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Equipment Solids Removal Efficiency for Minimum Volume of Drilling Fluid to Dilute Drilled Solids

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Abstract

If the equipment solids removal efficiency was high enough so that the volume of clean drilling fluid required was exactly equal to the total volume discarded, the total discard would be minimized. For any particular targeted concentration of drilled solids and concentration of drilled solids in the equipment discard stream, optimum equipment solids removal efficiency exists and can be calculated.

The same solids removal efficiency that provides the minimum quantity of new drilling fluid to be built will also be the removal efficiency that generates the minimum discard volume. This would be a condition where the volume of clean drilling fluid required to dilute the solids remaining after processing through the solids removal equipment is exactly the volume discarded by the equipment.

Dilution

When drilling a well, drilling fluid and associated solids are discarded in three different ways: solids rejected from the system while drilling; excess drilling fluid removed from the active system to create room for dilution; and dumping drilling fluid before final well completion or abandonment. To decrease waste from a drilling operation, the volume of drilling fluid required to keep drilled solids at a targeted concentration must be minimized. With all solids removal equipment used on active systems, some drilled solids are discarded and some are retained in the system. The solids retained must be diluted to the target drilled solids concentration.

Dilution is used to decrease drilled solids concentration in an active system. Dilution is defined in the dictionary as the reduction in the concentration of a solute. In this discussion, dilution will refer specifically to clean drilling fluid added to reduce the concentration of drilled solids in an active system. In practice, the clean drilling fluid is frequently added by components. A stream of liquid is added to the pits and required solids are added through the hopper.

As in illustration of this process, consider a typical drilling situation. During a drilling operation, 100bbl of newly drilled solids report to the surface and the equipment removes 70 bbl of those solids. This means that 30 bbl of drilled solids remain in the system. This would be an equipment solids removal efficiency (SRE) of 70%. Some clean drilling fluid must be added to the system to reduce the retained 30 bbl to the target concentration of drilled solids. If the system specifications require 6% by volume drilled solids concentration, 500 bbl of new drilling fluid would need to be created so that the drilled solids concentration of 6% by volume would be 30 bbl. [Calculated from the fact that 6% of 500 bbl is 30 bbl.] The new drilling fluid created would be 30 bbl of drilled solids and 470 bbl of clean drilling fluid. The clean drilling fluid would consist of the liquid phase, weighting agent (if needed), and required chemicals. The 470 bbl of clean drilling fluid would be the quantity of dilution.

If nothing is removed from the system, the pit levels would remain at the same level (except for the volume of drill pipe entering the well as it is drilled). In the above illustration, the 70 bbl drilled solids are not dry when they exit the solids removal equipment. If they are 35% by volume of the discard stream, the total volume removed would be 200 bbl. The discard stream would contain 70 bbl of the recently drilled solids and 130 bbl of drilling fluid. [The drilling fluid discarded with the 30 bbl of drilled solids would contain 7.8 bbl of drilled solids (6% of 130 bbl). However, the removal of these solids does not decrease the drilled solids concentration in the system; so these solids will not be considered in calculating equipment solids removal efficiency. Turning off the shale shaker would remove all of the drilled solids as all of the drilling fluid is dumped, but it would not reduce the drilled solids concentration in the system.

Dilution of the remaining 30 bbl of drilled solids requires the addition of 470 bbl of clean drilling fluid, as calculated above. Only 200 bbl of material was removed, so 270 bbl of excess drilling fluid must be dumped or stored to keep the pit levels constant.

Solids Removal Efficiency in an Unweighted Drilling Fluid from Field Data

Situation: NoProfit Drilling Company is drilling 100 bbl of hole daily in a formation with 15% porosity. For four consecutive days, 400 bbl of discards and fluid were captured each day in discard tanks. The pit levels remained constant but some drilling fluid was jetted to the reserve pits daily to keep the pits from overflowing. The unweighted drilling fluid weighed 9.4 ppg daily and contained 2% by volume bentonite.

Since no barite is contained in the drilling fluid, the V_{lg} (Volume of low gravity solids) is the same as the V_S (Volume of total solids). Assume a specific gravity of the low gravity solids to be 2.6.

The equation for determining V_{lg} is:

$$\mathrm{V_{lg}} = 62.5 + 2V_S - 7.5(MW) \text{ Or}$$

$$\mathrm{V_S} = \mathrm{V_{lg}} = 7.5(MW) - 62.5 = 8\%\, volume$$

Part of this 8% by volume low gravity solids concentration was 2% volume bentonite, so the low gravity drilled solids content was 6% by volume.

The pit levels decrease by the quantity of material removed from them. If no fluid or solids are removed from the system, the pit levels remain constant (except for the increase in volume of the drill pipe entering the hole). In this case the volume decrease is 400 bbl daily or 1600 bbl. This must also be the total volume of clean mud added to the system if the pit levels are returned to their original position.

The volume percent of drilled solids in the mud remained at 6% volume daily. So the drilled solids retained must be 6% volume of the new mud built, or

$$\text{Vol. of Retained Solids} = (0.06)(Vol.\, of\ new\, mud\ built)$$

The new drilling fluid built daily comprises the clean mud added and the drilled solids that remain in the drilling fluid after it is circulated through the solids removal equipment:

The quantity of drilled solids retained can be substituted into that equation, resulting in:

$$Vol.\, drilling\ \ fluid\ built = (0.06)(Vol\ new\, drilling\ \ fluid\ built) + clean\, drilling\ \ fluid$$

The volume of clean drilling fluid must be exactly the volume that was discarded or 1600 bbl. This gives one equation with one unknown:

$$Vol\ new\ mud\ built\ = (0.06)(vol\ new\ mud\ built + 1600\, bbls)$$

So:

$$Vol\, of\ \ new\, mud\ built = \frac{1600}{1-0.06} = 1702\, bbls$$

Since the drilled solids retained are 6% volume to the new mud built, the

$$Drilled\ solids\ retained = (0.08)(1702\, bbls) = 136\, bbls$$

With 15% porosity, the 400 bbl drilled resulted in the addition of 340 bbl of solids to the system. If 136 bbl of drilled solids were retained, 204 bbl were discarded. This gives a ratio (or solids removal efficiency) of 204 bbl/340bbl or 0.60. The solids removal efficiency is 60%.

For comparison, the procedure in API RP13C is used to calculate the same solids removal efficiency is presented in the Appendix.

Excess Drilling Fluid Built

Normal discards from fine screens on linear motion shale shakers and from hydrocyclones contain about 35% volume solids. If all of these 35% solids are drilled solids, the volume of drilling fluid discarded with the drilled solids can be calculated.

The statement that the volume of discarded solids is equal to 35% volume of the discarded volume could be written:

Discarded drilled solids = 0.35 (volume of fluid discarded with drilled solids)

204 bbl = (0.35) (volume of total fluid discarded with drilled solids)

Volume discarded with drilled solids = 583 bbl.

The 583 bbl of waste discard would contain 204 bbl of drilled solids and 379 bbl of drilling fluid. Since a total of 1600 bbl was discarded, 1017 bbl of good drilling fluid was removed from the system along with the 583 bbl of waste drilled solids and drilling fluid. The 1017 bbl of good drilling fluid is the excess clean fluid added to dilute the retained drilled solids and could be pumped to a storage pit. However, eventually this excess drilling fluid must go to disposal. Ideally, the amount of clean drilling fluid added to the system will be exactly the volume discarded with the drilled solids (583 bbl).

Consider if the discard from the hydrocyclones and the shale shaker was very wet (meaning a large volume of liquid was discarded with the drilled solids) so that the discard contained 20% volume drilled solids instead of 35% volume.

Discarded drilled solids = 0.20 (volume of fluid discarded with drilled solids)

50.5 bbl = (0.20) (volume of fluid discarded with drilled solids), or

Volume of fluid discarded with drilled solids = 253 bbl.

Again, since a total of 400 bbl was discarded daily, 400 bbl – 25 bbl, or 147 bbl, of good drilling fluid was also discarded.

A conclusion should be obvious at this point. Efforts to eliminate all drilling fluid from dripping from the end of the shale shaker are futile and not needed when the Solids Removal Efficiency is around 60%. This drilling fluid will need to be discarded eventually and shale shakers do a better separation when the effluent is still wet. This will usually point the way to using shaker screens with smaller openings. Coarse screens allow more drilled solids to pass through.

Estimating Equipment Drilled Solids Removal Efficiency for a Weighted Drilling Fluid

After drilling 1000 ft of hole with a 12.5 lb/gal drilling fluid circulated at 25 bbl/min, the hole was circulated clean. This required four hole volumes to eliminate all solids in the discard. Assuming the formation averaged about 13% volume porosity, a multi-armed caliper indicated that 97.3 bbl of new hole was drilled. The drilling fluid was a fresh water-base drilling fluid weighted with barite and containing 2 %vol. bentonite, no oil, and 5% drilled solids by volume. While drilling this interval, 1350 sacks (sx) of barite (100 lb/sx) were added to the system, and the drilled solids remaining in the system were diluted as required to control their concentration at the targeted 5% by volume. Some drilling fluid was pumped to the reserve pits and all solids control equipment discards were captured in a container to be shipped back to shore. One drilling fluid technician reported that 200 bbl were hauled to shore and another reported that 180 bbl were captured.

Discussion:

The data in this example represent information available in most field operations. Certainly the volume of solids reaching the surface is necessary for any calculation. This is one of the most difficult parameters to determine. Solids do not report to the surface in the same order that they were drilled nor do they report in a predictable period of time. This problem was deliberately set up to remove all of the drilled cuttings from the hole. Next, the volume of clean drilling fluid added to the active system to dilute the drilled solids remaining in the system is needed. With a weighted mud, the number of sacks of barite and an analysis of solids concentrations in the drilling fluid allows a calculation of the clean drilling fluid added. Similarly, if the liquid volume added (water, oil, or synthetics) is known, the volume of clean drilling fluid can be calculated. Finally, if all of the discard volumes are captured in a disposal tank or container, the volume of discard can be measured.

Calculation of equipment solids removal efficiency does not require knowledge of the volume of the circulating system if the other information is available. The system has reached a stable drilled solids concentration and the changes to the system are the primary concern. In actual practice, the system is dynamic with small amounts of drilling fluid ingredients added continuously and continuous discards from the solids removal equipment. At the drilling rig, sand traps are dumped with a variety of quantities of good drilling fluid. For this reason, these calculations should involve a reasonably long interval of hole to include all of the solids reaching the surface.

Solution:

Volume of new drilling fluid built while drilling interval Assuming a low gravity solids density of 2.6 gm/cc and a barite density of 4.2 gm/cc, the low gravity solids content can be calculated from the equation:

$$V_{\lg s} = 62.5 + 2V_S - 7.5(MW)$$

Where:

V_{lgs} = low gravity solids content, % by volume
V_s = total solids content, % by volume, and
MW = Mud Weight, lb/gal

Rearranging to solve for total solids:

$$V_S = \frac{(V_{\lg s} + 7.5(MW) - 62.5)}{2}$$

For a 12.5 ppg drilling fluid containing 5% vol drilled solids, 2% vol Bentonite (V_{lgs}=7% vol), the total solids are 19.1% vol. Since bentonite and drilled solids account for 7% vol, the total solids are 19% vol. Since the bentonite and drilled solids account for 7% vol, the remaining 12.1% vol. is barite.

A barrel of barite, specific gravity 4.2, weighs 1470 lbs calculated from:

$$1\,bbl\;of\;\;barite = (4.2)\left(8.34\,\frac{lbs}{gal}\right)\left(42\,\frac{gal}{bbl}\right)(100\%\,vol)$$

The 1350 sx of barite, or 13,500 lb, added during the drilling of this interval is equivalent to 91.8 bbls of barite. Assume that the mud weight and drilled solids were maintained at the stated levels during the drilling of the interval.

Stated in an equation:

Barite volume in the drilling fluid = (12.1%) (Volume of new drilling fluid built)
91.8 bbl barite = (0.121) (volume of new drilling fluid built)
The volume of new drilling fluid built is 759 bbl.
The volume of drilled solids would be 5 % (759 bbl) or 38 bbl

Equipment Solids Removal Efficiency

Equipment Solids Removal Efficiency (ESRE) is calculated from the ratio of the volume drilled solids discarded (97.3 bbl – 38 bbl) to the volume of drilled solids arriving at the surface (97.3 bbl).

$$ESRE = \frac{59.3\,bbl}{97.3\,bbl} = 61\%$$

The volume of clean drilling fluid added to dilute the 38bbl of retained drilled solids must be exactly the volume discarded if the pit levels remained constant. The new drilling fluid built consists of the retained drilled solids and the clean drilling fluid added to dilute those solids to 5% by volume.

This is stated mathematically:

$$New\,drilling\;\;fluid\;vol\;built = Clean\,drilling\;\;fluid\;added + drilled\;solids\;remaining$$

The volume of clean drilling fluid added would, therefore, be 759 bbl minus 38 bbl or 721bbl.

Volume of drilling fluid created from adding the clean drilling fluid

The volume of clean drilling fluid added was 721 bbl (as calculated from the amount of barite added). The pit levels would decrease by the volume discarded. The discarded volume is 57.3 bbl of drilled solids and the associated drilling fluid. After this decrease the pit levels increase by 721 bbl. This could have been added as water and a blend of ingredients or, as most common, as individual components during the drilling process.

Excess drilling fluid generated

The pit levels decrease only by the quantity of drilling fluid removed from the system. If nothing is removed, the pit levels would not change (except by the volume of drill pipe added to the system). The 97.3 bbl of drilled solids have been added to the system but 97.3 bbl of new hole means that the pit levels stay constant. The pit levels will drop by the amount of fluid and solids removed from the pits and will rise by the volume of new material added to the system.

The volume of clean drilling fluid added was 721 bbl. The volume of material removed was either 200 bbl or 180 bbl depending upon which drilling fluid technician is correct.
This would indicate that 521 bbl or 541 bbl of excess drilling fluid was built while drilling this interval.

Optimum equipment solids removal efficiency

If the equipment solids removal efficiency was high enough so that the volume of clean drilling fluid required was exactly equal to the total volume discarded, the total discard would be minimized. For any particular targeted concentration of drilled solids and concentration of drilled solids in the equipment discard stream, optimum equipment solids removal efficiency exists and can be calculated.

The same solids removal efficiency that provides the minimum quantity of new drilling fluid to be built will also be the removal efficiency that generates the minimum discard volume. This would be a condition where the volume of clean drilling fluid required to dilute the solids remaining after processing through the removal equipment is exactly the volume discarded by the equipment.

$$\text{Optimum SRE} = \frac{\text{(1- Target Drilled Solids Conc. in Drilling Fluid)}}{\text{1-Target Drilled Solids Conc.} + \dfrac{\text{Target drilled solids conc.}}{\text{Drilled solids conc. in discard}}}$$

Derivation for this equation is presented below. For the case above where the targeted drilled solids concentration is 6% volume, and the drilled solids concentration in the discard is 35% volume, the optimum Solids Removal Efficiency would be:

$$V_{lgs} = 62.5 + 2V_S - 7.5(MW)$$

Equation Derivation:

To develop the equation, the mathematical description of the volume of discard must equal to the mathematical description of the volume of clean drilling fluid added.

$$Volume\ of\ \ Discard\ = Volume\ of\ \ Clean\ Dilution\ Fluid$$

(Equation 1)

$$Vol.of\ discard\ = \frac{(ESRE)(Solids\ to\ surface)}{Drilled\ solids\ conc.in\ discard}$$

(Equation 2)

$$Vol.of\ clean\ drilling\ fluid = New\ drilling\ fluid\ built - retained\ drilled\ solids$$

(Equation 3)

$$Vol.clean\ drilling\ fluid = \frac{\text{retained solids}}{\text{target drilled solids conc.}} - retained\ solids$$

(Equation 4)

This assumes that the clean drilling fluid volume is the quantity needed to reduce the retained drilled solids to the target concentration.

$$Vol.\ clean\ \ drilling\ \ fluid\ \ = \ retained\ \ solids\left(\frac{1}{\text{target drilled solids conc.}} - 1\right)$$

(Equation 5)

$$Vol.\ clean\ \ drilling\ \ fluid\ \ = (vol.\ drilled\ \ solids\ to\ surface)(1 - SRE)\left[\frac{1}{\text{target drilled solids conc.}} - 1\right]$$

(Equation 6)

Set Equation 2 expressions equal to Equation 6 expressions and reduce to a ratio expression for optimum Equipment Solids Removal Efficiency:

$$\text{Optimum SRE=}\frac{\text{(1- Target Drilled Solids Conc. in Drilling Fluid)}}{\text{1-Target Drilled Solids Conc + (Target Drilled Solids Concentration)/(Drilled Solids Conc. in Discard)}}$$

(Equation 7)

Equating the volume of clean drilling fluid needed to the volume of discard results in the minimum volume of clean drilling fluid needed and, as a consequence, the minimum volume of drilling fluid disposal. For that reason the resulting solids removal efficiency required is called the optimum solids removal efficiency. It is independent of the volume of drilled solids reaching the surface, or the volume of the drilling fluid system.

Finding Optimum Equipment Solids Removal Efficiency

The optimum equipment solids removal efficiency, described in the equation presented above, is a function of both the targeted drilled solids concentration in the drilling fluid and the concentration of drilled solids discard. Selecting 35% volume concentration for the discard, the optimum value is presented in Figure 1.

The volume of discard per barrel of drilled solids reaching the surface decreases as more drilled solids are tolerated in the system.

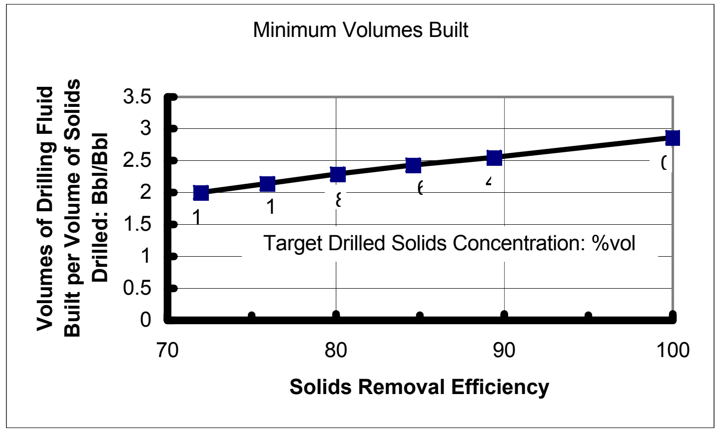


Figure 1
Minimum Volumes required for various Targeted Drilled Solids Concentrations for 35% volume Discarded Solids Concentration

Minimum volumes of drilling fluid required per barrel for 25% by volume and 45% by volume discarded solids concentration can also be calculated from equation 7. These values are presented in Figure 2.

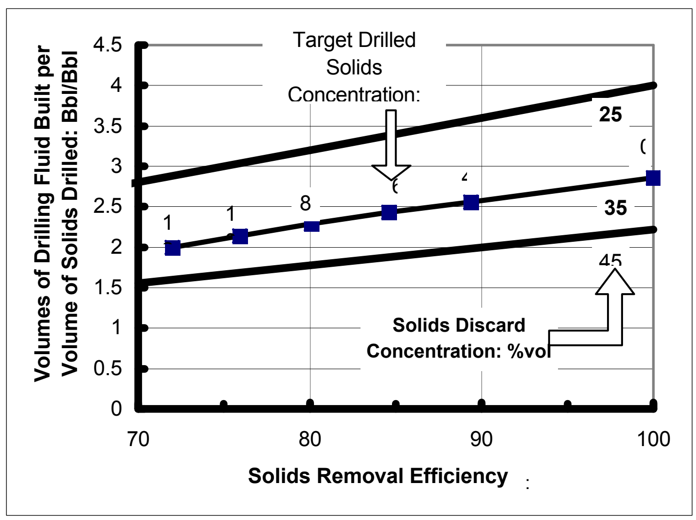
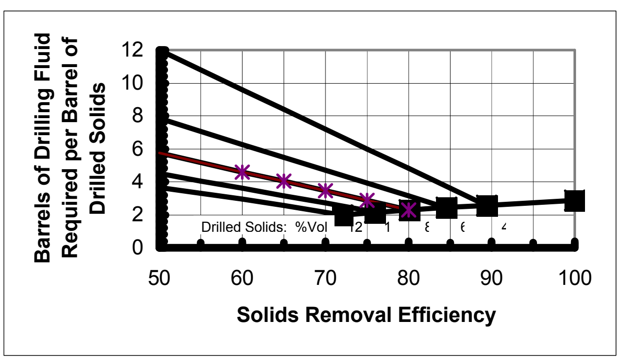


Figure 2
Minimum Volumes required for Various Targeted Drilled Solids
Concentrations for 25% volume and 45% voume Discarded Solids Concentration

If the equipment solids removal efficiency is less than the value required to achieve the minimum volume, the amount of fluid increases rapidly as the removal efficiency decreases. Figure 3 presents the results of calculations similar to the ones for the 4% volume targeted drilled solids concentration described above. As the targeted drilled solids concentration is increased, the volume requirements decrease for any particular solids removal efficiency. For example, at 70% equipment removal efficiency, maintaining 4% volume drilled solids requires adding 7 barrels of clean drilling fluid for every barrel of drilled solids. Maintaining 10% volume drilled solids requires adding 2.7 barrels of clean drilling fluid for every barrel of drilled solids. The consequences of permitting 10% volume drilled solids, however, will usually completely eliminate any economic advantage of the lower volume requirement. The most effective, economical procedure is to improve solids removal processing so that the efficiency approaches the minimum value for any targeted drilled solids concentration. The targeted solids concentrations must be carefully selected: artificially large values result in trouble costs and rig down-time; artificially low values will significantly increase drilling fluid and disposal costs. As in most decisions in drilling, a compromise must be made. Trouble costs and rig down-time are difficult to predict but usually follow decisions to permit large quantities of drilled solids to accumulate in the drilling fluid.



Effect of Targeted Drilled Solids Concentration on Discard Volume
Figure 3

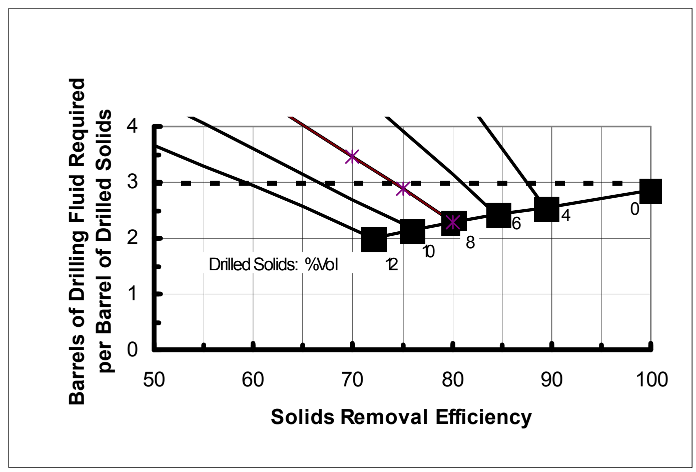
Economics:

Solids equipment and correct mud tank plumbing require an investment of both crew dedication and money. Poor equipment solids removal efficiency makes drilling fluid costs prohibitive if the targeted drilled solids concentration is low. High concentrations of drilled solids inevitably result in excessive drilling costs.

The volume of drilling fluid per unit volume of drilled rock, as presented in Figures 2 and 3, can be multiplied by the cost per barrel of drilling fluid. The cost should include drilling fluid preparation as well as disposal costs. Almost any drilling fluid cost used in this analysis will demonstrate the wisdom of investing in a good drilled solids removal system.

Rule of Thumb of Ratio of Drilling Fluid to Cuttings

Frequently, some rule-of-thumb is discussed in the literature about how much drilling fluid is required per barrel of drilled solids. In the illustration below, a common value of three is shown in Figure 4. This value depends upon the targeted drilled solids concentration and the equipment solids removal efficiency.



Comparison of Drilling Fluid Volume required with Rule of Thumb of "3"
Figure 4

Appendix

API Calculation of Removal Efficiency

API RP13C presents a method of determining System Performance for removing drilled solids. This method compares the volume of drilling fluid required for dilution with no solids removal equipment and the volume used while drilling a long interval of bore hole. It does not provide a method of determining the optimum value of solids removal and it does not provide a calculation to determine the excess quantity of drilling fluid used. Both of these parameters are of great interest, particularly when planning the next well.

5.4.1 Calculate the Volume of Drilling Fluid Built (V_{mb})

The volume of drilling fluid build is determined from the base fluid fraction with the assumption that the drilled solids concentration and the pit levels remain the same value before and after drilling an interval.

$$V_{mb} = \frac{V_{bf}}{F_{bf}} = \frac{1600\,bbl}{0.92} = 1702\,bbl \qquad (1)$$

Where: V_{mb} = Volume of drilling fluid built
V_{bf} = Volume of base fluid added
F_{bf} = Base Fluid Fraction

5.4.2 Calculate the Excavated Volume of Solids Drilled (V_{ds})

This value can be calculated from the dimensions of the wellbore (length and diameter). If caliper logs are run, the calculated volume from the logs should be used for the excavated volume. The excavated volume of drilled solids is the volume of the hole created multiplied by one minus the fractional porosity.

5.4.3 Calculate the Total Dilution (D_t)

The total dilution is the volume of drilling fluid that would be built if there were no solids removal system. In this case, all drilled solids would be incorporated into the drilling fluid system with dilution being the only form of solids control. The drilling fluid quality and drilling performance would remain equal whether using dilution exclusively or a drilled solids removal system.

$$D_t = \frac{V_{ds}}{F_{ds}} = \frac{340\,bbl}{0.08} = 4250\,bbl \qquad (2)$$

Where:
D_t = Total dilution
V_{ds} = Volume of solids drilled
F_{ds} = Drilled solids fraction

5.4.4 Calculate the Dilution Factor (DF)

The dilution factor is the ratio of the volume of drilling fluid built to the total dilution. It is the ratio of drilling fluid used to actually drill an interval using a solids removal system as compared to only using dilution. In both cases, the level of drilled solids in the drilling fluid remains constant and appears in both calculations. This expression also makes the assumption that the dilution volume reduces the remaining drilled solids in the system to the target concentration. The lower the dilution factor is, the more efficient the system.

$$\text{DF} = \frac{V_{mb}}{D_t} = \frac{1720 bl}{4250 bbl} = 0.40 \qquad (3)$$

Where:
DF = Dilution factor
D_t = Total dilution
V_{mb} = Volume of drilling fluid built

5.4.5 Calculate the Drilled Solids Removal System Performance (SP)

$$SP = (1 - DF)(100) = (1 - 0.40)(100) = 60\% \qquad (4)$$

Where:
SP = Drilled solids removal system performance
DF = Dilution factor

Conclusions

Summarize the major findings of the paper. All findings should be supported in the body of the paper.

References

1. Robinson L. “Optimizing Solids Removal Efficiency” Petroleum Engineer (September 1994)96) 50 – 64.
2. API RP 13 C