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DEVELOPMENT AND EVALUATION OF SOLID CONTROL SYSTEM TO OPTIMIZE DRILLING PERFORMANCE

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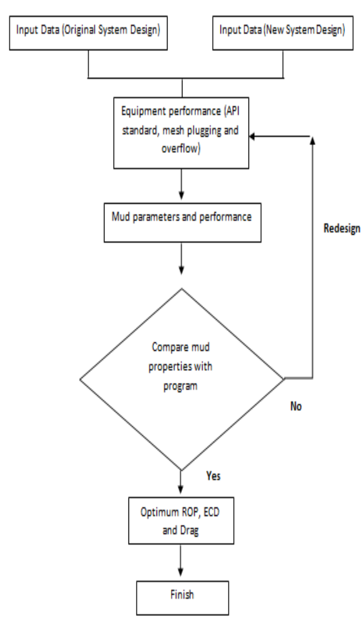
Graphical abstract



Abstract

The nature of solid content mechanism in drilling fluids directly affects its properties and causes adverse impact on drilling performance. It has rapidly evolved and become a paramount issue over the years because of challenging drilling operations. To control the impact of the drilled solids on drilling fluid properties, solid control system unit must be capable of removing the drilled solids before the re-circulation. Failure to establish good solid control management may end the operation strategy with dilution method. A rigorous analysis of drilled solid effects and its correlation with poor performance of solid control system significantly reflects on the overall rig performance in optimizing drilling operation. This paper presents a study of two different solid control system configuration used in two drilling wells. The study shows that installation of distributor tank reduces mud overflow and brings in flow control stability. Mud rheologies – Plastic viscosity, Yield Point and Low Gravity Solid are considered for the two solid control systems. The results of the new solid control system design are better than the old one. Plastic viscosity, yield point and low gravity solid values improve by 14 %, 17 % and 25 % respectively. These results can be used to check the drilling performance and also in characterization of the solid control system to enhance the drilling mud capabilities. This research shows the need of engineering evaluation in the solid control system to reduce the chances of frequent drilling problems, rig components wear issue and other drilling fluid related hazards.

Keywords: Drilling Performance, Plastic Viscosity, Solid Control Equipment, Yield Point, Low Gravity Solid

1.0 INTRODUCTION

The relationship between drilled solids and common drilling problems is well known. It has been proven that adverse effects of drilled solids to drilling operation become a catastrophic issue as the particle size decreases to colloidal form [1]. Formation cuttings are considered contaminants capable of degrading the performance of the drilling fluid. Solids which are not removed during the circulation and remain in the system will be reduced in size until it becomes difficult to remove with the normal solid control equipment (SCE). Smaller the particles, greater is the surface area build up. Consequently, greater the effect of solids on drilling fluid properties, the more difficult they are to remove from the drilling fluid. The introduction of flow distributor tank at the end of the flow line and redistribute the mud through lines to respective shale shakers is significantly useful to optimize the drilling performance. Furthermore, this improvement is to minimize the tendency of shale shakers overflow and reduce processing overloading. Excellent mechanical removal in solid control system manages to prolong the equipment life span and prevent severe downhole drilling problems [2]. Major advantages of reduced drill solid content in the mud system can significantly enhance the rate of penetration (ROP), minimize the torque and drag effect, prevent lost circulation due to excessive pressure imposed on the formation, enhance hole stability and reduce dilution rate.

Reduction of these mechanisms may improve the service life of the mechanical equipment, drill bits and pumps. Development of solid control system solves the problem attributed to drill solid contaminants and also the mud rheology can be maintained in acceptable operating window to ensure efficient hole cleaning and good cutting transport.

2.0 DRILLING OPERATION AND SOLID REMOVAL PROCESSING

This paper presents the methodology and field related application of two drilling wells with different solid control system configuration that comply to API RP 13C standard. The comparative analysis of the two different systems is established to gain improvement in equipment performance and operation optimization. The system is redesigned due to significant poor handling of mud return at shale shakers and high non-productive time (NPT) when drilling with old design solid control system shown in Figure 1. To control the mud flow from the well, distribution tank is installed at the end of the flow line and the mud is redistributed into respective shale. This improvement tremendously minimizes the tendency of shale shakers overflow and reduces processing overloading at downstream equipment. High pressure hose for mud transfer is replaced with steel pipe to minimize pressure loss and intermittent mud flow due to vibration. Figure 2 shows the new design solid control system.

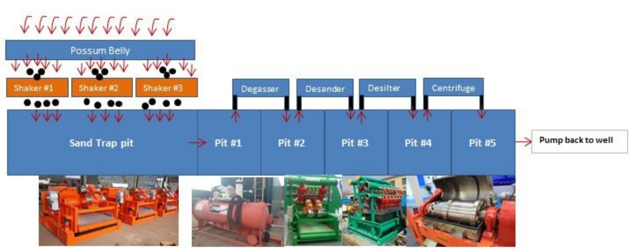


Figure 1 Old Design Solid Control System

Figure 2 New Design Solid Control System

In order to evaluate the removal capabilities of the mechanical separation equipment, solid particles classification should be understood according to their sizes as recommended in API 13C Standardization of Drilling Fluid Material. Each of mechanical separation equipment must fit the requirement and installed appropriately to ensure the units operate at peak performance. Each piece of solid-control equipment is designed to remove solids within a certain size range. Solid control equipment should be arranged to remove sequentially smaller and smaller solids [3]. Efficient elimination of drilled solids right after the fluid leaves the annulus with the best solution to avoid drilling fluid-cutting interaction which can subsequently increase the fluid density. Figure 3 shows the ideal equipment placement.

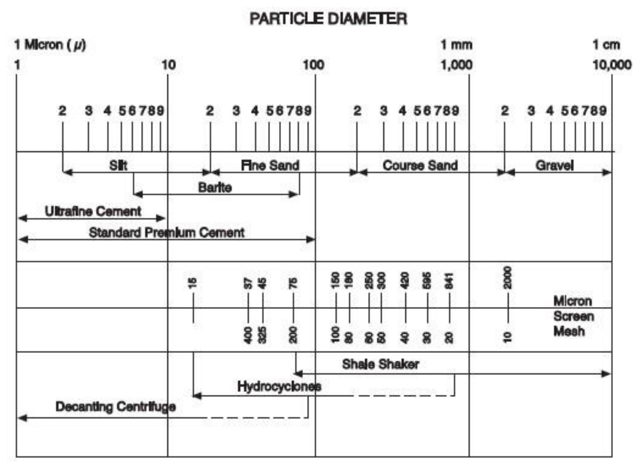


Figure 3 Ideal Equipment Placement

The drilling fluids parameters such as Yield point (YP), Plastic viscosity (PV) and Low gravity solid (LGS) is studied to investigate the significant effects attributed by the poor solid control system processing upon the drilling Rate of penetration (ROP), Equivalent circulating density (ECD) and hole cleaning. These parameters are to be compared before and after the introduction of proper routing mud circulation system.

3.0 OPTIMIZATION OF SOLID CONTROL EQUIPMENT

Good drilled-solids removal procedures start at the drill bit. The cuttings should be removed before another drill bit cutter crushes the rock that has already been removed from the formation [3]. Mud that leaves the well during drilling operation carrying load of drilled solid is fed into solid control equipment to separate from fluid. Solid control is the process of controlling the build-up of undesirable solid in the mud system. Solid separation sequence begins with the shale shaker removing the larger particles followed by the desander to remove the next largest solid. An intermediate cut is taken by the desilter and a final cut taken at centrifuge before the mud goes to suction tank.

The changes introduced in the developed system were the incorporation of a flow line distributor at the end of return line to the shale shakers for uniform mud flow stream and proper pipe routing sequence for the solid control system. Understanding the operation principles has led to the changes and the redesign of solid control removal system towards maximizing the equipment performance as well as separation efficiency. Solids that are not removed during the first circulation through the surface equipment are subjected to mechanical degradation. Optimization studies showed that an efficient solid control system to discard the drilled solid from the drilling fluids can aid in downsizing unnecessary expenditures and promote good drilling performance [4].

3.1 Effect of Solid on Plastic Viscosity

Plastic viscosity is part of the resistance to flow caused by mechanical friction. This parameter is a function of concentration of solids, size and shape of the solid particles and viscosity of liquid phase. Plastic Viscosity is regarded as a guide to solid control for field application [5]. Plastic viscosity increases if the volume percent of solid increases, or if the volume percent remains constant and the size of the particles decreases. Decreasing particle size may increases surface area that lead to fractional drag problem. This plastic viscosity is sensitive to the concentration of solid and depends largely on the bulk volume of solids in the mud [6]. YP/PV ratio is a significant indicator of drilling fluid condition, low ratio indicate smaller tendency for gas cutting, swabbing pressure and greater settling velocity of cuttings whereas high ratios indicate coagulation and flocculation [7]. However, if diameter of borehole is enlarges and not maintain during drilling, a fluid having a high YP/PV is desirable. Removal of drilled solids from a drilling fluid will decrease plastic viscosity and if this solid remain in the fluids, it will grind into smaller and more numerous particles which increases plastic viscosity and decreases drilling performance [8].

3.2 Effect of Solid on Yield Point

Yield point is the initial resistance to flow caused by the electrochemical forces between the particles. Yield Point is expected to be a function of the solid concentration of the mud solids and those factors, such as surface charges and potential, which affect the inter-particle forces [9]. High yield point may be due to the following: (a) Grinding of the solid by the bit and pipe with consequent increase in their specific surface area (b) Increase in solid content with consequent decrease in inter-particles distance (c) Contamination by salt and gypsum which favours flocculation of the particles (d) Insufficient concentration of thinning agent, the function of which is to neutralize the attractive forces.

The yield point can be reduced by the addition of substances neutralizing the electric charges such as thinning agent or by the addition of chemicals to precipitate the contaminants. If elimination of the contaminants is impossible, the yield point has to be reduced by dilution method [9]. Yield point and gel strength should be low enough to allow sand and shale cuttings to settle out and entrained gas to escape, minimize swabbing effect during pulling the string out of hole and permit the circulation to be started at low pump pressure [10]. Efficient elimination of drilled solids right after the fluid leaves the annulus was the best solution to avoid drilling fluid-cutting interaction that subsequently can increase the fluid density [11]. A change in the plastic viscosity of drilling mud can cause small changes in yield point. Yield point may be altered with little or no change in plastic viscosity. It is always important to keep the viscosity of a mud from getting too low. The mud should have minimum viscosity properties to lift the cuttings from bottom of the hole to surface. Moreover, mud must capable to keep weight material and cuttings in suspension while circulating and when the pump is shut down cuttings should not settle in the hole. Increasing of plastic viscosity will decrease the ability to bring cutting to surface and allow them to grind into smaller. Normal reaction is to increase the yield point, but significant increase of yield point cause too fine mesh at shaker screen unable to handle. Changing the mesh screen to a coarser screen decreases the quantity of drilled solid that can be removed [12].

3.3 Effect of Solid on Rate of Penetration

As a consequence of the increase solid loading in the fluid, the penetration rates and bit life decreases. Rheological and filtration properties become difficult to control when the concentration of drilled solid become excessive [1]. Drilling fluid properties can dramatically impact the drilling rate and this fact was established early in the drilling literature, and confirmed by numerous laboratory studies. Several early studies focused directly on the mud properties were clearly demonstrating that rate of penetration are decreased by increasing of mud weight [12]. Darley cited that low concentration of non-colloidal drilled solid below 4% capable to maintain ROP at high level [3]. Mud properties such as Plastic viscosity and Yield stress/gel strength showed that although these properties have effects on ROP but not very significant, only annular pressure losses seemed to drastically affect the ROP which is directly related to equivalent circulating density (ECD) [5]. This phenomenon has already been described in several literatures as "Chip hold down effect" where the principle explains that significant differential pressure between formation pore pressure and mud hydrostatic may lead to reduction in bit penetration [5]. Increase the Weight on bit (WOB) may establish good ROP for some time but may lead in faster bit wear and dulling. This condition then reduces ROP in the long run, hence making optimization difficult.

3.4 Effect of Solid on Hole Cleaning

Based on hole cleaning theory and field practice evaluation, the drilling fluid gel formed (particle bonding) in the cuttings bed is the primary cause of hole cleaning problem [13]. If the particle bonding is strong, large force is required to remove the cutting.

Therefore, hole cleaning can be optimized by the use of drilling fluids with low gel strength and with low viscosity within the shear rates exposed to the annular flow. In practical operation, the 10 seconds and 10 minutes gel strength should be as low as possible to obtain proper hole cleaning. The fluid rheology plays important role for solid transport and optimize the hole cleaning [14]. The best way to pick solid is with a low viscosity fluid in turbulent flow. Hole cleaning can be optimized by the use drilling fluids with low gel strength and with low viscosity within the shear rates exposed to the annular flow [13]. In situations where ECD is not a limiting factor, high – viscosity fluids with high YP/PV ratios are preferred28. Under situation where ECD is a limiting factor, the use of thin fluids in turbulent flow should be considered. Driller must ensure the ECD as well as its static density is within the safe limit. ECD is the effective density of a moving fluid and slightly more than the static density because of the friction pressure drop in the annulus. ECD depends on the pump rates and fluid viscosity. Therefore, maintain ECD within limits means keeping viscosity low. The main cause of elevated viscosity is low gravity solid (LGS) increased. Close monitoring on solid control equipment must be performed to ensure LGS are kept to a minimum [15].

4.0 METHODOLOGY AND SCOPE

In Figure4, solid control development systems were organized in several distinct levels. It acquired interactive tool of solid control system knowledge to solve the problem that associated with drilled solid contamination.

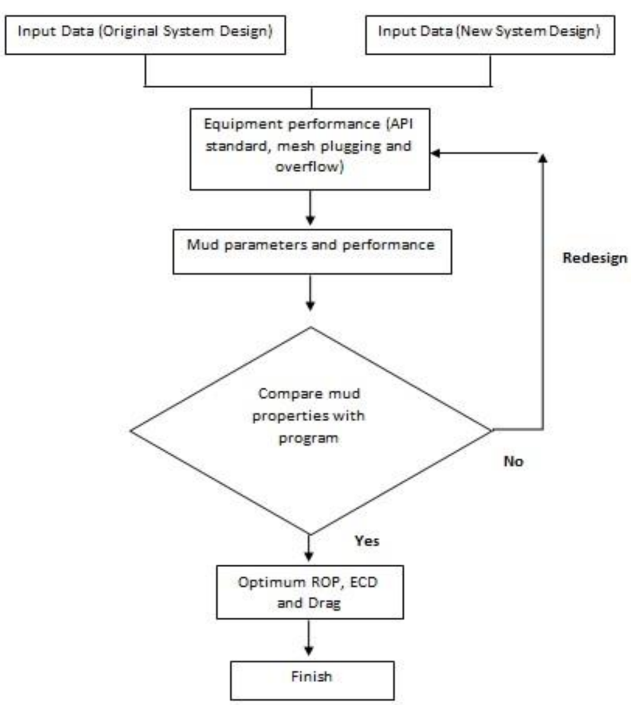


Figure 4 Flow Chart of Methodology

4.1 Step I: Setup of Solid Control System

In this stage, the work is focus on understanding the drilling fluid circulating system and solid separation stages. The observation not limited but including drill cutting trends (shape and flow), API RP 13C compliance and equipment working performance. The solids control comprises of three (3) shale shakers, mud cleaner (Desander & Desilter) and centrifuge. The introduction of flow distributor tank at the end of the flowline and redistribute the mud through lines to respective shale shakers is designed to optimize the mud flow performance. This improvement was minimized the tendency of shale shakers overflow and reduce processing overloading.

4.2 Step II: Data Acquisition and Measurement

This phase involves data collection and evaluation of the mud properties as per API RB13B-2 recommended procedures. PV, YP and LGS were measured conventionally and evaluated at each of the solid control equipment. This measures to be used as a tool to evaluate the efficiency of the mechanical equipment. The drilling parameters including ECD and ROP are obtained from real-time downhole acquisition tool. Torque and drag (T&D) are recorded after each drill pipe connection to monitor the hole cleaning. Mud parameters and drilling data are correlated to oversee the drilling performance. Gradual changes in mud properties, high ECD and poor ROP are significantly reflect to the ineffective of solid control system.

4.3 Step III: Comparison and Evaluation of Mud Properties

In this stage, mud properties for both system designs are compared and evaluated as it reflects the economic justification for mechanical solid control system. The mud rheologies are PV, YP and LGS while drilling parameters are ECD and ROP. Torque and Drag (T&D) is evaluated to monitor closely the hole condition. Drilled solids are essentially having direct and pronounced effect on the drilling fluids properties. Therefore, good solid control system significantly can maintain the desire drilling fluids properties.

5.0 RESULT AND DISCUSSION

Field data obtained from onshore drilling in Borneo Block. The purpose of this section is to evaluate the performance of the solid control system and effect of poor processing to mud properties during the drilling operation. All data used are obtained from 2 different wells but similar lithology. The Well #A was drilled using Original solid control system while Well #B was drilled with New developed design. The performance of both systems was compared while drilling the 12 ¼" section. A total of 40 mud samples were collected and measured to evaluate the PV, YP and LGS. These results act as a preliminary step to investigate the performance of the mud on Torque and Drag (T&D) data in order to justify the performance of the new design in this analysis.

5.1 Comparison DFata on Well #A and Well #B

5.1.1 Plastic Viscosity (cP) vs Data Point

Figure 5 shows the tabulated PV reading of Old Design and New Design solid control system. At the start of drilling operation, PV reading for both systems is effectively performed on the same trend. As drilling the hole deeper at Well #A and more drilled cuttings generated, the mud property that processed using Old system was getting thicker which result the PV reading gradually increased. Increase of PV reading is subjected to increase of solid content in the drilling fluid and for field application, plastic viscosity regarded as a guide for solid control. Frequent mesh screen plugging, discharge rope from the Hydrocyclone and solid recirculation contribute to poor solid removal and PV reading incremental. Spray discharge is not achieved because the Old Design utilized high pressure hose as a suction line to Desander and Desilter. Pressure generated to feed the mud into Desander and Desilter through suction hose causing vibration, pressure loss and inconsistent mud flow.

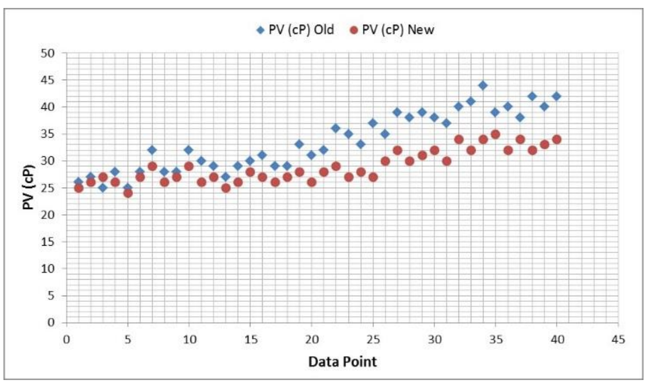


Figure 5 PV (cp) vs Data point

Drilling Well #B with New system design had improved the solid removal processing by 14% compared to Old Design. PV reading is reduced from 33cP (Average reading) to 28.9cP (Average reading). The performance of New system looks economic and reliable as it is justified by system capability to maintain the PV reading throughout the operation. T Inability of the Old Design to eliminate rapid development of mud contamination is significantly creates overloading works to the downstream equipment.

5.1.2 Yield Point (lbs/100ft²) vs Data Point

Figure 6 shows the tabulated YP for Old Design and New Design. The YP reading of Old Design is gradually increased because the solid in the drilling fluids is not properly discarded while drilling Well #A. Frequent mud overflow on the shale shakers at Old Design is considered surface losses while bypassing the shakers significantly overloading of downstream mechanical equipment. Overloading may result the equipment incapable to remove the solid efficiently and work at peak performance. Anything that causing changes in low shear rate viscosity is reflected in the YP reading. This is occur because colloidal clay platelets link together (flocculate) with consequent increase in their specific surface area. While mud at static condition, drilling mud contain high solid becomes attractive and repulsive. This indication reflects to the gel strength of the mud. High gel strengths are undesirable condition because it retards the separation of cuttings, retards to release entrained gas at surface and pressure required to re-establish circulation. The New Design of solid control system is utilized while drilling Well #B. A flat increase in YP reading observes but the New Design improves the mud processing by 17% with YP reading reduces from 26.5 lbs/100ft² (Average) to 21.85lbs/100ft². Stable and consistent mud flow distribution to shale shakers is significantly helpful in controlling the YP build up by removing the excessive solids return from the well. Changes in shear rates viscosity due to solid content is reflected in the YP. Ability of the New Design to maintain the YP also showed that the solids are properly inhibited by the system and result low pressure loss while the drilling mud is circulated. The consistence value of YP at New Design while drilling the section typically provides good cutting carrying capacity (CCC) of the drilling fluid. Good control of YP reduces the chances of pressure spike that can break the formation which may result lost circulation. Sufficient yield point and gel strength must be achieved at acceptable gel strength to help for cutting suspension while circulating and pump shut down. The mud must capable to lift the cuttings from bottom of the hole to surface. This requirement is excellence for hole cleaning without causing unnecessary high circulating pressure.

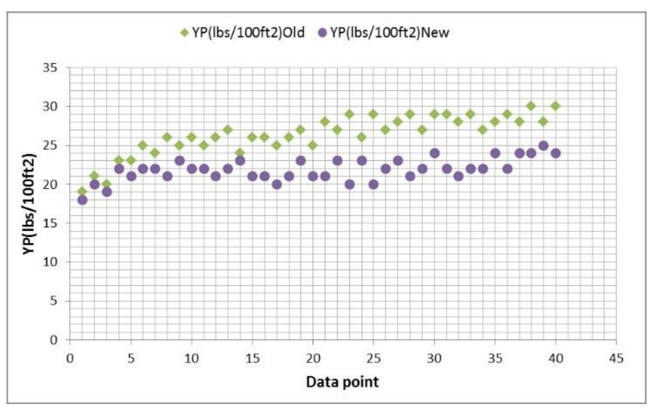


Figure 6 YP (lbs/100ft2) vs Data point

5.1.3 Low Gravity Solid (%) vs Data Point

Figure 7 shows the tabulated LGS for Old Design and New Design. Rapid incremental of LGS percentage while drilling the Well #A is obviously due to inability of the Old Design to remove the solid efficiently from the drilling mud. During drilling top formation, the Old Design and New Design of solid control configurations removed the solid effectively as the systems recorded the LGS (%) is still in the range of 7% to 8%. As drilling the Well #A deeper, the SCE of Old Design is observed poorly in handling the mud return from the well. Frequent shale shakers overflow and bypassing the shakers in order to prevent massive surface loss of expensive fluids is significantly creates additional risk to the solid removal optimization. The situation result LGS (%) in the mud system rapidly increase to 14%. High solid content in this mud is considerably abrasive and may degrade down the drilling equipment through silt size. The smaller the particles the more pronounce the effect on the mud properties because smaller particles are more difficult to remove or control its effect on the fluid. Re-circulate of mud that containing drilled solid may gradually deteriorates mud properties. The upper limit of the solid fraction should be in the range of 6% to 8% by volume. The New Design of solid control system as tabulated in graph 3 shows that the system LGS (%) improves the system removal by 25% while drilling the Well #B. The average reading of LGS (%) is 8.7%. A slight increase in LGS (%) is observed since the kick start of operation due to mud chemical additives and weighting material contamination.

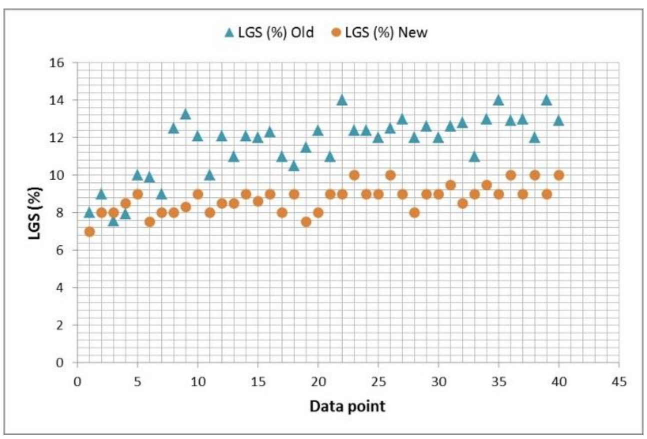


Figure 7 LGS (%) vs Data point

6.0 CONCLUSION

- The installation of distributor tank offers flow stability to control the mud return flow from the well by minimizing the tendency of frequent mud over flow, screen mesh plugging and tool wear issue.
- Proper mud flow control and routing in the New Developed design of solid control system effectively removes the solid in the drilling fluid. The mud properties and rheology of PV, YP and LGS are improved with at acceptable envelope. Comparing to the Old Design, the New Design improved the mud properties of PV by 14%, YP by 17% and LGS by 25%.
- A further study on ECD, ROP and T&D from the new design for the wells should enable proper characterization of the solid control system to enhance the drilling mud capabilities besides minimizing the number of equipment breakdown.

Nomenclature

PV	Plastic viscosity
YP	Yield point
ROP	Rate of penetration
SCE	Solid control equipment
LGS	Low Gravity Solid
ECD	Equivalent circulating density
NPT	Non Productive Time

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