Dec. 3, 1968 J. L. PEKAREK 3,414,068

METHOD OF TREATING ABRASIVE-LADEN DRILLING LIQUID

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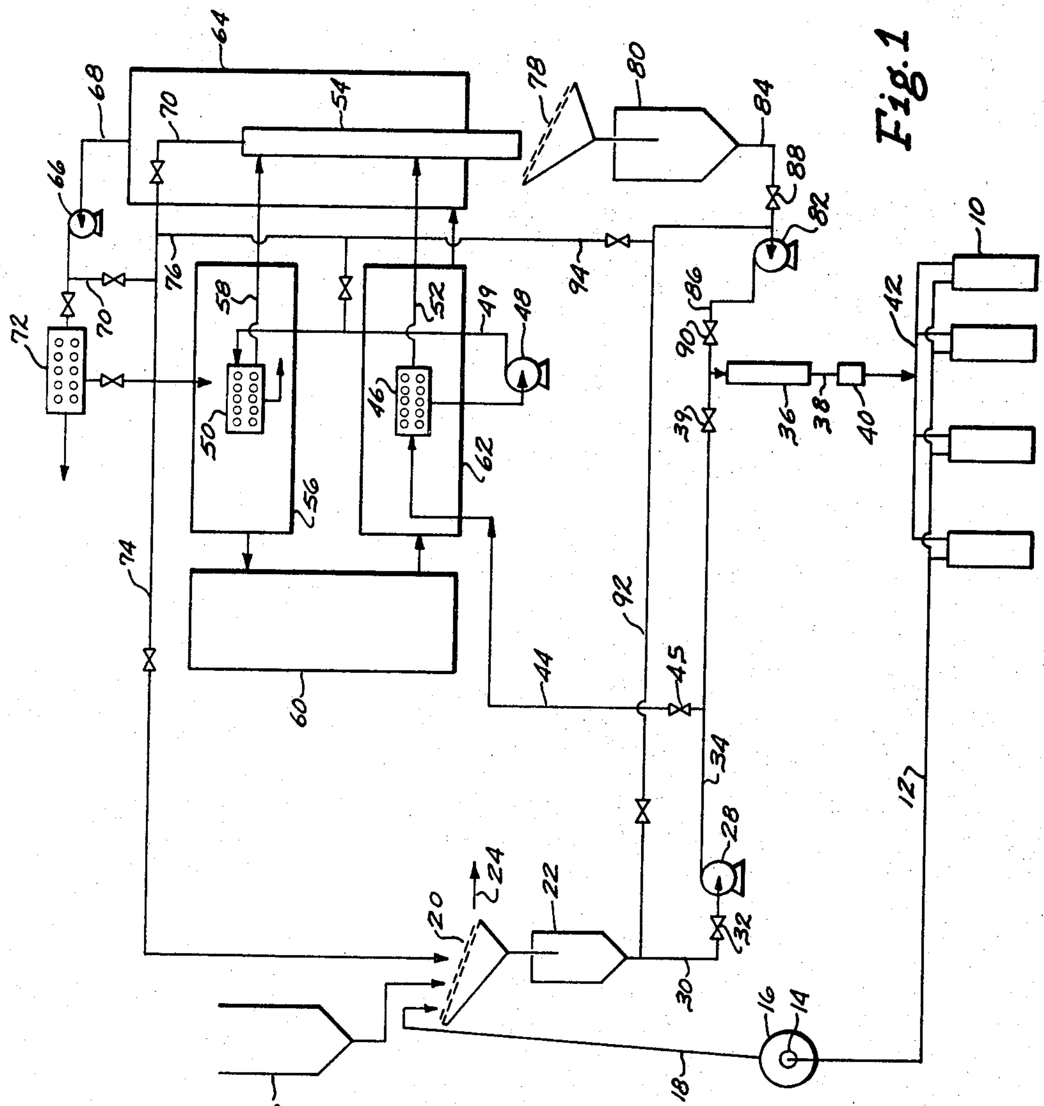

Fig. 1

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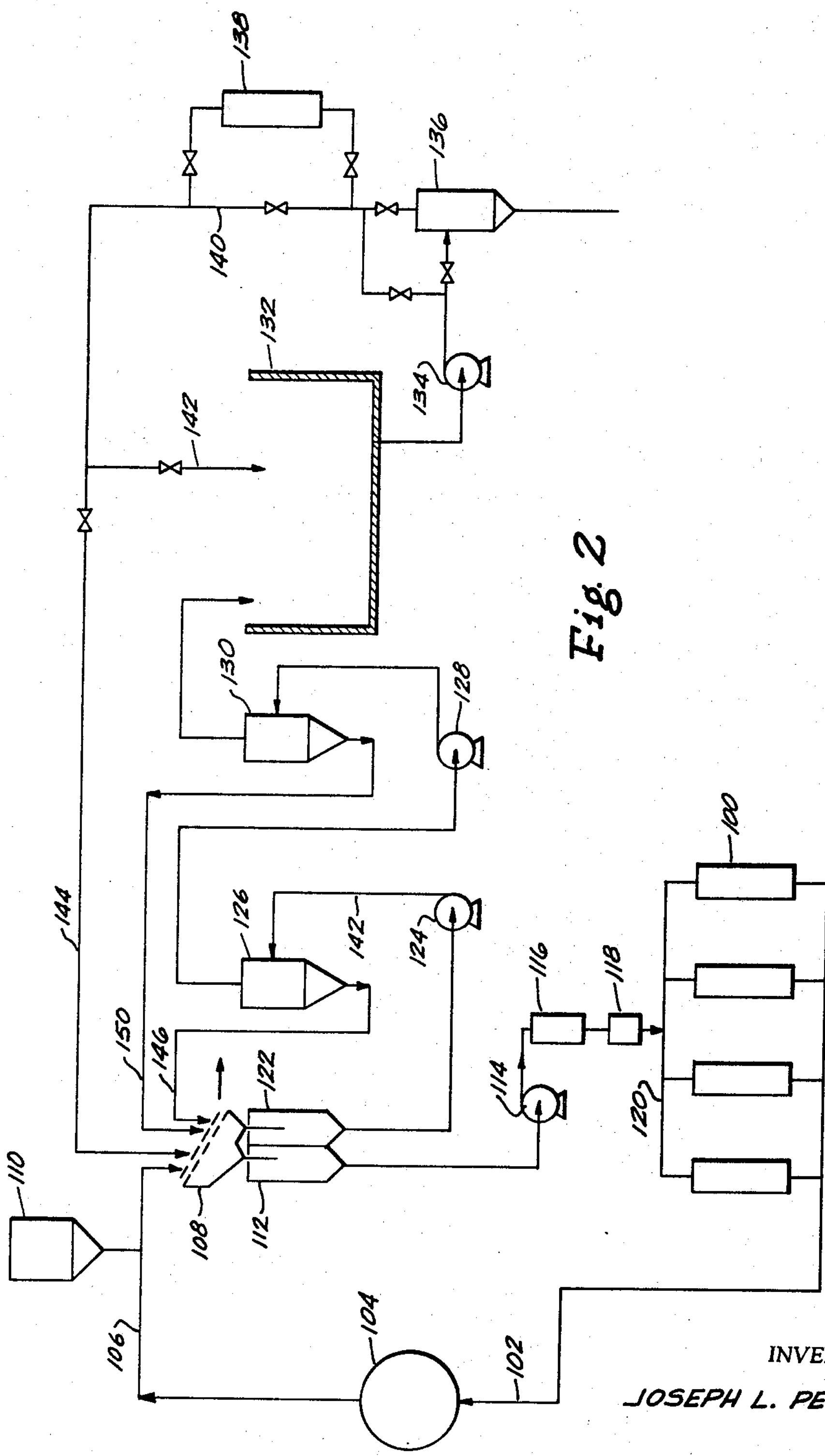

Fig. 2

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METHOD OF TREATING ABRASIVE-LADEN DRILLING LIQUID

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ABSTRACT OF THE DISCLOSURE

In a hydraulic jet drilling method in which high-velocity streams of a liquid laden with ferrous abrasive particles are used to penetrate the formation being drilled, excessive increases in the density of the drilling liquid must be prevented to avoid high pumping costs. Two to fifteen percent of the drilling liquid circulated is treated to remove all solid particles larger than 200 mesh to thereby form a clean liquid which is then circulated in the well. The treatment of drilling liquid and substitution of clean drilling liquid can be accomplished either continuously or periodically.

This invention relates to the drilling of wells and more particularly to hydraulic jet drilling of wells with liquids having ferrous abrasive particles suspended therein.

In the conventional rotary drilling method used to drill wells in hard formations, a rock bit having rotating cones mounted on its lower end is mounted on the lower end of drill pipe and rotated in the hole while a drilling mud is circulated down the drill pipe and upwardly through the annulus surrounding the drill pipe to remove cuttings from the borehole. The action of the drill bit is to crush rock at the bottom of the borehole. The circulating drilling mud sweeps the crushed rock from the bottom of the hole to avoid regrinding of rock particles. Bits referred to as jet bits in which drilling mud is discharged at a relatively high velocity and is directed between the rollers rather than against the rollers are effective in increasing the drilling rates in soft formations, but have little effect on drilling rates in the hard formations such as occur in West Texas.

The slow drilling of hard formations that has been possible by conventional methods has made necessary frequent replacement of many bits during the drilling of a well. Since many of the hard rocks are in deeper formations, the round trips necessary for replacement of bits are time consuming and contribute in an important manner to the cost of drilling.

One method that has recently been developed for drilling hard formations is referred to as hydraulic jet drilling. In that drilling method, abrasive-laden liquid is discharged from nozzles at extremely high velocities of at least 500 feet per second, and preferably 600 feet per second or more, against the bottom of the hole. The nozzles are mounted in a drill bit secured to the lower end of the drill pipe which is rotated during the drilling. A pressure drop from the inlet to the outlet of the nozzles of the order of 4,000 p.s.i. or more is required to impart the necessary high velocity to the stream. The outlet from the nozzles is maintained close to the bottom of the borehole whereby the velocity of the stream of liquid impinging against the bottom of the borehole is substantially the same as the maximum velocity in the nozzles. In the hydraulic jet drilling method, the penetration of rock at the bottom of the borehole is accomplished entirely by the abrasive-laden stream. Knock-off bars are provided on the bit to break off ridges between grooves cut by the abrasive-laden stream and thereby aid in rock removal.

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The abrasive particles in hydraulic jet drilling are substantially larger than the solid particles ordinarily incorporated in drilling muds. For example, if nozzles ⅛ inch in diameter are used, the preferred size of abrasive particles is 20 to 40 mesh. The rate of penetration of rock by an abrasive-laden stream from a nozzle of given size increases with the size of the particle; hence, it is desirable to use the largest size of abrasive particles that will not plug the nozzles. Plugging of a nozzle renders that nozzle ineffective, reduces the rate of drilling, and may make necessary a round trip to clear the nozzles of the plugging material.

Sand is an abrasive that is widely available and can be obtained at low cost. We have found that 50 percent or more of the sand particles are broken in a single pass through the system to a size, smaller than 40 mesh, having little value in hydraulic jet drilling. Moreover, as the sand breaks up, the drilling liquid becomes laden with fine sand particles which increase the density of the drilling liquid. The increased density of the drilling liquid increases the power required to pump the drilling liquid at the necessary high velocities. To maintain effective conditions for hydraulic jet drilling with a sand abrasive, it has been the practice to treat all of the drilling liquid circulated during each pass through the system to remove fine particles of cuttings and sand. Thus, the surface treatment of the drilling liquid in hydraulic jet processes heretofore available have required complicated systems of high capacity.

This invention resides in an improved method of hydraulic jet drilling in which a ferrous abrasive is suspended in a drilling liquid. The drilling liquid carrying cuttings discharged from the well is passed through screens to remove over-size solid particles, and the drilling liquid passing through the screen and containing suspended abrasives is delivered from the screen to the high pressure pumps without intermediate removal of abrasive particles. A minor part of the drilling liquid, less than 15 percent, frequently less than 5 percent and in very hard formations less than 3 percent of the total volume of drilling mud depending on drilling rate, is treated to remove finely divided solid particles. The treatment of the drilling liquid for removal of the finely divided solid particles can be accomplished periodically by replacing the drilling liquid circulating in the system with clean liquid or continuously by withdrawing a small stream of drilling liquid discharged from the screens, treating that small volume of liquid to remove substantially all particles in the 80 to 200 mesh range, and returning it to the system.

We have discovered that hydraulic jet drilling with a liquid having ferrous abrasives suspended therein results in a greatly reduced break-up of the abrasive particles as compared with sand. Whereas approximately 50 percent of the sand is broken in a single pass through the hydraulic jet drilling system, less than 2 percent and usually 1 percent or less of the ferrous abrasive is broken. Moreover, small sizes, such as 50–80 mesh, of ferrous abrasive particles are effective in hydraulic jet drilling; whereas sand particles of the same size are not effective. In the hydraulic jet drilling method, except when it is possible to drill at very high rates such as rates exceeding 100 feet per hour, the volume of drilling liquid circulated is large compared to the volume of rock removed from the hole; hence, the build-up of density of the drilling liquid because of fine cuttings is minor as compared to the density increase caused by the breaking of sand particles when sand is used as the abrasive. The low rate of break-up of ferrous abrasives permits long periods of direct circulation of drilling liquid without removal of fine particles and without encountering excessive drilling liquid densities.

FIGURE 1 of the drawings is a diagrammatic flow sheet of a hydraulic jet drilling system with apparatus for the treatment of drilling liquid and replacement of drilling liquid with clean drilling liquid.

FIGURE 2 of the drawings is a diagrammatic view of apparatus for the continual withdrawal of a minor stream of drilling liquid from the circulating system and return of a small stream of clean liquid to the system.

The ferrous abrasive particles can be either iron or steel particles in the form of shot or angular grit. The ferrous abrasives are commercial products widely used for cleaning of metals. They can be prepared by directing high pressure steam or compressed air against molten metal to blow globules of the molten metal into water. The resultant shot is then heat treated to the desired hardness and graded for size. Angular grit is obtained by crushing the shot and heat treating. Ferrous abrasives can be used in hydraulic jet drilling in sizes in the range range of about 7 to 80 mesh. An important advantage of ferrous abrasive particles is that substantial drilling rates can be obtained with ferrous abrasive particles in the range of 50 to 80 mesh in the U.S. Sieve Series; whereas sand particles of that size are largely ineffective.

The ferrous abrasive particles are suspended in a drilling liquid having a gel strength and viscosity adequate to suspend the abrasive particles in the hole when the high-pressure pumps are shut down for change of bits or other reasons. The required gel strength and viscosity depend to some extent on the particular drilling liquid. A suitable drilling liquid for suspending the ferrous abrasives is an invert emulsion containing about 25 to 60 percent diesel oil and water in which the diesel oil is the continuous phase of the emulsion. The emulsion is stabilized by a suitable emulsifier such as by 5 to 10 percent by weight of a potassium soap of sulfurized tall oil containing 5 percent sulfur. Other emulsifiers such as polyhydric alcohol fatty acid esters, sulfated sperm oil soaps, and polyvalent metal soaps of rosin acids can be used in the preparation of a stable emulsion. Other drilling liquids can be used. The particular drilling liquid used to suspend the ferrous abrasives is not a part of this invention, nor is this invention limited to the use of a particular drilling mud.

The ferrous abrasive particles are suspended in the drilling liquid in a concentration of 1½ to 6 percent by volume. A preferred concentration is 2 to 4 percent. In general, the rate of drilling increases with an increase in the concentration of the ferrous abrasive, but the increase in drilling rate with increases in concentrations above 4 percent by volume is slow and the total break-up of abrasives into fine particles increases with concentrations in excess of 6 percent without a corresponding increase in drilling rate.

Referring to FIGURE 1 of the drawings, ferrous abrasive particles suspended in drilling liquid are discharged from high-pressure pumps **10** through line **12** into drill pipe **14** extending down a well indicated by reference number **16**. The high-pressure pumps **10** are capable of maintaining a pressure drop of at least about 4,000 pounds per square inch through the nozzles in the bit to provide a drilling liquid velocity of at least about 500 feet per second at the outlet of the nozzles. In a typical hydraulic jet drilling operation for drilling a hole 7 inches in diameter, 4 pumps **10** driven by motors supplying a total of about 2,000 to 2,400 horsepower pump 450 to 600 gallons per minute of abrasive-laden drilling liquid at a pressure of 5,000 p.s.i. to the drill pipe **14** for delivery to a bit having a plurality of nozzles, for example, 10 to 20 nozzles ⅛ inch in diameter.

The drilling liquid is discharged through nozzles in a drill bit, not shown, mounted on the lower end of the drill pipe to cut the rock at the bottom of the borehole. Drilling liquid discharged from the nozzles in the drill bit and entrained cuttings are circulated up the annulus surrounding the drill pipe **14** and delivered through line **18** to a screen **20** of the vibrating type, known as a shale shaker, widely used to treat drilling mud. To avoid inadvertent inclusion of oversize particles in the drilling liquid resulting from holes worn in the screen, it is preferred that screen **20** consist of two screens of the same mesh size, one positioned above the other. For example, in drilling with a bit having nozzles with a diameter of ⅛ inch at the orifice, both of screens **20** have 10 mesh openings. Oversize cuttings and abrasive particles, if any, which fail to pass through the screens **20** are discarded from the system at **24**. Drilling liquid and abrasive particles of the desired size pass through the two screens into a suction tank **22**. A storage hopper **26** for abrasive particles is positioned to discharge abrasive particles onto the screens **20** for the addition of abrasive particles as required by the increased volume of drilling liquid required as a result of the increase in the depth of the borehole and for the replacement of abrasive particles broken into fines and discarded from the system during the drilling operation.

Drilling liquid with suspended abrasive is picked up from suction tank **22** by pump **28** through a line **30** having a valve **32** therein and delivered through line **34** to a cooler **36**. The cooled drilling liquid discharged from cooler **36** is delivered through a line **38** and sampler or monitor **40** to a header **42** from which the drilling liquid is picked up by the high-pressure pumps **10**.

Branching from line **34** is a line **44**, having a valve **45** therein, to a first bank **46** of cyclone separators. Overflow from the first bank **46** of cyclone separators is picked up by a pump **48** and delivered to a second bank **50** of cyclone separators. Cyclone separators **46** and **50** are suitable for separation of solid particles larger than 80 mesh from the drilling liquid. Underflow from the first bank of cyclone separators **46** is delivered through a line **52** to a trough **54**. Overflow from the second bank of cyclone separators **50** is discharged into a storage and circulating tank **56** while the underflow is delivered through line **58** to the trough **54**. In the apparatus illustrated in FIGURE 1, a series of interconnected storage tanks **56**, **60**, **62**, and **64** is provided for the storage of drilling liquid at the surface.

A pump **66** picks up suction from tank **64** through a line **68** and discharges drilling liquid, which has been cleaned as hereinafter described, through line **70** for delivery to the trough **54**. A third bank of cyclone separators **72** is connected to a line branching from line **70**. Cyclone separators **72** are preferably of a small size, such as 3 inch cyclone separators, adapted to remove from the drilling liquid substantially all solid particles having a size larger than 200 mesh. Solid particles separated from the drilling liquid in the cyclone separators **72** are discharged from the system in the underflow from those separators, and clean drilling liquid is returned as overflow to tank **56**. A second line **74** branches from line **70** for delivery of clean drilling liquid to the screen **20**. A line **76** connects line **70** with line **49** to permit the circulation of additional liquid through the cyclone separators **50**. Suitable valves are provided to allow the liquid discharged from pump **66** to be directed through line **70** to the trough **54**, to the cyclone separators **72**, to the screen **20**, to cyclone separators **50**, and to line **92**, as desired.

Clean drilling liquid discharged from line **70** into trough **54** mixes with abrasive particles separated from the drilling liquid in separators **46** and **50**, and the mixture is discharged onto a screen **78** which should have the same mesh size as screen **20**. Clean drilling liquid passing through screen **78** flows into a suction tank **80** from which a pump **82** pumps the clean drilling liquid through line **84** and line **86** to the cooler **36**. Lines **84** and **86** are provided with valves **88** and **90** for control of the flow of liquid to and from pump **82**. A suitably valved line **92** extends from line **30** to the inlet of pump **82** to allow pump **82** to be used as a stand-by for pump **28**.

In the operation of the apparatus illustrated in FIGURE

1 in accordance with this invention, the normal flow of drilling liquid is from the pumps **10** down the drill pipe **14** upwardly through the annulus surrounding the drill pipe in the well **16** and through line **18** to the screens **20**. The oversize cuttings and any oversize particles of ferrous abrasive which may be added from the storage hopper **26** are discarded from the screens and the drilling liquid and entrained abrasive are delivered into suction tank **22**. Pump **28** delivers drilling liquid through line **38** through cooler **36** and sampler **40** into the header **42** for recirculation in the well. During this operation, valves **45** and **90** are closed whereby all of the drilling liquid passing through the screens **20** is confined after passing through the screens and delivered to the pumps **10** for recirculation. In this manner, oversize particles which might plug nozzles in the drill bit are effectively kept out of the drilling liquid delivered to pumps **10**.

Flow of all of the drilling liquid passing through the screen **20** directly to pumps **10** is continued until the finely divided solids resulting from cuttings of the formations drilled and break-up of the ferrous abrasive increase the density of the drilling liquid above the desired limits. Ordinarily, an increase in the density of the drilling liquid of 1 pound per gallon will not interfere with the drilling operations. When drilling hard formations with ferrous abrasives, the break-up of the abrasives is so small that as many as 50 cycles of drilling liquid through the drilling system can be made before elimination of the finely divided solids is necessary. In all formations hard enough to warrant drilling by the hydraulic jet method, the drilling liquid can be circulated through 7 cycles and usually 10 cycles before removal of fines is necessary.

When the density of the drilling liquid reaches the maximum permissible limit, the pump **66** is started and the valves set to deliver clean drilling liquid from storage tank **64** through line **70** into trough **54** and then into the suction tank **80**. The valves **88** and **90** are opened and pump **82** started to supply clean drilling liquid to the header **42**. Valve **45** is opened and valve **39** closed and the drilling liquid and abrasive pumped by pump **28** passes through the cyclone separators **46**. The overflow from cyclone separators **46** is pumped by pump **48** to cyclone separators **50** and the overflow from cyclone separators **50** is delivered into storage tank **56**. Cyclone separators **46** and **50** are effective in removing particles larger than 80 mesh from the drilling liquid. The 10–80 mesh particles of abrasive delivered into trough **54** are picked up by the clean drilling liquid and passed through screen **78** and suction tank **80** for delivery into the drilling system. Delivery of clean drilling liquid to pumps **10** is continued for one cycle to replace the high-density drilling liquid in the well with clean drilling liquid. Then delivery of drilling liquid from suction tank **22** directly to pumps **10** is resumed.

Because the increase in density of the drilling liquid in a single cycle is small, a large degree of flexibility in when the high-density drilling liquid is replaced with clean liquid is available. It may be advantageous to make the replacement immediately before the pumps are shut down for pulling the drill pipe from the well. Damage to threads on the drill pipe during a round trip can be reduced by replacing the high-density drilling liquid in the drill pipe with clean, abrasive-free liquid immediately before a round trip. For this purpose a line **94** from line **76** to line **84** is provided. If abrasive-free clean drilling liquid replaces the high-density drilling liquid in the annulus as well as the drill pipe, settling of abrasive in the well during the round trip is eliminated. If the volume of tank **80** is not adequate to hold abrasive removed from the drill pipe and annulus, additional storage capacity can be provided.

Removal of smaller than 80 mesh particles from the drilling liquid in storage can be accomplished at the operator's convenience. During this operation, flow from line **70** is directed into the cyclone separators **72** which reduces the larger than 200 mesh particles in the overflow to a trace and returns clean drilling liquid to tank **56**. Operation of the cyclone separators **72** is continued until the drilling liquid in storage has been cleaned of solid particles larger than 200 mesh. The volume of the storage tanks and the normal time that the clean drilling liquid is in the storage tanks will ordinarily provide adequate cooling of the drilling liquid from which the 80 to 200 mesh particles are removed.

In the apparatus illustrated in FIGURE 2, a plurality of high-pressure pumps **100** similar to pumps **10** deliver drilling liquid through line **102** to drill pipe in a well indicated by reference numeral **104**. Drilling liquid circulated from the well **104** is delivered through line **106** onto a screen **108** similar to screen **20**. Make-up ferrous abrasive is added to the drilling liquid delivered to screen **108** as required from a storage hopper **110**.

Oversize solid particles are separated by screen **108** from the drilling liquid, and abrasive and a major portion of the drilling liquid are delivered from the screen into a suction tank **112**. The drilling liquid in suction tank **112** is pumped by pump **114** through a cooler **116** and sampler or monitor **118** into a header **120** for pumps **100**.

In the embodiment of the invention illustrated in FIGURE 2, the drilling liquid discharged from screen **108** is divided into two streams: a major stream and a minor stream. The major stream goes into suction tank **112**, as described above, and the minor stream goes into suction tank **122**. Drilling liquid is delivered from suction tank **122** by pump **124** into a drilling liquid cleaning system consisting of a first separator **126**. Alternatively, the suction of pump **124** can be connected to the line from suction tank **112** to pump **114** and a small part of the liquid flowing through that line withdrawn and delivered to separator **126**. Underflow from separator **126** containing abrasive particles having a size larger than 80 mesh is returned to the screen **108**. Overflow from separator **126** is delivered by a pump **128** to a second separator **130**. Underflow from the separator **130** also includes particles larger than 80 mesh and is returned to the screen **108**. The overflow from separator **130** is drilling liquid substantially free of particles larger than 80 mesh. It is delivered into a storage tank **132** of a size to provide sufficient volume of drilling liquid for flexibility in operations and for supplying the added volume of liquid required as the depth of the hole increases.

Drilling liquid from storage tank **132** is pumped by a pump **134** through a separator **136** to remove particles larger than 200 mesh from the drilling liquid and supply an overhead stream of clean drilling liquid. That overhead stream can be passed through a cooler **138** and returned to the storage tank **132** or can be delivered through lines **140** and **142** directly to the storage tank without an intermediate cooling. A line **144** connected to line **142** allows delivery of clean drilling liquid to the screen **108**.

In the embodiment of the invention illustrated in FIGURE 2, the volume of liquid passing through the cleaning circuit is about 2 to 15 percent of the volume of liquid circulated by high-pressure pumps **100**. It is possible therefore to use much smaller and less expensive equipment in the cleaning cycle than is necessary when the entire volume of drilling liquid is cleaned in the manner used when hydraulic jet drilling with sand as an abrasive.

I have found that because of the low break-up of the ferrous abrasive to fine particles and the effectiveness of ferrous abrasive particles as small as 80 mesh in cutting hard rock formations, the treatment of the drilling liquid in a hydraulic jet drilling operation can be greatly simplified. With the delivery of drilling liquid having ferrous abrasive suspended therein directly from the screens to the high-pressure pumps, danger of oversize particles in the drilling liquid plugging the nozzle in the drill bit is reduced.

I claim:

1. In a hydraulic jet method of drilling a well in which a liquid laden with 10 to 80 mesh ferrous abrasive particles discharged from high pressure pumps is delivered down the well through drill pipe and discharged from nozzles in a rotating bit mounted on the lower end of the drill pipe at a velocity of at least about 500 feet per second against the bottom of the borehole, abrasive-laden liquid and entrained cuttings are circulated up the well to the surface, the abrasive-laden liquid circulated up the well to the surface is passed through a screen to remove solid particles larger than the ferrous abrasive particles originally suspended in the liquid and the ferrous abrasive is retained in the liquid, and the abrasive-laden liquid passing through the screen is delivered directly to pumps for recirculating in the well, the improvement comprising treating at the surface 2 to 15 percent of the drilling liquid circulated in the well to remove substantially all particles larger than 200 mesh therefrom, and recirculating the treated drilling liquid in the well.

2. A method as set forth in claim **1** in which treated liquid from which substantially all particles larger than 200 mesh have been removed is mixed with ferrous abrasive particles having a size in the range of 10 to 80 mesh to form a clean drilling liquid, the clean drilling liquid is screened to remove particles larger than 10 mesh, and the clean drilling liquid passing through the screen is delivered to high-pressure pumps for recirculation in the system.

3. A hydraulic jet method of drilling a well comprising pumping a drilling liquid laden with ferrous abrasive down the well through drill pipe and discharging said drilling liquid from nozzles in a rotating bit mounted on the lower end of the drill pipe at a velocity of at least 500 feet per second against the bottom of the borehole of the well, circulating the drilling liquid and entrained cuttings up the well to the surface, screening the drilling liquid circulated to the surface to separate cuttings larger than 10 mesh therefrom and leave ferrous abrasive particles and smaller cuttings in said drilling liquid, returning drilling liquid passing through the screen to high pressure pumps for recirculation down the well, periodically replacing drilling liquid circulating in the system with drilling liquid substantially devoid of particles having a size in the range of 80 to 200 mesh to discharge solid particles smaller than 80 mesh from the circulating system, the periodic replacement of the drilling liquid with clean drilling liquid occurring once every 7 to 50 cycles of drilling liquid through the nozzles.

4. A hydraulic jet method of drilling a well comprising pumping a drilling liquid having suspended therein ferrous abrasive particles having a size in the range of 10 to 80 mesh down a well through drill pipe and discharging the drilling liquid from nozzles in a rotating drill bit mounted on the lower end of the drill pipe at a velocity of at least 500 feet per second against the bottom of the borehole, circulating the drilling liquid and entrained

cuttings upwardly through the well, screening the drilling liquid discharged from the well to remove cuttings larger than the abrasive particles from the drilling liquid and leave the abrasive particles suspended in the drilling liquid, delivering the drilling liquid from the screens to high-pressure pumps for recirculation down the well, withdrawing a portion of the drilling liquid passing through the screens, separating abrasive particles larger than 80 mesh from the withdrawn drilling liquid and returning the abrasive particles larger than 80 mesh to the circulating system, separating substantially all solid particles having a size in the range of 80 to 200 mesh from the withdrawn portion of drilling liquid to form a clean liquid, and replacing drilling liquid withdrawn from the system with clean liquid, the volume of clean liquid introduced into the system being in the range of about 2 to 15 percent of the volume of drilling liquid circulated in the system.

5. In a hydraulic jet method of drilling a well in which drilling liquid having ferrous abrasives suspended therein is discharged from high-pressure pumps, passes down the well through drill pipe to a drill bit mounted on the lower end thereof and is discharged from nozzles in the drill bit at a velocity of at least 500 feet per second against the bottom of the borehole of the well to penetrate the formation drilled, is circulated upwardly through the well to remove cuttings therefrom and is discharged from the well at the surface to drilling liquid conditioning apparatus, is passed through a screen to remove over-sized cuttings therefrom and returned directly to the high-pressure pump for recirculation in the well, and the drill pipe is periodically pulled from the well to replace the drill bit, the improvement comprising withdrawing 2 to 15 percent of the drilling liquid passing through the screen, treating the withdrawn liquid to remove substantially all particles having a size larger than 200 mesh to form a clean liquid and returning the clean liquid to the drilling liquid circulating through the well and surface treating apparatus to replace withdrawn drilling liquid, a part of the replacement of the drilling liquid with clean liquid being accomplished by pumping clean liquid down the well through the drill pipe to displace the drilling liquid from the well immediately before stopping circulation in the well to pull the drill pipe from the well.

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