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Novel Low Expense Cement Slurry Design Based on Enhanced Cenosphere Properties

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Abstract. In the mature stage of production cycle, depleted zone gives a big challenge in drilling operation especially in cementing part. Some of major risk in the well construction are well control and well integrity, thus loss circulation during cement job and the loss of zonal isolation afterwards is not negotiable. During the peak of oil price, new technology was introduced to have lightweight cement slurry based with the engineered Hollow Glass Sphere (HGS) material. Current fragile of oil price has pushed the needs of low expenses, which part of the major contribution is coming from the well construction. A fit to purpose designed cement slurry with a reasonable cost will be needed to have an economical well to be drilled.

HGS material is one of the main contribution in the high cost of well construction, despite the superb feature in having a stable properties of slurry in high pressure environment. Researches has been done by well construction team to reformulate the cement design, in order to have a fit design cement slurry with the unique necessity of Mahakam operation. The main objective is to substitute the HGS material with a conventional cenosphere. However, as the cenosphere is a by-product of coal combustion at power plant, it has wide variation in density and tends to break up in relatively low pressure. Consequently, the risk of loss circulation during cement job will be severe. A novel study has answered the challenge by applying a reduced cement slurry density at mixing stage of 1.38 SG, in which the Cenosphere will break up during cement placement resulting the cement slurry density when entering annulus is increased to 1.40 SG, hence it will not jeopardize the low fracture gradient of the well as the maximum cement slurry 1.40 SG had shown being tolerable. Additional of other material such as high surface area micro-silica has also helped in lowering the cement slurry density as the second extender. This micro silica is proven to enhance the compressive strength of the cement as well to reduce the waiting on cement time.

From four wells which has been drilled and cemented, the approach had shown the expected result, none of the wells has loss circulation and it is recorded until now the sustain casing pressure is nil. The impact of the new design cement slurry on the well expenses has given a 20% of lower cement cost per cement job. This novel cement slurry design has contributing to a new path on the life of Mahakam operation.

Keyword: Drilling, Well Construction, Cementing, Lightweight Cement

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1 Introduction

Narrow Equivalent Circulating Density (ECD) window during cement job has a vital risk in the outcome of the cement placement. This main risk could cause severe loss circulation which could lead to the presence of Sustain Casing Pressure (SCP). In area with shallow gas hazard, it is important to ensure the the top of cement (TOC) shall be set up to the surface. Thus no room for error in regard to the cement placement in the weak formation.

Several method has been commenced to encounter the risk worldwide, such as follow [1]:

1. Dual Stage Cementing
2. Lead and Tail cement slurry system
3. Lightweight slurry system,

For the past decade, cenosphere material has been a common material used in the cement blend for lightweight cement system in Mahakam area. However, as cenosphere is a byproduct material obtained from the coal burning process in power plant [5], thus the bulk properties vary between the product. And the ability of the material to sustain certain pressure is poor. Resultant from this poor feature is the dynamic change in cement slurry density due to bottom hole pressure (BHP) during cement job~~ is jeopardized~~. For instance, with the design of cement slurry density 1.40 SG, the output of cement slurry downhole could be increased to > 1.40 SG due to some of the cenosphere are breaking down. Leading to the risk of loss circulation and failure in obtaining green cement at surface.

To accommodate this, Mahakam also combined with the dual stage cementing method, which applied the installation of open hole external casing packer (ECP) and Port sub in the casing (DV Port). If the first stage cement pump indicated severe loss circulation, second stage cementing will be performed by inflating the ECP and burst the DV port to allow second stage cement job to cover the section up to surface. This method not only increase the drilling expense, yet potentially could jeopardize the well integrity if the DV is failed to be closed after the 2nd stage cementing.

By 2014, engineered light weight material was introduced used to replace the cenosphere, which could sustain higher certain BHP. The light weight material was engineered Hollow Glass Sphere (HGS). At that time, the available material in the market is HGS 8000, which could sustain up to 8000 psi isostatic pressure. Statistically, the replacement material is successfully reduced the number of cement job loss, and no more second stage cementing is performed onward.

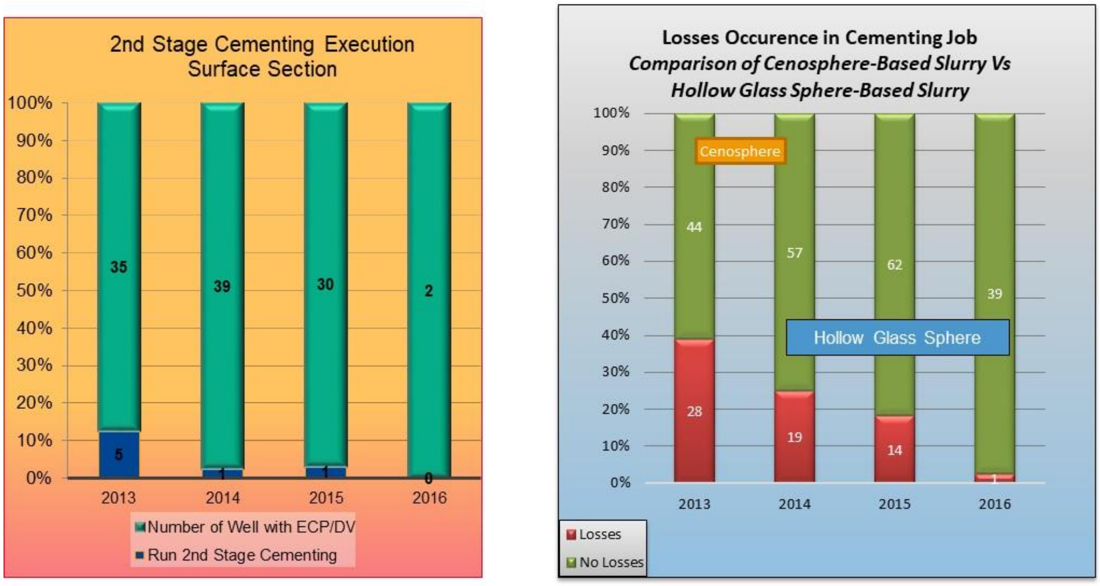


Figure 1.1 Statistic of loss circulation and second stage cement performed in the replacement of cenosphere to HGS

Speaking of the wonderful statistic in the cementing technical improvement, there is a cost which is need to be considered. The evolution of cement slurry improvement also impacting on the evolution of the cost per m^3 volume of the cement slurry itself. The cost of the cement slurry with HGS is increasing by 60% compared to the cenosphere system. The solution to the reducing drilling expense is by having a good enough cement slurry system, while not to jeopardize the well integrity itself.

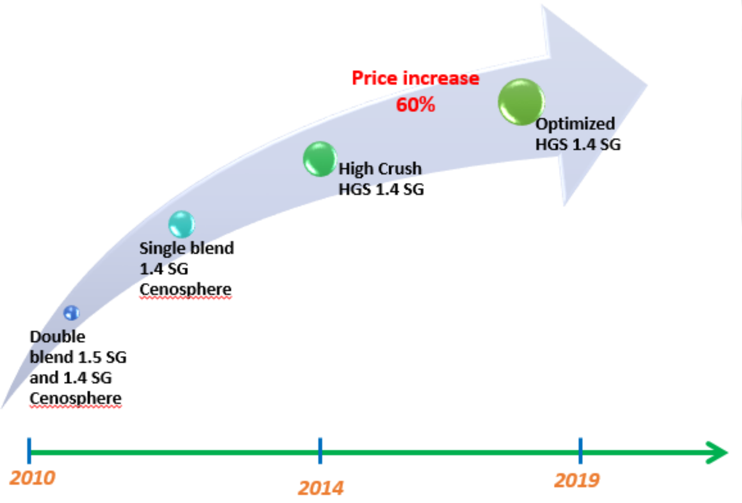


Figure 1.2 Evolution of cement slurry system with the cost increase impact

2 Lab Test Methodology

With the maximum expected BHP 4000 psi during cement job, it is worth to take a look on the degrading of lightweight material specification. Taking a backward step to 2013 by using cenosphere system could reduce the cost. However, there are risks associated as had been experienced before such as: Sustain Casing Pressure, Loss Circulation, dual stage cementing requirement.

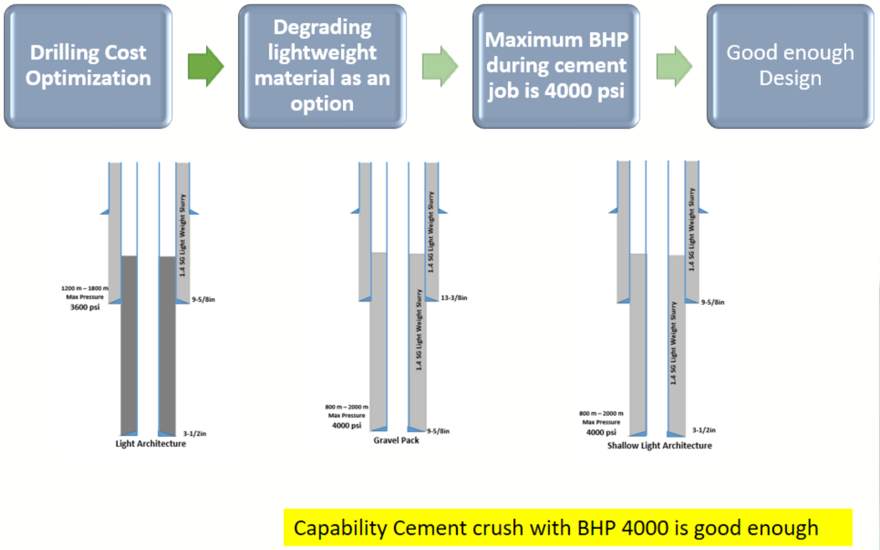


Figure 2.1 Option on re-design the cement slurry system as per BHP requirement

To overcome the challenge in crush with cenosphere, the design of cement slurry density was lowered to 1.38 SG in order to have a natural density increase to 1.40 SG when the slurry exposed to BHP, and resulting the expected density up to the surface. Consequence of this design is the higher requirement of lightweight additive, thus adding the concentration of cenoshphere will merely increasing the risk of material crush downhole. Additional challenge is that increasing extender concentration will eventually reduce the concentration of cement itself, which compromising the compressive strength of the set cement.

Numerous studies were performed to have a robust design with cenosphere material. One of the option is to increase the concentration of microsilica in the system which will work as secondary extender as well as to enhance the compressive strength. And other objective is to have the cement designed as gas tight slurry, considering high risk of shallow gas hazard in the operation.

2.1 Crush Test Deployment

To ensure that the cement slurry density is stable, the density crush test was performed gradually to maximum 3500 psi. The procedure is to mix the cement slurry in 5 minutes at 4000 rpm in waring blender, and then apply static pressure for 5 minutes at desired BHP. In this case, the pressure applied was from 500 psi, 1000 psi, 1500 psi, 2500 psi, and 3500 psi. This test later on to determine whether the final cement slurry density after crush is still suitable in term of ECD during cement job.

From the crush test result, performance of cement system with 27% BWOC cenosphere is much better compared to the 31% BWOC concentration. Maximum of cement slurry density at 3500 psi is 1.42 SG with 31% BWOC cenosphere. To be note that 3500 psi is the maximum BHP could occurs, while average BHP during cement job is merely 2500 psi. From ECD simulation for cementing job, 1.41 SG cement crushed density is acceptable.

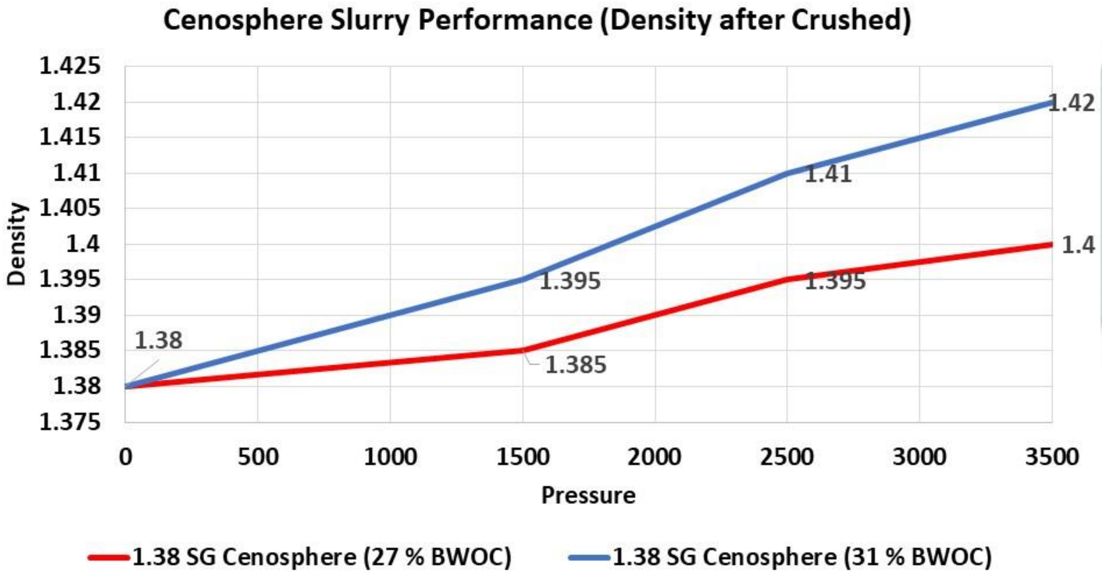


Figure 2.2 Cenosphere density crush test

2.2 Floating test after crush test

In the event that the cenosphere crushed by high pressure, the degraded cenosphere material will tend to float. The segregation event could cause in destabilized of the cement slurry which could lead to cement settling and reduced in top of cement in the annulus. As addition to the API settling test, floating test is performed after exposing the slurry to BHP 3500 psi and 5000 psi, and then observed for two hours if segregation is happening in the graduated cylinder.

2.3 Anti-gas migration test

Mentioned earlier that one of the main risk in the operation is shallow gas hazard, thus special test to ensure that the cement is gas tight slurry is vital. Refer to the API RP 65-1 [3], to comply with the gas-tight slurry requirement, the cement slurry has to have fluid loss below 50 ml/30 min, no free fluid in static condition, and also the Critical Gel Strength Period (CGSP) is below 45 minutes. The fluid loss and free fluid test is tested as per API RP 10B-2.

As well as to see the physical properties of the hard set cement, to avoid any gas migration after the cement is solid set due to traction failure, Brazilian test was performed to measure the tensile strength of the cement set [4]. Fiber based additive was added to the system to enhance the tensile strength properties, while also help in mitigate losses during cementing. Other uncommon test which is a non-API test is the Fluid Migration Analysis. This test measures the volume of fluid that travel through the cement slurry.

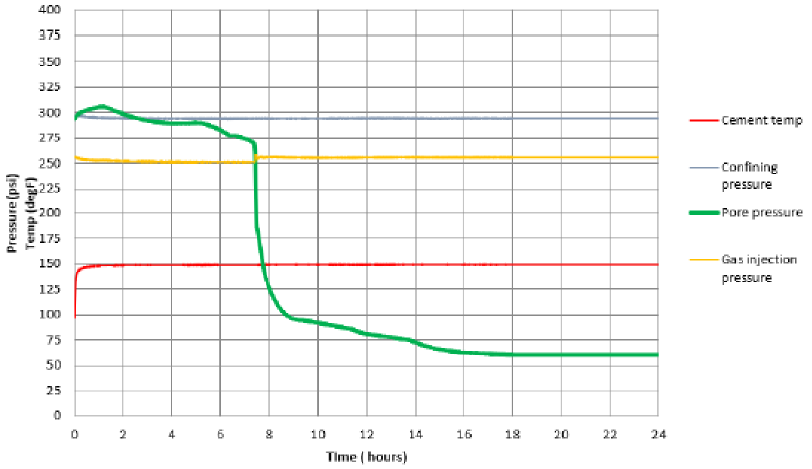


Figure 2.3 Fluid Migration Analysis Pass result

2.4 Other basic API cement Test

As part of the cement slurry property design, other basic cement test refers to the API RP 10B-2 [2]. As general, the slurry tests performed as follow:

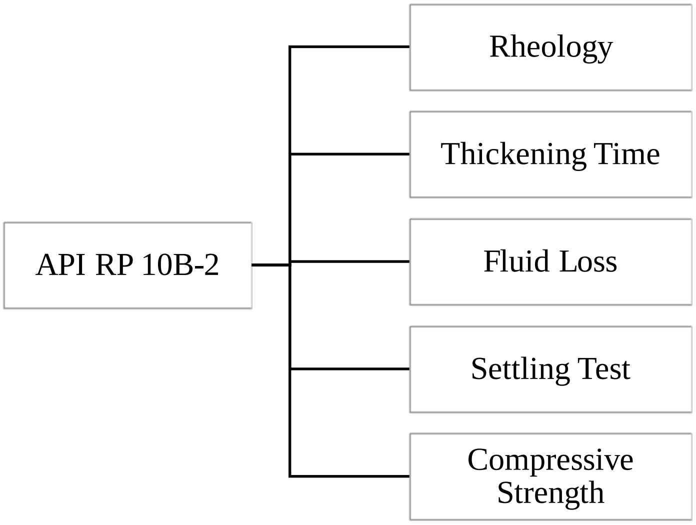


Figure 2.3 Cement lab test based on API Recommended Practice 10B-2

From the several lab test performed in the study, an effective design was determined by having 31% BWOC of cenosphere (dry-blended), and enhanced with 3 gps of microsilica in mixing fluid. Other chemicals were also added to the system such as antifoam, dispersant, fluid loss control, and accelerator/retarder to obtained other properties as per designed.

Table 2.1 Lab test summary

Parameter	**Cenosphere Concentration**		
	27% BWOC (A)	**31% BWOC (B)**	**31% BWOC (C)**
Cenosphere Density (SG)	0.83	0.83	0.83
BHP (psi)	3500	3500	3500
SVF (%)	37.6	40.62	40.46
Density before crush (SG)	1.38	1.38	1.38
Density at BHP	1.4	1.42	1.42
Microsilica (gps)	2.3	2.3	3
Pv after mixing (cP)	28.3	28.7	31.3
Ty after mixing (lbf/100 ft^2)	8.91	12.06	19
Pv after conditioning (cP)	33.9	33.4	39.5
Ty after conditioning (lbf/100 ft^2)	15.32	18.74	26.3
Set hard (hrs)	20	20	16
UCA (psi)	**1452 psi in 61 hours**	**Under Spec**	**2241 psi in 24 hours**

3 Field Implementation

The novel design of cenosphere cement slurry designed was implemented in 4 wells in swamp area of Mahakam field. The cement slurry system was pumped in the surface casing section with typical minimum fracture gradient of 1.42 SG. The cement slurry was mixed on fly with 1.38 SG surface density.

Thedensity of cement slurry observed in return line was closely monitored until the top wiper plug is bumped. Rheology measurement was also performed to ensure that the cement slurry pumped downhole is as per lab report. In addition to the return tank monitoring, cement job pressure tendency was also checked to determine whether loss circulation is occurred or not. Refer to **Table 3.1**, the rheology laboratory test was performed by using Rotational viscometer model Chandler 3500, while on rig the actual rheology was measured by Fann35 viscometer utilizing rig mud laboratory. Thus the comparison is looking at the reading by each rotational speed to see the consistency.

Table 3.1 Rheology measurement on rig

	AA		*BB*		*CC*		*DD*	
Rheology AM	Lab test	Actual	Lab test	Actual	Lab test	Actual	Lab test	Actual
300 rpm	47	55	55	46	65	50	74	92
200 rpm	37	48	40	38	55	40	58	75
100 rpm	28	38	30	30	39	33	43	56
6 rpm	15	28	18	19	26	25	28	35

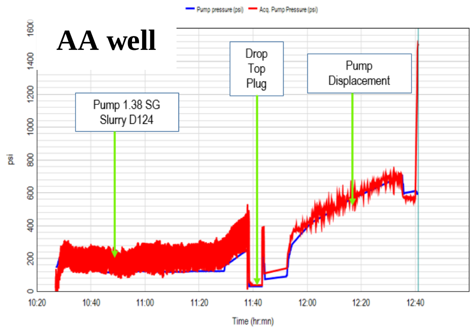
3 rpm	14	25	16	16	24	24	26	33

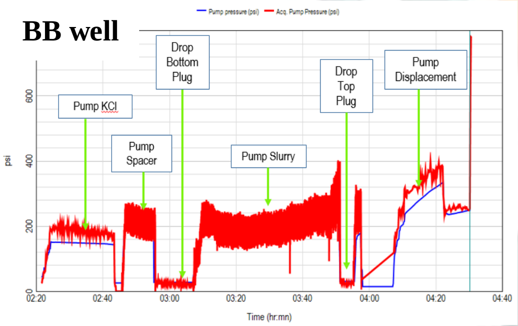
Result from all the cement jobs was no losses, and obtained 1.40 SG cement slurry at the surface as expected. The estimated hole cavity or washout is calculated based on the cement volume that return on surface versus the pumped cement slurry excess. It is a best practice in company to have a statistic of calculated annular cavity to determine the annular excess volume in the upcoming job design, considering no caliper was run in the surface section. This method is to ensure the volume pumped downhole is suitable with the hole volume requirement.

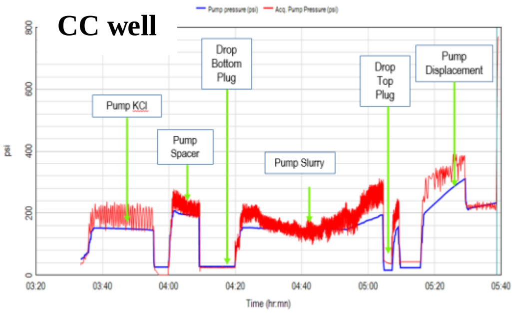
Table 3.2 Summary of the cement job performed in 4 wells

No	Well Name	Job Type	Final Displacement Press (planned) psi	Final Displacement Press (actual) psi	Estimate Annular Cavity	Designed top of cement (TOC)	Volume of 1.4 SG Cement return to surface (m^3)
1	AA	9-5/8" Surface	541	564	31%	Surface	15.43
2	BB	9-5/8" Surface	252	230	62%	Surface	2.7
3	CC	9-5/8" Surface	248	257	58%	Surface	3.32
4	DD	9-5/8" Surface	780	812	70%	Surface	2.0

From the post-job cement playback, by comparing the simulated pressure to the actual recorded pressure, it is shown that the simulated cement job pressure is match with the actual pressure. It concludes that all parameter such as density, rheology and annular cavity is as per design.







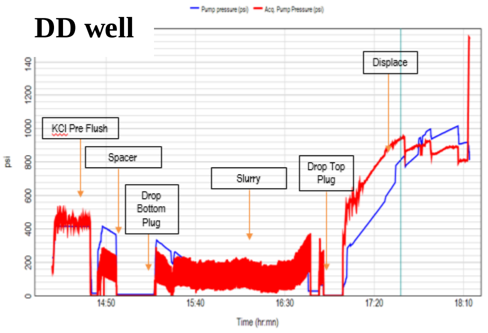


Figure 3.1 Post cement job playback

Typical cement job performed in surface casing section when no issue during the cement job, no CBL evaluation was performed. However, early compressive strength is required to support next section drilling. Thus from the field evaluation, actual sample set hard was observed. The requirement to drill shoetrack to continue drilling of the next section is 500 psi of compressive strength and require to have surface sample cement in hard set condition. It was observed that the set hard was obtained in 10 to 12 hours, while from the lab test 500 psi is on range of 9 to 10 hours.

Other critical parameter observed is the annulus pressure record. From all the cement job, no SCP was observed until to date that the well is produced.

4 Conclusion

The Cenosphere material could be used as a lightweight material in shallow well with BHP below 4000 psi. To compensate the density increment at bottom hole due to crush materiala lower density at mixing stage at surface (1.38 SG)is a possible solution. For compensating the slurry stability and compressive strength by adding microsilica is proven to be work with 3 gps concentration.

This novel slurry design using cenosphere material is proven to be an innovative solution for the Mahakam operation, especially in the shallow wells where the BHP would not reach more than 4000 psi during the cement job. Objective of having the fit for purpose cement slurry design has been obtained.

From this project, cost saving of each cement job is reached in range of 20% to 23% compared with cement slurry using HGS material Which affect to the reduce of drilling expense significantly for 2 sections cement job per well. This innovation lead to the new path of Mahakam life to drill shallow wells with lower cementing job expenditure.

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