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Incremental Dilution Calculations

Sam Bridges, Derrick Equipment Company; Dr. Leon Robinson, Retired and Ron Morrison, Derrick Equipment Company

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Improving Drilling Performance

Drilling performance is directly affected by the quantity of drilled solids in the drilling fluid. Maintaining a low concentration of drilled solids is required to drill with the lowest cost per foot. To drill as cheaply as possible, procedures should include:

1. Maximizing the hydraulic impact or power to assist removal of cuttings from beneath the bit. This will allow the fastest drilling rate possible for the rig and situation. Plastic viscosity should be as low as possible – which means the removal of drilled solids should be a priority.
2. The weight on the bit and the rotary speed should be selected so the bit is operating below the founder point. This will create the largest drilled cuttings possible. Cuttings are more easily removed from the drilling fluid when they are large. This prevents an increase in plastic viscosity because of small drilled solids.
3. The hydraulic adjustment in step 1 will specify the flow rate in the well. Hole cleaning can then be adjusted with the proper selection of the rheological characteristics of the drilling fluid. In vertical wells, both the plastic viscosity and yield point affect the carrying capacity of the drilling fluid. The plastic viscosity should be as low as possible – which means eliminating drilled solids.
4. When the cuttings reach the surface, the majority should be removed with the shale shaker. Only API compliant screens should be used on the shale shaker. Smaller openings in the screens remove more solids. Screens that are touted to handle large flow rates usually have larger openings and remove fewer solids.
5. The drilling fluid removal section should be properly arranged to achieve the maximum equipment solids removal efficiency possible. This will create a drilling fluid which produces a thin, slick, compressible filter cake. A compressible filter cake can not be produced if many drilled solids are allowed to remain in the drilling fluid. A compressible filter cake will decrease the instances of stuck pipe and fracture-induced lost circulation.
6. Good equipment solids removal efficiency will decrease the quantity of drilling fluid needed to maintain a low drilled solids concentration. This also reduces the drilling fluid waste volumes generated when dilution is used to maintain the targeted drilled solids concentration.

In all of these steps, the quantity of drilled solids directly affects either the plastic viscosity or the filter cake characteristics.

Introduction

Knowledgeable drillers now recognize that too many drilled solids in the drilling fluid can create expensive wells. Drilling performance suffers if too many drilled solids remain in the drilling fluid. The cost of poor performance is frequently not observed, since it is inside other costs like the drilling fluid and non-productive time.

Although the cost of poor drilling performance can far exceed trouble costs, rig down-time [non-productive time] is more obvious and is usually cited as the reason for improving equipment solids control efficiency. Another cost, also seriously affecting drilling costs, is the cost of waste disposal.

While each drilling area can have different drilled solids concentration before trouble costs increase, all drilling performance is affected by the solids concentration allowed in a drilling fluid. In general, as the solids concentration increases, the cost of drilling increases.

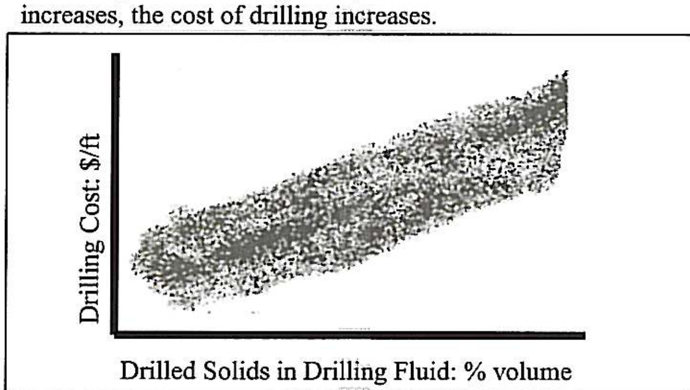

Figure 1. Drilling costs increase with increases in drilled solids concentration

Good drilled solids removal requires that cuttings are removed from beneath the drill bit as quickly as possible to prevent regrinding. Large solids are more easily removed at the surface. Good bottom hole cleaning requires good hydraulics and a low plastic viscosity. Plastic viscosity depends upon four things: liquid phase viscosity, size, shape, and number of particles. Low plastic viscosity can more economically be achieved by proper solids control procedures. After the cuttings enter the annulus, they should be brought to the surface without tumbling. Grinding solids in the annulus from tumbling action increases the plastic viscosity and decreases the carrying capacity index. Cuttings removed from the shale shaker screen should have very sharp edges. The quantity of cuttings is NOT a unique indication of good hole cleaning – sharp edges indicates the lack of tumbling and a good hole cleaning process.

Once the cuttings arrive at the surface, they should be removed with the solids control equipment. The new API RP13C screen designation should be used to indicate the opening sizes in shaker screens. Most manufacturers' labels do not indicate the equivalent opening sizes and cannot be used to compare shale shaker screens. Screens that are sold on the basis of 'handling more fluid' usually have much larger openings to provide that feature. A shale shaker screen should remove as many solids as possible from the fluid. Screens with smaller openings removed more solids than screens with larger openings. Read the API labels to determine the largest openings in a shaker screen.

Solids removal efficiency is defined as the volume of drilled solids removed divided by the volume of drilled solids reporting to the equipment. If 100bbl of drilled solids report to the shale shaker and 60bbl are removed, the equipment solids removal efficiency is 60%. On a drilling rig, solids do not arrive at the surface in the same order in which they are drilled. Many drilled solids arrive long after the lag time measured by the mud logger. Calculation of solids removal efficiency requires that a long interval be drilled with the complete removal of all of the drilled solids.

If a 12 ¼" hole is drilled from 4000ft to 8400ft, the total drilled solids reporting to the surface can be determined with a caliper log and a calculation of the volume of rock removed. If nothing is removed from the drilling fluid system, the pit levels will stay constant [if the drill pipe is removed from the drilled interval]. Rock does not expand much when it is brought to the surface. The volume of rock (drilled solids) exactly matches the volume of new hole drilled,

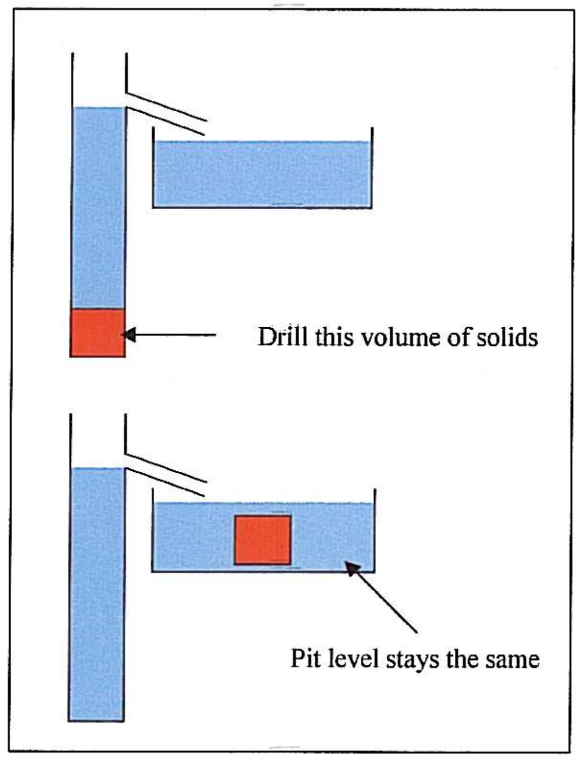

Figure 2. The hole volume generated is exactly the volume of solids which reach the pits

Pit levels will only decrease when fluid or solids are removed from the system. Cuttings removed from the system with the shale shaker will be wet with drilling fluid. Both drilled solids and drilling fluid are rejected from the system. The pit levels will decrease by the volume of this discard. The best system is one in which the volume removed (or decrease in pit volume) exactly matches the volume of fluid required to dilute the remaining drilled solids.

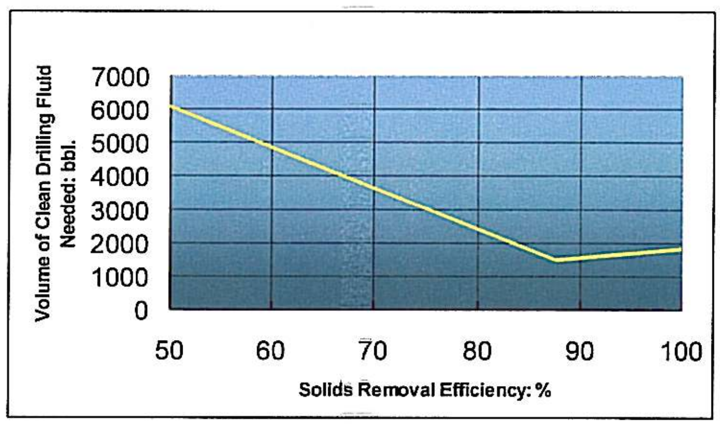

Figure 3. Clean drilling fluid required to maintain drilled solids concentration at 5% volume

If the drilled solids removal efficiency is 100%, clean drilling fluid must be added to the system to replace the quantity of material removed. In situation shown in Figure 3, this would be a volume of about 1900bbl. If the solids removal efficiency is 90%volume, some of the drilled solids will remain in the system and less material is removed. The volume of clean drilling fluid needed is lower or about 1600bbl as shown in Figure 3. With 5% volume targeted drilled solids concentration; the amount of material removed from the system at 86% efficiency is exactly the volume of clean drilling fluid needed to dilute the retained drilled solids.

If the drilled solids removal efficiency is 60%, the volume of solids remaining in the pit system can be calculated. The volume of discard depends upon the quantity of liquid and drilled solids removed or the drilled solids concentration in the discarded fluid. Assume 1000bbl of drilled solids arrive at the surface during drilling of one interval. [This would be equivalent to drilling about 972ft of a hole about 10" in diameter.] With the 60% removal efficiency, 400bbl of drilled solids would remain in the system and 600bbl of drilled solids would be discarded. If the discarded solids are 35%volume of the total discard, the volume removed from the system would be 1714bbl [or 600bbl/0.35]. This would be the volume available to add clean drilling fluid to dilute the remaining solids. If only this volume of clean drilling fluid is added, the 400bbl of remaining drilled solids would be dispersed in 1714bbl of clean drilling fluid. The new drilling fluid volume would be 2114bbl. The drilled solids concentration in this new addition would be 18.9% volume. This level of drilled solids contamination would quickly increase the total cost of the well.

In the above example, if the target drilled solids concentration is 5%volume, the new drilling fluid volume would have to be 8000bbl [or 400bbl/0.05]. The quantity of clean drilling fluid would need to be 7600bbl [or 8000bbl – 400 bbl] only 1714bbl of fluid was removed, so 5786bbl [or 7600bbl – 1714bbl] of excess drilling fluid must be built.

The cost of this excess drilling fluid can be excessive, also. Even at $10/bbl, the excessive drilling fluid cost would be $59/ft [or (7600bbl/972ft) ($10/ft)]. The total cost of the clean drilling fluid would be $78/ft [or (7600bbl/972ft) ($10/ft]. If the drilled solids removal efficiency was increased so that the only fluid needed was the 1714bbl needed to keep the pit levels constant, the cost would be only about $19/ft.

Conclusions

A question arose about the calculation procedure: How much different is reality compared to the 'perfect' case? Obviously, a smaller quantity of dilution drilling fluid is required if the drilling fluid is dirtier.

The above calculations assume that the drilled solids concentration in the pits remain constant throughout the interval. In field operations, this is difficult to do. Pits are dumped regularly to allow addition of clean drilling fluid to maintain a low drilled solids concentration. At the drilling rig, drilling fluid is dumped for a variety of reasons and the decisions are predicated upon many different concepts. One drilling foreman said he dumped the sand trap frequently to get rid of mud that was 'worn-out'. With poor solids removal equipment efficiencies, derrick men or mud engineers have severe problems maintaining a low drilled solids concentration. Fluid is dumped on a time schedule, on whims of the rig personnel, on a footage basis, on perceived increases in solids content, or for a variety of other reasons. For this discussion, drilling fluid dilution adjustments will be calculated on the basis of footage drilled.

This question concerning matching the perfect case with reality was answered by making a series of calculations for various concentrations of targeted drilled solids concentrations. These calculations are illustrated by explaining the details of one scenario. The targeted drilled solids concentration is 5%volume. A hole is drilled from 4000ft to 8400ft and the solids removal efficiency is assumed to be 60%. From the caliper log the new hole created had a volume of 0.146 bbl/ft. A series of calculations of the volume of dilution [volume to keep tanks full and the excess volume needed to decrease the drilled solids concentration to the target value] was made assuming the adjustment was made after drilling 100ft. These calculations were also made for intervals of 200, 300, 400, 500, 600, 700, 800, 900, and 1000ft for target concentrations of drilled solids from 4%volume to 8%volume. In each case, the assumption was made that all of the drilled solids drilled in these intervals was circulated from the well bore before the dilution volumes were added. This, of course, does not represent field behavior but calculating well bore storage of cuttings would complicate the calculations beyond comprehension.

If the drilled solids concentration is calculated for the 100ft intervals, the drilled solids increase from 5%volume to around 5.2%volume before the adjustment is made, as shown in Figure 4.

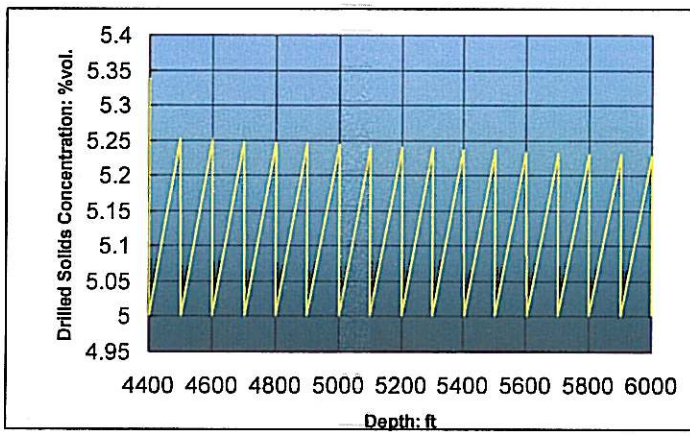

Figure 4. Drilled solids concentration for 100ft intervals

If the adjustment is made after drilling 1000ft, the drilled solids concentration increases from 5%volume to around 7 to 8%volume while drilling.

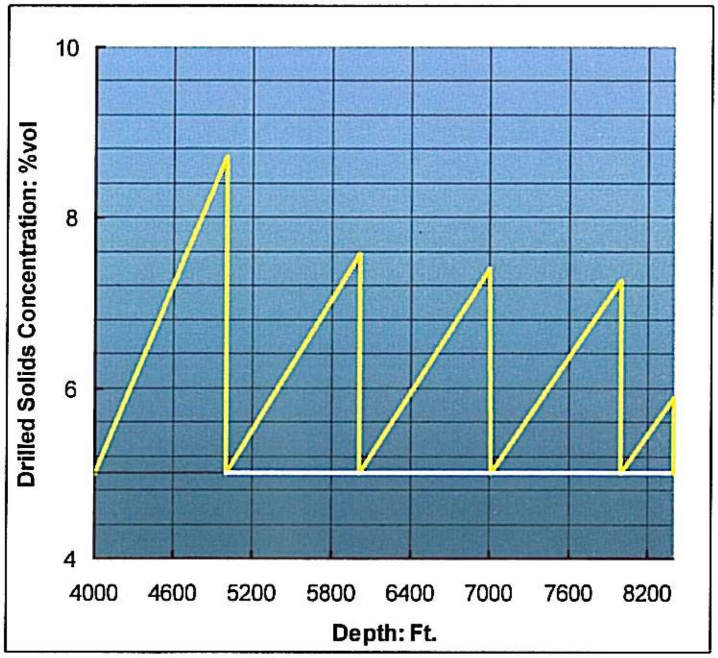

Figure 5. Drilled solids concentration for 1000ft intervals

The effect of postponing the adjustment can be observed at the 5000ft depth in the well by comparing the maximum drilled solids concentration for different drilling intervals before adding dilution, as seen in Figure 6. The drilled solids concentration rises as the distance drilled increases.

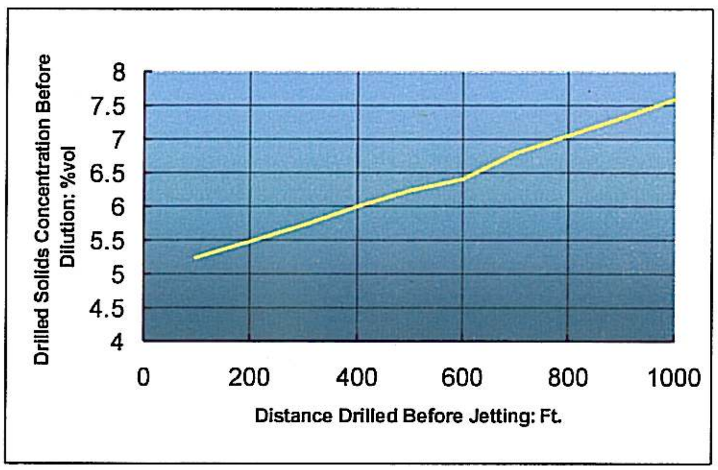

Figure 6. Drilled solids concentration increases as the distance between dilution adjustments increases

Of course in each instance, the quantity of clean drilling fluid decreases as the interval between dilution additions is increased, Figure 7. However, that would be expected, because less fluid is required for dilution when the drilling fluid is allowed to acquire more drilled solids.

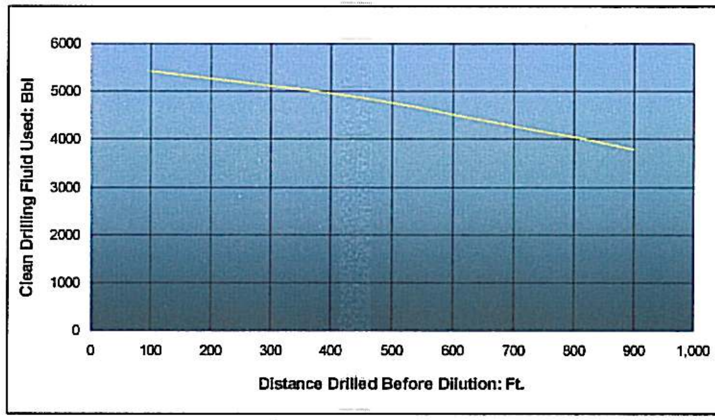

Figure 7. The quantity of clean drilling fluid correlates well with the incremental value calculated in the proposed original method

Acknowledgments

Nomenclature

References