



Economic Consequences of Poor Solids Control

Dr. Leon Robinson

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This paper was prepared for presentation at the AADE 2006 Fluids Conference held at the Wyndam Greenspoint Hotel in Houston, Texas, April 11-12, 2006. This conference was sponsored by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

Abstract

The economic consequences of solids control practices affect not only trouble costs but also drilling performance. Experience has shown that many people preach good solids control practices but few actually do anything about it. The various problems generated by poor solids control practices will be briefly discussed [briefly - because they have been the subject of many technical papers -during the past 50+ years]. The effect that poor solids control practices have on actual drilling costs has not been emphasized. These costs are usually not obvious and the resulting poor drilling practices become accepted performance. These costs will be discussed.

Introduction

Drilled solids decrease drilling performance. This is a relatively obscure fact because the most noticeable effect of drilled solids is the large increase in non-productive time, or trouble costs, when drilled solids are not removed from the drilling fluid. Poor filter cake quality can cause differentially stuck pipe and lost circulation. Filter cakes become incompressible when excessive drilled solids are present. This provides a good seal which allows the well bore pressure to seal drill collars against the side of the well bore.

Thick filter cakes caused by drilled solids also create a seal around the drill bit and collars causing large surge and swab pressures. The cost associated with these events is easily identified in post well analysis.

Unfortunately, these costs are relatively minor compared to the effect drilled solids have on drilling performance. These costs are usually hidden from scrutiny because they are not obvious while drilling nor in post-well analysis. Drilled solids prevent drilling the 'Perfect Well' and most drillers remain oblivious to these costs.

Processing all drilling fluids on the surface involves removal of undesirable ingredients and the addition of beneficial products. Drilled solids are detrimental to the

drilling process and their removal will greatly decrease drilling trouble costs and improve drilling operations. Solids are indicated in a drilling fluid by two parameters: retort solids and plastic viscosity. The retort indicates the total quantity of solids, the plastic viscosity responds to more than that. Plastic viscosity is the viscosity a drilling fluid has at a very high shear rate and depends upon four factors:

1. Liquid phase viscosity,
2. Size,
3. Shape, and
4. Number of Particles.

Effect of Drilled Solids on Drilling Performance

Problems with drilling performance are seldom recognized, and difficult to quantify at the rig site.

Excellent drilling performance means drilling a well as cheaply as possible, and eliminating problems. Usually improving drilling rates will significantly decrease drilling costs if this increase in drilling rates create other problems and does not wear bits too swiftly. Drilling rate for a roller cone bit increases as a square of the weight on the drill bit up to the founder point. The drilling rate, or rate of penetration (ROP), for a particular bit drilling on bottom, can be calculated from the equation¹.

$$ROP = \frac{K N^{\lambda} W^2}{m + \Delta P},$$

Where K and m are constants,

N is the rotary speed, rpm;

W is the weight on bit, lbs

ΔP is the differential pressure across the bottom of the hole, psi.

This equation matches the data in the literature up to the founder point. The concept of the founder point was presented initially by Rubin Feenstra in the fifties. For many years the full significance of this contribution was not appreciated.

The founder (or flounder) point is the point at which the drilling fluid ceases to remove all of the drilled cuttings from the bottom of the hole and the drill bit is drilling cuttings instead of new rock. The founder point is a function of the ability of the drilling fluid to remove those cuttings. Without knowing whether drilling is taking place above or below the founder point renders data totally incomprehensible. Below the founder point for example, increasing drilling fluid flow rate might decrease drilling rate because of the increase in ECD. Above the founder point, better bottom hole removal of cuttings will show a significant increase in drilling rate. So, does improved hydraulics improve drilling performance? Obviously, it depends upon whether the drilling is above or below the founder point.

A drill-off test with a 9 7/8" carbide insert bit on this rig, while drilling, reveals that the founder point for the hydraulics available is 30,000lb and, at this weight on bit (WOB), the drilling rate is 37 ft/hr. The driller was following instructions from the drilling program and drilling with 44,000lb WOB. The drilling rate is 20 ft/hr and the bit was lasting about 80 hours. Bit manufacturer guidelines for weight/RPM for a particular bit require that cuttings be removed from the bottom of the hole. Poor performance results if this is not true. Notice that the drilling rate is not only lower but the bits will not last as long.

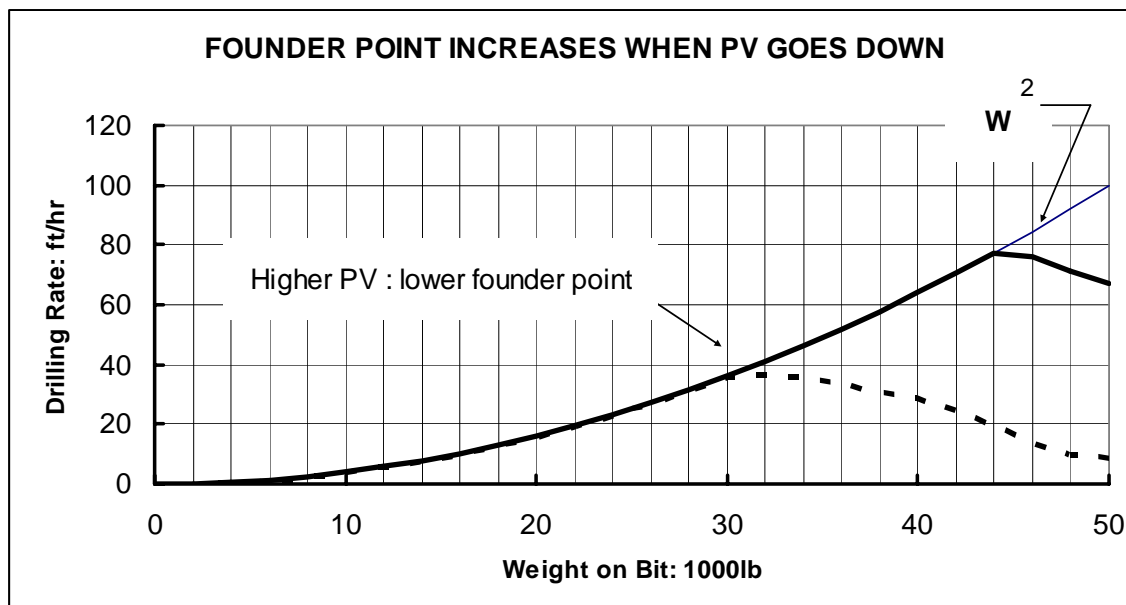
Assuming the bit bearings wear rate is proportional to WOB squared, the consequences of drilling above the founder point can be expensive. If the bit lasts for 60 hours with the 44,000lb WOB, it would last 85 hours with 37,000lb WOB. The bit with 44,000lb would drill 1200 ft

before it needs to be pulled; the bit with 37,000lb WOB would drill 3145ft before it needs to be pulled. If a 6000ft interval [perhaps from 6000ft to 12,000ft] is to be drilled, it can be drilled with only two bits in 162 hours. In the foundered condition, five (5) bits would be required with a drilling time of 300hours. As an approximation of the difference in costs, assume, at the depth being drilled, each bit trip requires one day and each bit costs \$10,000, the difference in cost would be \$180,000. Combine this with the difference in drilling time of 138 hours, or 5.75days @ \$50,000/day, \$287,500, \$467,500 will be spent that could be saved with proper attention to drilled solids removal.

To properly use a bit, however, the bit should be supplied with the proper hydraulics. This means, not only supplying the proper hydraulic power or hydraulic impact, but the proper drilling fluid properties.

Cleaning beneath the bit is more effective with low plastic viscosity. The founder point is higher with low plastic viscosity. If all of the cuttings are being removed and the bottom of the hole is clean, increasing the hydraulic cleaning of the bottom of the hole will not increase penetration rate in hard rock. Decreasing the plastic viscosity will provide the capability to increase bit loading.

Removal of drilled solids from a drilling fluid will decrease plastic viscosity. If drilled solids remain in the drilling fluid, they will grind into smaller and more numerous particles which increases plastic viscosity and decreases drilling performance.



If the plastic viscosity is decreased, the founder point can be increased to 44,000lb. In this case the drilling rate will be 76 ft/hr instead of the 20 ft/hr obtained in the founder condition. The time to drill the 6000 ft interval will decrease from 300 hours to 79 hours [12.5 days to 3.3 days].

If the bit lasts 60 hours (as in the preceding case), two bits will still be required but not the 5 bits required before.

For a nominal rig rate of \$50,000/day, the rig cost just to drill this interval will decrease from \$625,000 to \$164,580. The cost of 5 bit trips should also be compared to 2 bit trips and the cost of 5 bits compared to 2 bits.

Cleaning cuttings from the bottom of the hole without regrinding will provide the largest solids possible entering the annulus. The solids must be brought to the surface as quickly as possible without tumbling and grinding in the annulus. Failure to keep the cuttings moving upward as they are brought to the surface, will result in smaller solids and a larger number. Both of these effects will increase plastic viscosity.

Effect of Drilled Solids on Cuttings Transport

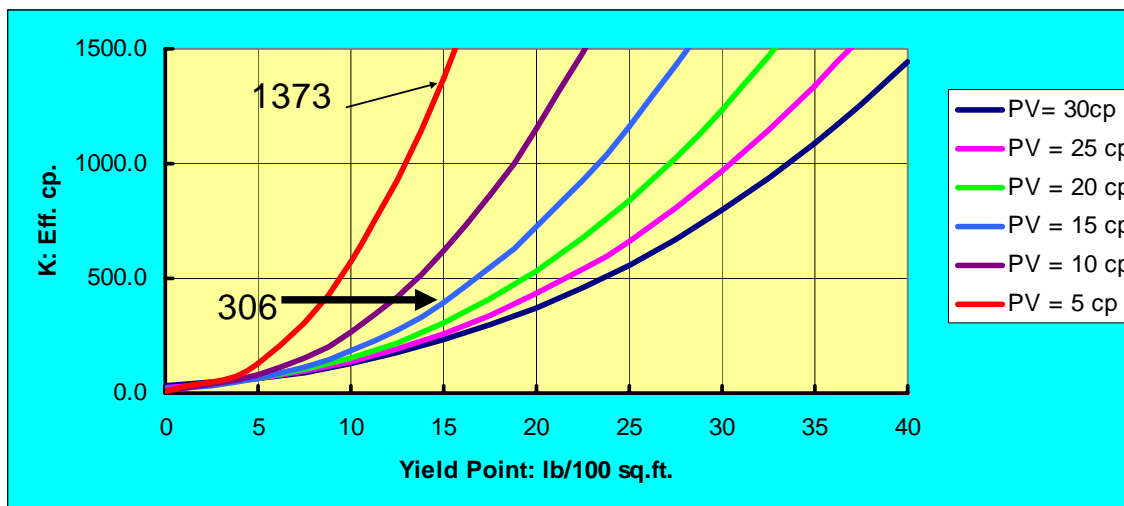
To remove cuttings as quickly and as efficiently as possible the solids control equipment should receive cuttings that are as large as possible. Good solids control starts with rapid removal of solids from beneath the drill bit AND good transport up the annulus. Good transport can be verified by examination of cuttings removed from end of shale shaker - They should have sharp edges.

Large cuttings will also appear if they are in the annulus. The quantity of solids on the shale shaker screen does NOT indicate whether the hole the cuttings are being transported correctly. Cuttings will reach the surface if a thin fluid is pumped fast enough and long enough. These cuttings will tumble in the annulus and assume a well-rounded shape. The detritus from this tumbling increases the concentration of small solids and will increase plastic viscosity.

Surprisingly, removal of drilled solids will also increase the very low shear rate viscosity as measured by the K value of the Power Law Model of drilling fluid.

Good carrying capacity requires the drilling fluid bring drilled solids to the surface in a vertical well (or well angles less than 30°) without tumbling. Three things control the ability of a drilling fluid to transport cuttings: Annular velocity, mud weight, and fluid viscosity in the annulus. Fluid viscosity can be identified with the 'K' value for viscosity.

The K viscosity from the Power Law Model : $[\text{Shear Stress} = K (\text{Shear Rate})^n]$ is the viscosity of the fluid at one reciprocal second. This viscosity must be large enough to bring cuttings up a vertical hole. Decreasing the plastic viscosity from 15 cp to 5 cp while the yield point remains at 15 lb/100 sq.ft., the K viscosity will increase from 306 eff.cp to 1373 eff.cp.



Review of K-value:

If $n=1$ in the Power Law model, the K becomes the ratio of shear stress to shear rate, which is the definition of viscosity. Multiply the viscometer dial readings by 511 to convert the readings to dynes/square centimeter. The shear rate is calculated by multiplying the viscometer sleeve revolutions per minute by 1.7. These units are used here so that a calculation of K for a Newtonian viscosity will be in poise. To convert to centipoise for the 300RPM reading, the equation becomes:

$$K = (511)^{1-n} [PV + YP], \text{ and}$$

$$n = 3.322 \log \frac{(2PV + YP)}{(PV + YP)}$$

As drilled solids are removed, the plastic viscosity decreases. Decreasing the plastic viscosity will increase the low shear rate viscosity (K), which will bring larger, more easily removable, solids to the surface. The system also works the other way. Failure to bring cuttings to the surface while they are large enough to be removed by the equipment will increase the plastic viscosity. Increasing plastic viscosity will decrease the ability to bring cuttings to the surface and allow them to grind into smaller, more numerous particles. This increases the plastic viscosity which decreases the carrying capacity.

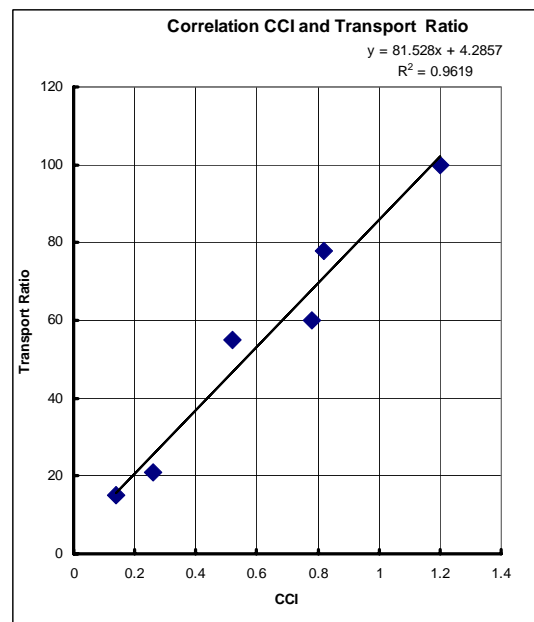
When this happens, the normal reaction is to increase the yield point. When the yield point increases significantly, the shale shaker screens may be too fine to handle the more gelled fluid. The screens will need to be changed to a coarser screen. This decreases the quantity of drilled solids that can be removed which again increases the plastic viscosity. This cyclic change requires careful attention and some drastic action to

Comment about Calculation of Effect of Drilled Solids on Drilling Performance.

Drill-off curves can follow the shape shown in the preceding section or can maintain the same drilling rate of the cut point. The economics of improving drilling performance will vary considerably depending upon the exact shape of the drilling curve. A specific set of conditions were arbitrarily selected to demonstrate the large potential savings available. Each particular situation will offer different potentials; however, there is always an opportunity to improve drilling performance and prevent trouble. The order and magnitude of the savings will depend upon many things, such as, the improvement possible, the rig cost per day, the cost of the bits, the type of bits, the cost of the drilling fluid, and many others.

reverse the cycle. This is a 'solids problem' which arises without always having an increase in total solids content.

Failure to bring solids to the surface expeditiously results in a storage of cuttings in the annulus and will increase the pressure differential across the bottom of the hole. The carrying capacity index (CCI) has been correlated with the Transport Ratio which indicates the fraction of cuttings arriving at the surface. The remainder of the cuttings will stay in the annulus and increase the mud weight. CCI can be increased by removing drilled solids which decreases plastic viscosity. Decreasing PV will not only increase the ability to remove cuttings from beneath the bit but will also have an effect on the drilling rate because of the differential pressure.



TROUBLE COSTS

Trouble costs are the most commonly recognized effect of too many drilled solids. Most solids control courses concentrate on trouble costs. Stuck pipe, lost circulation, and surge/swab pressures are related to the quality of filter cake.

Surge and Swab Pressure

Thick filter cakes make good seals around a drill bit. As the bit is moved passes the thick filter cake, it acts like a piston. As the bit is raised from the bottom of a borehole, drilling fluid will have difficulty flowing down the annulus to fill the hole beneath the bit. This can swab a kick into the well. As the bit moves into the hole, the fluid from beneath the bit must be displaced up the hole. With a thick filter cake sealing or restricting the flow, the pressure beneath bit increases and can cause lost circulation. This is particularly true when casing is run in the hole.

Cement Placement

If filter cakes are thick, cement will not move the filter cake to make a good seal with the formation. With contact with the calcium in the cement, filter cakes become very permeable and can cause flow behind the casing.

Wear

Expendables [like seals, pump parts, swivels, etc] wear much faster when impacted with abrasive solids. Large drilled solids act like sandpaper and erode metal.

Disposal Costs

Poor solids removal equipment and arrangement results in excessive quantities of dilution. Most drilling fluid programs specify the maximum drilled solids content (or they should). Failure to remove enough solids with the removal equipment means that additional clean drilling fluid must be added to keep the drilled solids under control. This will increase drilling fluid costs and disposal costs. Poor solids removal efficiency requires generating excessive quantities of drilling fluid with significant cost consequences

Formation Damage

Thick filter cakes are an indicator of large quantities of filtrate entering the formation. Filter cakes containing drilled solids are not compressible. Fluid loss may appear satisfactory for the API 100psi but at higher pressures fluid loss can increase. When the filtrate interacts with the formation fluid, some insoluble products may be formed and precipitate in the pore space. This will plug the formation. If the damaged region next to the well bore is thicker than the penetration expected from a perforator, production may be permanently diminished. A thin, slick, compressible filter cake would decrease the quantity of fluid entering the formation. This requires eliminating drilled solids from the drilling fluid.

Log Interpretation

Thick filter cakes usually mean that a large quantity of filtrate has entered the formation. Now instead of the original fluid, the formation is filled with filtrate. Any measurement must be made through this invaded zone and may hide the true concentration of fluids in the formation. Some production might be lost.

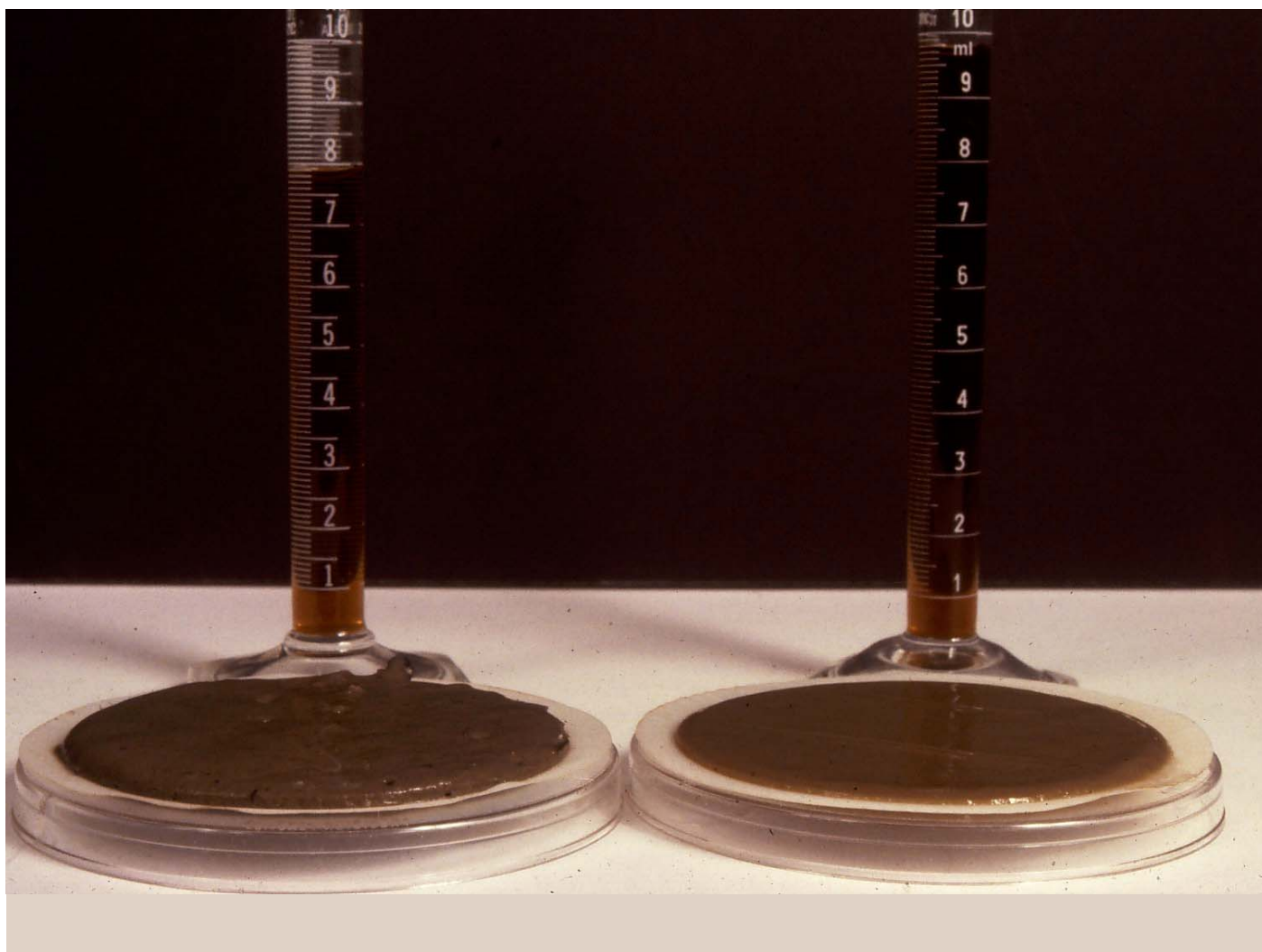
Stuck Pipe

What is frequently unobserved is the effect of drilled solids on filter cake quality. Drilled solids can decrease the fluid loss of a drilling fluid and at the same time increase the filter cake thickness as shown in the figure below:

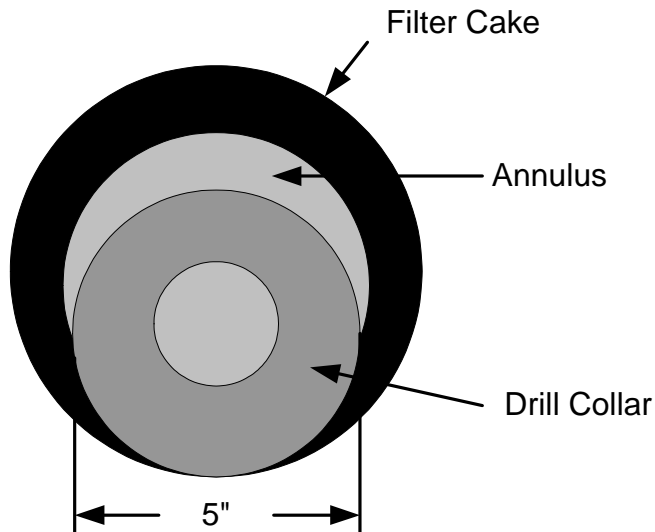
The 9.8cc of filtrate on the right came from a fluid containing water, bentonite, and a small quantity of lignosulfonate. The fluid was split into two volumes. A couple of handfuls of dirt was added to one portion of the fluid. The filter cakes from an API test cell are shown below the graduated cylinder containing the filtrate. The filtrate volume from the dirty fluid decreased to about 8 cc but the filter cake was noticeably thicker. This filter cake is not compressible. If the clean fluid is placed in an HTHP filtration cell and 500 psi applied at room temperature for 30 minutes, the fluid loss of the base fluid would be about the same or even a little less because the filter cake compresses and becomes much less permeable.

The fluid loss for the fluid with the 'drilled' solids, or dirt, would increase to almost twice the volume shown here and the filter cake would also be much thicker. The API 100psi filtration test may yield a false sense of security. Drilled solids will reduce the fluid loss but down hole, where the differential pressure is higher, the fluid loss may be significantly higher and the filter cake will be horrible.

Trouble costs caused by drilled solids are frequently not attributed to drilled solids. Drilled solids removal results in wells that are not only drilled faster and cheaper but also without very much NPT (non productive time). The most prevalent trouble created by drilled solids is caused by thick poor filter cakes. They are responsible for stuck drill pipe, kicks and lost circulation from excessive surge and swab pressures, poor cement placement, and difficulty with log interpretation.



Most drilling operations attempt to keep at least a 200psi overbalance between the well bore and the formation pressures. Consider the BHA (bottom hole assembly) touching 200ft of formation with a filter cake deposited around some 7" drill collars in a 9 7/8" hole. The sealed area around the collars would expose about 5 inches of formation to the drill collar. For an approximation, assume the area of contact is a rectangle 5inches wide and 200ft long, or an area of 12,000 square inches.



The force holding the two surfaces together (drill collar against the formation) is the product of the pressure (200 psi) and the area (12,000 sq.in.) or 2,400,000 pounds. The force to pull free or slide the drill collar along the wall of the hole is the weight of the drill collar plus the frictional force. The frictional force is the product of the coefficient of friction and the force holding the two surfaces together. For a thick filter cake with large drilled solids the coefficient of friction is around 0.3 and 0.4. Selecting the lowest number, the force to pull free is 720,000 lb above the drill collar weight. This is a very large force and the drill collar would probably be firmly anchored in the hole.

If the filter cake was changed so that the drilled solids were removed to provide a thin slick, compressible filter cake. This would reduce the area of contact to 200ft by 1/2 inch and decrease the coefficient of friction to 0.08. The force to pull free could now be calculated by the procedure presented above.

Force holding surfaces together:

$$\begin{aligned}
 &= (\text{Pressure}) (\text{Area}) \\
 &= (200 \text{ lb/sq.in.}) (200 \text{ ft} \times 12 \text{ in/ft} \times 1/2 \text{ in}) \\
 &= 240,000 \text{ lb}
 \end{aligned}$$

$$\begin{aligned}
 \text{Force to pull} &= (0.08) (240,000 \text{ lb}) \\
 &= 16,400 \text{ lb}
 \end{aligned}$$

A thin, slick, compressible filter cake requires removal of drilled solids.

CONCLUSION

DRILLED SOLIDS ARE EVIL.

References

- ¹ AADE-04-DF-HO-42, "Effect of Hole Cleaning on Drilling Rate and Performance", Leon Robinson and Mark Morgan

Appendix

The Ten Commandments of Hydrocyclones:

When the IADC Mud Equipment Manual Committee started writing the Handbooks, some one suggested that each piece of equipment should have its own Ten Commandments. Although this seemed a great idea, not all authors participated. George Stonewall Ormsby wrote the first set for Hydrocyclones.

1. Thou shalt forthwith remove from thy unit any cone that is plugged, yea, that is plugged even partially. For a cone that is plugged worketh not for thee and a cone that worketh not for thee worketh iniquity against thee.
2. Thou shalt not operate any other device in parallel with the hydrocyclone unit, for the hydrocyclone unit is a jealous unit. The results will be displeasing for all to see.
3. Thou shalt apply thyself to centrifugal pumps with diligence, for it is written that without good centrifugal pumping there can be no cleaning.
4. Thou shalt not hide the hydrocyclones in remote and cursed places. For hydrocyclones need to be observed by day and by night; lest they fall by the wayside and become laggard and thou knowest not.
5. Thou shalt not place the cones on the highest mountain nor in the lowest valley, nor in any other inaccessible place, for maintenance is the staff of life for the cyclone. For this, it will repay thee forever.
6. Thou shalt not close the discharge of the hydrocyclone from the suction of the centrifugal pump. Instead, thou shalt permit the discharge to equalize in the mud tank with the suction compartment. Yea, by a lower route thou shalt permit it and this will save thee and thy seed many evils.
7. Thou shalt not close the underflow of the hydrocyclone nor make it heavy. This shall liken it to a serpent and thou processing shalt come to naught. Instead thou shalt open the underflow like unto the rain; for this is the essence of fine drilled solids removal.
8. Thou shalt not cast away drilling fluid in the wholeness thereof to rid thyself of unwanted solids, but when barites are not therein, thou shalt instead release the cone underflow from

all bondage, for by this shall your drilling fluid be freed of unwanted solids and your purse will remain heavy and your family will know their parents.

9. Thou shalt know and love thy hydrocyclone units and care for it as thine own, and it will cause thee and thy seed to prosper forever.
10. Let not thy new man servants, nor even thy maid servants, remain in darkness but instead teach them of the many bountiful blessings which accrue from following the wise teachings of the hydrocyclones.

