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Economic Considerations and Impacts for Using Low Grade Barite

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Abstract

The economic evaluation of using low grade barite for drilling fluids is not straightforward and the overall impact is often not realized in field operations. A method is presented that allows an easy estimation of the relative increased cost and impacts of using low grade barite.

Barite is often sourced regionally and minimally processed such that lower quality products are used for drilling fluids. Also high quality supplies deplete with time. This has been the case in North America over the past three years where higher quality 4.2 specific gravity (SG) barite production from Nevada has been replaced by a 4.1 SG product for most land based drilling. A discussion of the original options presented for making this change and the consequences of having done so will be presented.

Lower grade barite has a density significantly below pure barium sulfate and can contain significant quantities of contaminants. These non barite contaminants not only impact fluid quality but also significantly increase the quantity of drilling fluid required to drill a given well over and above what is required to formulate the fluid, which in turn increases the quantity of waste generated. The decision to use a readily available lower quality product at one cost over a more difficult to supply higher quality product at a higher cost is difficult to make without a method to estimate the most relevant factors. The method and data presented will allow an easy estimation of the relative cost differential for using various grades of barite.

Introduction

Barite is the mineralogical name for barium sulfate ($BaSO_4$), a high density mineral used primarily as a weighting agent for drilling fluids. While it is used for other purposes, drilling fluids account for over 80% of the total worldwide barite ore production and consumption. It is particularly well suited as a weighting agent for drilling fluids due to its low solubility, low hardness (Mohs hardness of 3-3.5) which prevents abrasion and erosion of drilling equipment and relatively high density which is sufficient to formulate drilling fluids to the weights required to control the range of subsurface pressures normally encountered in oil and gas drilling.

Barite occurs in numerous locations around the world with commercial mines in various locations. The purity of the raw material and the contaminating minerals vary with the source and the quality tends to degrade with time as the main deposit is mined. Pure barium sulfate has a specific gravity of 4.50, drilling-grade barites have historically been >4.2. Contaminants in barite ore and drilling-grade barite include quartz, carbonate minerals (calcite and siderite), sulfide and sulfate minerals (pyrrhotite, gypsum, anhydrite, and celestite), hematite and other trace minerals. Heavy metals such as mercury, cadmium, and lead are present in some barite ores and may make a particular ore undesirable due to regulatory discharge limits on these elements in some countries. Quartz and calcium carbonate are the primary contaminants that cause barite ore to have a low specific gravity.

The specifications for ground barite used in drilling fluids began with the first use of paint pigment grade barite to kill a well was near Opelousas, Louisiana in 1924. The pigment grade barite was manufactured by the Dutch Boy Paint and Pigment Division of the National Lead Company. Pigment grade barite sold as a lower cost material as an alternative to white lead in paints. The specifications for pigment grade barite at the time were 94 % minimum content of barite with a specific gravity of 4.2 - 4.3. This specification and test procedures were adopted as an ASTM specification in 1941.[1]

By 1926, the Baroid Division of the National Lead Company was formed and began selling barite specially ground for the drilling fluid market, trade named Baroid®, out of Los Angeles with a specific gravity 4.25. The name Baroid® was widely used instead of the name barite for many years regardless of which drilling fluid company brand name was on the sack and is still used as a common name for barite in some places today.[1]

American Petroleum Institute (API) specifications for barite was first published in 1950. Appendix A of the API Recommended Practice RP29 Manual of Procedure for Laboratory Evaluation of Drilling Mud Materials, had three specifications. It is suspected that these three specifications were due to regional practices and suppliers. Spec 1 required a purity of 94% minimum barium sulfate, a specific gravity between 4.0 and 4.25, however, for every 0.1 SG less than 4.25, the cost of goods was reduced 5% over that of the 4.25 material. Spec 2 required a SG of 4.25 SG and that the product be free of abrasive material, particularly sand. Spec 3 required only that the product be a minimum of 95 % barium sulfate, with a SG above 4.25 and calcium carbonate below 0.1 %. Spec 3 was the only specification that did not also have a drilling fluid performance test.[2]

Before 1958 the API specification listed in RP13A was 4.25 SG then around 1958 the density requirement was reduced to 4.20 SG. This allowed some manufacturers to reduce the amount of processing required to produce an API specification product.[1]

In 2006 the API subcommittee 13 was approached by a major barite supplier to consider an addition specification of a lower grade barite based on the fact that the quantity of 4.20 SG material that could be produced from depleted mines in Nevada was limited to about 5 years.[3] It has been reported that production of 4.2 SG barite began in July 2006.[4]

Economic Considerations of using low grade barite

The economic considerations for using a lower grade of barite is not straightforward. Simplistic calculations of relative cost based on the additional quantity of lower grade barite to formulate the same density fluid substantially underestimate the cost of using this material for the end user.

In the original case for a lower grade barite specification it was stated that using a 4.10 SG material as opposed to a 4.20 SG material result in an increase in weight material solids of only 1.1% for a heavily weighted 18.0 lb/gal slurry. However, the actual quantity of low gravity solids (LGS) increased on the order of 2.2% or 20 lb/bbl. In this case it is stated and data is presented that the primary cause of the low SG product is an increase in the quantity of quartz in the product.[3] Using this simplistic comparison of only considering the quantity of additional weight material required to formulate a fluid significantly underestimates the cost of using low grade barite for the end user.

The question might also be asked, What volume of contaminant is required to reduce the specific gravity of pure barium sulfate from 4.5 to the 4.1 specific gravity of the low grade barite product? If x represents the volume of LGS and y represents the volume of 4.5 SG material, an equation can be written: [$x(2.6) + y(4.5) = 100(4.1)$], where 100cc of 4.1 SG material is being created. Obviously, with only the two ingredients (LGS and barium sulfate), $x+y = 100$. Solving these two simultaneous equations for both the 4.2 and 4.1 SG barite produces the volume % contaminant verses SG of contaminant curves shown in Figure 1.

To show the effect of lower specific gravity materials, the lower end of the curve from Figure 1 is enlarged in Figure 2. No matter what the contaminant is, about 5% volume more is required to reduce the specific gravity of 4.2 down to 4.1. In some mined material used for barite, the contaminant is not just the predominant quartz as it is in Nevada ore, but may be a combination of several other minerals. Note as the SG contaminant increases, an additional volume of contaminant is required to reduce the SG from 4.5.

The two possibilities of how the additional quartz (and other low gravity contaminants) is present in the lower grade material are that 1) the quartz exists as a integral portion of each ground low grade barite particle such that the discrete particles have a specific gravity of 4.10, or 2) that the quartz (and other low gravity contaminants) exists as separate particles with a specific gravity of +/- 2.6 and that pure barite particles exist as separate particles with a specific gravity of 4.5. The authors and most industry experts believe that the quartz is present as separate particles and that the discrete barite particles have a +/- 4.50 SG. So by using a volume and mass balance, 4.20 SG barite contains 15.8% by volume LGS and 4.10 SG barite contains 21.1% by volume solids, a 34% increase. The original case presented for the low grade specification also supports that the quartz exists as a separate particle in that it states that the contaminant can be removed with additional ore processing.[3]

This concept seems to be validated from field operations. When the drilling fluid weight is increased substantially during a ‘weight-up’, drilling rigs with incorrect plumbing frequently cycle the new additions through mud cleaners. A large amount of the newly-added barite is discarded. The mud cleaner usually is shut-down for one or two circulations to prevent excessive barite losses. Upon restarting the mud cleaner the quantity of discarded barite is significantly lower. The degradation of barite in the active system has been monitored for two weeks by measuring actual particle size distribution with a SediGraph™. After this initial significant reduction in particle size, additional diminution of particle size continues but at a very slow rate. Generally, this is ascribed to the degradation of particles by jetting through the bit nozzles and possibly due to thermal cycling. This supports the concept that some minor quantity of the particles in low grade barite contain both a contaminant, such as quartz, and barium sulfate loosely combined to form a discrete 4.1 specific gravity particle.

An additional issue with regard to the fact that the additional quartz is present as a separate solid is that drilling fluids solids analysis assumes that the weight material particles are of a lower density and most likely underreport the actual quantities of low gravity solids present in all drilling fluids. This is a technical issue that the API subcommittee 13 should evaluate further.

To properly evaluate the economic cost and impact of using a low grade barite, the quantity of additional low gravity solids must be considered and its impact on the volume of drilling fluid that must be used and disposed of to drill a given well. Table 1 and Table 2 show the relative amounts of the weight material used for a wide range of fluid densities and how that breaks down with regard to pure barite (4.5 SG) and low gravity solids (LGS 2.6 SG). Using this simplistic approach, a 12.0 lb/gal drilling fluid using 4.10 SG barite appears to only require 203.6 lb/bbl of barite as compared to 202.0 lb/bbl if 4.20 SG barite was used, a 0.8% increase.

During the API subcommittee 13 task group 8 work group 3 evaluation of establishing a low grade barite specification, several Nevada samples were evaluated by x-ray diffraction in 2007, as shown in Table 3. This analysis confirmed the approximate 34% increased in volume of low gravity contaminant calculated above.

The increased volume of low gravity solids in fluids formulated with low grade barite to have less intrinsic value to the end user than fluids formulated with lower LGS. Fluids with higher LGS content have less capacity to incorporate drill solids and in use will have less desirable rheology and filtration properties. These factors can lead to reduced rates of penetration, higher bit and pump wear, higher equivalent circulating densities, higher standpipe pressures, higher torque and drag, higher surge and swab pressures, and higher potential for stuck pipe with a less compressible filter cake.

The volume of drilling fluid (DF) that is required to drill a given well is determined by the volume of rock which is removed, or drill solids (DS), the maximum concentration of LGS that yield acceptable properties, and the solids removal efficiency (SRE). In general, a simplistic mass balance equation, shown below, can be used to determine an approximate volume of drilling fluid that will be required to drill a given hole volume.

$$\frac{\text{DF Vol.}}{\text{DS Vol.}} = \frac{100 - \text{SRE }\%}{\text{Max. LGS }\%} \qquad \text{(Equation 1)}$$

A more accurate method is to consider the drilling fluid and retained drill solids that are discarded with the drill solids that are generated and circulated to the surface.[5]

$$\frac{\text{DF Vol.}}{\text{DS Vol.}} = \frac{1 - \text{SRE} - [(1 - \text{SRE}) \times \text{Max LGS}\%]}{\text{Max LGS }\%} \qquad \text{(Equation 2)}$$

Equation 2 describes the clean drilling fluid required if the solids control equipment efficiency is not optimum. For example, if all of the drilled solids were removed from the system and they were dry, then the quantity of clean drilling fluid required would be exactly the hole volume created. If the discarded solids were 50% of the total discard volume (that is, if they comprised an equal volume of drilling fluid and drilled solids), then the volume of clean drilling fluid would be twice the hole drilled.

Using this relationship and expressing the drilling fluid volume as a multiple of the DS volumes at the surface yields a series of lines to estimate the drilling fluid volume required for various maximum LGS% and SRE%, as shown in Figure 3. This example is intended to demonstrate the concept and disregards the LGS that come from the barite and other drilling fluid products. As an example of how to use this graph, for a 65% SRE and 8% maximum LGS, the drilling fluid volume required is 4.0 times the drill solids volume generated.

From a practical standpoint it is hard to achieve solids removal efficiencies above 85-90% and depending on the drilling fluid type and drilling fluid weight, the maximum LGS% for water based drilling fluids is usually in the 6-8% range and for oil based drilling fluids is usually in the 8-10% range. This “solids tolerant” nature of an oil-based drilling fluids, or other non-aqueous fluids (NAF), really needs to be discussed further. This concept is common in the field and comes from the fact that the low-shear-rate viscosity and gels of NAF does not change as much as it does with a water-based drilling fluid. Actually, plastic viscosity (PV) still increases, and PV controls the ability of the drilling fluid to remove cuttings from beneath the drill bit. Increasing the PV can decrease the drilling rate just as much in NAF as it does with a water-based drilling fluid. This, however, might be called invisible Non-Productive Time (NPT), as it is extremely hard to quantify, especially during normal drilling operations.

The optimum value of solids removal efficiency is lower termination line shown on Figure 3 and uses 35% as the discarded solids volume of the total discard volume. The tendency in the field is to try to allow the largest concentration of drilled solids possible in the fluid since that reduces the quantity of clean drilling fluid required, as shown in Figure 3.

Using Equation 2 the increased volume of drilling fluid that will be required to drill a given hole volume with 4.10 SG barite as compared to using 4.20 SG barite can be calculated by subtracting the LGS% for each barite product from the max LGS%. Figure 4 shows the increase drilling fluid volume and cost factor for using 4.10 SG barite instead of 4.20 SG.

One of the conclusions that can be derived from evaluating Figure 4 that unless a drilling fluid can tolerate high low gravity solids, like oil based drilling fluids, the use of 4.10 SG barite should be limited to drilling fluids less than 12 lb/gal or less due to economic and environmental considerations. Often LGS are limited to 7% to achieve acceptable drilling fluid properties, so from Figure 4 it can be seen that for a 12.0 lb/gal fluid the volume required and the total fluid cost increase by 21%.

Using this more representative approach, a 12.0 lb/gal drilling fluid using 4.10 SG barite requires an increased drilling fluid volume and total drilling fluid cost of 21% for 7% LGS, not the 0.8% increased cost of only the additional barite using the simplistic approach. For this same density, 8% LGS has increased volume and cost 17%, 9% LGS is 15%, and 10% LGS is 13%. It is the authors opinion that these much higher fluid volumes and total drilling fluids costs, on the order of 10 to 100%, were not presented to the end users when the low grade barite product from Nevada was introduced to the industry and have not been as clearly presented as shown in Figure 4.

Impact of Low Grade Nevada Production on Fluid Costs and Volumes

The increase volumes and cost associated with using a low grade barite are often very difficult to detect on a single well as most wells do not measure the actual volumes of drilling fluid used or the actual solids removal efficiency with accuracy.

While the US Nevada production of barite varies year-to-year depending on drilling activity, an average of the past 3 ½ years during which 4.10 SG barite has been produced is around 500,000 tons per year. While most of this production was intended for the Rocky Mountain, California, Mid-Continent, and West Texas regions where drilling fluid weights are generally low and where the low grade product is more acceptable, its distribution is continuing to expand with time.

Making some gross assumptions with regard to the average drilling fluid weights, solids removal efficiencies, drilling fluid cost, and end user barite cost, the overall increase in drilling fluid volume and cost to the end users can be estimated for this change from 4.20 SG to 4.10 SG barite. The values used below are educated guesses only and are not based on any market data, so they may significantly over or under estimate the true impacts. The intent here is to only to demonstrate that lower grade barite significantly increases total drilling fluid cost and fluid volumes required by the end user and that the methods presented can be used to calculate the relative value and impacts. This shifts investment cost from the drilling fluid suppliers which would be required for additional ore processing to maintain a higher grade product to the end users operational cost and results in a large negative value to the end purchaser of low grade barite.

If the average drilling fluid weight where 4.10 SG barite is used is 12.0 lb/gal where each barrel of drilling fluid requires 203.6 lb/bbl then the 3½ year consumption of 4.10 SG barite production would have generated 4,911,591 barrels of drilling fluid each year.

If the average maximum LGS percent to maintain acceptable properties is 7% volume and the average solids removal efficient is 70%, then the dilution factor for 4.10 SG barite is 7.2 times hole volume and for 4.20 SG barite is 5.9 times hole volume, a 21% decrease in the volume of hole that can be drilled. For these gross averages, the 4.20 SG barite could have drilled 825,420 barrels of hole and the 4.10 SG barite could have drilled 682,165 barrels of hole volume. If 4.20 SG barite had been used to drill the 682,165 barrels of hole volume the drilling fluid volume would have only been 4,024,774 barrels. So using 4.10 SG barite generated about 925,726 additional barrels of drilling fluid each year.

If the average drilling fluid cost was $30 per barrel, this additional volume of drilling fluid cost the aggregate end users an additional 27.8 million dollars each year in additional total drilling fluid cost. For the 3½ year period of time this is an additional 97.3 million dollars of cost to the aggregate end users, roughly the original cost estimate to continue 4.20 SG production for all Nevada suppliers for 20 years. These estimates do not include the additional costs of disposal for the increase drilling fluid waste volumes.

It is difficult to quantify the actual aggregate sales cost of 4.10 SG barite, but the authors believe it is in the $150/ton range for this 3 ½ year period. If this $27.8 million increased cost of using 4.10 SG barite was instead applied to the increased cost of processing required to supply 4.20 SG barite, the potential value to the end user is equal to an additional $56/ton. The potential value is some 6.5 times higher than the original estimate of $8.50/ton to add equipment for additional processing to remove the contaminant and continuing to produce a 4.20 SG product from Nevada.[3] In addition to reducing the required waste volumes and total drilling fluids costs to the end user, additional ore processing would have significantly increased (almost double) the potential supply of 4.20 SG barite from Nevada and extended the reserves by at least 9 years (almost double). See Figure 1 in SPE 103135.[3] Considering that China dominates the barite supply with over 50% of worldwide supply, any improvement in domestic production would have reduced the dependency and potential for market disruptions from having such a large single supplier.

Given these clear economics in support of added value for investment and production of higher SG drilling grade barite, barite is sometimes priced at or under actual production cost for drilling fluids companies to win competitive bidding. The authors fully understand that most end users are not knowledgeable enough to realize the cost benefit of using a higher grade barite and would be reluctant to accept this significantly higher price for barite, but it appears to us that they are paying this additional hidden cost unknowingly.

At a point in time where the industry is increasing concerned over cost and environmental stewardship, a good case can be made for reducing low gravity solids in barite and for additional ore processing to supply higher grade barite products. The drilling fluids suppliers embrace being environmentally responsible and should address this issue with products and services that help the end users generate less waste and operate more efficiently.

Conclusions

- Simplistic calculations significantly underestimate the real cost of using low grade barite to the end user
- The contaminant that causes Nevada ore to be low grade barite is quartz and is most likely present as separate quartz particles
- Solids analysis calculations from the drilling fluid companies and API assume that the barite particles are of a lower density and underreport the actual quantities of low gravity solids present in all drilling fluids
- To properly evaluate the cost of using low grade barite, the quantity of additional low gravity solids must be considered as it reduces the quantity of drill solids that the drilling fluid can incorporate and still have acceptable fluid properties
- Equation 2 and Figure 4 allow easy estimation of the relative increased fluid volume and total fluid costs of using low grade barite which is generally in the 10 to 100% range
- The production of low grade 4.10 SG barite from Nevada has substantially increased the total drilling fluid cost and volumes of fluid required for the end user
- The negative value of using low grade barite is significantly higher than the original life-cycle cost estimate ton to continue production of the higher grade of barite with additional processing

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Tables

Table 1: 4.2 SG Weight Material

Fluid Density lb/gal	Volume Liquid %	Volume Weight Material %	Concentration Weight Material lb/bbl	Volume Pure Barite %	Concentration Pure Barite lb/bbl	Volume Low Gravity Solids %	Concentration Low Gravity Solids lb/bbl
9	97.5	2.5	36.7	2.1	33.1	0.4	3.6
10	93.8	6.2	91.8	5.3	82.8	1.0	9.0
11	90.0	10.0	146.9	8.4	132.5	1.6	14.4
12	86.3	13.7	202.0	11.6	182.3	2.2	19.7
13	82.5	17.5	257.2	14.7	232.0	2.8	25.1
14	78.8	21.2	312.3	17.9	281.8	3.4	30.5
15	75.0	25.0	367.4	21.0	331.5	3.9	35.9
16	71.3	28.7	422.5	24.2	381.2	4.5	41.3
17	67.5	32.5	477.7	27.4	431.0	5.1	46.7
18	63.8	36.2	532.8	30.5	480.7	5.7	52.1
19	60.0	40.0	587.9	33.7	530.4	6.3	57.5
20	56.3	43.7	643.0	36.8	580.2	6.9	62.9

Table 2: 4.1 SG Weight Material

Fluid Density lb/gal	Volume Liquid %	Volume Weight Material %	Concentration Weight Material lb/bbl	Volume Pure Barite %	Concentration Pure Barite lb/bbl	Volume Low Gravity Solids %	Concentration Low Gravity Solids lb/bbl	4.2 vs 4.1 LGS Difference %	4.2 vs 4.1 LGS Difference lb/bbl
9	97.4	2.6	36.9	2.0	32.0	0.5	4.9	0.1	1.3
10	93.6	6.4	92.5	5.1	80.1	1.4	12.3	0.4	3.4
11	89.7	10.3	148.0	8.1	128.3	2.2	19.8	0.6	5.4
12	85.8	14.2	203.6	11.2	176.4	3.0	27.2	0.8	7.4
13	81.9	18.1	259.1	14.3	224.5	3.8	34.6	1.0	9.5
14	78.1	21.9	314.7	17.3	272.7	4.6	42.0	1.3	11.5
15	74.2	25.8	370.2	20.4	320.8	5.4	49.4	1.5	13.5
16	70.3	29.7	425.8	23.4	368.9	6.2	56.8	1.7	15.5
17	66.5	33.5	481.3	26.5	417.1	7.1	64.3	1.9	17.6
18	62.6	37.4	536.9	29.5	465.2	7.9	71.7	2.2	19.6
19	58.7	41.3	592.4	32.6	513.3	8.7	79.1	2.4	21.6
20	54.9	45.1	648.0	35.6	561.5	9.5	86.5	2.6	23.7

Table 3: X-ray diffraction analysis for 4 low grade barites and one 4.20+ lab stock barite

Air Pycnometer SG	Sample ID	Quartz % vol	Barite % vol	Sum 2:1 Clay and Mica % vol	Calculated SG from XRD
4.10	4.1 SG Barite A	19.00	81.00	0.00	4.13
4.13	4.1 SG Barite B	16.00	84.00	0.00	4.20
4.10	4.1 SG Barite C	19.00	76.00	4.00	4.05
4.12	4.1 SG Barite D	15.00	85.00	0.00	4.20
4.11	4.1 SG Barite Average Values	17.25	81.50	1.00	4.15
NA	4.2 SG Lab Stock Barite	13.00	84.00	0.00	4.24

Figures

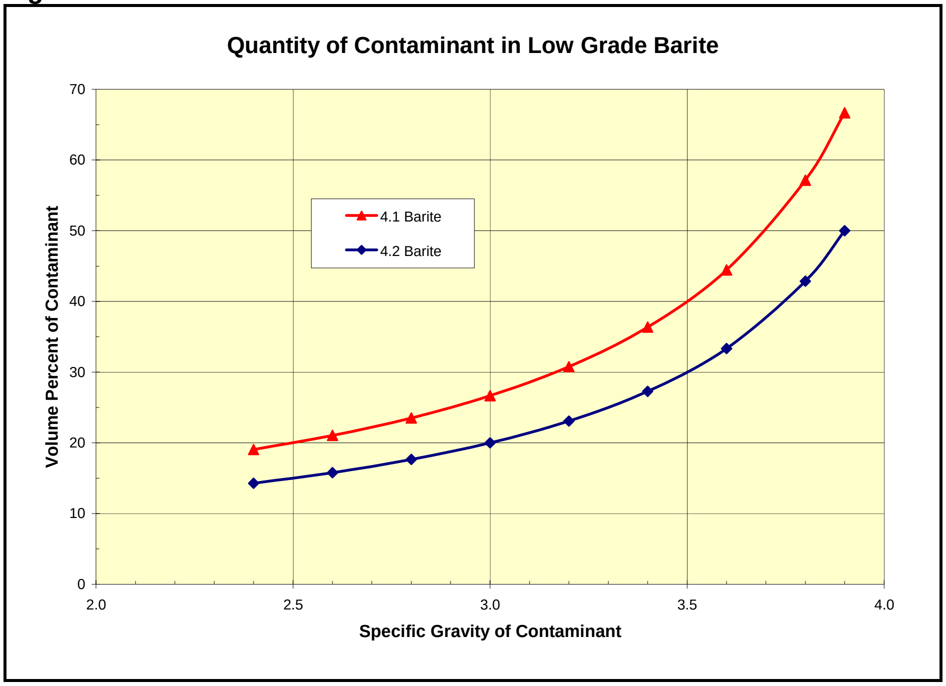

Figure 1: Volume % Contaminant vs SG for 4.20 and 4.10 barites

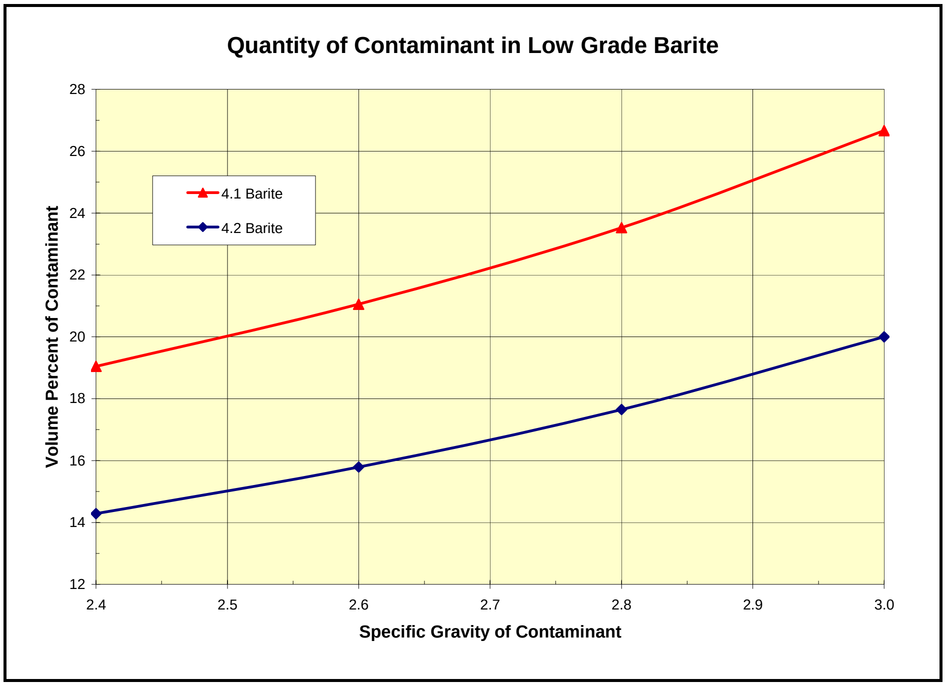

Figure 2: Volume % Contaminant vs SG for 4.20 and 4.10 barites

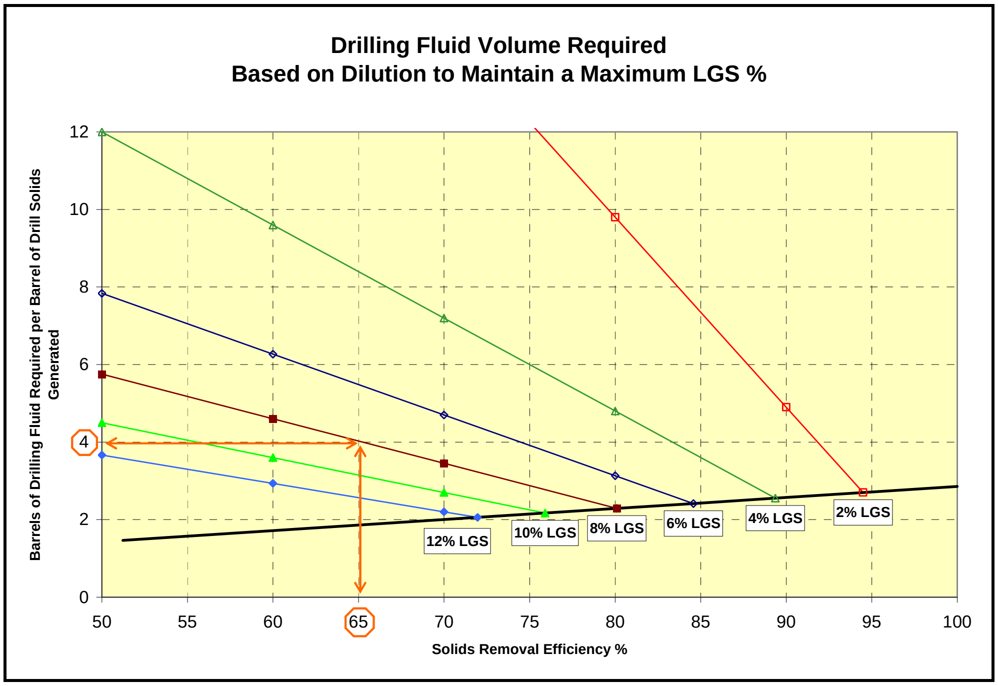

Figure 3: Drilling Fluid Volume Required Based on Dilution to Maintain a Maximum LGS% for various SRE values

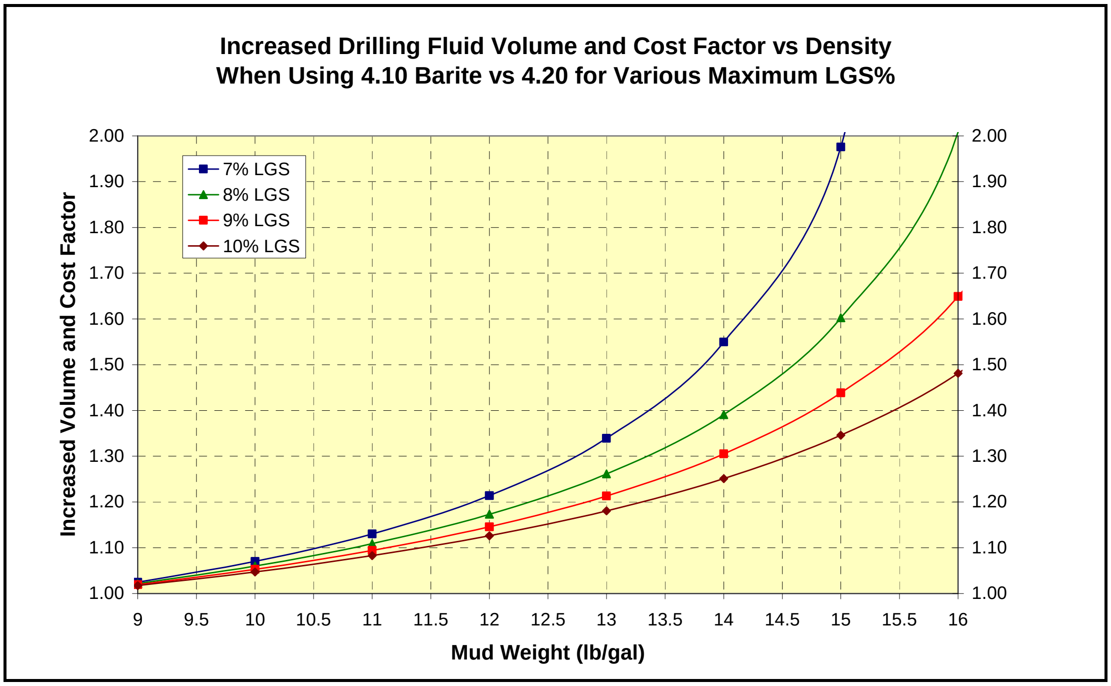

Figure 4: Increased volume and cost factor verses drilling fluid density for various maximum LGS values when using 4.10 SG barite instead of 4.20 SG barite