

June 26, 1962

J. W. GRAHAM ET AL

3,040,822

METHOD OF INCREASING WELL DRILLING RATE

Filed Aug. 21, 1958

3 Sheets-Sheet 1

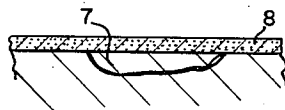
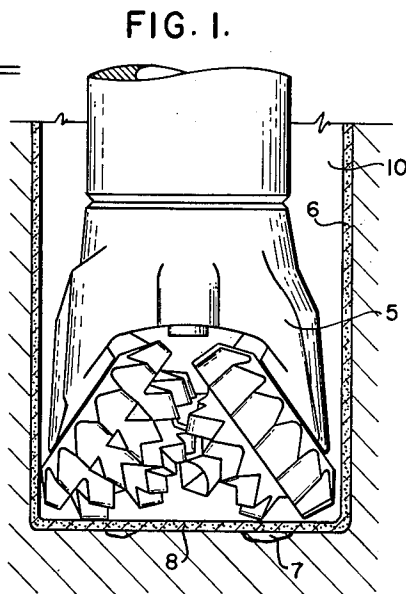
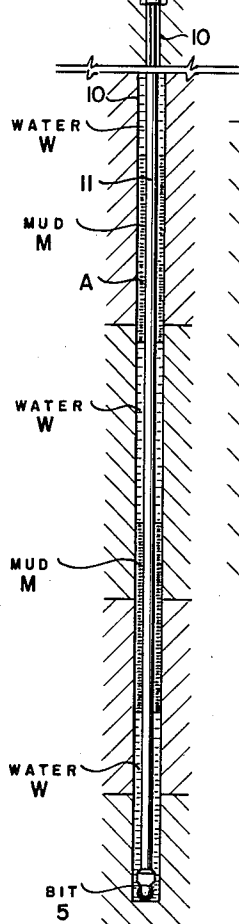
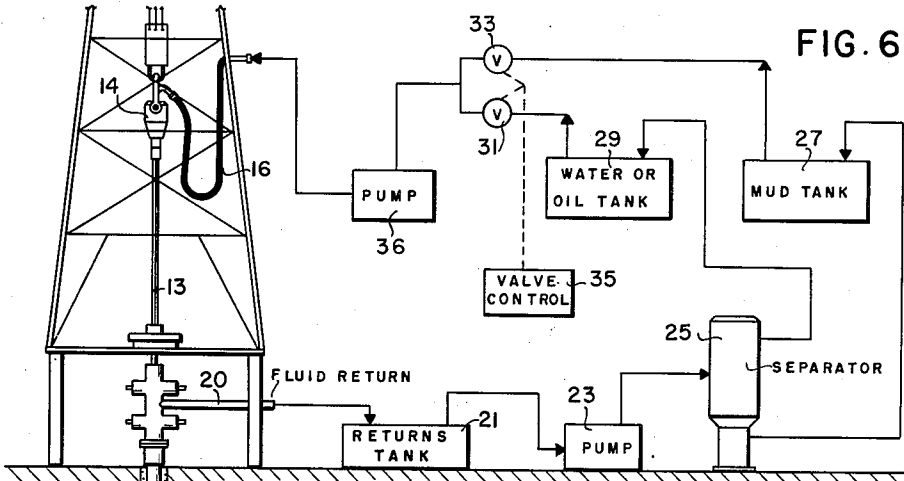


FIG. 1A.

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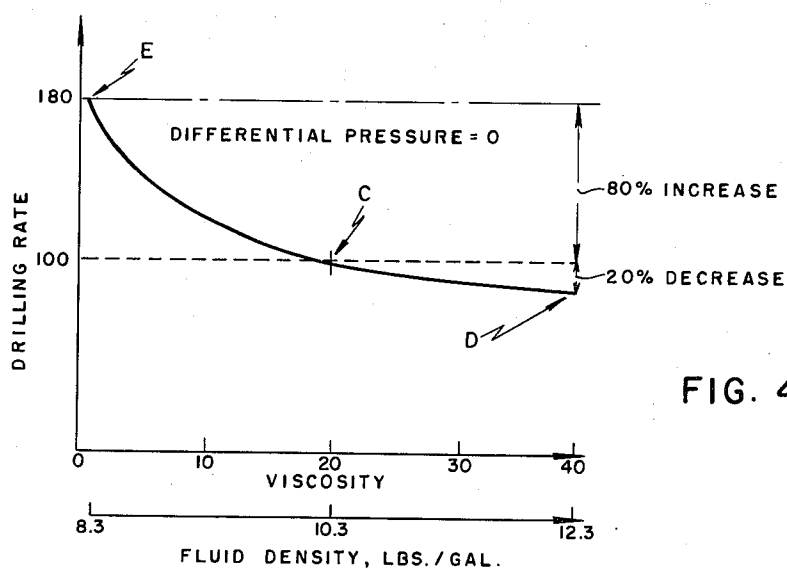
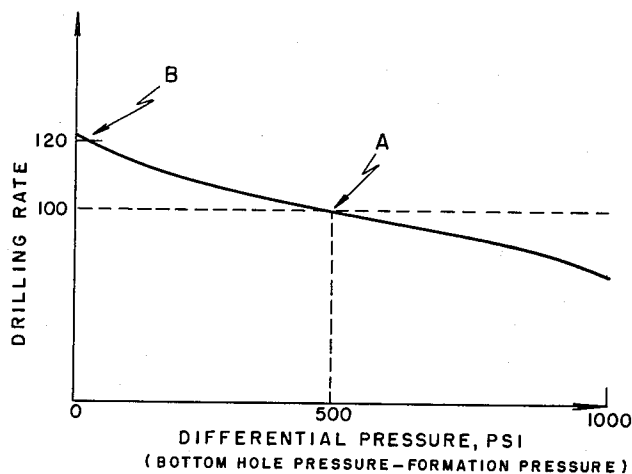
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METHOD OF INCREASING WELL DRILLING RATE

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3 Sheets-Sheet 2



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METHOD OF INCREASING WELL DRILLING RATE

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3 Sheets-Sheet 3

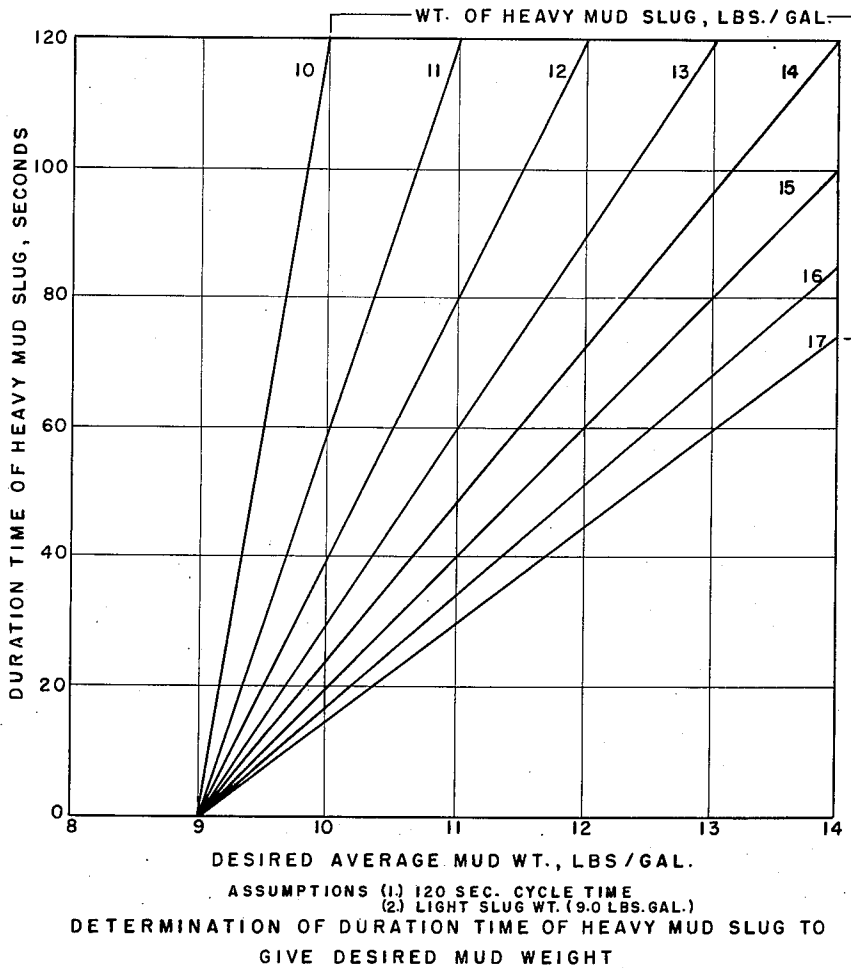


FIG. 5.

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METHOD OF INCREASING WELL DRILLING RATE
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This invention is directed to a method for increasing well drilling rate. More particularly, the invention concerns a method for increasing well drilling rate which utilizes the interrelation between drilling rate and the properties of drilling fluids.

In drilling wells by the rotary method, a drilling fluid is circulated down the drill string and up the annulus between the drill string and the bore-hole wall while the drill string and attached drill bit are rotated.

Important functions of this drilling fluid are: To clean the borehole of chips and cuttings and carry these to the surface; to lubricate the drill bit and drill stem; to maintain the walls of the borehole and prevent formation damage; to control the pressure in the annulus to prevent blowouts or formation breakdowns and lost returns; to sustain the cuttings in the event of rig shutdown so that these do not fall to the bottom of the hole and stick the drill pipe; and to protect the surrounding formation to some extent in order that the well bore may thereafter be successfully surveyed by current well logging methods.

To perform these functions the drilling fluid should possess certain properties. For example, the property of density is useful in controlling the pressure in the annulus; the property of viscosity is useful in suspending cuttings; and a filter cake forming property is useful in maintaining the wall of the borehole. For purposes herein by "filter cake forming property" is meant the formation of a zone of extremely low permeability in the vicinity of the interface between the fluid and the formation rock. A properly weighted and chemically treated drilling mud possesses the properties for performing the above functions and is a common drilling fluid in present use.

However, some of these desired properties adversely effect drilling rate. Thus, with regard to the filter cake forming property, a filter cake forms not only on the borehole wall but also beneath the drill bit where it interferes with removal by hydraulic action of chips formed at the rock surface by the mechanical bit action. For purposes herein by "filter cake" is meant the aggregation of particles on the rock surface and/or within the rock immediately below the rock surface so as to reduce permeability. Also, with regard to the viscous property a high viscosity fluid provides less turbulence and poorer bit cleaning action.

Therefore, an ideal drilling fluid insofar as rate of penetration of the drill bit is concerned is a low viscosity fluid having low or zero filter cake forming properties under the drill bit and conventional filter cake forming properties on the borehole wall. A low viscosity drilling fluid efficiently lifts the cuttings from the bottom of the hole thereby preventing the bit from recutting the chips that it has formed and although bottom hole pressure must be maintained at a value greater than formation pressure, the effective differential pressure in the region of chip formation can be reduced by reduction of the filter cake forming property of the drilling fluid so that bottom hole pressure and formation pressure can equalize in the critical region immediately below the drill bit.

Attempts to increase drilling rate by manipulating the drilling fluid system consistent with the required drilling fluid functions have been made. However, these investigations were confined to the consideration of a homogeneous system.

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The method of the present invention involves an inhomogeneous system wherein slugs of fluids having different properties are employed as the drilling fluid. Briefly, the method comprises circulating two fluids having different properties alternately to the drill bit; the properties of these fluids are such that an increased drilling rate is obtained when one of the fluids is at the drill bit; the other fluid has the property of forming a filter cake; and the densities of said fluids and the lengths of the slugs of each fluid are selected so as to control subsurface formation pressures. The faster rate drilling fluid may have a lower viscosity than the other fluid.

Circulation of the slugs is down the drill pipe and up the annulus between the pipe and the borehole wall at sufficient velocity to insure turbulent rather than laminar flow. This action results in a minimum amount of intermixing of the two fluids. However some mixing will occur and therefore, the method includes separating the fluids at the surface prior to recirculation down the drill string.

Preferably the faster rate drilling fluid is water or oil and the other fluid is drilling mud. The use of alternate slugs of water or oil and a heavily weighted drilling mud as the drilling fluid clearly satisfies all the required drilling fluid functions including maintenance of desired bottom hole pressure. The latter requisite is met by adjusting the relative densities and lengths of the slugs.

An increased drilling rate is obtained when the bit is drilling in water. A decreased drilling rate is obtained when the bit is drilling in mud. However because of the non-linear dependence of drilling rate on mud properties such as viscosity, filtration rate and density, the increase far exceeds the decrease in drilling rate thereby increasing substantially the overall drilling rate.

Thus, an object of the present invention is to provide a method whereby the actual drilling time required to penetrate subsurface formations is reduced.

This and other objects of the invention will be apparent from a description of the invention taken in conjunction with the drawings wherein:

FIG. 1 is a vertical view, partly in section, of a drill bit arranged in a borehole;

FIG. 1A is an enlarged view showing the critical region, below the drill bit, when using conventional drilling fluids;

FIG. 2 is a view similar to that of FIG. 1 illustrating the present invention when the faster rate drilling fluid is adjacent the drill bit;

FIG. 2A is an enlarged view similar to that of FIG. 1A illustrating when the fast drilling fluid is adjacent the drill bit according to the present invention;

FIG. 3 is a plot showing the effect of differential pressure on drilling rate;

FIG. 4 is a plot showing the effect of viscosity (a function of mud weight) on drilling rate;

FIG. 5 is a graph illustrating the determination of duration time of a mud slug of particular weight to give a desired mud weight; and

FIG. 6 is a view, partly in section, showing the arrangement of the drilling apparatus and including a schematic diagram of the surface equipment according to the invention.

Available data show the dependence of drilling rate on drilling fluid properties.

The effect of filter cake properties on drilling rate may be explained as follows:

Differential pressure between bottom hole pressure and formation pressure exists in a system employing a filter cake forming drilling fluid because this fluid builds up a filter cake on the bottom of the borehole immediately after the cutting teeth of the bit pass that portion of the borehole.

FIGS. 1 and 1A illustrate the use of conventional filter

cake forming homogeneous drilling fluid system and FIGS. 2 and 2A illustrate the use of the inhomogeneous drilling fluid system of the invention wherein slugs of a fluid having a filter cake forming property and one without such a property are alternately circulated through the drill bit.

FIGS. 1 and 2 show a drill bit 5 positioned in a borehole 10. In each of the systems a filter cake 6 forms on the borehole wall adjacent permeable formation surfaces when the filter cake forming fluid is circulated up the borehole. However, as seen in FIG. 1A a piece of rock 7 fractured by drill bit 5 is held in place by a filter cake 8 deposited on the formation below drill bit 5 and also by the difference in hydrostatic pressure and formation pressure whereas as seen in FIG. 2A the piece of rock 7 is easily removed when the filter cake 8 is absent. Elimination of the filter cake, which occurs when the non-filter cake forming fluid is circulating at the bit, reduces or eliminates the differential pressure between the formation and the bottom of the hole in the critical region below the bit.

Reduction of total differential pressure is possible only by reduction in bottom hole pressure. This reduction is impractical since it is inconsistent with maintenance of control of the well as, for example, prevention of blow-outs. However, the differential pressure in the critical region just below the bit can be reduced or eliminated by eliminating or reducing the effect of the filter cake. Elimination or reduction of the filter cake effect is possible because of rapid grinding of the formation by the drill bit in the presence of the non-filter cake forming fluid which will be present a substantial portion of the drilling time.

In a well drilled with ordinary drilling mud, the differential pressure is in the range of 500 pounds per square inch in order to have a safety factor against possible blow-outs of the well. Referring to FIG. 3, the drilling rate when a differential pressure of 500 pounds per square inch exists is assigned a value of 100 as indicated at A. If the differential pressure is reduced to 0, the drilling rate increases to 120, as indicated at B. Thus, a 20 percent increase in the drilling rate may be expected when the differential pressure is reduced in the critical region below the bit by modification of the cake forming property of the drilling fluid.

The effect of fluid viscosity and fluid density on drilling rate is illustrated in FIG. 4. Assuming, for purposes of illustration, that a fluid density of 10.3 pounds per gallon is required or a viscosity of 20 cp., the drilling rate at this density and viscosity may be assigned a value of 100 as indicated at C. When a more heavily weighted fluid or a more viscous fluid is in the vicinity of the drill bit, a lower drilling rate is obtained as indicated at D. For example, with a drilling mud of 12.3 pounds per gallon or about a 38 cp. viscosity, the decrease in drilling rate is 20 percent. However, when a less dense or less viscous fluid is in the region of the drill bit, the drilling rate will be higher as indicated at E. For example, with water of 8.3 pounds per gallon and 1 cp. viscosity or with oil near the same density and viscosity, the increase is approximately 80 percent. Therefore, the increase averaged over the increased drilling rate employing oil or water slugs and the decreased rate employing heavy mud slugs is approximately 30 percent. The increase in drilling rate is dependent upon, therefore, the non-linear relationship between drilling rate and viscosity or mud density.

Thus, the absence of differential pressure produces a 20 percent increase in drilling rate and the viscosity or density effect produces a 60 percent increase in drilling rate. Therefore, by circulating slugs of fluids of different properties alternately through the drill bit, an average net of 40 percent increase is obtained when the slugs are of equal length.

One other factor must be considered. That is the fluctuation of bottom hole pressure caused by the fact that the drilling fluid is present in the annulus in slugs of different

density. At any given time there can be, at most, one more or one less slug of one of the fluids in the annulus. For purposes of illustration using water and drilling mud as the fluids, the fluctuation in bottom hole pressure may be computed in the following manner.

The highest pressure occurs when there is one extra slug of drilling mud in the annulus.

Assume $(2N+1)L=D$:

$$\begin{aligned} P_{\max} &= 0.052[(N+1)L\rho_m + N\rho_w L] \\ P_{\max} &= 0.052[N(\rho_m + \rho_w)L + \rho_m L] \\ P_{\max} &= 0.052[2N(\rho_{\text{ave}})L + \rho_m L] \end{aligned}$$

The lowest pressure occurs when there is one extra slug of water in the annulus.

$$\begin{aligned} P_{\min} &= 0.052[N\rho_m L + (N+1)\rho_w L] \\ P_{\min} &= 0.052[N(\rho_m + \rho_w)L + \rho_w L] \\ P_{\min} &= 0.052[2N(\rho_{\text{ave}})L + \rho_w L] \end{aligned}$$

The fluctuation in pressure

$$\begin{aligned} P_{\max} - P_{\min} \\ = 0.052(\rho_m - \rho_w)L \end{aligned}$$

Therefore,

$$L = 19.2 \frac{\text{Max Allowable } \Delta P}{\rho_m - \rho_w}$$

$$\rho_{\text{ave}} = \frac{(\rho_m + \rho_w)}{2}$$

wherein

N = Number of slugs

L = Length of a slug in feet

D = The total depth in feet

$P_{\max}$ = The highest pressure in p.s.i. at the bottom of the borehole

ρ_m = Mud density in lbs./gal.

ρ_w = Water density in lbs./gal.

ρ_{ave} = Average density in lbs./gal.

$P_{\min}$ = Lowest pressure in p.s.i. at the bottom of the borehole

0.052 = a constant having units of

$$\frac{\text{gal.}}{(\text{in.}^2)(\text{ft.})}$$

The above result indicates that the length of the slug in the annulus must be less than 19.2 times the maximum allowable pressure fluctuation at the bottom of the borehole divided by the difference in the weights of the mud and water slugs. For example, if the maximum pressure fluctuation which may be sustained is plus or minus 100 p.s.i. and the average mud weight is 10.3 pounds per gallon, then the length of the slug in the annulus may be up to 960 feet in length. At a flow rate in the annulus of 120 feet per second, the pump must be switched from oil or water to mud every 8 minutes. If the pump is switched more frequently than this, as for example, every two minutes, the pressure fluctuation at the bottom of the borehole assuming 10.3 pounds per gallon mud weight can be no more than plus or minus 25 p.s.i. Thus, the problem of pressure fluctuation is readily solved.

In the preceding calculations, it has been assumed that the slugs are of equal length. However, this is not a necessary requirement. For example, if the average mud density requirement is as high as 16 pounds per gallon, then requirements indicate that the length of the water slug must be somewhat shorter than the length of the heavy mud slug.

FIG. 5 illustrates graphically how the duration time of the heavy mud slug may be readily determined when the desired average mud weight, the cycle time, and the light slug weight is given. In this instance, the light slug weight is 9 pounds per gallon and the cycle time is 120 seconds. Thus, for example, where an average mud weight of 10 pounds per gallon is required and the mud

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slug weight is 11 pounds per gallon, the duration time of the heavy mud slug is 60 seconds.

In FIG. 6, apparatus is illustrated for carrying out the method of the invention. In this figure is shown a borehole 10 in which is arranged a drill string 11, the lower end of which has connected thereto a drill bit 5 and the upper end of which has connected thereto conventional drilling equipment including a Kelly joint 13, a swivel 14, and a swivel hose 16. A drilling fluid return line 20 connects the annulus A between the drill string and the borehole wall to a returns tank 21. Returns tank 21 connects to a pump 23 which, in turn, is connected to a separator 25. One portion of separator 25 is connected to mud tank 27 and another portion of separator 25 is connected to a water or oil tank 29. Water or oil tank 29 is connected to a valve 31 and mud tank 27 is connected to a valve 33. Valves 31 and 33 are controlled by means of a valve control 35. Valves 31 and 33 are connected to the intake of a pump 36, the discharge of which is connected to swivel 14 by means of swivel hose 16. The interior of hose 16 fluidly communicates with the interior of drill string 11 via Kelly joint 13.

In operation the desired duration time for the mud slug is determined according to the foregoing computation and in accordance with FIG. 3. Valve control 35 is set to regulate valves 31 and 33 for the desired time sequence. Then drilling mud and water or oil are alternately fed to pump 36 by valves 33 and 31. The slugs of mud designated M and water or oil designated W circulate down the drill string 11 through the drill bit and up annulus A into return conduit 20 whence the return fluid enters tank 21. The return fluid is then pumped into separator 25 by means of pump 23. The water or oil and drilling mud are separated in separator 25, the separated water or oil being transmitted to tank 29 and the separated drilling mud being transmitted to tank 27.

Desired mud properties are obtainable by various formulae. A formula for a highly satisfactory 9.6 lb./gal. mud is: 1 barrel of water, 4 lbs. calcium chloride, 15 lbs. Aquagel, 7 lbs. starch, $\frac{1}{10}$ lb. starch preservative, and 80 lbs. barium sulfate. When mixing this mud, it is necessary that the calcium chloride be added to the water prior to the addition of the Aquagel. This mud has the property that the solids settle rapidly but not so rapidly that there is danger of sticking the drill pipe in the event of a prolonged shutdown of the well. Also, this mud has the property that when separated into water and a heavy mud, the heavy mud has a low water loss. Additionally, the heavy mud is one of negligible settling rate. A mud, according to this formula, is especially adaptable for use with a centrifugal cyclone type separator. Other muds may be readily composed for use with a settling tank type separator if this type separator is desired. If a settling tank is used instead of a centrifugal type separator, water tank 29 and mud tank 27 may be omitted and suction to pump 36 may be taken alternately from the top of the settling tank and the bottom thereof in order to feed slugs of oil or water and drilling mud to the drill string 11.

Although the method of the invention has been described herein utilizing only two fluids, the scope of the invention is not to be considered limited thereto. More than two fluids may be sequentially circulated so long as the various drilling fluid functions are maintained and the overall drilling rate is increased.

Having described the operation, objects, and apparatus of our invention, we claim:

1. A method for increasing well drilling rate over that achievable with a single well drilling circulating liquid having a desired filter cake forming property, a selected viscosity, and a selected density comprising:

injecting at least two liquids into a drill pipe string sequentially and continuously while rotating the drill pipe string and drill bit attached thereto, the liquids

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circulating down the drill pipe string and up the annulus between the drill pipe string and the wall of the borehole being drilled;

the frequency of injection of the liquids being such that slugs of each liquid are located in the annulus at all times, at least one of the liquids having a filter cake forming property and greater viscosity than the selected viscosity of said single circulating liquid and at least one other of the liquids having a nonfilter cake forming property and lesser viscosity than the selected viscosity of said single circulating liquid;

the density and the injection rate and the duration of injection of each liquid being selected such that there is hydrostatic pressure at least as great as formation pressure at any point in the annulus.

2. A method as recited in claim 1 in which said one liquid has a greater density than said other liquid.

3. A method for increasing well drilling rate over that achievable with a single well drilling circulating liquid having a desired filter cake forming property, a selected viscosity, and a selected density comprising:

injecting two liquids alternately and continuously into a drill pipe string while rotating the drill pipe string and drill bit attached thereto, said liquids circulating down the drill pipe string and up the annulus between the drill pipe string and the wall of the borehole being drilled;

the frequency of injection of the liquids being such that slugs of each liquid are located in the annulus at all times, only one of the liquids having a filter cake forming property, said one liquid having a greater viscosity than the selected viscosity of said single circulating liquid, said other liquid having a lesser viscosity than the selected viscosity of said single circulating liquid;

the density and the injection rate and the duration of injection of each liquid being selected such that there is hydrostatic pressure at least as great as formation pressure at any point in the annulus.

4. A method as recited in claim 3 in which said one liquid is of greater density than said other liquid.

5. A method as recited in claim 3 in which said one liquid is drilling mud and said other liquid is water.

6. A method as recited in claim 3 in which said one liquid is drilling mud and said other liquid is oil.

7. A method for increasing well drilling rate over that achievable with a single well drilling circulating liquid having a desired filter cake forming property, a selected viscosity, and a selected density comprising:

injecting at least two liquids into a drill pipe string sequentially and continuously while rotating the drill pipe string and drill bit attached thereto, the liquids circulating down the drill pipe string and up the annulus between the drill pipe string and the wall of the borehole being drilled;

the frequency of injection of the liquids being such that slugs of each liquid are located in the annulus at all times, at least one of the liquids having a filter cake forming property and greater viscosity than the selected viscosity of said single circulating liquid and at least one other of the liquids having a non-filter cake forming property and lesser viscosity than the selected viscosity of said single circulating liquid;

the density and the injection rate and the duration of injection of each liquid being selected such that there is a hydrostatic pressure at least as great as formation pressure at any point in the annulus;

separating said liquids after circulation; and then re-injecting said liquids into the drill pipe string alternately as before.

8. A method as recited in claim 7 in which said one liquid is of greater density than said other liquid.

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9. A method as recited in claim 8 in which said one liquid is drilling mud.

10. A method as recited in claim 8 in which said other liquid is water.

11. A method as recited in claim 9 in which said other liquid is oil.

12. A method for increasing well drilling rate over that achievable with a single well drilling circulating liquid having a desired filter cake forming property, a selected viscosity, and a selected density comprising:

injecting at least two liquids into a drill pipe string sequentially and continuously while rotating the drill pipe string and drill bit attached thereto, the liquids circulating down the drill pipe string and up the annulus between the drill pipe string and the wall of the borehole being drilled;

the frequency of injection of the liquids being such that slugs of each liquid are located in the annulus at all times, at least one of the liquids having a filter cake forming property and at least one other of the liquids having a nonfilter cake forming property and a greater density than the remaining liquid and said single circulating liquid;

the density and the injection rate and the duration of injection of each liquid being selected such that there is hydrostatic pressure at least as great as formation pressure at any point in the annulus.

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13. A method as recited in claim 12 in which at least one of the other liquids is of lesser viscosity than the remaining liquid and said circulating liquid.

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