SOME SOLUTIONS TO IMPROVE THE CEMENT BOND QUALITY FOR CARBONATE ZONES IN BLOCK 05-1A, OFFSHORE VIETNAM

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Summary

Cement work at Dai Hung wells has faced many problems with carbonate zones. Improving the cement bond across carbonate reservoirs to avoid remedial cement works and production problems is very critical for future drilling in Dai Hung field. The article presents the results of substantial study to find out the most suitable type of cement, formula, properties and cementing tools for cementing carbonate zone sections.

Key words: *Cement bond, carbonate zone, Dai Hung well, cementing solution.*

1. Introduction

PVEP POC has been drilling many exploration, appraisal and production wells (22 exploration/appraisal wells and 19 production wells) in Block 05-1a (Dai Hung field), which is located in the north-western part of Nam Con Son basin. For cementing service of these wells, PVEP POC has been using different cementing companies and cement slurry types. However, cement bonds across carbonate zones were not qualified in terms of zone isolation that resulted in spending rig time on remedial cement squeeze works and causing a problem with well production later on.

In the past, the incidents of gas blow when entering the DH-8X and the well control problem with the DH-13P drilling operation were all related to the poor cement bond across carbonate section. Specially, the recent incident of gas leaking on the 18¾ inch subsea wellhead of DHN-1X had a root cause of poor cement quality behind 9⅝ inch casing. Therefore, it is essential to study and find suitable kinds of cement for the carbonate zones.

2. Cement bond issues in Block 05-1a

From the drilling database of Dai Hung wells drilled between 2013 and 2015, the high mud loss rates were encountered while drilling across the carbonate reservoir zones. These loss rates of drilling fluid through the fractured limestone (carbonate reservoirs) cannot be completely treated by conventional methods (pumping $CaCO_3$ LCM) [1]. Besides that, no cement or permanent lost circulation materials were allowed to pump as they could permanently damage these potential reservoirs. As the wells were still in the partial loss condition, the conventional cement slurries were lost into fractured zones during cementing 9⅝ inch casings. Subsequently, this resulted in poor cement quality through the limestone and the top of cement dropped lower than the plan [1].

With poor cement quality behind the casings and the characteristics of interbedded layers containing water, oil and gas, it was an issue for zone isolation when the well was completed and put into production. The water or gas would leak into the oil zones and caused the reduction of oil production. Therefore, technically, remedial cement squeeze works were required to improve the zone isolation prior to completing the wells. Time for each cement squeeze work was from 3 to 7 days, thus it increased the well costs and could pose a risk of reservoir damage during this remedial work. In 2014 and early 2015, a total of 17 remedial cement squeeze works were conducted due to poor quality cement across carbonate zones for wells DH-21XP, 22XP, 18P, 23XP, 10PST and DHN-1X [1].

3. Proposed cement bond improvement study

3.1. Laboratory testing results of new cement slurry type for carbonate formations

Many laboratory tests were performed using special cement materials to design a suitable lightweight cement slurry for cementing the 9⅝ inch casing on well DHN-1X. Laboratory testing results for new cement slurry type are shown in the following tables:

Table 1. *Well information*

Casing/Liner size	9⅝ inch
Hole size	12¼ inch
Pressure	440bar/6,377psi
Depth MD	3,435m/11,270ft
Depth TVD	3,109m/10,201ft
Bottom hole static temperature (BHST)	130°C/266°F
Bottom hole circulating temperature (BHCT)	96°C/205°F

***Table 2.** Cement information - Lead design*

Concentration	Unit of measure	Cement/Additive	Sample date (dd.mm.yy)	Lot No.	Cement properties	
100.00	% BWOC	Holcim class G			Slurry density (lbm/gal)	11.5
10.95	gal/sack	Sea water			Slurry yield (ft^3/sack)	3.1535
15.00	% BWOC	HGS 8000X (PB)			Water requirement (gal/sack)	10.9547
2.50	gps	Silicalite liquid	11.11.14		Total mix fluid (gal/sack)	14.39
0.05	gps	D-Air 3000L	14.11.14			
0.50	gps	HALAD-344EXP	13.09.14	309471		
0.14	gps	SCR-100L	20.11.14	310044	Water source	Sea water
0.30	gps	CFR-3L	11.11.14		Water chloride	N/A
35.00	% BWOC	SSA-1 (silica flour) - PB				

***Table 3.** Pilot test results [1, 2]*

<table>
<tr><th colspan="12">Mixability (0 - 5) - 0 is not mixable</th></tr>
<tr><th colspan="6">Mixability rating (0 - 5)</th><th colspan="6">Average round per minute mixing under load (~12,000)</th></tr>
<tr><td colspan="6">4</td><td colspan="6">12,000</td></tr>
<tr><th colspan="12">API rheology</th></tr>
<tr><td>Temperature (°F)</td><td>600</td><td>300</td><td>200</td><td>100</td><td>60</td><td>30</td><td>6</td><td>3</td><td>Conditioning time (min)</td><td colspan="2">Plastic viscosity/Yield point</td></tr>
<tr><td>190</td><td>270</td><td>162</td><td>121</td><td>74</td><td>56</td><td>37</td><td>15</td><td>11</td><td>30</td><td colspan="2">148/19</td></tr>
<tr><th colspan="12">Thickening time</th></tr>
<tr><td>Temperature (°F)</td><td>Pressure (psi)</td><td>Reached in (min)</td><td>Start BC</td><td>30 Bc (hh:mm)</td><td>50 Bc (hh:mm)</td><td>70 Bc (hh:mm)</td><td colspan="5">100 Bc (hh:mm)</td></tr>
<tr><td>205</td><td>6,377</td><td>145</td><td>10</td><td>05:00</td><td>05:14</td><td>05:20</td><td colspan="5">05:25</td></tr>
<tr><th colspan="12">UCA compresive strength (CS)</th></tr>
<tr><td>End temperature (°F)</td><td>Pressure (psi)</td><td>50psi (hh:mm)</td><td>500psi (hh:mm)</td><td>12 hours CS (psi)</td><td colspan="7">24 hours CS (psi)</td></tr>
<tr><td>266</td><td>3,000</td><td>03:35</td><td>05:05</td><td>1,074.38</td><td colspan="7">1,231.29</td></tr>
<tr><th colspan="12">API fluid loss</th></tr>
<tr><td>Test temperature (°F)</td><td>Test pressure (psi)</td><td>Test time (min)</td><td>API fluid loss (cc/30min)</td><td>Measure volumne</td><td colspan="7">Conditioning time (min)</td></tr>
<tr><td>190</td><td>1,000</td><td>30</td><td>30</td><td>15</td><td colspan="7">30</td></tr>
<tr><th colspan="12">Static gel strength</th></tr>
<tr><td>Temperature (°F)</td><td>Time CSGS (hh:mm)</td><td>Time 100 lb/100ft^2 (hh:mm)</td><td>Time 200 lb/100ft^2 (hh:mm)</td><td>Time 300 lb/100ft^2 (hh:mm)</td><td>Time 400 lb/100ft^2 (hh:mm)</td><td colspan="6">Time 500 lb/100ft^2 (hh:mm)</td></tr>
<tr><td>266</td><td>00:37</td><td>04:14</td><td>04:31</td><td>04:39</td><td>04:49</td><td colspan="6">04:51</td></tr>
<tr><th colspan="12">Crush compressive strength</th></tr>
<tr><td>Conditioning time (min)</td><td>Curing temperature (°F)</td><td>Curing pressure (psi)</td><td>Time 1 (hours)</td><td>Strength 1</td><td>Time 2 (hours)</td><td>Strength 2</td><td colspan="5">Foam Q (%)</td></tr>
<tr><td>48</td><td>266</td><td>3,000</td><td>48</td><td>1,400</td><td>48</td><td>1,295</td><td colspan="5">0</td></tr>
</table>

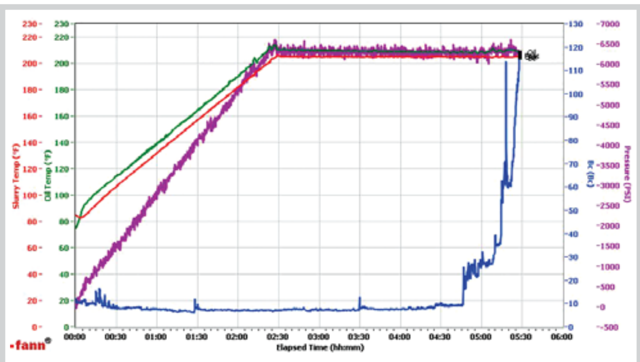


***Figure 1.** Transition time chart result [2]*

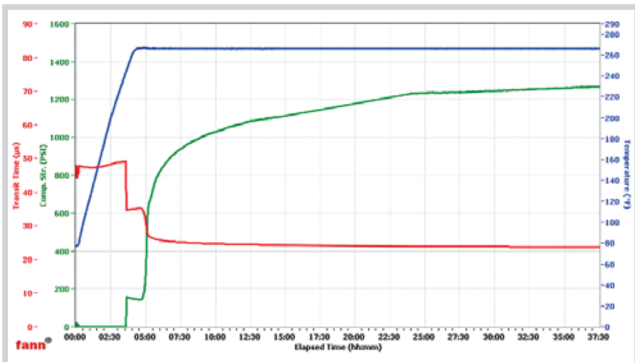


***Figure 2.** Ultrasonic cement analyser chart result [2]*

From the above laboratory testing results, it was obvious that the new cement slurry (lightweight - tuned light) can be designed at low density (11.5ppg for this case) but still provide good compressive strength of ~1,250psi at 24 hours to ensure a good zone isolation.

3.2. Laboratory testing results for the new cement spacer to be applied for carbonate formations

Figure 5a presents the hydraulic bond strength, shear bond strength and compressive strength for the dry

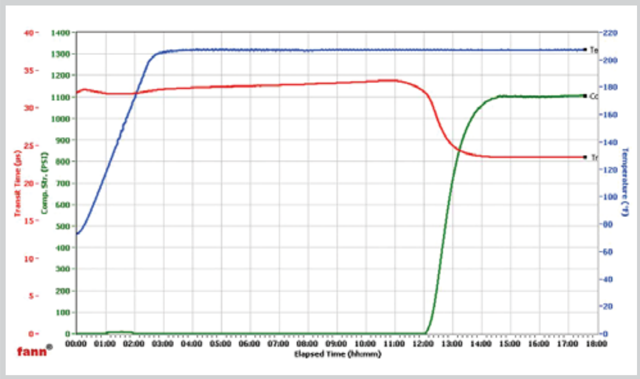


Figure 3. UCA result at 13⅜ inch shoe [2]

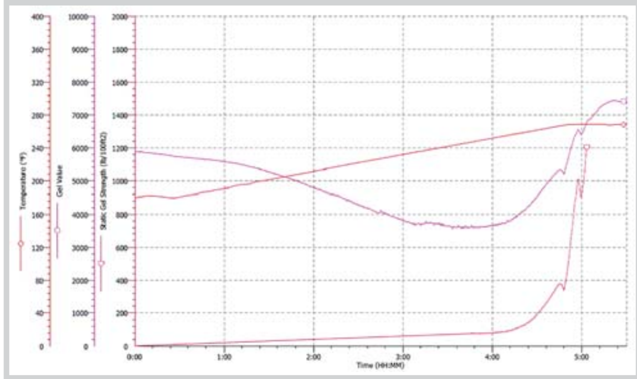
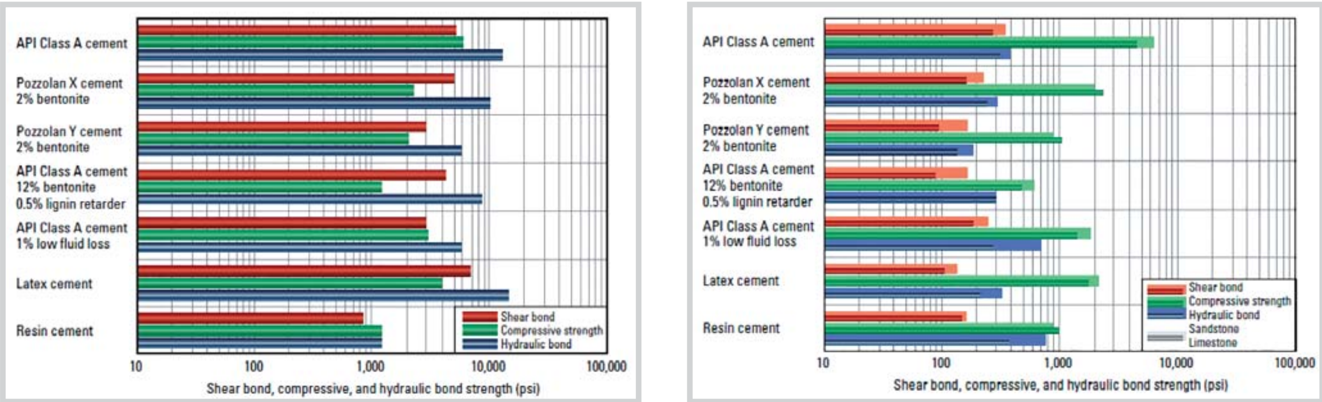


Figure 4. Static transition time result [2]



(a) (b)

Figure 5. Bond strength of dry core by cementing with different kinds of slurries (a); Bonding strength of a core after treatment with water-based drilling mud and then placed against different slurries after the removal of mud cake (b) [3]

limestone. Seven different kinds of cements were placed against the dry limestone. According to that, bonding strengths are maximum in case of using API class A cement and Latex cement.

In the next case, cores were firstly treated with water-based drilling mud. Then the cement was squeezed against the cores at a pressure of 100psi. The mud cake was removed in this case. A significant decrease in shear bond strength can be observed in Figure 5b as compared to the dry cores.

Based on the lost circulation condition of 12¼ inch hole section of Dai Hung wells, it is very important to have a new cement spacer which can provide both mud cake removal and loss curing effectiveness.

The SealBond cement spacer is a new cement spacer which can aid in reducing lost circulation problems in fragile, unconsolidated and fractured carbonate formations. It will form a non-evasive seal to minimise filtrate invasion into the formations to "only inches" and work with differential pressure - high regained permeability. Spacer mixture viscosity can be adjusted to help cleaning the mud from the hole and increasing sealing properties. SealBond Plus lost circulation material can be added into this spacer in cases of severe to total loss circulation. For each cement job, a volume of 50 - 100bbl of this spacer can be pumped ahead of cement slurry to help improve the cement bond quality.

3.3. Proposing the best cement system

3.3.1. Tuned light cement system - lightweight cement

High-strength performance from a lightweight slurry. Tuned light cements rely on microspheres to produce lightweight slurries with excellent strength characteristics. Tuned light cement can yield strengths equal to or better than cements of equal density made by any other lightweight technique. Advantages of tuned light cement include low density, thixotropic, faster transition times and compressive strength [4].

3.3.2. Tuned light cement system - Technical information

• Tuned light low-density slurry system:

Depending on the required slurry density, the tuned light system base blend may include the following materials:

- Various types of cement (API Class A, C, G, and H).

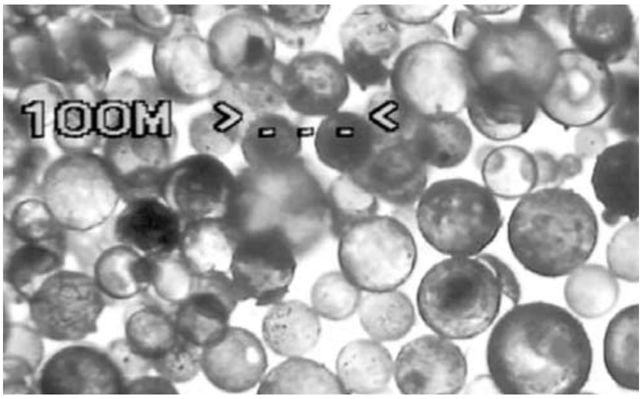


Figure 6. *Metasphere 50 microspheres at 0psi [2]*

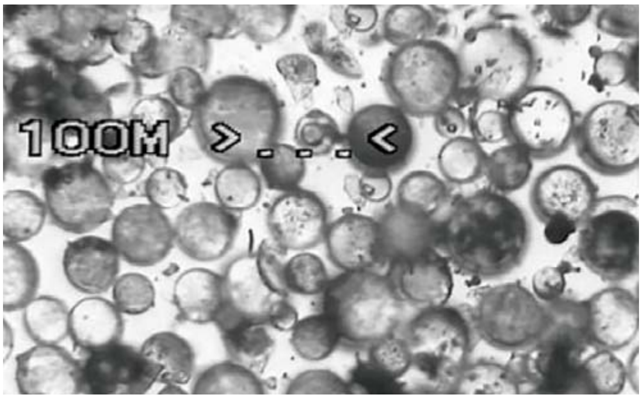
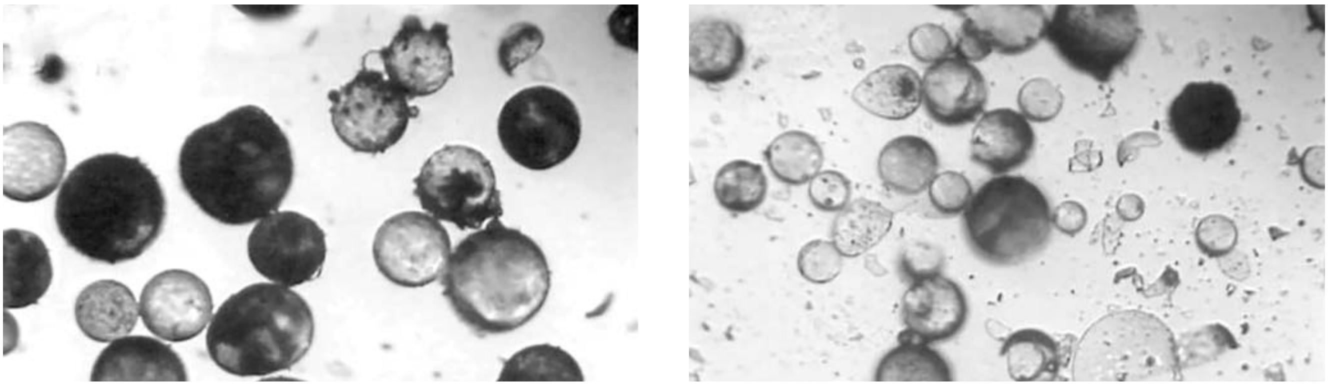
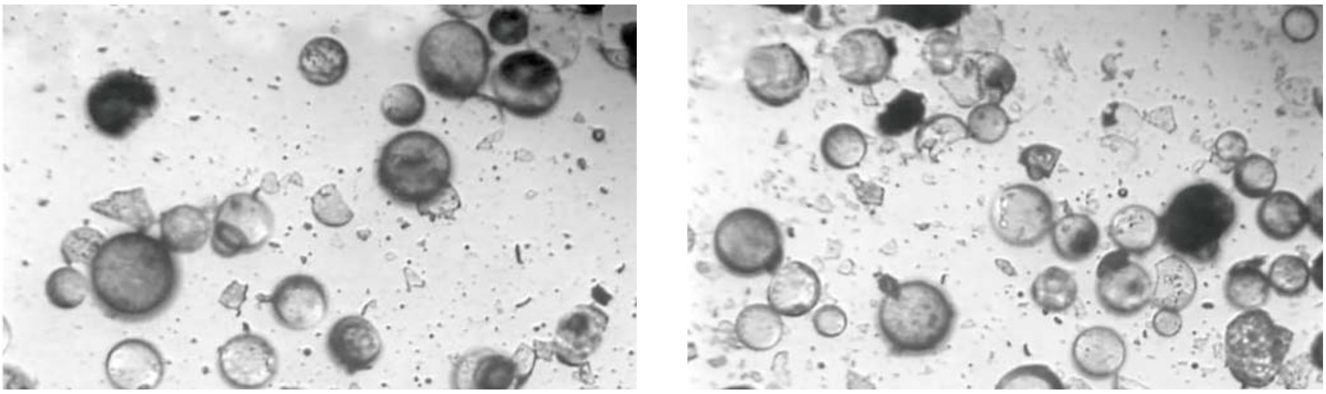


Figure 7. *Metasphere 100 microspheres at 0psi [2]*



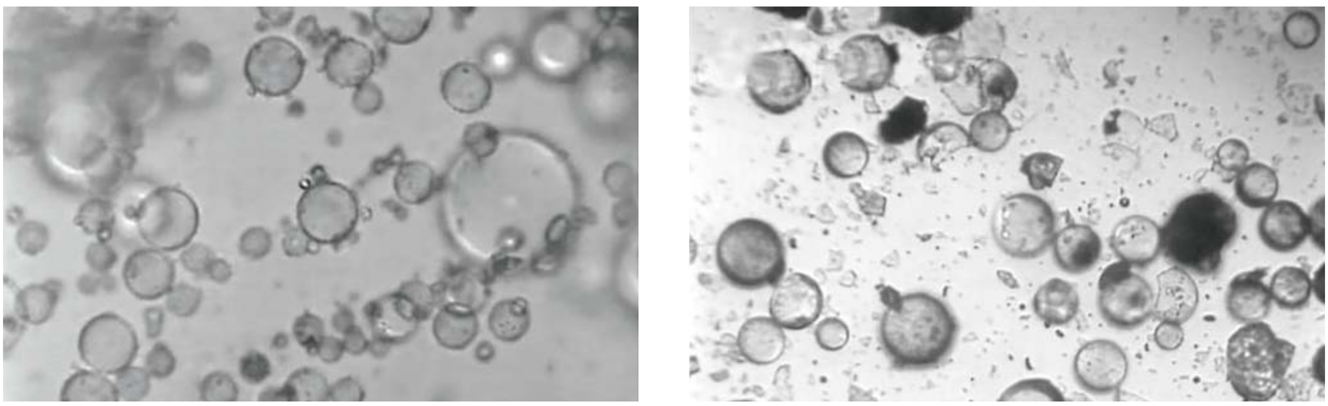
(a) *(b)*

Figure 8. *Metasphere 50 microspheres: (a) 0psi, (b) 4,000psi [2]*



(a) *(b)*

Figure 9. *Metasphere 100 microspheres: (a) 0psi, (b) 4,000psi [2]*



(a) *(b)*

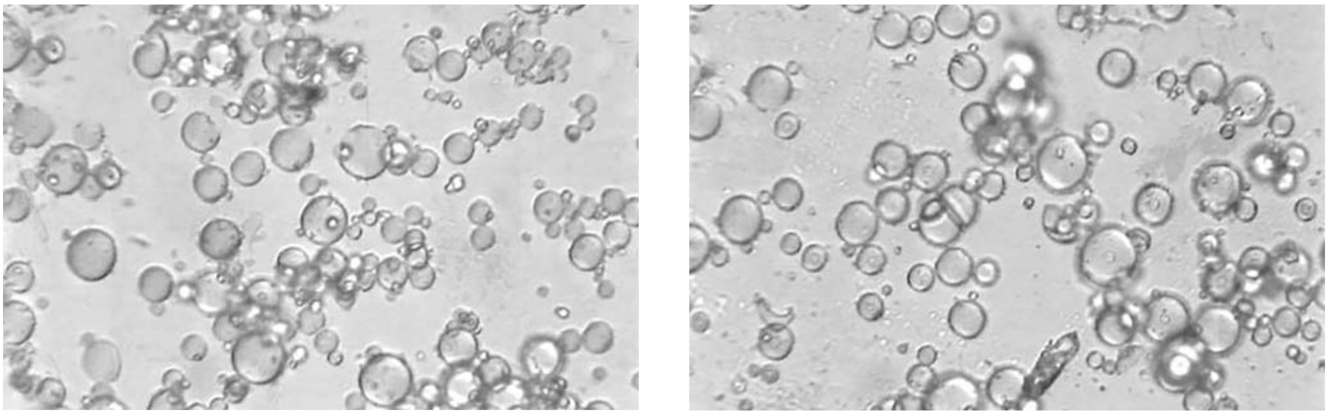
Figure 10. *3M glass bubbles S38HS: (a) 0psi, (b) 4,000psi [2]*

- Micro matrix cement, FineCem cement blend, or Enhancer 923™ additive.
- Silicalite additive.
- Hollow microspheres.
  + Spherelite additive (Metasphere 50, Metasphere 100).
  + 3M Scotchlite glass bubbles.
- Universal cement additive material.

The tuned light system can be stabilised for high-temperature applications by incorporating SSA-1, SSA-2, or MicroSand cement additives. The system is compatible with all cement additives, such as retarders, fluid-loss additives, free-water materials, and suspension additives. The tuned light system can be formulated for use in any application requiring a low-density slurry, such as cementing offshore conductor casing, cementing casing in weak or fractured carbonate formations, cementing in geothermal wells, and cementing in fragile permafrost formations.

- 3M Scotchlite glass bubbles (Synthetic hollow spheres) are shown in Figure 10 and 11.
- Tuned night system designs:

The basic tuned light system has been developed and composed of different additives and/or microspheres. Each design was tested to meet common customer criteria for low-density cements (Table 4).



(a) (b)

Figure 11. 3M glass bubbles S60 (a) 0psi, (b) 4,000psi [2]

Table 4. Physical properties of tuned light system

Slurry No.	Surface density (lbm/gal)	Density at 4,000psi (lbm/gal)	Yield at 4,000psi (ft^3/sk)	Water (gal/sk)
1	6	6	11.31	30.38
1R	6	6	-	-
1A1	6	6	7.51	21.01
1A2	6	6	7.51	21.01
1B	6.45	6.5	9.31	27.77
2	7	7	8.37	24.93
2A	7	7	14.35	45.15
2B	7	7	14.4	45.15
2C	7.5	7.5	5.73	16.93
2D	7.5	7.5	18.06	6.16
3A	7.95	8	7.41	20.32
3B	8.02	8	7.83	22.57
3C	7.93	8	7.67	21.44
4A	9	9	4.67	13.83
4B	9	9	5.05	15.59
4C	9	9	4.86	15.16
5A	10	10	3.46	11.06
5B	10	10	3.71	12.16
5C	10	10	3.39	9.26
6	9.3	11	3.36	10.89
7	11.15	12	2.53	9.57
8	12.69	13	2.01	7.43

Table 5. *Tuned light system blend design*

Slurry No.	PZ-55 cement (lbm)	Micro matrix cement (%)	Silicalite additive (%)	KCl (%)	CFR-3 dispersant (%)	Halad-344 fluid- loss material (%)	Halad-413 fluid- loss material (%)	UCA (%)	Diacel LWL retarder 90°F CT 120°F ST (%)	HR-5 retarder ISOf'F CT 200°F ST (%)	D-Air 30 OOL Defoamer (gal/sk)	Spherelite additive/ metasphere 50 microspheres (%)	3M scotchlite glass bubbles		
													S60 (%)	S38S (%)	K46 (%)
1	94	-	-	-	0.43	0.43	0.85	-	-	-	0.05	-	-	170.9	—
1R"	-	-	10	-	-	-	-	-	-	-	-	-	40	-	—
1A1	-	-	-	3	4.0	-	3.0	-	-	0.7	-	-	-	207	—
1A2	-	-	-	3	4.0	-	3.0	-	-	1.5	-	-	-	207	—
1B	94	-	-	3	0.64	0.43	0.85	-	-	-	0.05	-	-	128.2	—
2	94	-	-	-	0.43	0.43	0.85	-	-	-	0.05	-	-	-	145
2A	94	100	-	3	4.0	-	4.0	-	-	1	-	-	-	181	—
2B	94	100	-	3	4.0	-	3.0	-	-	2.5	-	-	-	182	—
2C	94	15	-	3	-	-	2.0	-	-	1.0	-	-	-	73	—
2D	94	15	10	3	1.4	-	2.0	-	-	0.5	-	-	-	78.5	—
3A	94	-	15	5	2.0	0.5	1.0	0.5	0.1	0.4	0.05	-	160	-	—
3B	94	-	15	5	2.0	0.5	1.0	0.5	0.2	0.4	0.05	15	160	-	—
3C	94	15	-	5	2.0	0.5	1.0	0.5	0 3	0.5	0.05	-	165	-	—
4A	94	-	15	5	2.0	0.5	1.0	0.5	0.2	0.4	0.05	-	85	-	—
4B	94	-	15	5	2.0	0.5	1.0	0.5	0.2	0.4	0.05	15	82	-	—
4C	94	15	-	5	2.0	0.5	1.0	0.5	0.3	0.4	0.05	-	87	-	—
5A	94	-	15	5	2.0	0.5	1.0	0.5	0.2	0.4	0.05	-	53	-	—
53	94	-	15	5	20	0.5	1.0	0.5	0.4	0.4	0.05	15	47	-	—
5C	94	15	-	5	2.0	0.5	1.0	0.5	0.05	0.6	1.1	-	55	-	—
6	94	-	15	5	1.0	0.5	1.0	0.5	0.2	0.4	0.05	80	-	-	—
7	94	-	15	5	1.0	0.5	1.0	0.5	0.2	0.4	0.05	40	-	-	—
8	94	-	15	5	2.0	0.5	1.0	0.5	0.2	0.4	0.05	25	-	-	—

4. Proposing new cementing tools to be applied as two-stage tool, inflatable packers

4.1. Two-stage cementing tool

With the use of multiple-stage cementing tools, cement slurry can be placed at selected intervals around the casing string (Figure 12).

4.2. External sleeve inflatable packer collar (ESIPC™) tool

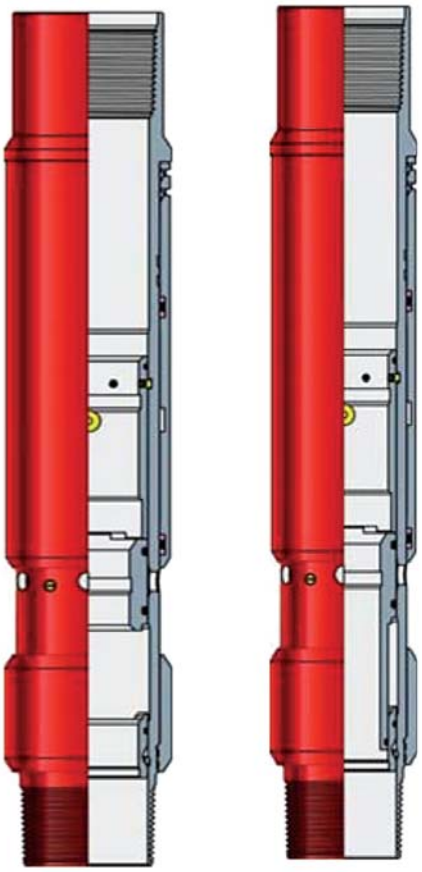
The external sleeve inflatable packer collar (ESIPC™) tool is a combination of the ES (type P or type H) cementer and a casing inflation packer. This tool provides a controlled packer element inflation through the stage-tool opening seat, eliminating hydraulic valve bodies normally used with inflatable packer elements. The ESIPC tool is commonly used in horizontal well applications for cementing casing in the bend radius or vertical portion of the wellbore, above an openhole completion or a slotted liner [4].

- Multi-stage inflatable packer collar (MSIPC):

The multi-stage inflatable packer collar (MSIPC) is a combination of the reliable plug-operated Halliburton MS cementer tool and a metal bladder casing inflation packer. This economical tool provides controlled packer element inflation through the stage-tool opening seat, eliminating hydraulic valve bodies normally used with inflatable packer elements. The metal bladder tools are recommended for use when setting a hard rock formation or inside casing [5].

- Multi-stage packer cementing collar (MSPCC):

The multi-stage packer cementing collar (MSPCC) is a stage cementer with an integral, solid rubber, compression-set packer element. Like the other stage-cementing packer collars, the MSPCC is used either to prevent gas migration or to support the hydrostatic pressure of the cement with a packer. However, the compression-set (or mechanical) packer elements, that do not hold as much differential pressure as inflatable elements, are sensitive to hole size [5].



Type P ES-II* Cementer

Type H ES-II** Cementer

** Plug operated, external sleeve*

*** Hydraulic operated, external sleeve*

Figure 12. *Two-stage cement tools [5]*

Type H ESIPC Tool

Figure 13. *The external sleeve inflatable packer collar [4]*

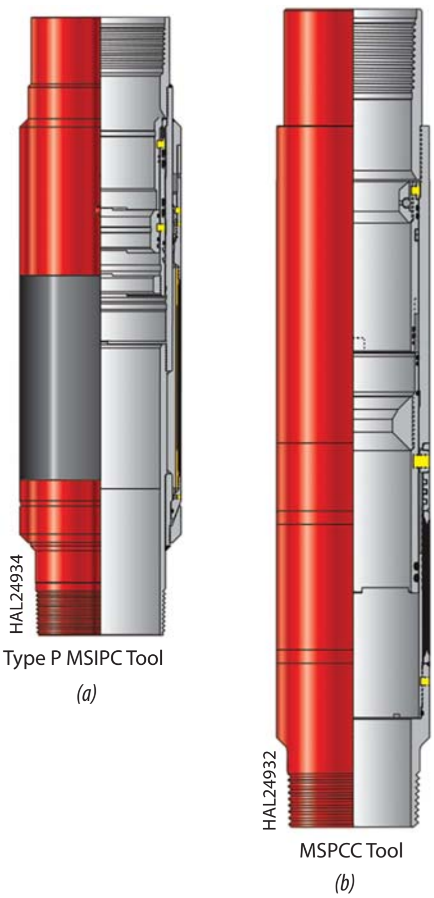


Figure 14. *The plug-operated multi-stage inflatable packer collar (a) multi-stage packer cementing collar (b)[5]*

4.3. Swell packer

Swell packers can be considered to use in Dai Hung wells as back-up zone isolation in case of poor cement bond. Swell packers can also provide extra sealing capability/redundant seal to prevent a micro-annulus or mud channel when the packers are cemented in. The placements of swell packers are designed to place above the top of cement or between zones of interest to avoid cross-flow or communication between zones.

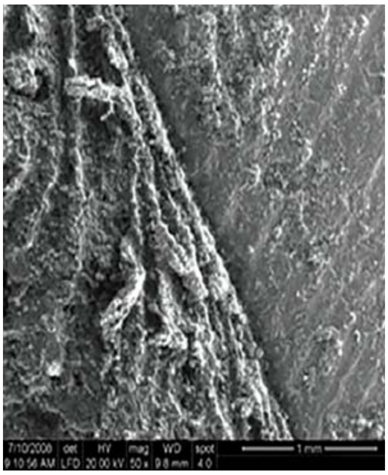


Figure 15. *Cement/rubber interface*

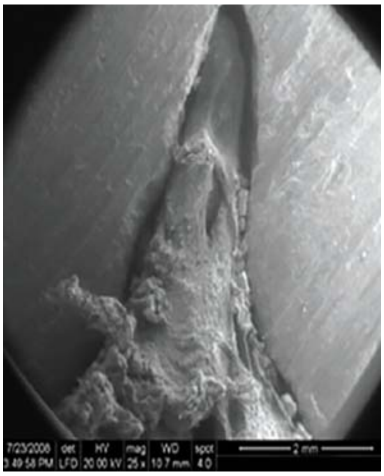


Figure 16. *Rubber swelling into crack*

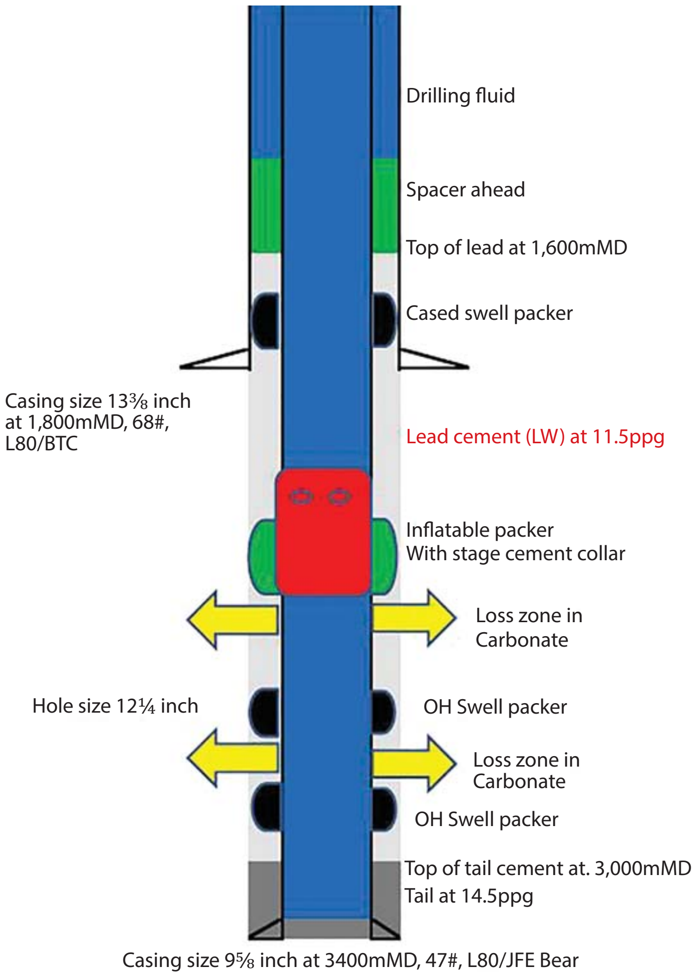


Figure 17. *Schematic with new cement system and tools for Dai Hung field [6]*

5. Conclusions

Based on laboratory testing and field application results, the light weight cement slurry has proved to meet the technical requirements for cementing across the fractured carbonate zones with the partial loss condition in Dai Hung field. The 9⅝ inch casing can be cemented with a low cement density but this cement slurry still provides the same compressive strength as the conventional cement slurry for ensuring zone isolation. Also, this light weight cement is to help in the bridging top of cement to the designed depth.

The successful solution to improve the cement bond quality for 9⅝ inch casing with lost circulation issue must combine one or several technologies. The schematic in Figure 17 would provide a clearer view of this combined solution including lightweight cement, special cement spacer, a two-stage cementing tool integrated with an inflatable packer and swell packers. The engineer would need to design and propose a suitable cement system/tools basing on the conditions of each well in Dai Hung field.

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