Solid Control System for Maximizing Drilling

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Abstract

This chapter focuses on the development of solid control system that is suited for drilling 12.25-inch hole. The first part discusses the performance of rate of penetration (ROP), equivalent circulating density (ECD) and drill string drag while the second part of the chapter discusses about the effect of solid control system performance to mud properties plastic viscosity (PV), yield point (YP), and low gravity solid (LGS). The input parameters were gathered from two different set up of solid control systems that were used in Well A and Well B. The result is mainly based on the performance of original solid control system new design vs. old design. Installation of distributor tank and channeling the mud to respective shale shakers significantly enhanced the system and operational performance. The ROP at 12.25-inch drilling was improved by 20%. New design, on an average, improved the ECD margin by reducing additional pressure exerted using original mud from 4.9 to 2.9%. High ECD margin is not recommended because it can break the weak formation. Mud properties while drilling the 12.25-inch hole section; PV, YP and LGS values were improved by 14, 17, and 25% respectively.

Keywords: solid control, 12.25-inch hole, ROP, ECD, mud rheology, LGS

1. Introduction

The effective performance of solid control equipment is to remove drilled solids from the drilling mud which acts as a key factor to have good mud properties [1]. Solid and particles that are not removed during the circulation will remain in the system and lead to reduction of size that may increase the difficulty on removing process using mechanical solid control equipment (SCE). Mud properties must be maintained within the acceptable specification to allow efficient cutting transport to surface [2]. Quantities of high solid content present in mud always perceived as a vital factor affecting the operation efficiency and equipment wear issues. Ineffective solid control system and inadequate understanding of mud properties create additional risk and uncertainties to downhole condition. Drilling the 12.25 hole section using old design solid control system produced unequal distribution of the mud flow over the shakers screen. The mud flow only concentrated at middle shale shaker that connected to flow line while the others shaker received minimal flow. This situation tends to be overloaded only in the middle shale shaker unit. In rig site practice, the shakerman adjusting the baffle plate at possum belly increases the flow. However, it increased mud losses through the solid control unit and continuous plugging of the mesh in the solid control unit. Due to ineffective shale shaker and overflow of mud at possum belly, the flow was bypassed to prevent mud surface losses but it plugged the apex cones of hydrocyclone. By-passed the shale shaker unit result high drilled solids content circulated back and not remove from the system. Mud properties, such as YP, PV and LGS, were studied to investigate the significant effect of poor solid control system processing toward the performance of ROP, ECD and drag. This investigation evaluated the performance of solid control equipment before and after the introduction of mud flow distributor tank for mud return from the well while drilling the 12.25 inch hole. The methods used were gathering from various sources including case study on the rig operation, reports, personnel experience, publication and discussion for drilling the 12.25-inch hole section. The theory and literature review related to solid control system, mud properties and correlation to drilling operation also were studied to gain previous research related to the problem. Solid control system was then redesigned to investigate its affect toward mud properties and operation

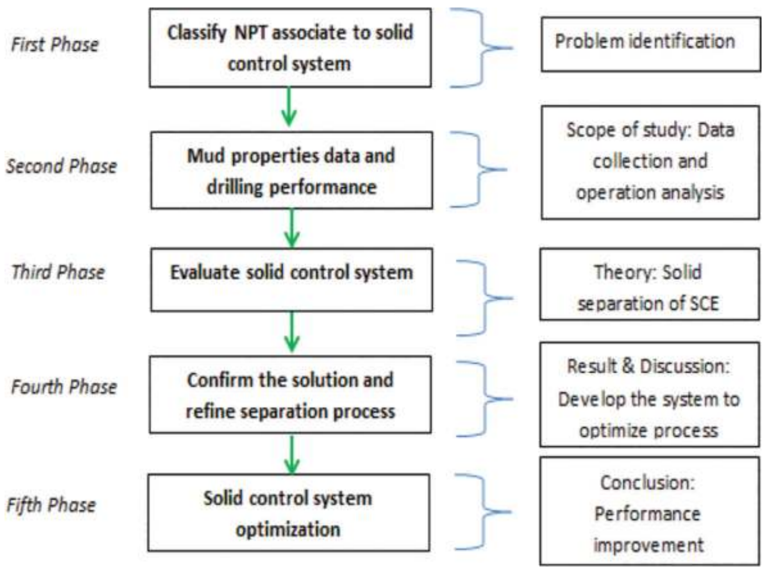

Figure 1. Solid control phases diagram. (Note: Personal experience).

performance. Comprehensive analysis was made to discuss the relation of poor solid control system, mud properties and drilling operation (**Figure 1**).

2. Solid content and mechanical solid control system

The commercial solids (barite) and non-commercial solid (drilled cuttings) are two primary sources of solid particles that exist during drilling. Solid that are concentrated in the mud are classified either based on specific gravity (SG) or density and particle size. Solid SG higher than 4.2 (weight material) are categorized as high-gravity solid (HGS) while solid with SG 1.6 to 2.9 (average 2.6) is categorized as low-gravity solid (LGS) **(Figure 2).**

The solid control system sequence consists of shale shakers, hydrocyclones (desander and desilter) and centrifuge. Each mechanical equipment work independently depends on the solid particles sizes. The equipment is connected in series, and each stage of processing performance is partly dependent upon the previous equipment. By-passing the shaker screen is not recommended because failure to discard the solid particles at the shale shakers unit would overload the downstream equipment. Drilled solids that are not removed during the first circulation through the surface equipment are always subject to mechanical degradation [3]. The smaller the particle, the greater the surface area may develop, and it is causing greater effect to the mud system (**Figures 3** and **4**).

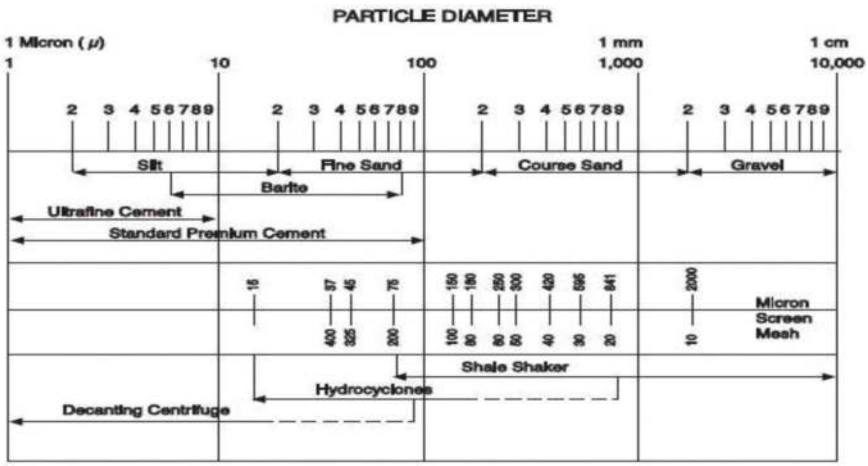

Figure 2. Particle diameter [7].

Figure 3. Old design solid control system.

Figure 4. New design solid control system. (Note: **Figures 3** and **4** is based on personal experience).

3. Development of solid control equipment

During drilling operation, the circulated mud carries drilled cuttings to surface. These solids are then treated at mechanical solid control system by separating them from the mud according to the particles size. In this chapter, the research focuses on maximizing the efficiency of equipment performance and separation because the old design was inefficient to remove the solid from the mud. The flow line distributor was installed at the end of return line to the shale shakers and replaced the high-pressure hose to rigid piping system for reducing pressure loss due to vibration. This system allows the solids containing drilling mud to be divided equally between the desire numbers of shale shakers. Mud circulation without any reduction in solid concentration may thicken the fluid viscosity and develops resistance to flow character of the mud. This brings to the changes in its density, rheology and other properties. The utmost advantage is to remove as much solids practically to reduce down time which contributed from plug flow lines, fluid end repair, drill string erosion and re-drilling of solids as drilling fluid recycles itself through the mud system loop [1].

3.1. Effect of solid particles on MW

Density or MW is measured and expressed in pounds per gallons (lb/gal), pound cubic feet (lb/ft^3) and grams per cubic centimeter (g/cm^2). It is an important property to maintain the well hydrostatic and prevent gas influx migration into the wellbore. Some of weight material such as barite and hematite are added into the mud to increase the mud weight. Mud in the wellbore column must exert a greater pressure than the fluids in porous rocks that are penetrated by the bit. The pressure exerted by the drilling mud at any depth or gradient of pressure is related to its density. Denser or viscous mud may exert excessive pressure to the wellbore and causing loss of circulation.

3.2. Effect of solid particles on well bottom-hole pressure

High solid content ultimately can increase the density and viscosity of the mud. Hence, it exposes the well to high BHP and mud properties contamination. Moreover, high horse power is also required to break up the gel and pump the mud for circulation. This not only triggers to hydraulic fracturing effect but also induces the tendency of mud losses into the formation. Under the primary well control requirement, the mud density must be formulated to compensate the desire BHP either meet or exceed the pore pressure of the rock formation. Failure to control the build of solid and regrinding the same drilled cutting may increase the mud surface area become very difficult to remove using mechanical solid control equipment. High solids are abrasive and can increase filter cake thickness. The higher of filter cake, the higher chances of drill string to get stuck due to differential sticking effect. Thin and impermeable filter cake is important to reduce contact area across the drill string.

3.3. Effect of solid particles on PV

PV is a function of solids concentration, size and shape of the solid particles and viscosity of liquid phase [4]. It is regarded as a guide to solid control for field application [5]. PV is directly proportional to the increasing of solid volume percentage, or if the volume percent remains constant, the size of the particles decreases. Decreasing particle size may increases surface area that leads 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]. A low PV implies lower ECD exerted at bottom while high PV trigger to an increase of ECD because high pumping pressure is needed to break the gel. YP/PV ratio is a significant indicator of drilling fluid condition, low ratio indicates smaller tendency for gas cutting, swabbing pressure and greater settling velocity of cuttings whereas high ratios indicate coagulation and flocculation [7]. Removal of drilled solids from a drilling fluid will decrease plastic viscosity, and if this solid remains in the fluids, it will grind into smaller and more numerous particles which increases plastic viscosity and decreases drilling performance [8].

3.4. Effect of solid particle on YP

YP is the initial resistance of the fluids to flow caused by the electrochemical forces between the particles. It is also expected to be a function of the solid concentration of the solids and those factors, such as surface charges and potential, which affect the interparticle forces [9]. YP 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 PV of drilling mud can cause small changes in YP. Therefore, 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. The mud must capable to keep the weighting material and drilled cuttings in suspension while circulating or stop pumping. Normal reaction in the event of poor cutting transport is to increase the YP of the mud. However, the significant increase in YP may result poor performance of the finest mesh at shaker screen. Changing the mesh screen to a coarser screen decreases the quantity of drilled solid that can be removed [12].

3.5. Effect of solid particle on ROP

Rheological and filtration properties become difficult to control when the concentration of drilled solid become excessive [1]. High particulate solids in the mud reduce ROP because of increase in mud density and viscosity. The higher the mud density, the greater the differential pressure exerts. ROP decreases when differential pressure increases. Lower mud density may decrease the dynamic chip hold down and permitting faster RPM. Low viscosity mud promotes fast penetration because of good scavenging of drilled cuttings. Despite applying more WOB and RPM can comfortably achieve the desire ROP, but drilling with contaminated mud properties decreases in ROP in a long run. Darley mentioned that low concentration of noncolloidal drilled solid below 4% capable to maintain ROP at high level [3]. Mud properties such as PV 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 ECD [5].

3.6. Effect of solid particle on drag and ECD

The fluid rheology plays an important role for solid transport and optimizes 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 of drilling mud 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 preferred. 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, regulation of 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 that LGS are kept to a minimum [14].

4. Methodology

4.1. Setup of solid control system

The solids control comprises of three: shale shakers, hydrocyclones (Desander and Desilter), and centrifuge. The introduction of flow distributor tank at the end of the flowline and

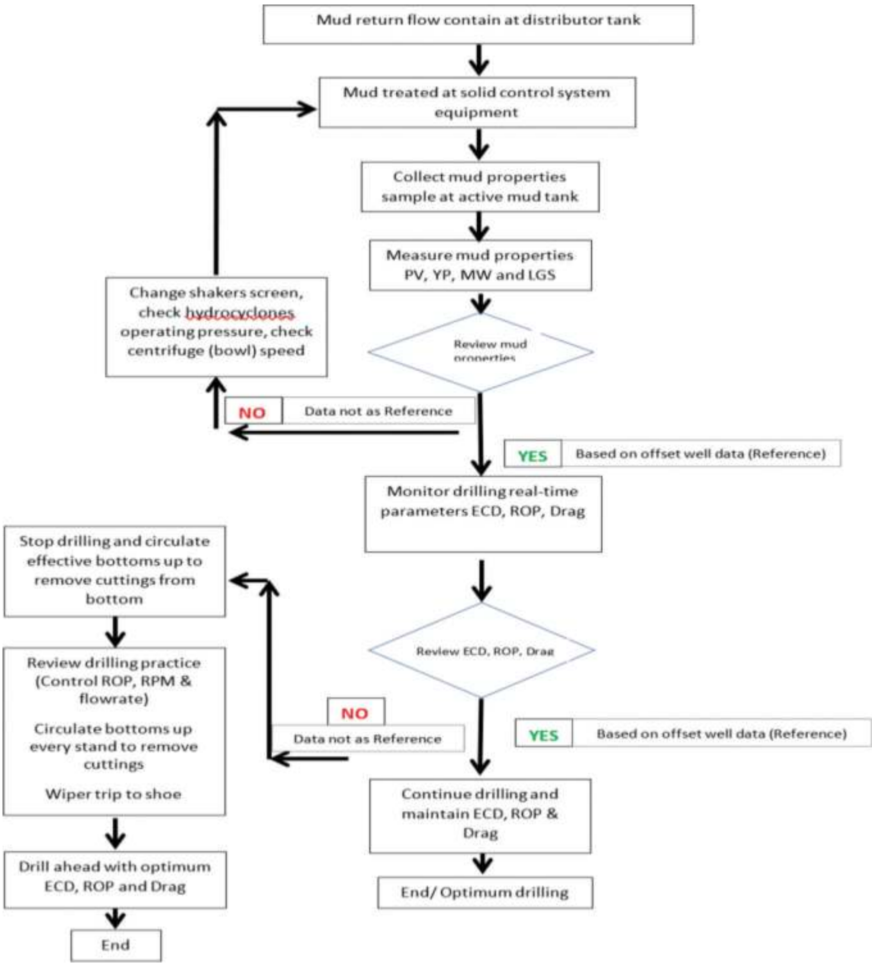

Figure 5. Flow diagram of the methodology. (Note: Based on personal experience).

redistribute the mud through lines to respective shale shakers is designed to optimize the mud flow performance. This improvement minimized the tendency of shale shakers overflow and reduced processing overloading (**Figure 5**).

4.2. Data acquisition and measurement

Data collection and evaluation of the mud properties include PV, YP and LGS. These measures are 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. Drill string drag is recorded after each drill pipe connection to monitor the hole condition. Mud parameters and drilling data are correlated to oversee the drilling performance. Gradual changes in mud properties such as high ECD and poor ROP are significantly reflect to the ineffective of solid control system.

5. Results and discussion

Field data are obtained from onshore drilling in Borneo Block. All data are obtained from two different wells with similar lithology called Well A and Well B. 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 12.25 inch 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 ROP, ECD and drill string drag to justify the performance of the new design in this analysis.

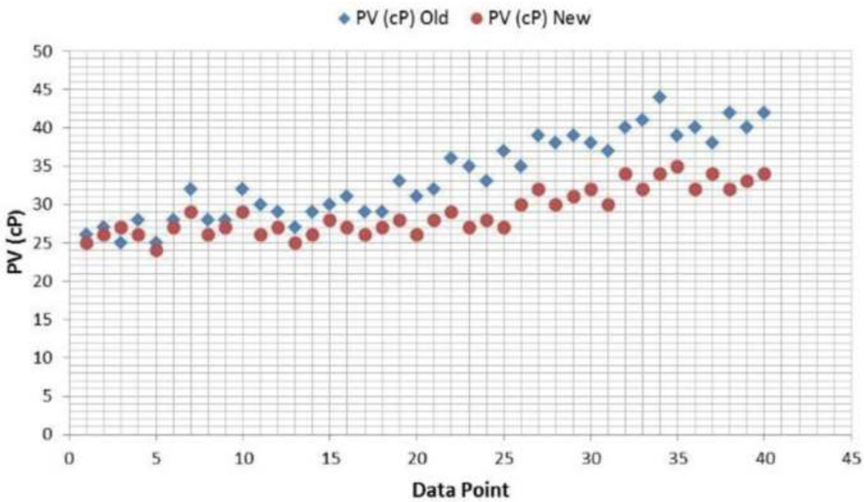

Figure 6. YP (lbs/100 ft^2) vs. data point. (Note: Based on personal experience).

5.1. Performance of solid control system on plastic viscosity

Figure 6 shows the tabulated PV of new design and old design solid control system. At the start of drilling operation, PV for both systems performed on the same trend. This reflects the solid separation and treatment was working effectively. As drilling deeper at Well A with old system and more drilled cuttings excavated, the mud viscosity was getting thicker that resulted the PV to gradually increase. Increase of PV is subjected to drilling the Well B with new system design had improved the solid removal processing by 14% as compared to old design. The performance of new system was economical and reliable as system capability justifies it to maintain the PV reading throughout the operation. The inability of the old design to eliminate rapid development of mud contamination significantly leads to overloading works at downstream equipment which increase solid contents in the drilling mud. Frequent mesh screen plugging, discharge rope from the hydrocyclone and solid recirculation contributed to poor solid removal and PV increment. Spray discharge was 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 caused vibration, pressure loss and inconsistent mud flow.

5.2. Performance of solid control system on yield point

Figure 7 shows the tabulated YP for old design and new design. The YP of old design gradually increased because solid in the drilling mud was not properly discarded while drilling well A. Mud overflow on the shale shakers was frequently observed, and occasionally the

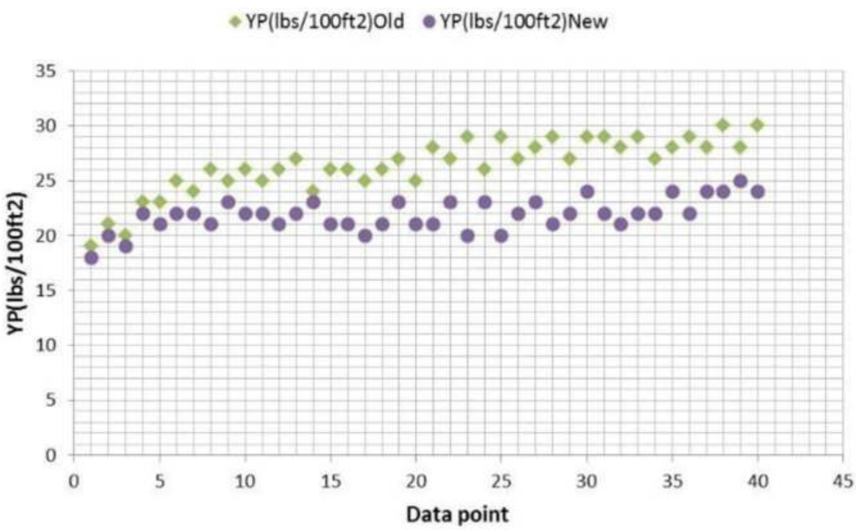

Figure 7. YP (lbs/100 ft^2) vs. data point. (Note: Based on personal experience).

unit was bypassed to minimize the surface losses. By passing the solid control unit significantly overload the downstream mechanical equipment and result the equipment incapable to remove the solid efficiently. Changes in low shear rate viscosity reflect to the mud YP. In this condition, colloidal clay platelets link together (flocculate) with consequent increase in their specific surface area. When mud is at static condition, the mud contains high solid and becomes attractive and repulsive. Stable and consistent mud flow distribution to shale shakers was helpful in controlling the YP build up. The ability of the new design to maintain the YP showed that the solids were properly separates by the system and result in low pressure loss while the drilling mud was circulated. Consistent 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 circulation lost. Sufficient YP and gel strength were achieved at acceptable gel strength to help for cutting suspension while circulating and pump shutdown. Moreover, the mud was capable to lift the cuttings from bottom of the hole to surface.

5.3. Performance of solid control system on low-gravity solid

Figure 8 shows the tabulated LGS for old design and new design. Rapid increment of LGS while drilling Well A was obvious due to inability of the old design to remove the solid efficiently from drilling mud. At the start of drilling operation, both designs removed the solid effectively from the drilling mud as the LGS was tabulated at the range of 7–8%. As drilling Well A deeper, the solid control equipment (SCE) of old design was observed getting poor in handling the mud

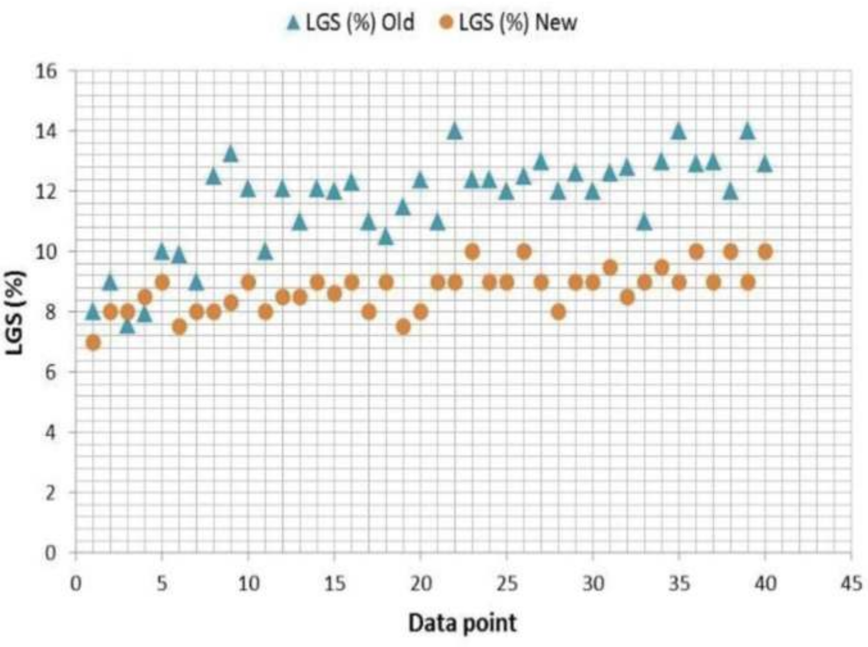

Figure 8. LGS (%) vs. data point. (Note: Based on personal experience).

return from the well. Frequent shale shakers overflow and bypassing the shakers in order to prevent massive surface loss of expensive fluids significantly created additional risk to the solid removal processing. The situation results of the LGS in the mud system rapidly increased to 14%. High solid content in this mud was considerably abrasive and may degrade down the drilling equipment through silt size. The smaller the particles, the more pronounced the effect on the mud properties because smaller particles are more difficult to remove or control its effect on the fluid. Recirculating of mud that contained drilled solid may gradually deteriorate mud properties. The upper limit of the solid fraction should be in the range of 6–8% by volume. The new design of solid control system as tabulated in **Figure 8** shows that the system LGS was improved with system removal by 25% when drilling Well B which showed an average reading of LGS at 8.7%.

5.4. Performance of solid control system on mud weight and equivalent circulating density

Well A was drilled using old design solid control system. The section was from 760 to 2163 m MDRT. MW was gradually increased from 10 to 11.6 ppg mud to maintain the hydrostatic

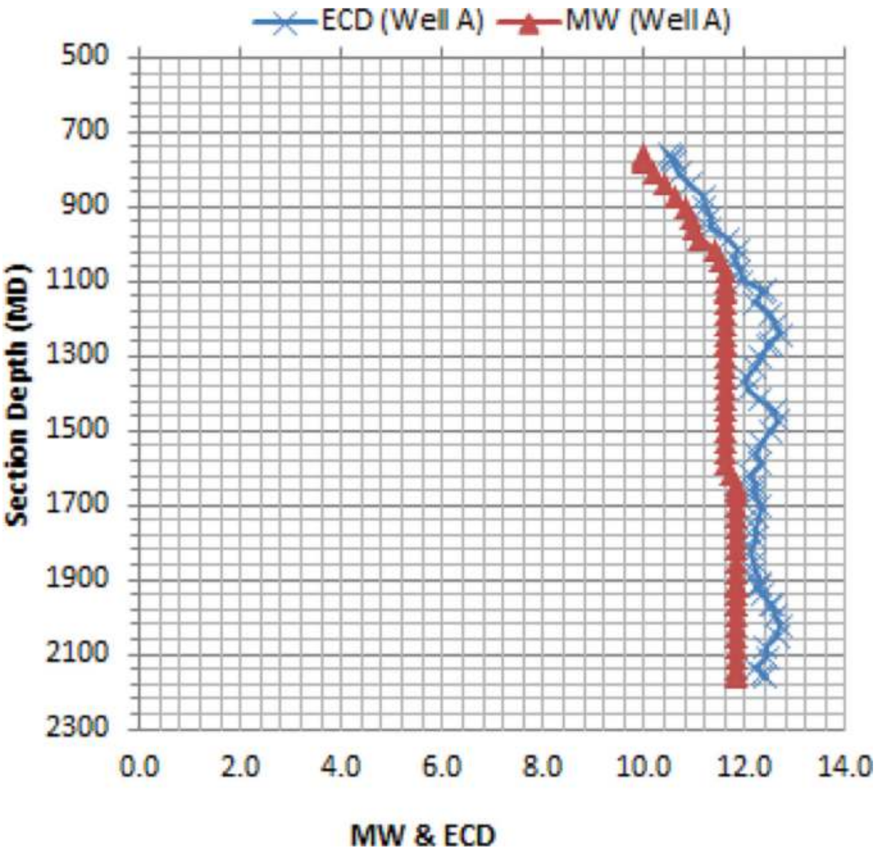

Figure 9. Section depth vs. MW & ECD (new design).

pressure in the column. Early tabulated data on the top section demonstrated a good ECD trend with no significant pressure spike. As drilling reached to 1124 m MDRT depth, ECD spike was increased up to 12.4 ppg. Failures to transport the cutting effectively to surface exposed the formation to pressure spike. It occurred because drilled cutting that remains in the well created tight tolerances between hole and drill string geometries. Poor hole cleaning triggered high ECD that can break the formation and losses of mud. ECD trend progressively built up, and pressure spike was observed at 1244 and 1474 m MDRT. Well circulation was commenced until the hole clean, but the entire operation progress became slows. The flow rate was ramped up in controlled manner to minimize the risk of pressure spike and high ECD. The ROP was also controlled to reduce the impact of high ECD. The average ECD additive factor was 0.6 ppg that is equivalent to 4.9% increment from original MW during mud than in dynamic condition (**Figures 9** and **10**).

Well B was drilled using new design of solid control system. The section was drilled from 750 to 2200 m MDRT. The MW used to drill this section was 10.0 to 11.9 ppg and gradually increased to maintain the hydrostatic pressure in the column. The tabulated data show that the ECD was consistent at safe drilling margin until section TD at 2150 m MDRT. No significant ECD spike was observed throughout the operation. A slight increase was observed at 1935 m MDRT with 12.32 to 12.5 ppg, but the impact is still below the fracture gradient. Increase in ECD occurred because more cutting bed accumulated on the low side of drill string. Due to

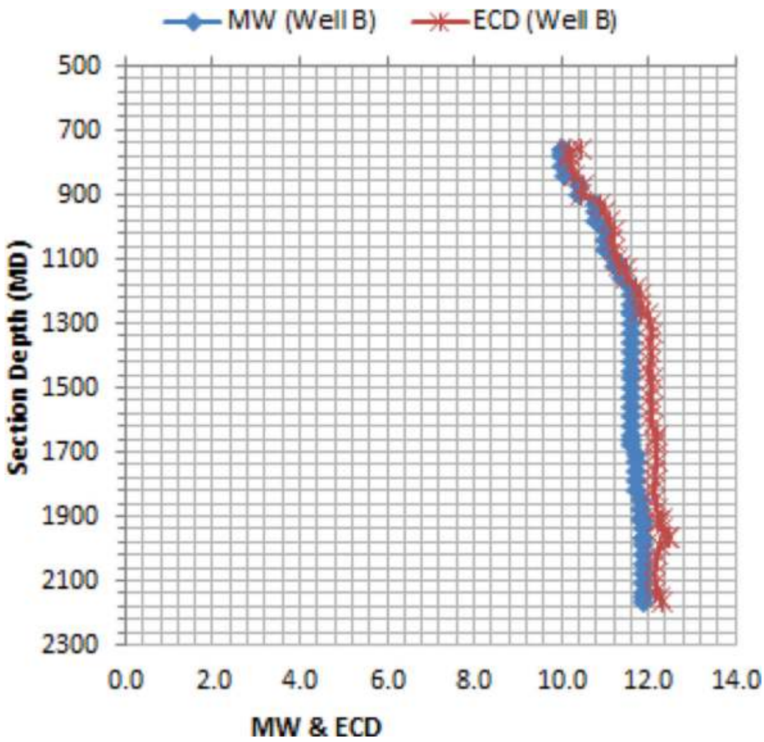

Figure 10. Section depth vs. MW & ECD (old design).

gravity effect at deviated hole, heavier cuttings and mud along the lower side of the hole moved at lower rate than the clean mud on the upper side. Peak performance of solid separation equipment is essentially important to ensure the LGS, YP and PV are maintained within the acceptable envelope. These parameters provide good cutting transport and no excessive pumping pressure required to break the gel. The average ECD additive factor was 0.3 ppg that is equivalent to 2.9% increment from original MW during mud flow in dynamic condition.

5.5. Performance of solid control system on rate penetration

The ROP trend of old design was seen concentrated at range between 40 and 60 m/h. ROP was controlled in such manner due to ECD surge. Mud properties specification was not within the recommended limit, and it significantly influenced the ROP consistency. Continuous of solid built up in the mud system altered the mud properties which eventually causing in poor drilling performance. Drilled solids circulated up the annulus increased the pressure differential and lead to slower drilling. Instantaneous maximum ROP achieved using old design SCE was 62 m/h with 48.78 m/h on average. Drilling the same section for Well B using new design solid control system showed improvement on ROP trend. Maximum instantaneous ROP was registered at 77 m/h with 61 m/h in average. Efficient solid removal using new design improved the ROP performance by 25% (**Figure 11**).

5.6. Performance of old design of solid control system on hooks load

Drag force is known as difference between free rotating weight and the force required to move the string up and down in the hole. Pick-up (P/U) drag force usually higher than the free rotating weight while slack-off (S/O) force is lower than the free rotating weight. String weight or

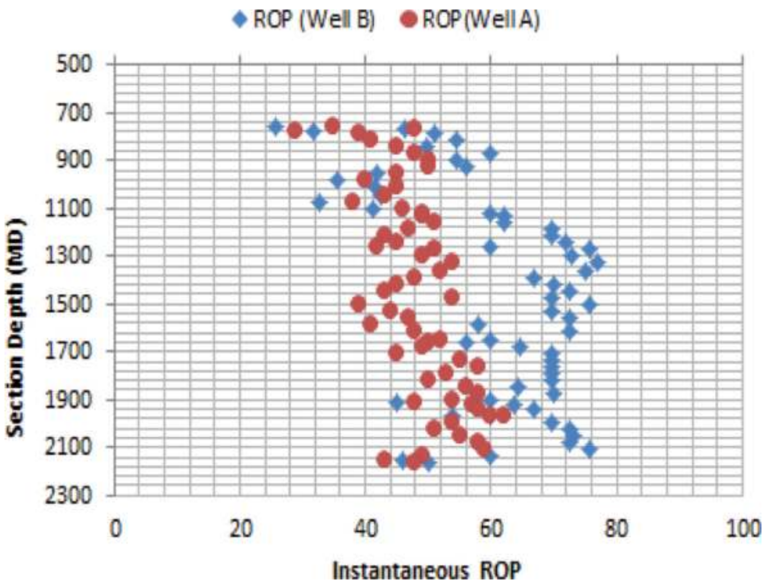

Figure 11. Section depth vs. ROP.

free rotating weight on this analysis represented by the green curve. Data were taken while the string was off bottom to compare0 the modeling string weight and actual weight. As designed expectation, the plots should tabulate across and along the modeling string weight at any well depth. Drilling the Well A using old design system, more solids were not properly separated from the mud. This increased the mud viscosity and altered the mud properties. In this chart, the hook load readings when P/U the drill string was tabulated between 0.2 and 0.3 FF as shown in **Figure 12**. Occasionally, the plot exceeded that friction factor line as observed at depth around 1550 and 1900 m MDRT. Pile up of drilled cuttings bed and accumulation increased the drill string contact with the wellbore. Mud circulation for hole cleaning was performed to remove the cuttings from the well. S/O weight of the drill string in this chart was observed between 0.2 and 0.3 FF. The plots were occasionally tabulated exceeding the 0.3 FF. This condition indicated that more drilled cutting was still sticking and restricting

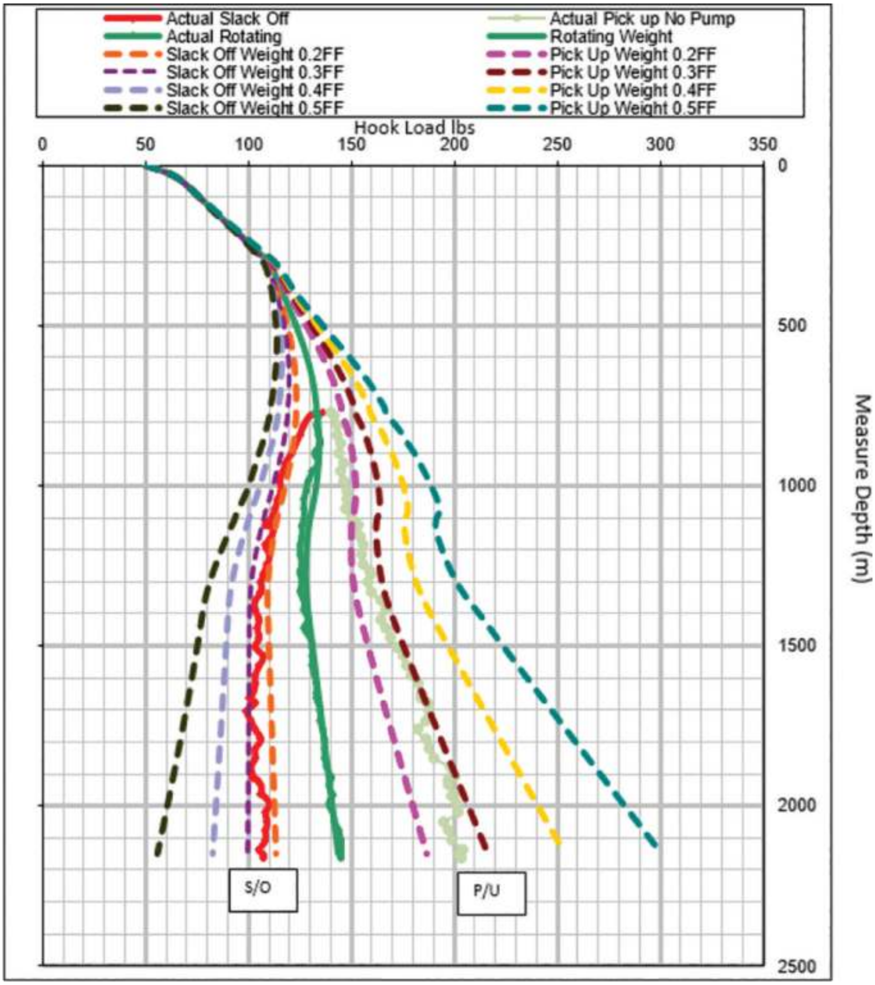

Figure 12. Hook load effect vs. depth (old design).

the drill string to move down. It required extra cumulative axial force to free the drill string. Lower S/O FF represents high hook load and vice versa. Failure to effectively transport the cuttings to surface result in a number of drilling problems including: excessive overpull on trips, high rotary torque, stuck pipe, hole-pack off, excessive ECDs and cutting accumulation.

5.7. Performance of new design of solid control system on hook load

The new design system effectively separated the drilled cuttings from the mud and allowed each of the equipment to work at peak performance. Mud properties were within the design specification with no severe solid contamination result improvement on PV, YP and LGS reading.

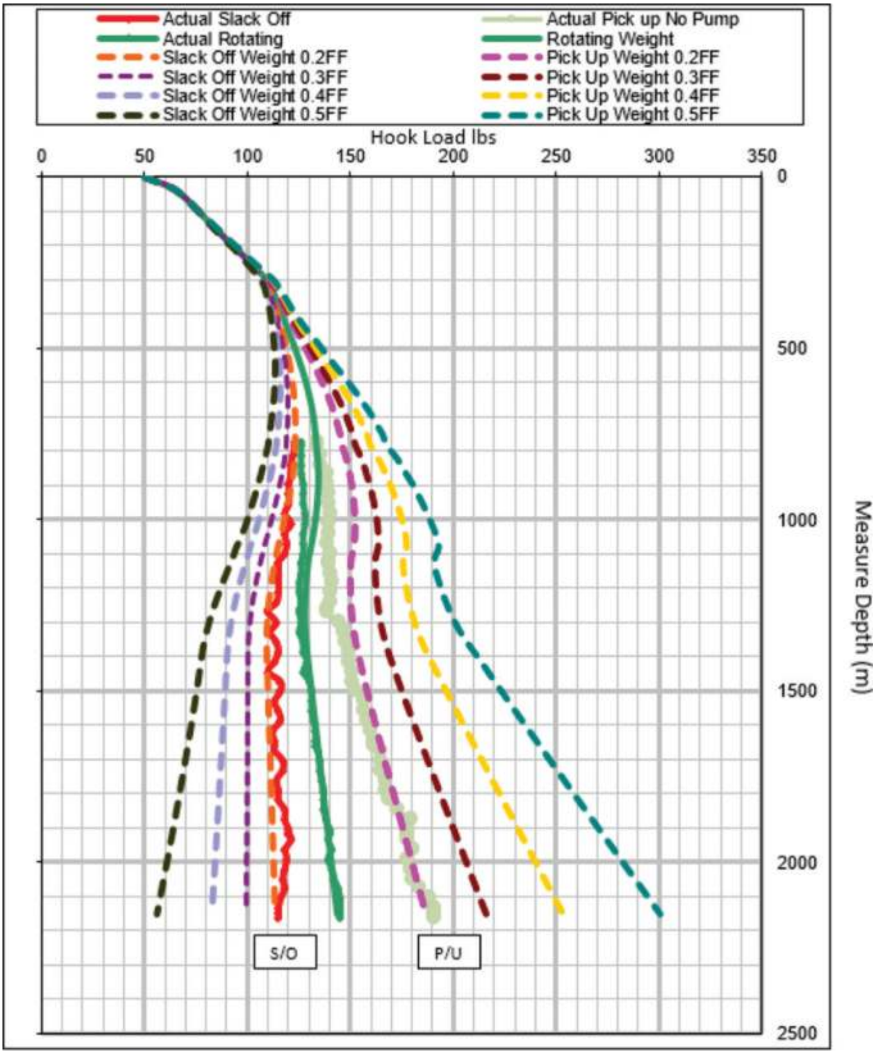

Figure 13. Hook load effect vs. depth (new design).

The hook load chart indicated that P/U weight was concentrated at 0.2 FF but occasionally exceeded 0.2 FF. Good control of mud return and consistent distribution flow to solid control system allowed effective solid particles separation. S/O weight of the drill string was observed tabulated below the 0.2 FF but occasionally exceeded 0.2 FF. This indication represented that the hole was not piled up with drilled cuttings. Less axial force was required to move the drill string as there was no severe contact of drilled cuttings with the string (**Figure 13**).

6. Conclusion

A new solid control system was developed with detailed studies on the effect of drilled solids to mud properties and drilling performance. The following conclusion can be drawn from this investigation and as an improvement of the rig solid control system.

1. The installation of mud distributor tank enhance the flow stability and regulate the circulation of mud from the well.
2. Comparing the old design while drilling 12.25-inch hole section, the new design improved the mud properties of PV by 14%, YP by 17% and LGS by 25%.
3. New design improved the ROP by 20% while drilling the 12.25-inch hole section.
4. New design improved average ECD margin by reducing additional pressure exerted using original mud from 4.9 to 2.9% at 12.25 inch. High ECD margin is not recommended because it can break the weak formation.
5. Drill string drag effect to the hook load for P/U and S/O at Old design were tabulated between 0.2 and 0.3 FF while drilling the section with New design were mostly tabulated at 0.2 FF and less.

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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
CCC	cutting carrying capacity
P/U	pick up
S/O	slack off
FF	friction factor

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