from prior-art drill bits. A distinction is made between prior-art drill bits which are of the mechanical type wherein the rock-cutting action results from physical contact of the metal bit surfaces with the rock formation at the bottom of the hole, and the jet bits of this invention wherein the rock-cutting action results from the erosive action of a high-velocity jet stream issuing from a nozzle that does not contact the rock formation and which functions most advantageously when the nozzle is spaced a specified distance (called the "standoff") from the rock being drilled.

In hydraulic jet drilling a jet drill is employed to penetrate the earth to form a borehole. By a jet drill is meant one whose rock-cutting action results substantially entirely from a plurality of hydraulic jet streams issuing from nozzles in the tool at a velocity that exceeds the critical minimum cutting velocity. The critical minimum cutting velocity is that fluid velocity below which substantially no cutting action of the jet takes place, whereas above this critical velocity the cutting action increases rapidly with increasing velocity. The critical minimum cutting velocity varies with the target material being drilled and also with the nature of the jetting fluid. The drilling fluid employed is pumped to the drill bit under pressure sufficiently high so that the jet stream emerging from the bit exceeds the critical minimum cutting velocity of the rock being drilled.

The cutting action of a high-velocity jet stream can be increased by the use of a fluid medium that contains entrained material, as for example, sand. We have found as disclosed in our copending application Ser. No. 311,088, filed Sept. 24, 1963, and assigned to the same assignee as this application, that at velocities above the critical minimum cutting velocity the target removal rate of the jet varies with the sand concentration. We have found that with a particular type of entrained material, the cutting rate is larger for a particular range of concentrations of the entrained material and the cutting rate is less for concentrations above and below this range. One possible explanation of this is that there is too little entrained material, the cutting rate is increased by the addition of more material until a concentration is reached that is so high that an appreciable number of entrained particles simply strike the top of a previous particle and fail to strike and cut the rock being attacked. Accordingly, it is desirable to maintain the drilling fluid in a condition so that it carries an optimum concentration of desirable entrained particles.

We have further found that upon passing through the drill bit at a velocity exceeding the critical minimum cutting velocity and returning to the surface of the earth, a substantial portion of the material entrained in the drilling fluid will be reduced in particle size. Thus the drilling operation produces fines at the expense of the useful sized entrained particles. The fines are inimical to the drilling operation because they increase the power required to develop a specified jet velocity and they get in the way of the useful particles to reduce cutting action of the drilling fluid in a manner similar to the effect of excessive particle concentration. The fines contribute nothing to the cutting action of the drilling fluid. Accordingly, it is desirable to remove the fines from the spent drilling fluid and add desirable sized particles to build up the concentration of the desirable sized particles before the drilling fluid is again recirculated to the jet bit.

It is an object of this invention to provide an apparatus for jet drilling that maintains optimum conditions in the drilling system.

Another object of this invention is to provide an apparatus for jet drilling that avoids excessive wear on the pumps and other equipment required.

These and other useful objects of the invention are attained by the apparatus described in this specification with reference to the accompanying drawings forming a part thereof, and in which

FIGURE 1 is a diagrammatic illustration of one form of jet drilling operation in which solid material is entrained in the drilling fluid and to which this invention is applicable; and

FIGURE 1A is a diagrammatic representation of processing equipment that may be employed in this invention to reconstitute drilling fluid containing entrained solid particles.

This invention resides in apparatus for the treatment of an abrasive-laden drilling liquid useful in hydraulic jet drilling operations to recondition the liquid for recirculating down the well for further drilling. The apparatus includes a first separator for removal of cuttings from drilling liquid discharged from the well. A conduit delivers the cuttings-free drilling liquid to a second separator in which abrasive particles are separated from the drilling liquid. A third separator receives the abrasive-free drilling liquid and separates fine solid particles therefrom to produce a clean liquid for making up drilling liquid to be returned to the well for further drilling operations. Means are provided for mixing abrasive particles with the clean drilling liquid to produce a drilling liquid substantially free of oversize particles and fines.

Referring to FIGURE 1 there is diagrammatically shown a borehole **10** penetrating rock formation **11** in the earth. The drill comprises a conventional drill stem **12** having at its upper end a swivel **13** and supported at least in part by a hoisting line **14** in conventional manner. The upper part of the borehole **10** is usually cased as indicated at **15**. The drill stem is rotated in conventional manner by means of rotary table **16** powered by a prime mover **17**. Drilling fluid under very high pressure is supplied to the drill **20** by pipe **18**. As the drill makes hole, it is lowered by lowering of hoisting line **14** from the hoist. The rate at which drilling progresses is measured by a conventional drilling rate recorder **19** whose recording mechanism is connected to swivel **13** by line **24** in conventional manner.

The bottom of the drill stem carries a jet bit **20** indicated diagrammatically since its structure per se does not form a part of this invention. The jet bit **20** may, for example, be of the type described in our copending applications Ser. Nos. 311,034 and 311,088, filed Sept. 24, 1963, and assigned to the same assignee as this application. Drilling fluid under high pressure is pumped down the drill stem as indicated by the arrows **21** and issues from the nozzles of bit **20** in the form of a very high velocity jet stream. The velocity of the jet stream issuing from the bit **20** exceeds the critical minimum cutting velocity so that rock cutting action takes place. The spent drilling fluid returns upward through the annular space around the drill stem as indicated by the arrows **22** and leaves the well through fluid return pipe **23**.

The drilling action of the hydraulic jet stream issuing from the bit **20** may be augmented by having entrained in the drilling fluid a certain amount of solid material. We have found that drilling action is a maximum for a particular range of concentration of a particular entrained solid material. By way of example, as disclosed in the aforementioned application Ser. No. 311,088 when using entrained sand whose particle size is predominantly 20 to 40 mesh optimum penetration rate of the drill is obtained when the sand concentration is in the range between about 5 percent and about 15 percent by volume (using the A.P.I. procedure for measuring sand content of drilling fluid).

We have found that when drilling fluid containing entrained material strikes a target at a sufficiently high velocity to cut the target, the entrained material is broken up into smaller fragments. Thus when sand particles of a certain size are used in a jet drill, the sand particles are comminuted by the jet drilling process. Accordingly, after a jet drilling fluid has been in use for a comparatively short time, the entrained sand particles are no longer of optimum size and the drilling ability of the drilling fluid deteriorates. It is the purpose of this invention to provide an apparatus for maintaining a jet drilling fluid in optimum cutting condition by reconstituting the drilling fluid to contain material of optimum size and concentration.

In the case of the above-mentioned example wherein a sand concentration in the range between about 5 percent and about 15 percent is employed, the particle size of predominantly between 20 mesh and 40 mesh is determined by conventional sieving techniques. Particles larger than 20 mesh are considered impractical because of the resultant clogging of nozzles, pump valves, etc. We have found that the presence of entrained solid particles smaller than 40 mesh have substantially no beneficial effect on the drilling effect of the drilling fluid, whereas these smaller particles interfere with the drilling effect of the larger particles in a manner similar to the effect produced by excessive particle concentration. The fines also increase the density of the drilling fluid so that greater horsepower is required to obtain the same nozzle exit velocity. Furthermore, the presence of the very fine particles, particularly abrasive particles, substantially reduces the life of pumps and other equipment employed. Accordingly, in the apparatus of this invention the fines are removed from the spent drilling fluid as are any large rock fragments that result from the drilling operation. The drilling fluid is subsequently reconstituted to optimum condition prior to reinjection into the drill stem through pipe **18**.

Referring now to FIGURE 1A which shows a generally top view of the mud processing equipment, the spent drilling fluid returning from the well through pipe **23** is conducted to a double-screen shale shaker **25** that is driven by motor **26** in conventional manner. The shale shaker **25** has two vertically spaced superposed screens **27** and **28**. The lower screen **28** has smaller openings than the upper screen **27** and is only partially shown in the figure where the upper screen is cut away for purposes of illustration. The spent drilling fluid from pipe **23** is discharged onto the upper screen **27** which retains the larger rock fragments, the latter being dumped into a trough **29**. These rock fragments may be studied by the geologist but they are discarded as far as the drilling operation per se is concerned. The drilling fluid carrying smaller particles goes through screen **27** and falls on the lower screen **28** having smaller openings. Those particles that are retained on screen **28** are dumped into a trough **31** and carried away by pipe **32** to be reused as will be explained later. Drilling fluid that carries particles smaller than the openings in screen **28** goes through the screen **28** into a trough **36**.

FIGURE 1A shows a top view of the shale shaker **25** located above one end of the mud tank **33**. The tank **33** has a flow baffle **34** near the outlet end of the tank. The baffle **34** serves to separate stored drilling fluid from that being circulated, the latter being contained in the section **47**. The drilling fluid that passes through screen **28** drops into the trough **36** and is put through a desanding operation. The fluid that passes through screen **28** contains fines produced both as a result of cutting of the rock being drilled and as a result of comminution of the originally entrained abrasive sand. Drilling fluid that falls into trough **36** passes via lines **37** to a centrifugal pump **39** and into a battery of desanders **40** shown generally in elevation in FIGURE 1A. The desanders **40** may be conventional mud cyclones or special desanders known for removing sand and cuttings from drilling mud, as for example the Bowen Desander manufactured by S. R. Bowen Co., Sante Fe Springs, Calif. Three desanders **40** are shown, but any number may be used that is required to efficiently remove the fines from the fluid delivered by pump **39** to the input manifold **41**. The desanders **40** extract the fine sand and cuttings which exit through the bottom discharge openings of the desanders. These fines are discarded. The desanded drilling fluid is delivered to manifold **42** and flows via pipe **43** to a cooling tower **44**. From the bottom of the cooling tower the drilling fluid is picked up by centrifugal pump **45** and passes via line **46** to trough **31**. The desanded fluid washes the trough **31** and carries the useful sand particles from trough **31** via line **32** into the end **47** of the mud tank for reuse. Alternatively, the desanded drilling fluid from the cooling tower may flow through line **46**, trough **31**, and line **32** by gravity into tank **47**. It is thus seen that the drilling fluid is continually being circulated through the desanders **40** and returned to the mud tank. The rate of circulation through pump **39** and the number of desanders **40** is adjusted with respect to the circulation rate through the well **10** so that the drilling fluid in the output end **47** of the mud tank **33** has only a tolerable small concentration of fines.

The solids caught on the lower screen **28** and which are dumped into trough **31** previously mentioned are washed by the desanded fluid from pump **45** and delivered by pipe **32** to the output end **47** of the mud tank. These solids are in the size range known to be desirable in the drilling fluid for the purpose of augmenting its cutting ability. In order to make up for solids lost through fines, sand **48** of desired size is added to the drilling fluid in **47** by means of a sand mixer **49** whose feed screw **51** is driven at controlled rate by variable-speed motor **50**. The drilling fluid in tank **47** may be kept well mixed by means of a circulating pump not shown. The concentration of sand in the drilling fluid in tank **47** may periodically be checked by taking a sample and determining its sand concentration by standard A.P.I. procedure. The size of the sand particles in tank **47** is determined by the openings in the shale shaker screens **27** and **28**. For the previously mentioned example, the openings of upper screen **27** are 20 mesh and those of lower screen **28** are 40 mesh.

The drilling fluid in the output end **47** of the mud tank is thus reconstituted to carry the proper amount of solid abrasive particles of size that results in optimum drilling rate. The thus reconstituted drilling fluid is then pumped from tank **47** by means of one or more high-pressure pumps **52** to a manifold **53** and thence to the line **18** leading to the swivel **13** for circulation down the well to the jet bit **20**. The line **18** is provided with a pressure gauge **55**. The spent fluid returning from the well through pipe **23** returns again to the processing apparatus of FIGURE 1A for retreatment.

This invention thus provides for removing from the spent drilling fluid those particles that are detrimental or inimical to the drilling operations. The openings in the upper screen **27** are of a size to retain particles that are larger than those desired, these usually being chips or large cuttings of the rock being drilled. The openings in the lower screen **28** are of a size to retain useful sized particles and pass the fines. Thus particles whose size is such as to be useful in the drilling fluid are delivered by the shale shaker **25** to trough **31** and these particles are reused by combining them with the drilling fluid in the output end **47** of the mud tank.

The pumps **52** deliver reconstituted drilling fluid to the drill at a sufficiently high pressure so that the pressure differential at the jets in the bit is sufficient to effect a nozzle exit velocity that exceeds the critical minimum cutting velocity. This is easily determinable by means of the drilling rate recorder **19**. When drilling in any given rock, it is found that upon gradually increasing the pressure (as shown by gauge **55**) the drilling rate will be practically nil for low pressures, and when the pressure reaches the critical minimum cutting pressure, the drilling rate will suddenly increase rapidly with further increase in pressure as the critical minimum cutting pressure is exceeded. We prefer to operate at a pressure as indicated by gauge **55** that exceeds 4000 p.s.i.g.

It is found that the critical minimum cutting pressure varies with the sand concentration. At a given pressure that exceeds the critical value, the drilling rate will be a maximum for some concentration value of entrained sand or other abrasive particles. Since the operator does not always know the nature of the rock in which the bit **20** is drilling, the optimum concentration is best found by simple experiment. The rate at which sand, for example, is added by means of sand mixer **49** is adjusted by adjusting the speed at which the sand-feed screw **51** is driven so as to maintain a maximum drilling rate as indicated on drilling rate recorder **19**. By way of example, a concentration in the range between about 5 percent and about 15 percent of sand whose particle size is predominantly between 20 mesh and 40 mesh may be employed, but by means of this invention any desired concentration of any desired size may be maintained during the drilling operation.

We claim:

1. Apparatus for treating abrasive-laden drilling liquid for the hydraulic jet drilling of wells comprising a first screen having openings therein of a size prohibiting the passage of particles larger than approximately 20 mesh and allowing smaller particles to pass therethrough to remove cuttings from the drilling liquid, means for delivering drilling liquid discharged from the well onto the first screen, a second screen positioned below the first screen adapted to receive the cuttings-free drilling liquid and solid particles passing through the first screen and to separate abrasive particles from the liquid to form an abrasives-free drilling liquid, means below the second screen for collecting the abrasives-free drilling liquid that passes through the second screen, a separator adapted to separate fine solid particles from the abrasives-free drilling liquid to produce a clean liquid, conduit means from the collecting means to the separator for delivery of abrasives-free liquid to the separator, and means for mixing abrasives particles with the clean liquid to form a drilling liquid for recirculating to the well.

2. Apparatus as set forth in claim **1** including means for feeding abrasive particles separated from the drilling liquid to the mixing means, and conduit means from the separator to the mixing means for delivering clean liquid to the mixing means.

3. Apparatus for treating abrasive-laden drilling liquid for the hydraulic jet drilling of wells comprising a first separator adapted to remove cuttings larger than the abrasive from the drilling liquid, means for delivering drilling liquid discharged from the well to the first separator, a second separator constructed and arranged to receive cuttings-free drilling liquid discharged from the first separator and remove abrasives therefrom to form an abrasives-free liquid, a third separator constructed and arranged to receive abrasives-free liquid and separate fine solids therefrom to form a clean liquid, means for incorporating in the clean liquid abrasives removed from the cuttings-free liquid to form a reconstituted drilling liquid, a high-pressure pump adapted to discharge drilling liquid at a pressure of at least 4000 p.s.i. for recirculating the drilling liquid in the well, and means for delivering

the reconstituted drilling liquid to the high pressure pump.

4. Apparatus as set forth in claim 3 in which the second separator separates abrasive particles having a size substantially in the range of 20 to 40 mesh.

5. Apparatus as set forth in claim 3 including a cooler and means for circulating clean liquid from the third separator through the cooler.

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