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Enhanced Lost Circulation Control through Continuous Graphite Recovery

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Abstract

Graphitic materials have gained popularity over the past few years as focus on their utility has shifted. Originally, these materials were applied as additives to reduce seepage loss in permeable sands and other matrix-type formations that were susceptible to whole mud losses. While still used to reduce losses, graphitic materials are now believed to be essential components for strengthening formations that are depleted or naturally possess a lower fracture gradient than surrounding formations. For both of these applications, the sizing of the graphitic materials is important for effective performance and maximum benefit.

One drawback to these types of materials is their loss at surface over solids-control equipment that is part of the drilling fluids circulating system. This necessitates a decision regarding the screen size – whether to screen up to effectively remove unwanted cuttings along with the larger grind sizes of graphitic materials, or to screen down to allow these graphitic materials to return to the system and suffer the consequence of elevated solids loading in the fluids system. Consequently, this dilemma has traditionally restricted the use and ultimate benefit of graphitic materials.

A novel Graphite Recycling System (GRS) has been developed to resolve this quandary. This system strips out certain sizes of graphite and allows it to be added back into the system, thus reducing the amount of graphitic material that is sacrificed on the surface. The savings are two-fold – increased drilling performance because of lost circulation avoidance, and reduced product consumption.

Introduction

Sized particles have been added to aqueous and non-aqueous drilling fluids for decades in an attempt to reduce seepage and/or whole mud losses. In the late 1980's and early 1990's industry projects advanced new lost circulation theories and recommendations [1] which clarified the role of sized particles in preventing losses or minimizing their frequency and severity.[2, 3] In spite of this body of initial work, many field applications at that time only focused on matrix plugging to prevent seepage losses without addressing the larger opportunity of wellbore strengthening.

Applications of sized carbonates and graphites persisted throughout the 1990's. Eventually, the role that graphite materials (GM) played in potentially increasing fracture propagation and re-opening pressures was noted. In response, several joint industry projects (JIPs) were launched to study this phenomenon.[4,5] Additional field applications and theoretical studies[6,7,8] validated much of the industry-wide perception that these materials were essential in not only reducing overall losses of drilling fluid but also, in many cases, apparently extending the drilling operating window in critical wells, thus appearing to "strengthen" the wellbore.

New testing devices arose from the JIPs to determine the most effect type and size of graphites or graphite blends that would be the most suitable for a particular application in sealing fractures and "strengthening" the wellbore. Although this work is the subject of another forthcoming paper,[5] Figures 1 and 2 illustrate some typical results of the fracture testing apparatus which we have used in our laboratory studies. Figure 1 illustrates an ineffective sealing/strengthening additive. The blue line represents "leak-off (mL)" through the tip of the fracture, while the red line corresponds to mud pressure (psi) build-up and the green line shows the relative change in fracture width (μm) from the initial fracture width – in this case 530 μm. In the case illustrated in Figure 1, the leak-off through the fracture tip is linear (uncontrolled) and the build-up of mud pressure is minimal (no fracture sealing) and thus the ability to strengthen the wellbore and increase fracture width is negligible.

By contrast, Figure 2 illustrates the effective sealing provided by a GM blend. In this illustration, leak-off behavior levels off very quickly after test initiation. This means that flow through the tip of the fracture is being shut down and fracture propagation is prevented, while the mud pressure builds up substantially to more than 1000 psi. Additionally, the fracture aperture itself increases from 530 μm to approximately 900 μm without an increase in fluid loss or decrease in sealing pressure. This technique has been validated with several successful field applications of fracture-sealing lost circulation materials.

Fundamental to the approach of strengthening the wellbore and reducing losses is type and size of additive. As stated earlier, graphites are very effective for wellbore strengthening, either when used individually or as a component in a blend. A key element to using graphite additives pro-actively in the field is maintaining both their size and concentration. However, in doing this there are two major concerns: (1) losses via solids-control equipment, and (2) degradation caused by the drilling operation itself.

Since the particle size of graphite and sized materials is usually greater than that of mud solids, it is estimated that a majority, *i.e.* probably >70%, of the materials added to the mud system will be removed by shale shakers and other solids-control equipment. Additional material may be lost due to degradation and whole mud losses to downhole formations.

The removal of graphite by solids-control equipment can adversely increase the cost of operation and restrict the continuous use of the material in sufficient quantities for desired downhole effects during the drilling operation. Consequently, the application of GM is often restricted to spotting treatment with limited benefits. In order to maintain an effective concentration of graphite during drilling operation to achieve the desired benefits, recycling of the GM is a necessity. For this purpose, chemical, thermal and mechanical methods of recovering GM have been evaluated.

Chemical and Thermal Methods of Recovery

The chemical method of graphite recovery involves treatment with surfactants to aid in separation of GM from the drilling fluid, especially if this involves an invert emulsion fluid. In the field, the GM is expected to be intimately mingled with drilled cuttings and coated with emulsifier and wetting agent, making the separation process technically and economically challenging. In addition, the ratio of graphite to drilled cuttings can be unfavorable for effective separation.

To investigate chemical separation, an invert emulsion fluid pre-treated with known amounts of shale cuttings and GM was sieved through a 60-mesh screen to recover the solids. The recovered wet solids were treated with sufficient surfactant to break the emulsion and allow the reactive solids to become water-wet and form a dispersed slurry. The graphite was subsequently removed with the same sieve for recycling. This process was economically impracticable because of the high dosage of surfactant required, the volume of the waste by-products generated, and the inferior quality of the recovered graphite (Figure 3).

Alternatively, a thermal desorption process was investigated in an attempt to eliminate the use of surfactant. It was believed that the aqueous and non-aqueous components of the cuttings could be driven off by processing at high temperatures. Afterwards, the dried cuttings could then hydrate rapidly with water, thus facilitating its separation from the graphite. Lab tests showed that the thermal desorption process improved the quality of the recovered graphite and eliminated the use of chemicals. Despite these improvements, the process still generated some waste by-products and required mechanical agitation to accelerate the hydration and dispersion of cuttings. Furthermore, not all the cuttings could be separated from the GM because of the incomplete dispersion of the cuttings (Figure 3). In addition, cost, required footprint and deckload, waste disposal, etc. were all issues that made the deployment of thermal desorption units offshore less desirable.

The above results led to investigating a mechanical method of GM recovery that centered around concentrating the material in the cuttings separation process, as described in the following.

Mechanical Method of Recovery

The mechanical method of recovery focused on using various solids-control equipment including shakers, centrifuges, desanders and desilters for separation. Since the GM has a relatively unique and narrow Particle Size Distribution (PSD), a major portion of the material can be separated from cuttings and mud solids using appropriate selection based on particle size (Figure 4).

A yard test was conducted to evaluate the feasibility of separating GM from invert emulsion mud (IEM). A known amount of GM was added to the IEM and circulated through shale shakers dressed with screens of various sizes. Laboratory analysis of samples collected from different screens showed that optimal separation of the drilling fluid and GM could be achieved by carefully selecting the size of the shaker screen. Either too coarse or too fine a screen resulted in little recovery of GM or extra solids in the recovered material. An effective screen size for separation was found to be around 80-100 meshes (Figure 5). Before designing an appropriate flow chart process utilizing solids control equipment to recover GM, it was necessary to confirm that the material could endure the mechanical shearing and processing without suffering significant degradation.

Mechanical Degradation

To simulate degradation, mechanical shearing of graphite and other sized materials was conducted using Hamilton Beach Single-Spindle and Silverson mixers. Weight measurements showed that the degradation was insignificant for graphite after shearing for five minutes at 7,000 rpm with the Single-Spindle mixer (<2%). Compared with a Silverson mixer, this value rose to 12%. Prolonged shearing at 7,000 rpm on the Silverson caused further degradation of graphite up to 34% after 15 minutes. Sized cellulose materials showed a (low) degradation rate very similar to graphite. In contrast, sized calcium carbonate was highly susceptible to mechanical degradation due to its relative softness. These degradation results are displayed in Figure 6.

Scanning Electron Microscope (SEM) examinations of the GM before and after shearing showed that the sheared particles became more rounded and slightly smaller in grain size (Figure 7), indicating that the re-usability of graphite may be limited under high-shear conditions. Too much roundness on the particles will adversely impact the performance of the GM as interlocked bridging may become less effective.[5]

Nonetheless, these results were encouraging enough to pursue the mechanical method for recovery of the GM and other sized particles that were more resilient to shear degradation than carbonate particles.

Development of a Graphite Recovery System

A graphite recovery system (GRS) was developed to recover graphite that is added to a drilling fluid to provide formation strengthening and minimize mud losses. Before the introduction of the GRS in field operations, the typical treatment of graphite with concentrations ranging from 7 to 10 lb/bbl would begin just prior to drilling the potential losses zone. At that time, the drilling fluid would be circulated to obtain the required concentration, shaker screens would be changed out to a coarser mesh screen, such as a 40 mesh or greater, to allow a majority of the graphite to stay in the drilling fluid. Too coarse of a screen would allow more of the graphite to remain in the drilling fluid, but at the same time allow more drill solids to be retained in the fluid system. Too fine a screen would discard too much of the GM, raising costs and complicating addition logistics. As a compromise, a 40-mesh screen became the optimum size. Testing showed that about 40% of the graphite is lost while using 40-mesh screens. The interval would be drilled while retaining a majority of the graphite at the expense of allowing solids to build up. At the end of the interval, the screens would be changed out to the finer mesh, removing most of the graphite and other loss circulation material as well as attempting to play catch-up on controlling the volume of unwanted fine drill solids.

This approach proved acceptable in smaller hole sections (typically 6 to 8.5-in. hole) where only a relatively small amount of drill solids was generated compared with the total volume of mud in the circulating system. It is less applicable when the sections to be drilled generate high volumes of fine sand or other drill solids that have a detrimental effect on mud properties and rig equipment. The GRS not only recovers synthetic graphite (and any other loss circulation material in the same particle size range as the GM, a necessary trade-off that has not resulted in any operational problems, see below), but it also keeps undesirable drill solids out of the drilling fluids system by allowing proper application of the solids-control equipment.

GRS Design

The main scope of the initial design was to keep the solids-control system operating at maximum efficiency while attempting to retain the maximum amount of GM and maintain a true low-gravity-solids drilling fluid. This requires the use of the finest screens that the drilling conditions would allow. Without the recovery process, the valuable GM, which is mixed with the drilled cuttings, would be discarded with the drilled cuttings.

A series of yard tests and sampling procedures was performed to determine exactly where in the waste stream the greatest concentration of the GM occurred. The configuration of drilled cuttings processing equipment for the yard test included primarily shale shakers and mud cleaners. Table 1 shows the percentage recovery for various screen sizes. The yard test basically confirmed the feasibility of graphite recovery and identified that a screen coarser than 84-mesh makes the recovery process less efficient.

The graphite recovery package consists of the transport system, the cuttings dryer system, and the recovery system. GM recovery is achieved as follows. The transport system collects all cuttings and GM discharged from the shale shakers, dressed with 84-mesh or finer screens. Using 9-in. augers, the cuttings with associated GM are transported to the cuttings dryer. This dryer was selected for its flexibility to change screens, thereby helping to maximize recovery. After being stripped from associated fluid and GM, dried cuttings are discarded from the cuttings dryer and sent directly overboard. The dryer underflow, which contains the bulk of the GM, flows by gravity to the recovery tanks, where it is diluted with base fluid to lower the viscosity for further processing (Figure 9 and Figure 10).

From the recovery tanks, there are two options available to process the GM for recycling. The first option is to send the diluted slurry to a recovery shaker with 84-mesh or finer screen where the graphite is stripped out and returned to the active system. The effluent then flows to the tanks below the recovery shaker and is processed with dual centrifuges as needed.

The second option is to pump the diluted slurry to 4-inch hydrocyclones with adjustable apex ranging from ¼ to ⅝-inch. The GM discharged from the cones (along with any drill solids in the same size), is subsequently processed over a recovery shaker with an 84-mesh or finer screen to further separate the solids and graphite. Both the effluent from the recovery shaker and overflow from hydrocyclones can be processed with dual centrifuges as in the first option.

In both cases, high amounts of GM can be recovered for recycling along with a small amount of low gravity solids (LGS).

Field Results

Before reviewing the results from the implementation of the Graphite Recovery System (GRS), it is of interest to address the utility of graphitic materials (GM) in the field. As mentioned earlier, the GM additives have found great acceptance in invert systems for reducing overall losses of whole fluid, while drilling, running casing or cementing. Figure 11 illustrates an example of their utility in one of these capacities.

In the cases represented in Figure 11, 68 sections were monitored for losses while cementing casing. The diameter of these sections ranged from 18 to 5½ inches. Of these 68 sections, 32 utilized the practice of adding the GM to the concentration of 7 - 10 lb/bbl prior to drilling the depleted zone. Average whole mud losses were recorded while cementing. Of the 38 sections in which the yield point of the drilling fluid was below 20 lb/100 ft^2, whole mud losses were decreased by 39% (from an average of 594 bbl per section to 361 bbl per section). Clearly, yield point had a large influence on the severity of mud losses while cementing. For both high yield point and low yield point mud, we observed further mud loss reductions when adding GM: for instance, for those drilling fluids that had yield points which ranged between 20 – 25 lb/100ft^2, the decrease in whole mud losses while pumping cement was almost 50% when employing GM in the drilling mud (984 bbl to 491 bbl per section, see Figure 11). The key to effectively reduce mud losses is not only adding the GM to the drilling fluid, but also maintaining an effective concentration of the product. When the wells discussed above were drilled prior to the implementation of the GRS, only 7 – 8 lb/bbl of GM could be maintained in the drilling fluid. After the GRS was introduced, the concentration could be increased to a range of 10 – 15 lb/bbl with further reduction in losses.

Initial Findings

As stated previously, the GRS was designed to maintain the desired concentrations of GM in the mud circulating system (typically in the range of 10 - 15 lb/bbl). Since its recent implementation into the field, the GRS has been used on 5 different wells for a total of 15 hole sections ranging from 22 – 7 inch in diameter. On the first well that the GRS was operated, the system recovered 141,907 pounds of material over two hole sections – most of which was GM. Samples were taken during the recovery process and sent to the laboratory for testing. Those tests confirmed the composition and concentration of the material recovered by the recovery unit was primarily GM and another lost circulation additive (80 – 85% GM).

Based on the success of this first field trial, two other off-shore wells were drilled utilizing the GRS. Table 3 provides data from 3 hole sections on two different wells. The well that drilled the 10⅝-inch section and only employed 7 lb/bbl of GM suffered significant losses in a depleted sand and eventually had to be sidetracked. During the sidetrack, it was decided not only to leave the GM in the fluid to drill the upper intervals, but also to increase the GM concentration. Therefore, the loss zone was redrilled with approximately 14 lb/bbl of the GM in the system with no losses. Instead of setting an expected 9⅜-inch liner, the decision was made to drill into the production zone. Not only was the well TD'd with no losses in this interval, but one string of casing (liner) was eliminated. We attribute this to the lost circulation prevention benefits provided by elevated concentration of GM in the mud, which was enabled by the Graphite Recovery system.

Throughout this field trial stage, samples were taken from the active system, the slurry of GM recovered from the GRS as well as the underflow sent to the centrifuge. These samples were sent to a laboratory for Particle Size Analysis (PSA) and X-ray analysis of fluid streams in the GRS and the mud system to determine composition and concentration. Furthermore, rig testing was performed on the active system and GRS slurry to determine GM concentrations in both the mud and recovered from the GRS.

The PSA showed that 86% of the material recovered from the GRS for reuse was greater than 200 microns, while the underflow material from the GRS (sent to a centrifuge for further processing) contained 99% particles of sizes less than 200 microns. This underflow contained less than 0.5% GM and a bulk of it was composed of barite, clay and sand. Further analysis of the slurry showed that the GRS recovered 92% of the material that it processed. The other particles associated with the recycled GM were primarily barite and some drilled cuttings (Figure 12).

Conclusions

- The continuous application of GM in mud systems, particularly SBMs and OBMs, is highly effective in "strengthening" wellbores by elevating fracture propagation pressures.
- Until now, the application of GM, taking into account such factors as costs, logistics associated with addition, the need to use coarser screens to keep GM in the mud, etc., have prevented us from using these materials for continuous use in hole sizes greater than 8½ inch.
- The GRS system presented here allows for recovery of GM at high efficiency, thereby enabling its application on larger hole sizes where narrow drilling margins jeopardize drilling success, as has been demonstrated in recent and ongoing field applications.
- GM is recovered by the GRS with minimum modifications of the rig's existing solids control recovery system.
- Detailed solids analysis shows that the GRS recovers GM with a minimum of detrimental drilled solids returned to the mud system.
- The application of GM at appropriate concentrations in conjunction with GRS provides enabling technology for the delivery of complex wells in narrow drilling-margin environments.

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Table 1 – Optimizing Screen Size to Recover Graphite Material	
Screen Size	**% GM in Discard**
10	5
40	50
84	75
110	95
140	95
175	95
Mud cleaner Cones	50
Mud cleaner/210 mesh	70

Table 2 - Recovered GM on First Well		
Hole Size (in.)	11.75	10.25
Length of Section (ft)	1769	2752
Drilling Days	2.5	4.5
Material added (lb)	6280	73,027
Material recovered (lb)	32,806	109,101
Concentration maintained in Active System (lb/bbl)	14.0	9.5

Table 3 – Recovered GM in Second Group of Wells			
Hole Size (in.)	19	17½	10⅝
Length of Section (ft)	2030	1346	3026
Material Recovered (lb)	44,554	102,383	31,792
Concentration maintained in Active System (lb/bbl)	9	9	7

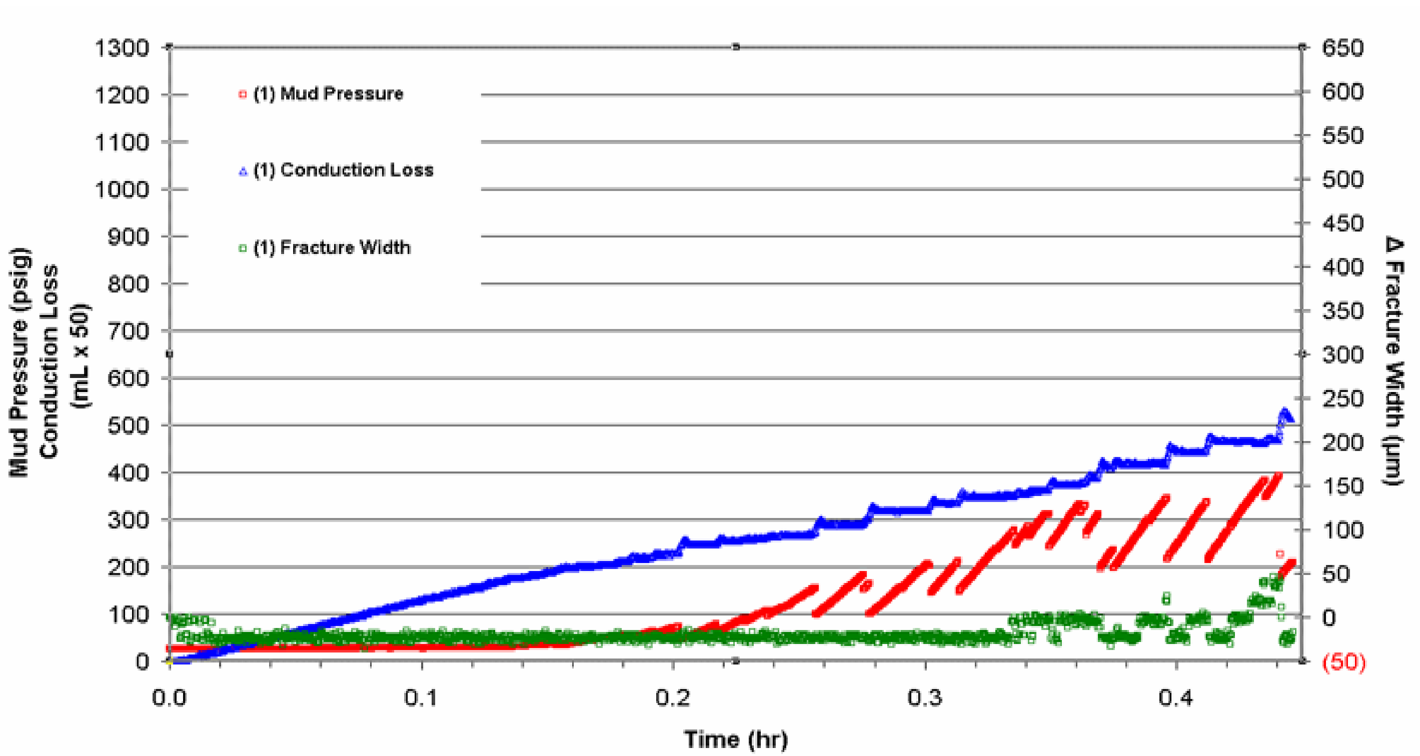


Figure 1 - Graphical analysis from Fracture Testing Device used in JIP on Fracture Sealing Studies.[5] This profile shows minimal to no sealing.

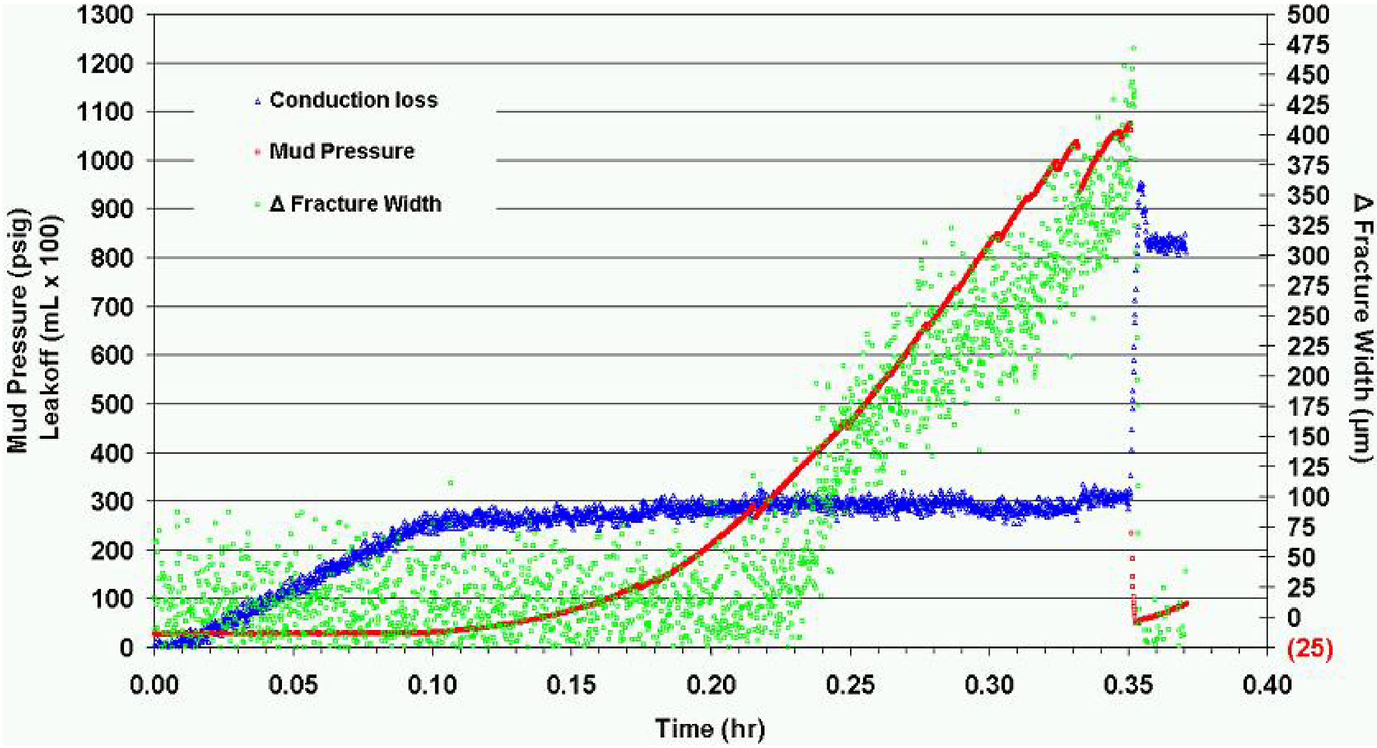


Figure 2 - Graphical analysis from Fracture Testing Device used in JIP on Fracture Sealing Studies.[5] This profile indicates good sealing.

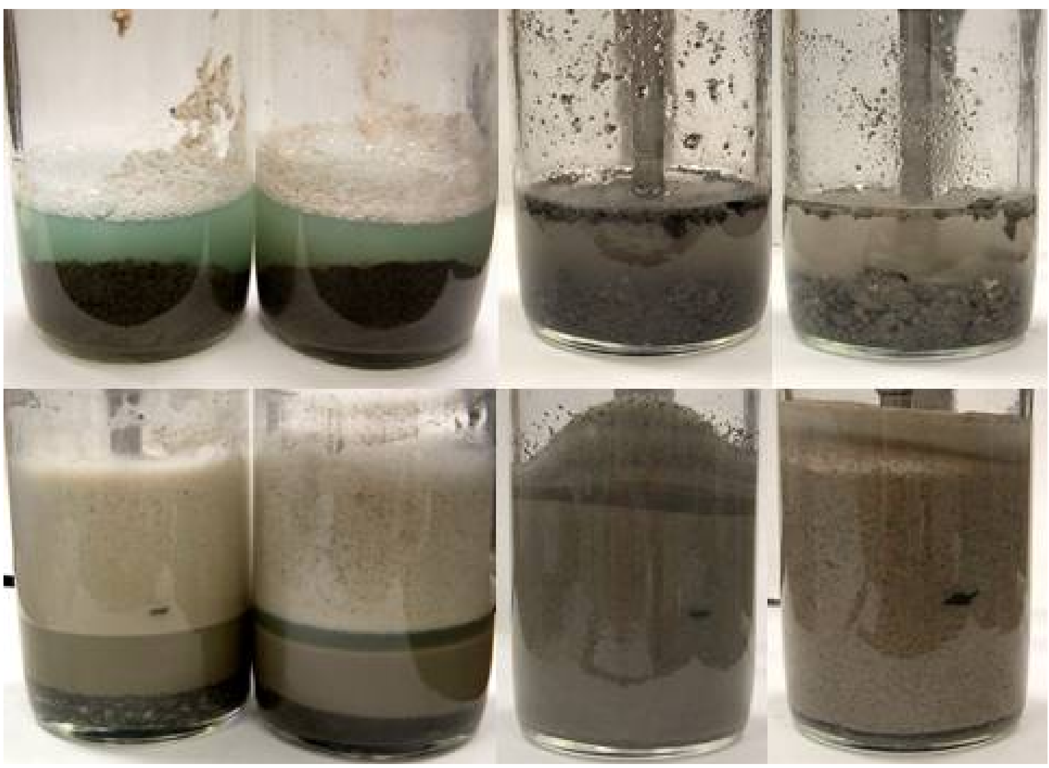


Figure 3 – Separation of graphite from IEM cuttings by chemical process (top and bottom left) and thermal desportion process (top and bottom right).

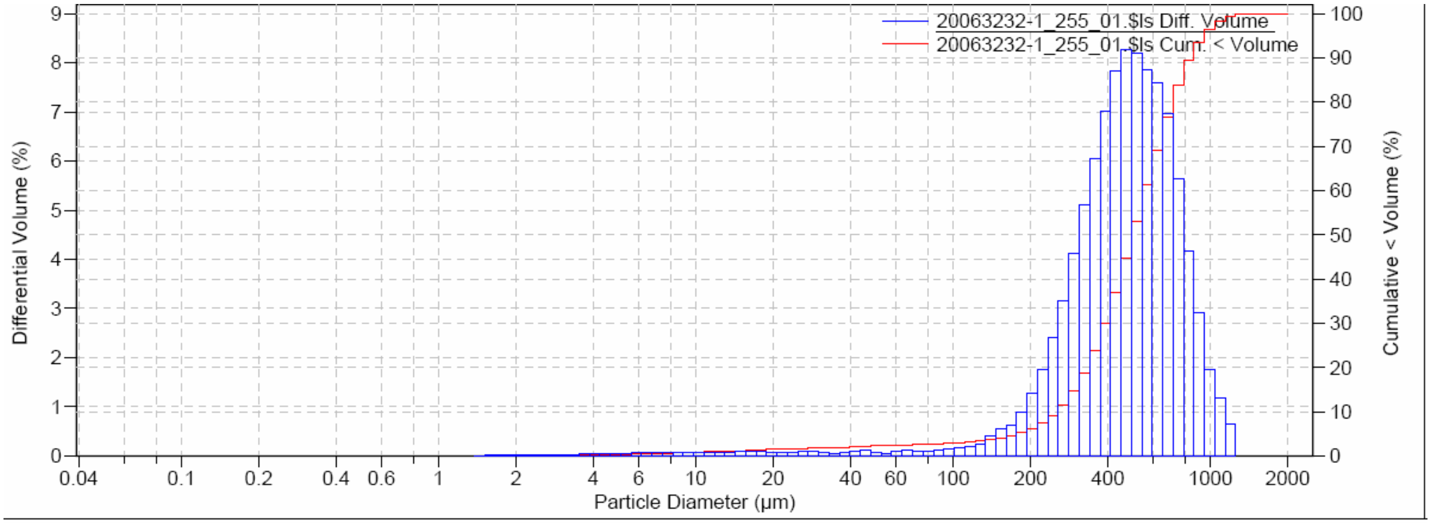


Figure 4 – Particle size analysis of GM shows a unique and narrow PSD, which can be utilized for recovery.

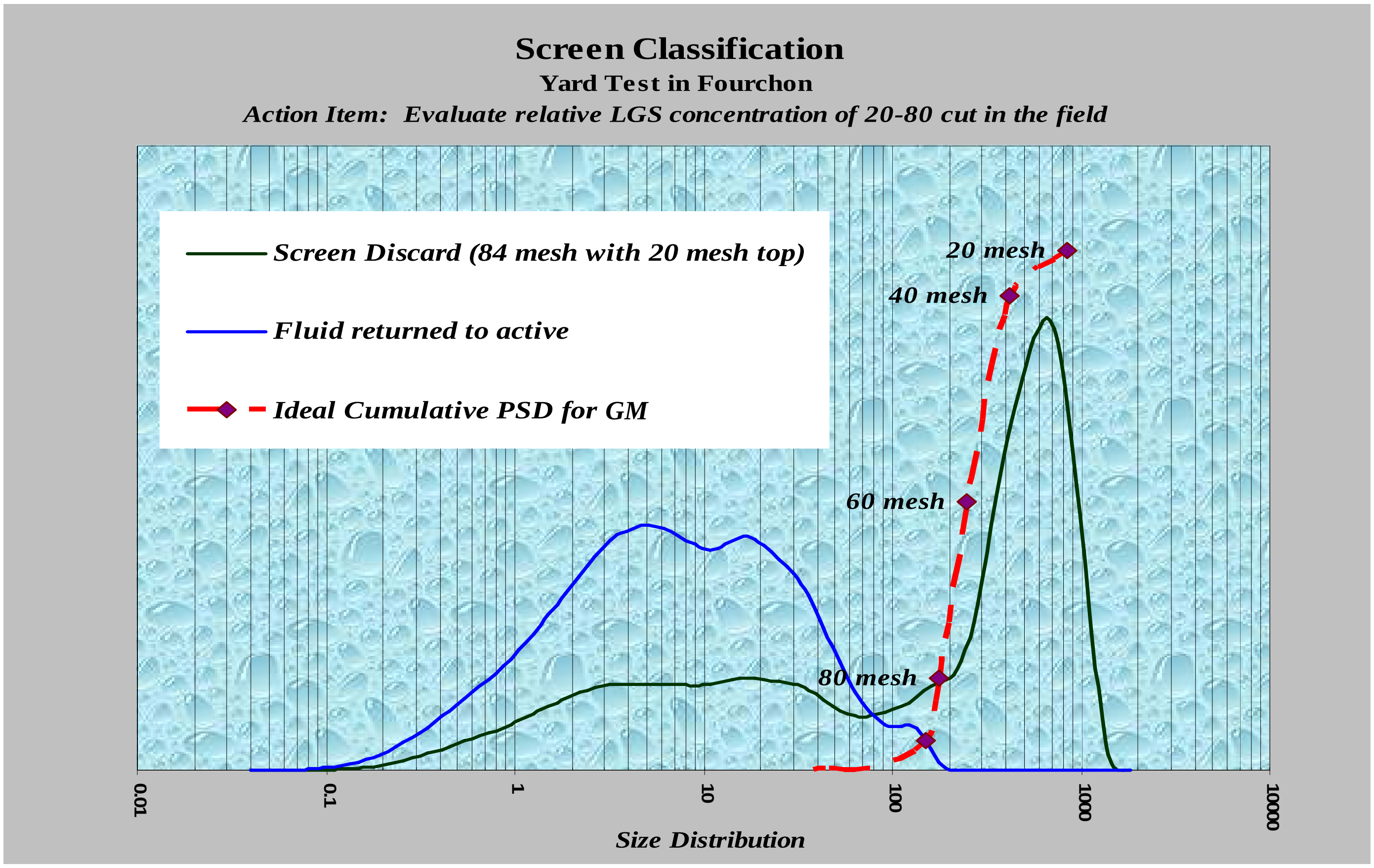


Figure 5 - PSD of GM indicates certain sizes of shaker screens can be more effective for its separation from fluid

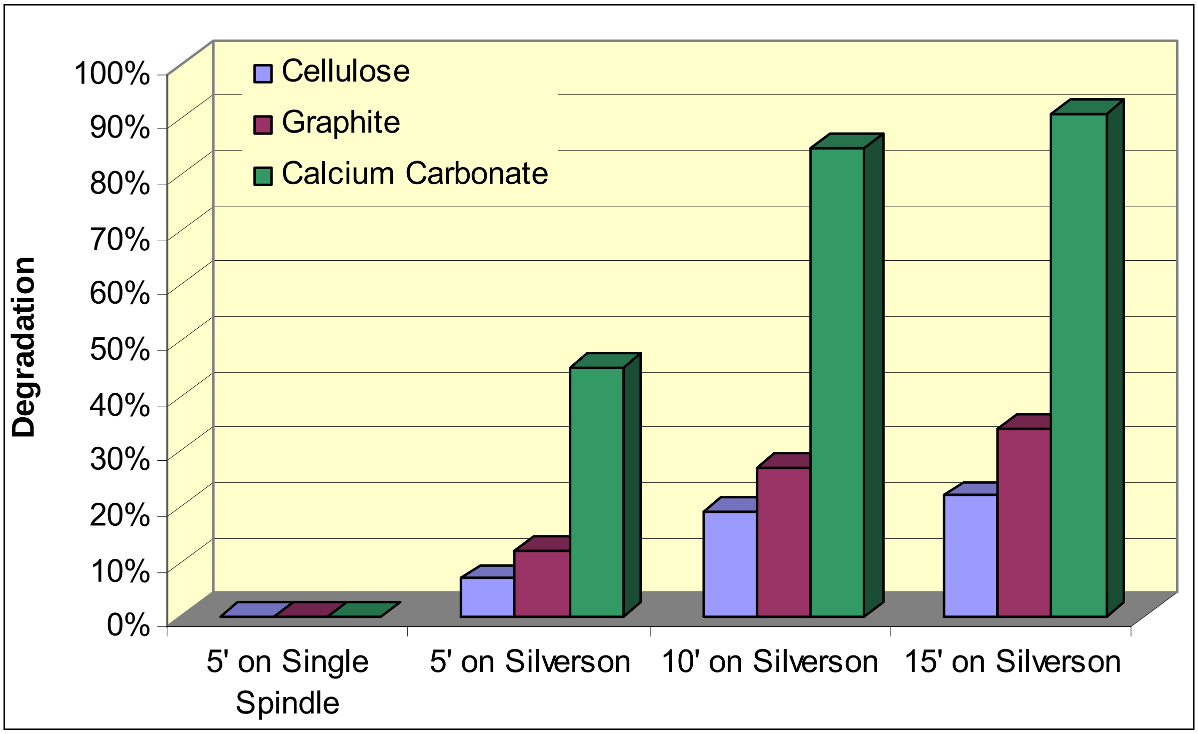


Figure 6 - Mechanical degradation of cellulose, graphite, and calcium carbonate after shearing with HB Single-Spindle and Silverson mixers at 7,000 rpm for time period indicated.

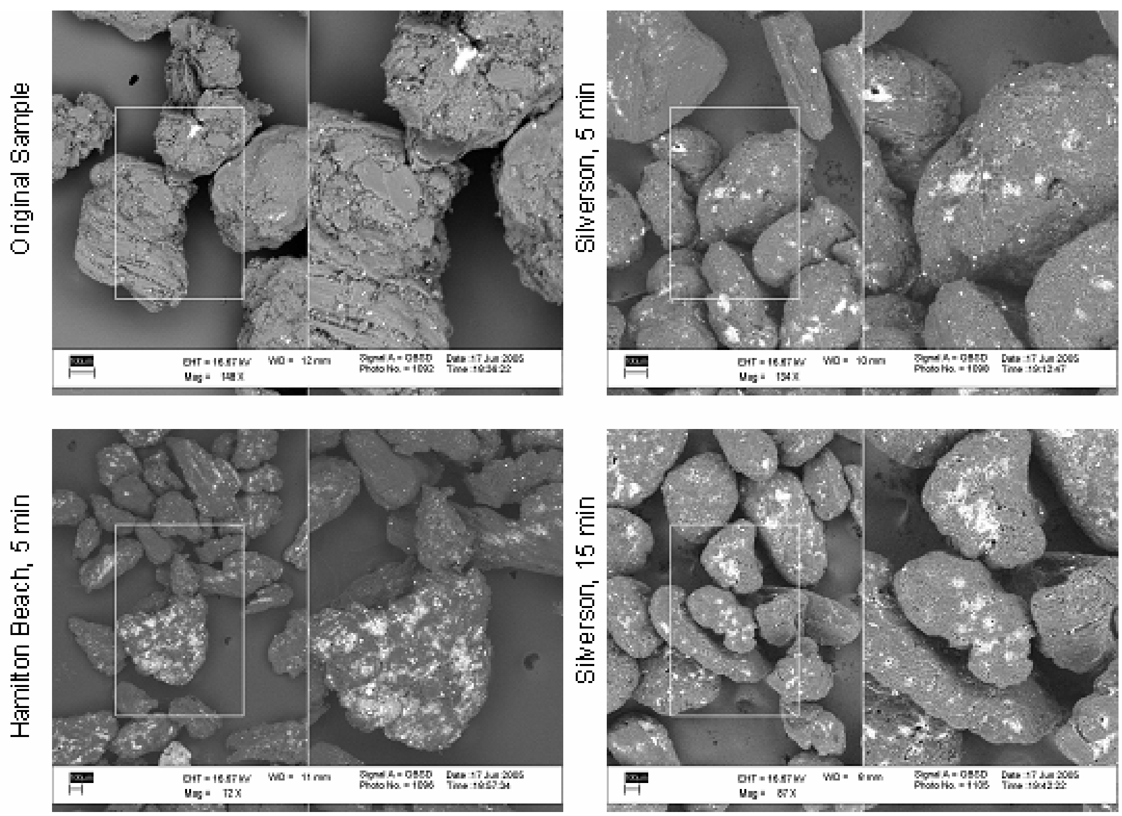
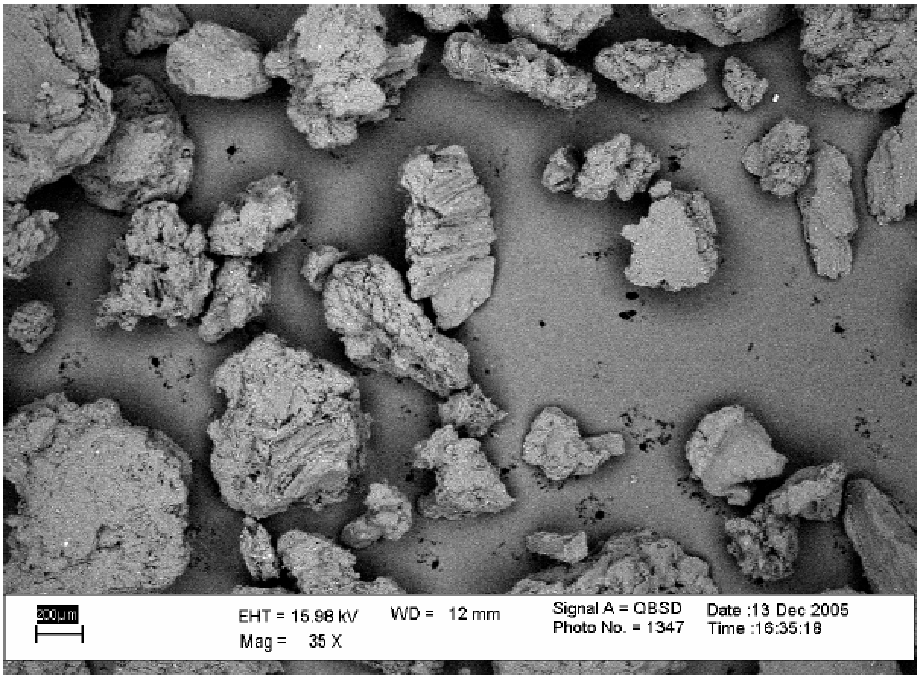


Figure 7 - SEM graphs of graphite showing changes in morphology before (top left) and after shearing for 5 min on Single spindle mixer (bottom left) and on Silverson mixer for 5 min (top right) and for 15 min (bottom right).



Size Range 600-200 µ Average 450 µ

Discard Sample Mesh # 110

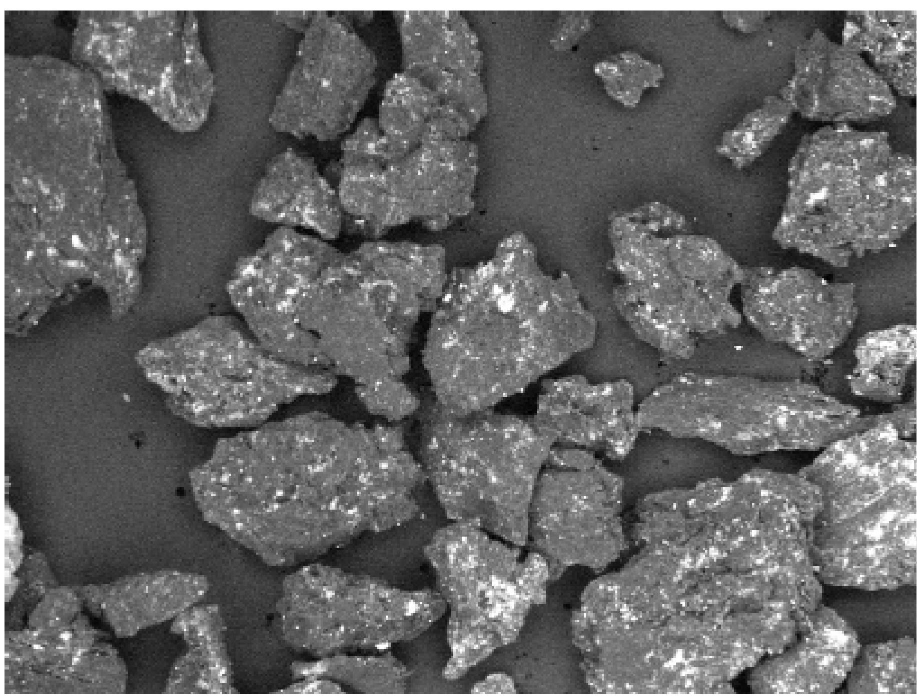


Figure 8 - GM before being added to system (top) and GM discarded from 110-mesh screen (bottom).

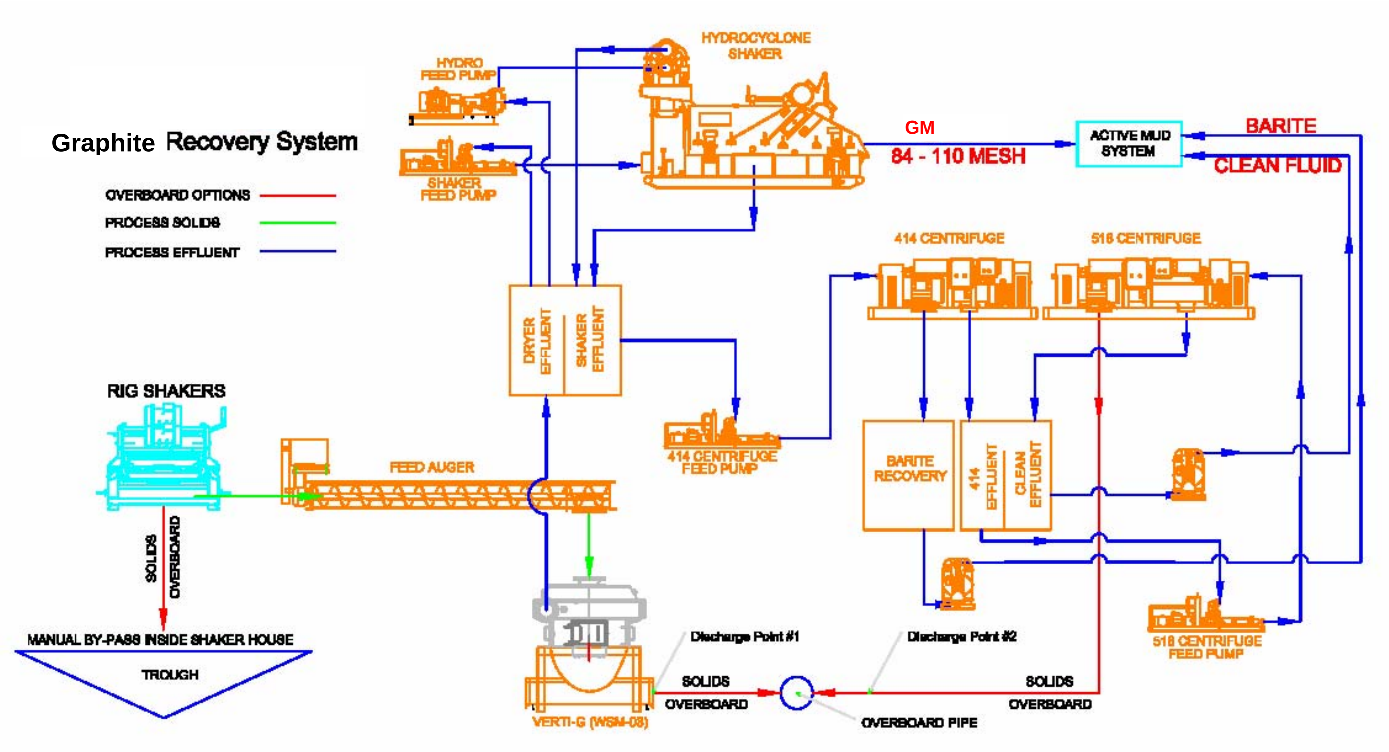


Figure 9 – Schematic of Graphite Recovery System.

Figure 10 - GM Recovery Unit.

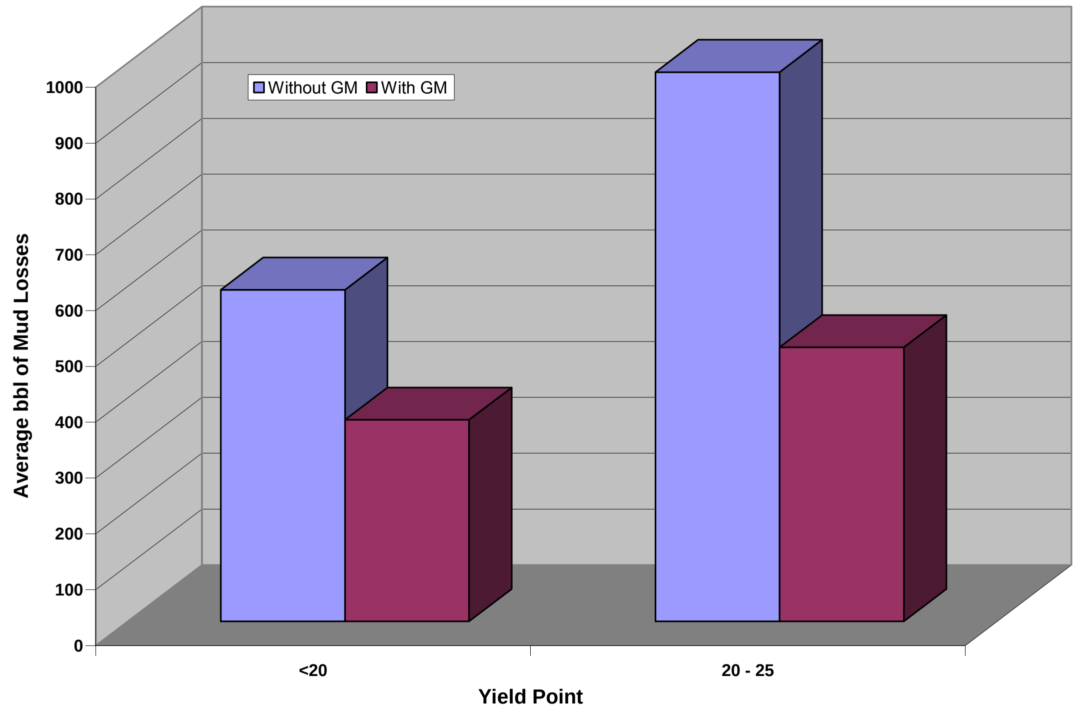


Figure 11 – Comparison of effectiveness of graphite material additions to reduce losses while cementing.

Figure 12 – Visual comparison of graphite material recycled from Graphite Recovery Unit (left) and underflow material sent to centrifuge from Graphite Recovery Unit (right).