Rheology of Cement Mixed with Hollow Microspheres

by

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Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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Approved by,

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MAY 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Vinod Kumar a/l Selvakumaran

ABSTRACT

Hollow microspheres cement is lightweight cement solution that is designed to have the highest strength ratio and lowest permeability of any cement design at a given slurry density, and rapid compressive strength to reduce Wait on Cement (WOC). Hollow microspheres used to reduce hydrostatic pressure on weak formations and to cement lost circulation zones. Hollow microspheres are produced from a mixture of liquid sodium silicate glass and a foaming agent [2]. For example, carbonates, bicarbonates, sulphates, nitrates, and acids are used as foaming agent. The mass is then dried and crushed. In this study, the focuses are mainly cementing the intermediate and production casing in a single stage using low density cement that was based on hollow microspheres. The objectives of this work is to analysis low density cement in High Pressure High Temperature (HPHT) formation which also includes the lab tests such compressive strength, fluid loss and thickening time test. Hollow microspheres cement is a High Strength, Low Density (HSLD) cement system which suggested for increasing primary cementing success in steam injected, low fracture gradient areas. It is incompressible cement which provides consistent and predictable density from the top of the borehole to the bottom. The hollow microsphere cement system is HSLD acknowledged as a feasible solution because conventional cement designs lose the formation. Advantages of using hollow microspheres cement are that it gives an excellent mud displacement, enhanced mechanical properties, good strength to density ratio and long lasting zonal isolation. A programme is developed using software to test the parameters such as temperature, pressure and density of the cement. Although the microspheres operations can be very complex, hollow microspheres cement has many applications that can justify the increase complexity. Cement slurry using hollow microspheres can be applied in high permeability formations, poorly consolidated formations and HPHT formations.

1

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMECLATURES

WOC	Wait on Cement
LDC	Low Density Cement
HSLD	High Strength Low Density
HPHT	High Pressure High Temperature
SG	Specific Gravity
ECD	Equivalent Circulation Density
BHST	Bottomhole Static Temperature
BHCT	Bottomhole Circulating Temperature

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Cementing is one of the most critical steps in well completion. Cement fills and seals the annulus between the casing string and the drilled hole. It has three general purposes: zone isolation and segregation, corrosion control, and formation stability and pipe strength improvement [9]. Cement forms an extremely strong, nearly impermeable seal from a thin slurry. Typical cement fluid density ranges from 12 to17 lb/gal. Certain conditions can be encountered during the well construction process that requires application of cement with much lower density. Lowed density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, named lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Sections of a well in which lost circulation occurs include the upper sections: surface casing and intermediate casing. Since formation covered by these casing are relatively close to the Earth's surface, application temperatures for these low density cements are relatively low. The properties of cement slurry and its behavior depend on the components and the additives in the cement slurry. An innovative approach to use as cement additives are hollow microspheres.

Hollow microspheres also known as Spherelite cement is a lightweight cement solution that has become widely especially in HPHT wells. The density reduction of oilwell slurries is through the addition of low Specific Gravity (SG) microspheres [1]. When using microspheres bulk blended with dry cement, the equipment footprint is smaller than that required for foamed cement. A hollow microspheres slurry can be designed to have the highest strength ratio and lowest permeability of any cement design at a given slurry density, and rapid compressive strength development is beneficial because it reduces the WOC times. Some of hollow microspheres advantages are excellent mud displacement, enhanced mechanical properties, good strength to density ratio and long lasting zonal isolation. The possibility of changing the density up to last minute also gives a good flexibility in addressing unexpected downhole conditions.

This phase of project involves analysis of physical and chemical properties of hollow microspheres with cement.

This project is designed to develop cementing systems using Hollow Microspheres. The development will be achieved through a carefully analysis of modeling design, laboratory testing and field application.

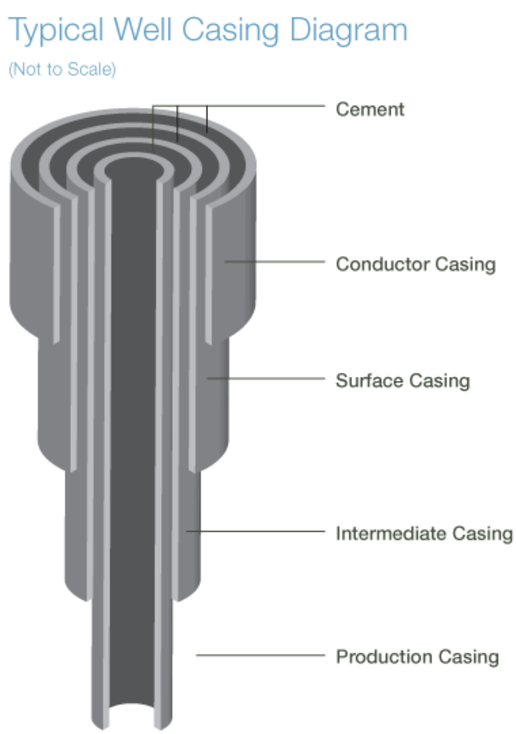

Figure 1 : Typical well casing diagram [9]

1.2 Problem Statement

Cementing in HPHT formation increases the hydrostatic pressure and lead to lost of circulation zones. In addition, HPHT wells give a sensitive effect to the cement slurry, particularly reduce the thickening time, affect the cement slurry rheology and also the compressive strength of the cement.

1.3 Objective

The two main objectives of this project are:

1. To investigate the on Low Density Cement on high pressure and high temperature conditions.
2. To analysis on the properties of Hollow Microspheres cement such as compressive strength, fluid loss, slurry rheology, thickening time and free water.

1.4 Scope of Study

This study is focused on new cement additive which is Hollow Microspheres for the use in the cement design for high temperature and high pressure wells. Initial studies on cementing design for HPHT wells and cement testing procedures should be covered.

Properties and characteristics of the research materials should be studied. This part includes being familiarised with Hollow Microspheres properties of materials. Study also covers API RP 10B testing procedures for cement testing to measure the required properties of cement.

1.5 Relevancy of the Project

This project is relevant to my field of engineering which is Petroleum Engineering. These are related with three of my core subjects; Drilling Engineering, Advance Drilling Engineering, and Well Completions and Production which are very much about drilling and cementing well. Besides that, it is indeed an opportunity for me to implement all my theoretical studies into practice by carrying out this project.

1.6 Feasibility of the Project

The time given to complete this project is feasible and is within the scope. I will be having adequate period from the beginning of January 2013 semester till the end of my final year semester on August 2013 which is approximately eight months. The given time frame is very suitable to conduct this project systematically as possible and also effectively.

CHAPTER 2

LITERATURE REVIEW

2.1 HPHT Wells

According to Society of Petroleum Engineering (SPE) Exploration and Production (E&P) [6], high temperature is where the undisturbed bottom hole temperature (at prospective reservoir depth or total depth) is more than 300 °F or 150 °C. When high pressure, the maximum anticipated pore pressure of the porous formation to be drilled exceeds a hydrostatic gradient of 0.8 psi/ft, or the well requiring pressure control equipment has a rated working pressure in excess of 10,000 psi or 69 MPa. HPHT wells are as follows:

Table 1: HPHT borehole temperature and pressure

	Borehole Temperature	Borehole Pressure
HP/HT	>300°F (150°C) - 350°F (175°C)	>10,000 psi (69 MPa) - 15,000 psi (103 MPa)
Extreme HP/HT	>350°F (175°C) - 400°F (200°C)	>15,000 psi (103 MPa) - 20,000 psi (138 MPa)
Ultra HP/HT	>400°F (200°C) and above	>20,000 psi (138 MPa) and above

HPHT gives a sensitive effect to the cement slurry, particularly to the thickening time [3]. It will reduce the thickening time which could set the cement quicker compared with normal temperature wells. HPHT also could affect the cement rheology. The plastic viscosity and yield point will decrease with an increase of temperature. A correct equivalent circulation density needed for HPHT wells. Cement weight should withstand the formation pressure by creating minimum overbalance. As pressure increase, compressive strength development and higher ultimate compressive strength are observed to result from the high pressure. When the depth increases, hydrostatic pressure will increase as well as the Equivalent Circulating Density (ECD) and vice versa as rise of temperature will reduce ECD due to thermal expansion.

In HPHT wellbore, it is suspected to have high temperature variation which will give effect to expansion and contraction of casing and plastic formation it will lead to crack in set cement. Cement physical and chemical behavior changes significantly at elevated temperatures. Cementing in HPHT environment is encountered in three principal types of wells; deep oil & gas well, geothermal wells and thermal recovery wells. Drilling with high temperatures, high pressures, narrower annulus, and sometimes corrosive fluids are often found in HPHT wells. Therefore, the cement design should consider a combination between silica, retarders, weighting agent, extender, expanding additive, fluid loss agent, casing eccentricity, mud removal and laboratory test, which lead to the original objective to provide complete isolation in the proper zone over the life of the well.

2.2 Low Density Cement (LDC) – Hollow Microspheres

LDC slurries are used to reduce the hydrostatic pressure on weak formations and to cement lost circulation zones [4]. Examples of low density cements are water extender cements, foam cements and hollow microsphere cements. Water extender cements are limited in density to nearly 11.5 lb/gal³. Cement fallback often occurs and top of set cement can be hundred feet below the ground level because the formations cannot withstand the hydrostatic load exerted by water extender cements even if full circulation is maintained to surface and cement returns are noted. Sulfide containing water can then corrode the uncemented casing resulting in expensive surface casing remedial treatments.

The idea of mixing hollow microsphere with cement was developed a few decades ago. Hollow microsphere cement was used for the first time in the oil industry in 1980 to prepare 9.2 lb/gal cement [5]. A gas is contained in the microspheres to reduce cement density down to 8 lb/gal.

There are several methods to prepare hollow microsphere cement. One way is to prepare a mixture of coarse and fine cement particles, fly ash, fumed silica, hollow glass spheres and water. Another method is to add hollow glass or ceramic microsphere to plasticizer, cement and a strengthening agent such as aluminum metal powder and sodium sulfate.

Figure 2: Hollow microspheres [8]

2.2.1 Hollow glass microsphere

Hollow glass microspheres can be used as a continuous medium in low-density cement slurries with addition of hollow glass microspheres [7]. The slurry is incompressible and all wells are uniform in density. Used in drilling fluid, sludge cakes formed have good lubrication, reducing the risk of sticking. Hollow glass microspheres have an irreplaceable advantage for it cannot affect the system signal. Hollow glass microspheres have a good rolling performance, and can increase the drilling rate, and significantly improve the drilling efficiency. Cementing with hollow glass microspheres has feature of high temperature resistance, high pressure resistance, stability, durability, and can be recycled. With the increase of pressure layer, low-density slurry cementing with hollow glass microspheres were adopted to consolidate the wells to prevent or reduce leakage, increase the cement top. It will improve single well production, and can be used effectively to obtain underground oil and gas and high temperature geothermal resources. It owns features with light weight, large bulky, low thermal conductivity, high compressive strength, and smoothly mobility.

2.2.2 Hollow ceramic microsphere

Hollow ceramic microsphere can be used as a continuous medium in low density cement slurries with addition of hollow ceramic microspheres. The use of ceramic microspheres for cementing applications results in substantial savings by reducing the environmental impact of the cementing application, reducing the consumption of oilfield cement and by replacing the need to import expensive cementing additives. The ceramic microspheres of the present invention are an advantageous well cementing constituent that may be successfully implemented in differing temperature dependent processes, such as the steam injection technique employed for heavy crude oil extraction. The ceramic microspheres of the present invention are granulated materials with a small size and a spherical shape [10]. Once used in a cementing material, the microspheres impart high flowability to the cementing material. The microspheres are used in cement slurries, such as oil well cement slurries, construction cement slurries, squeeze cement slurries, cutting treatment cement slurries, as extenders and light weight pozzolanic and viscosity reducing additives.

2.2.3 Hollow metallic microsphere

Hollow metallic microsphere is not widely used as additives to cement because it easily can damage the tools, cement pump, mud pump and other equipment.

2.3 Physical and Chemical Properties of Hollow Microspheres [13]

Form	: Solid, hollow, fine particle powder. Particle size range (5-300) µm.
Colour	: Gray, off-white or gray/brown.
Odour	: A slightly earthy odour may be present.
Melting point (^{o}C)	: 1200-1400
Solubility (water)	: Insoluble/Slightly soluble
Solubility (organic solvents)	: Insoluble/Slightly soluble
Specific Gravity (water=1)	: 0.60-0.85
pH value	: 6-8 in a 50% solid concentration

2.4 API Class G Cement Properties

Among the classes of cement, Portland Class G cement will be likely to use as cement as it is mainly used in high temperature and high pressure environment. Slurry of Portland cement in water is used in wells because it can be pumped easily and hardens readily, even under water. Basically, it is intended for use from 10 000 ft to 16 000 ft (3050 m to 4880 m) depth as manufactured, or can be used with accelerators and retarders to cover a wide range of well depths and temperatures [19]. Class G cements are usually specified for deeper, hotter and higher pressure well conditions.

Cements are made from the same basic ingredients as regular cements. However, a certain properties are altered so that the cements can performs as intended at the higher temperatures and pressures. Admixtures and other ingredients such as sand, bentonite, pozzolan and diatomaceous earth are incorporated into the mixture for the purpose of controlling its fluid properties while organic compounds are added to control its setting time.

Table 2 and Table 3 show the basic components of Portland Cement Class G.

Table 2:Typical composition and properties of API classes of portland cement [20]

API Class	Compounds, %				Wagner Fineness, cm^2/g
	C_3S	C_2S	C_3A	C_4AF	
A	53	24	8+	8	1,500 to 1,900
B	47	32	5–	12	1,500 to 1,900
C	58	16	8	8	2,000 to 2,800
G & H	50	30	5	12	1,400 to 1,700

Property	How Achieved
High early strength	By increasing the C_3S
Better retardation	By controlling C_3S and C_3A
Low heat of hydration	By limiting the C_3S and C_3A content
Resistance to sulfate attack	By limiting the C_3A content

Table 3:Typical mill run analysis of portland cement [20]

Oxide	Class G, wt%	Class H, wt%
Silicon dioxide, SiO_2	21.7	21.9
Calcium oxide, CaO	62.9	64.2
Aluminum oxide, Al_2O_3	3.2	4.2
Iron oxide, Fe_2O_3	3.7	5
Magnesium oxide, MgO	4.3	1.1
Sulfur trioxide, SO_3	2.2	2.4
Sodium oxide, Na_2O		0.09
Potassium oxide, K_2O		0.66
Total alkali as Na_2O	0.54	0.52
Loss on ignition	0.74	1.1
Insoluble residue	0.14	0.21
Phase Composition		
C_3S	58	52
C_2S	19	24
C_3A	2	3
C_4AF	11	15
Physical Properties		
% passing 325 mesh	87	70
Blaine fineness, cm^2/gm	3,470	2,610
Physical Requirements		
Thickening time, min, Sch 5	1:40	1:38
B_c at 30 min	14	15
8 hr compressive strength, 110°F (38°C)	928 psi (6.4 MPa)	650 psi (4.5 MPa)
8 hr compressive strength, 140°F (60°C)	2,247 psi (15.5 MPa)	1,650 psi (11.4 MPa)
Free fluid, mL[13]	4.4	4.0

Table 4, Table 5 and Table 6 shows the physical and chemical requirements of Portland Cement Class G.

Table 4: Physical requirements for API cements [20]

Well cement class:				A	B	C	G	H
Mix water, wt% of well cement:				46	46	56	44	38
Fineness tests (alternative methods):								
Turbidimeter (specified surface, minimum, m_2/kg):				150	160	220	—	—
Air permeability (specified surface, minimum, m_2/kg):				280	280	400	—	—
Free-fluid content, maximum, mL:				—	—	—	3.5	3.5
Compressive-strength test, 8-hour curing time	Schedule number, Table 7	Curing temp., °F (°C)	Curing pressure, psi (kPa)	Minimum Compressive Strength, psi (MPa)				
	—	100 (38)	Atmos.	250 (1.7)	200 (1.4)	300 (2.1)	300 (2.1)	300 (2.1)
	—	140 (60)	Atmos.	—	—	—	1,500 (10.3)	1,500 (10.3)
Compressive-strength test, 24-hour curing time	Schedule number, Table 7	Final curing temp., °F (°C)	Final curing pressure, psi (kPa)	Minimum Compressive Strength, psi (MPa)				
	—	100 (38)	Atmos.	1,800 (12.4)	1,500 (10.3)	2,000 (18.8)	—	—
Pressure/ temperature thickening-time test	Specification test schedule number, Table 10		Maximum consistency, 15 to 30 min stirring period, B_c	Minimum Thickening Time, min				
	4		30	90	90	90	—	—
	5		30	—	—	—	90	90
	5		30	—	—	—	120 max.	120 max.

B_c = Bearden units of consistency, obtained on a pressurized consistometer, as defined in Sec. 9 of API *Spec. 10A* and calibrated as per the same section.[8]

Table 5: Chemical requirements for API cements [20]

	Cement Class				
Ordinary Grade, *O*	A	B	C	G	H
Magnesium oxide, MgO, maximum, %	6.0	—	6.0	—	—
Sulfur trioxide, SO_3, maximum, %	3.5[1]	—	4.5	—	—
Loss on ignition, maximum, %	3.0	—	3.0	—	—
Insoluble residue, maximum, %	0.75	—	0.75	—	—
Tricalcium aluminate, $3CaO{\cdot}Al_2O_3$, maximum, %	—	—	15	—	—
Moderate-Sulfate-Resistant Grade, MSR					
Magnesium oxide, MgO, maximum, %	—	6.0	6.0	6.0	6.0
Sulfur trioxide, SO_3, maximum, %	—	3.0	3.5	3.0	3.0
Loss on ignition, maximum, %	—	3.0	3.0	3.0	3.0
Insoluble residue, maximum, %	—	0.75	0.75	0.75	0.75
Tricalcium silicate, C_3S maximum, %	—	—	—	58[2]	58[2]
minimum, %	—	—	—	48[3]	48[3]
Tricalcium aluminate, C_3A, maximum, %[2]	—	8	8	8	8
Total alkali content expressed as sodium oxide, Na_2O, equivalent, maximum, %[3]	—	—	—	0.75	0.75
High-Sulfate-Resistant Grade (HSR)					
Magnesium oxide, MgO	—	6.0	6.0	6.0	6.0
Sulfur trioxide, SO_3,maximum, %	—	3.0	3.5	3.0	3.0
Loss on ignition, maximum, %	—	3.0	3.0	3.0	3.0
Insoluble residue, maximum, %	—	0.75	0.75	0.75	0.75
Tricalcium silicate, C_3S, maximum, %	—	—	—	65[2]	65[2]
minimum, %	—	—	—	48[2]	48[2]
Tricalcium aluminate, C_3A, maximum, %[2]	—	3	3	3	3
Tetracalcium aluminoferrite, C_4AF, plus twice the tricalcium aluminate, C_3A, maximum, %[2]	—	24	24	24	24
Total alkali content expressed as sodium oxide, Na_2O, equivalent, maximum, %[3]	—	—	—	0.75	0.75

[1] When the tricalcium aluminate content (expressed as C_3A) of the Class A cement is 8% or less, the maximum SO_3 content shall be 3%.

[2] The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds. When the ratio of the percentages of Al_2O_3 to Fe_2O_3 is 0.64 or less, the C_3A content is zero. When the Al_2O_3 to Fe_2O_3 ratio is greater than 0.64, the compounds shall be calculated as $C_3A = (2.65 \times \%\ Al_2O_3) - (1.69 \times \%\ Fe_2O_3)$, $C_4AF = 3.04 \times \%\ Fe_2O_3$, $C_3S = (4.07 \times \%\ CaO) - (7.60 \times \%\ SiO_2) - (6.72 \times \%\ Al_2O_3) - (1.43 \times \%\ FeO_3) - (2.85 \times \%\ SO_3)$. When the ratio of Al_2O_3 to Fe_2O_3 is less than 0.64, the C_3S shall be calculated as $C_3S = (4.07 \times \%\ CaO) - (7.60 \times \%\ SiO_2) - (4.48 \times \%\ Al_2O_3) - (2.86 \times \%\ Fe_2O_3) - (2.85 \times \%\ SO_3)$.

[3] The sodium oxide equivalent (expressed as Na_2O equivalent) shall be calculated by Na_2O equivalent = $(0.658 \times \%\ K_2O) + \%\ Na_2O$.

Table 6: Physical requirements of various types of cements [20]

Properties of API Classes of Cement	Class A	Class C	Classes G and H
Specific gravity, average	3.14	3.14	3.15
Surface area, range, cm^2/g	1,500	2,000 to 2,800	1,400 to 1,700
Weight per sack, lbm	94	94	94
Bulk volume, ft^3/sk	1	1	1
Absolute volume, gal/sk	3.6	3.6	3.58

Properties of Neat Slurries	Portland	High Early Strength	API Class G	API Class H
Water, gal/sk, API	5.19	6.32	4.97	4.29
Slurry weight, lbm/gal	15.6	14.8	15.8	16.5
Slurry volume, ft^3/sk	1.18	1.33	1.14	1.05

Temperature, °F	Pressure, psi	Typical Compressive Strength, psi at 24 hours			
60	0	615	780	440	325
80	0	1,470	1,870	1,185	1,065
95	800	2,085	2,015	2,540	2,110
110	1,600	2,925	2,705	2,915	2,525
140	3,000	5,050	3,560	4,200	3,160
170	3,000	5,920	3,710	4,830	4,485
200	3,000	*	*	5,110	4,575

Temperature, °F	Pressure, psi	Typical Compressive Strength, psi at 72 hours			
60	0	2,870	2,535	—	—
80	0	4,130	3,935	—	—
95	800	4,670	4,105	—	—
110	1,600	5,840	4,780	—	—
140	3,000	6,550	4,960	—	7,125
170	3,000	6,210	4,460	5,685	7,310
200	3,000	*	*	7,360	9,900

Depth, ft	Temperature, °F		High-Pressure Thickening Time, hr:min			
	Static	Circulation				
2,000	110	91	4:00+	4:00+	3:00+	3:57
4,000	140	103	3:26	3:10	2:30	3:20
6,000	170	113	2:25	2:06	2:10	1:57
8,000	200	125	1:40*	1:37*	1:44	1:40

*Not generally recommended at this temperature.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The following flow chart summarizes the overall work flow of this project:

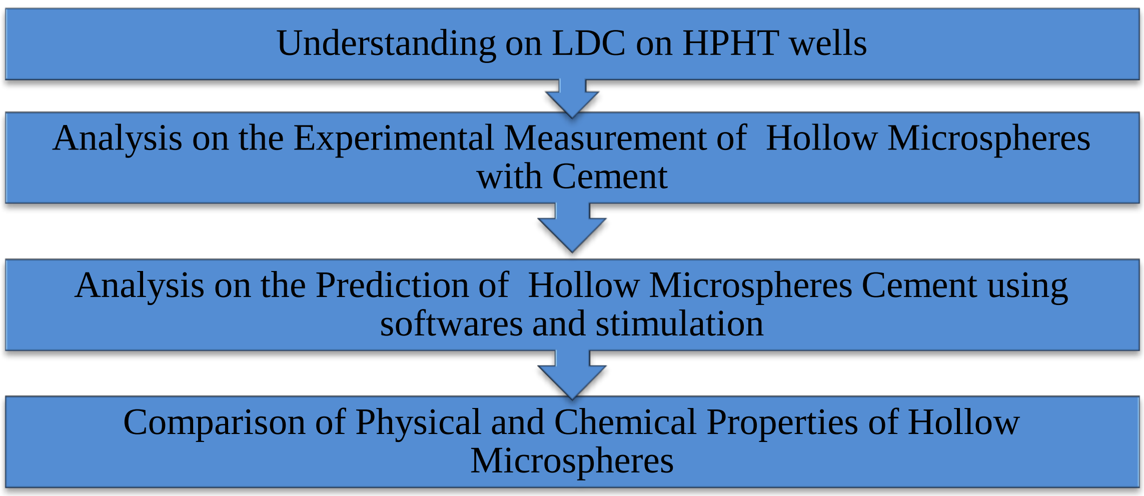

Figure 3: The schematic diagram depicting the general approach in this project

3.1.1 Understanding on Low Density Cement on high pressure and high temperature conditions.

- Reading many articles, journals and books regarding the hollow microspheres with cement to get a deep understanding on how hollow microspheres behaves at various pressures and temperatures.

3.1.2 Analysis on the Experimental Measurement of Hollow Microspheres with Cement

- Wear proper PPE such as lab coat and eye protector while conducting the measurement experiment and handle necessary equipment's with care.
- Interpret and analysis the properties of indication cementing composition:

a. Thickening Time Test as per API 1997 Specification 10

Thickening time is to evaluate the pumpability of the cement slurry. Prepared slurry is poured into consistometer slurry cup for measure thickening time.

b. Compressive Strength Test

Equipment used to measure compressive strength of cement slurry is shown in Figure 4 below:

Figure 4: Carver press compressive strength tester

c. **Free Water Test**

Free water test is to measure water separation using 250ml graduated cylinder and after standing for 2 hours, the volume of free water at the top of the cylinder is measured. This is when cement slurry is allowed to stand a period of time prior to test water may separate from the slurry migrating upwards. Settling can be measure by comparing densities of different sections of the cement column cured.

d. **Fluid Loss Test**

Fluid loss is the rate at which water comes out of cement when contacted with permeable formation. This property of cement is important to maintain the slurry pumpable and avoid dehydration. Fluid loss incorporates high pressure and specific filters to stimulate wellbore pressure. Figure 5 shows equipment to measure the fluid loss of the cement slurry.

Figure 5: Stirred fluid loss tester

e. **Rheology Test**

Rheology is the study of flow and deformation of fluids. This parameter is measured using rotational viscometer as shown in Figure 6.

Figure 6: Rotational viscometer

3.1.3 Analysis the results of Hollow Microspheres Cement using Software Stimulation.

- Get familiarize with necessary stimulation software such as Landmark (Compass, Wellplan and Stress Check).
- Interpret lab results.

3.1.4 Comparison on the Physical and Chemical Properties of Hollow Microspheres

- Compare the physical and chemical properties of the cement slurry when added with spherelite and without spherelite.
- Compare the features and benefits of Hollow Microspheres.

3.2 Project Activities

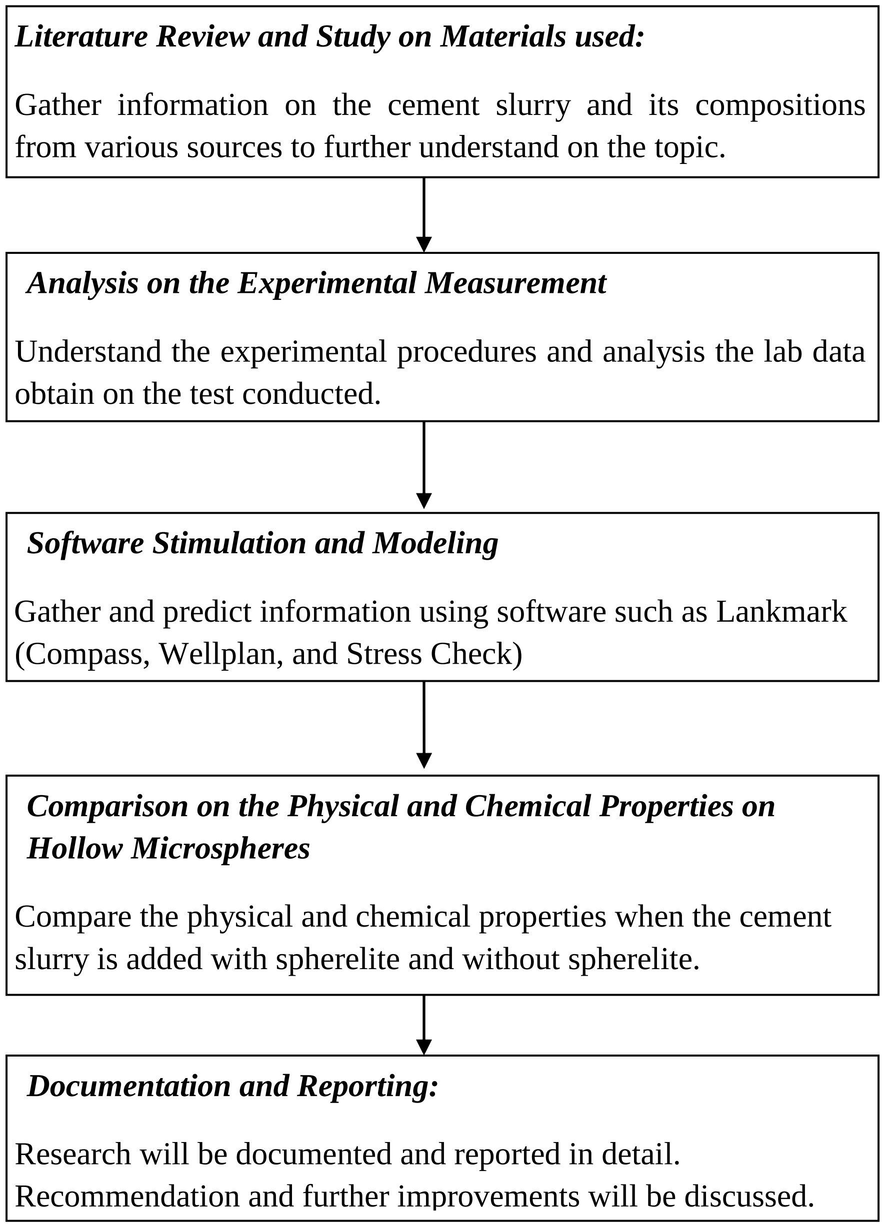

Figure 7: Project activities flowchart

3.3 Key Milestone

Table 7: Events or deliverable of key milestones of FYP I

Event or Deliverable	Week	Responsibility
Project Selection and Acceptance by Supervisor	Week 1-2	Discuss the project topic and approval of topic from Supervisor.
Project execution initiated	Week 2-5	Conduct all the project activities as planned in the project charter
Submission of Extended Proposal	Week 6	Submission of Extended Proposal to FYP Coordinator
Proposal Defence (Seminar Presentation)	Week 8-9	Report on the progress of project to supervisor, fellow students and other lecturer.
Project execution continued	Week 10-12	Continue on project activities
Submission of Interim Report	Week 14	Hand in Interim Report to FYP Coordinator

Table 8: Events or deliverable of key milestones of FYP II

Event or Deliverable	**Week**	**Responsibility**
Project execution continued	Week 1-6	Conduct all the project activities as planned in the project charter
Submission of Progress Report	Week 7	Submission of Progress Report to FYP Supervisor
Project execution continued	Week 8-9	Conduct all the project activities as planned in the project charter
Pre-SEDEX	Week 10	Explain verbally to the audience through poster
Submission of Draft Report	Week 11	Hand in Final Draft Report to FYP Supervisor
Submission of Dissertation (soft bound) and Technical Paper	Week 12	Hand in Final Report in soft copy and Technical Paper to FYP Coordinator
Oral Presentation (viva)	Week 13	Verbally report the outcome of project to Supervisor and External Examiner
Submission of Project Dissertation (hard bound)	Week 14	Hand in Final Report to FYP Coordinator

3.4 Tools

In order to accomplish these project objectives, several methods will be used throughout these project which are lab experiment, computer and also modeling software. Computer software that will be using is Landmark (Compass for well design, Wellplan and Stress Check).

3.5 Gantt Chart

Gantt Chart showing the study plan and schedule for each activity planned in this project is as below:

Table 9: FYP I implementation gantt chart

No.	Details / Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic															
2	Preliminary Research work i. Literature reviews ii. Identification of hollow microspheres cement															
3	Submission of Extended Proposal						●		MID SEM BREAK							
4	Proposal Defence															
	Project work continues i. Literature reviews (continue) ii. Identification of hollow microsphere cement (continue) iii. Selection of experiment result for simulations															
5	Submission of Interim Draft Report														●	
6	Submission of Interim Report															●

■ Process

● Suggested Milestone

Table 10: FYP II implementation gantt chart

No.	Details / Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continues	■	■	■	■	■	■	■	MID SEM BREAK							
2	Submission of Progress Report							●								
3	Project Work Continues									■	■	■	■	■		
4	Pre-SEDEX											●				
5	Submission of Draft Report												●			
6	Submission of Dissertation (soft bound)													●		
7	Submission of Technical Paper													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (hard bound)															●

■ Process

● Suggested Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

Slurry Composition (Slurry Type: Single)

Table 11: Slurry compositions

Material/Information	Amount
Indocement Class G	94 lb/sk
SSA – 1	70 %bwoc
Spherelite	78 %bwoc
Microblock	3 %bwoc
HALAD – 344	0.8 %bwoc
CFR – 3	0.2 %bwoc
CaCl 2	0.8 %bwoc
D – Air 2	0.005 gal/sk
Total Water required	14.991 gal/sk
Total Fluid required	17.996 gal/sk
Slurry Weight	11 lb/gal
Slurry Volume	4.777 cuft/sk
Water Type	Drill Yard Water

BHCT	95 °F
BHST	115 °F
Depth	500 ft

4.2 Experimentation or Modeling

Below are the laboratories tests of Hollow Microspheres cement and Conventional cement Class G that were conducted according to the API Specification 10A.

4.2.1 Thickening Time Test Result

Thickening time testing is used to ensure that the cement slurries have enough pumpable time to allow placement of the cement slurries in the formation. The lab experiment should simulate the placement process including the wellbore pressure and temperature schedule.

Final Temperature, °F : 95

Final Pressure, Psi : 700

Table 12: Thickening time result

Components	40 Bc (hrs:mins)	70 Bc (hrs:mins)	100 Bc (hrs:mins)
Spherelite	1.96	2:02	2:04
Conventional	1:46	1:68	1:90

4.2.1.1 Interpretation and Discussion

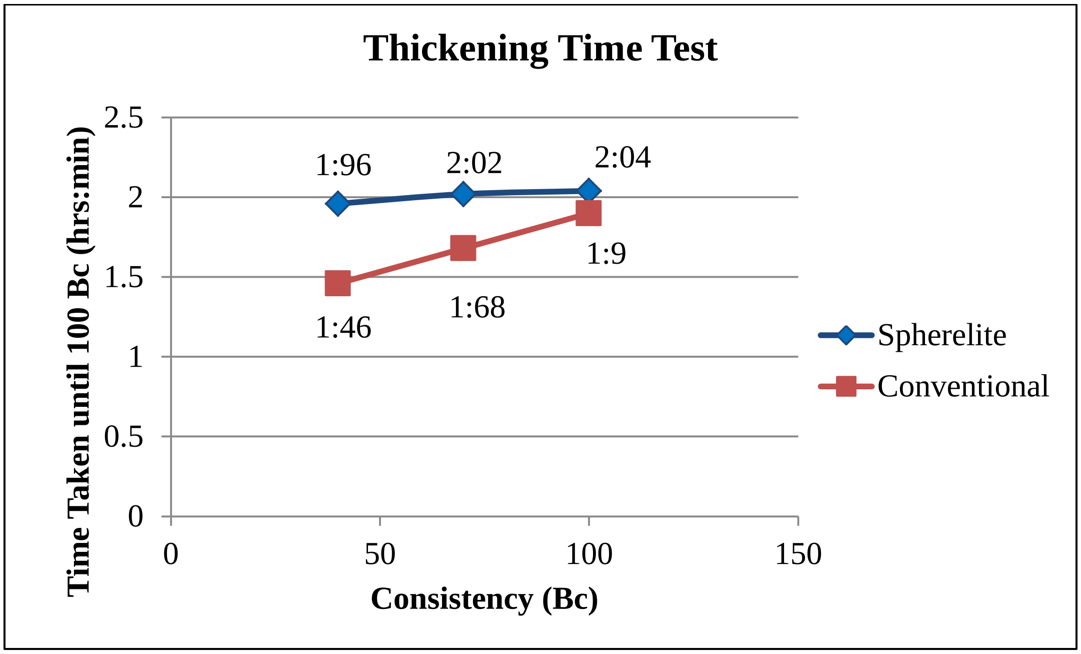

Figure 8: Graph of thickening time result

Excessive thickening time should be avoided to prevent delays in resuming drilling operations, settling and separation of slurry components, formation of free water pockets, and loss of hydrostatic head and gas cutting. The longer the thickening time the better pumpable time.

4.2.2 Free Water Test Result

Free water is to determine the amount of free fluid that will gather on the top of cement slurry between the time it is placed and the time it gels and sets up [12].

Temperature, ^oF : 95

Incline angle, Degree : 45

Free Water, % : 0.1

4.2.2.1 Interpretation and Discussion

The smaller the free water percentage, the more stable the cement slurry. Which have high compressive strength and prevent ECD.

4.2.3 Fluid Loss Test Result

Fluid loss is an important parameter especially for HPHT cement where the well depth is high. Slurry fluid loss should have minimum requirement for successful well cementing without any cement bridging occurred. Depending on the types of cement jobs, different fluid loss is required which can be attained by adding fluid loss additives into cement. However, in this experiment we want to see the effects of the new additives on the fluid loss without adding any fluid loss additives. The testing temperature is 95 ^oF and at 1000 psi differential pressure. Result of fluid loss shown below:

Table 13: Fluid loss result

Spherelite (ml/30min)	152
Conventional (ml/30min)	210

4.2.3.1 Interpretation and Discussion

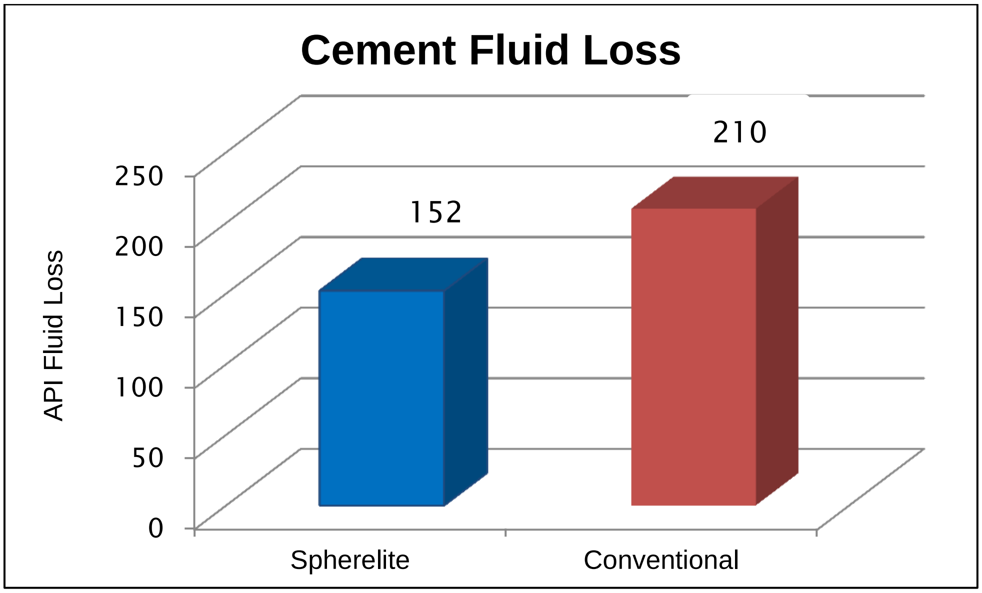

Figure 9: Graph of cement fluid loss

Dynamic fluid loss (i.e., loss of fluid from the slurry while placement) result in an increase in slurry density which may cause loss circulation. Other properties, such as rheology and thickening time may be adversely affected. Static fluid loss (i.e., loss of fluid from the slurry after placement), if not carefully controlled, will lead to a slurry volume reduction and the associated drop in interstitial that can allow formation fluids to enter the slurry. Thus, if a large volume of water is lost, the slurry becomes too viscous or dense to pump. Following the simple rule of thumb used in the field[16]:

0 – 200 ml/30min = Good control

200 – 500 ml/30min = Moderate control

500 – 1000 ml/30min = Fair control

Over 1000 ml/30min = No control

4.2.4 Rheology Test Result: Fann dial Reading (sf=1)

Rheology tests conducted to test intrinsic fluid properties, mainly viscosity, which is necessary to determine the relationship between the flow rate (shear rate) and the pressure gradient (shear stress) that causes the movement of the fluid. According API 10B specifications, rotational viscometer is used to measure the shear stresses of the cement slurry at different shear rates. Results obtained are shown below:

Table 14: Slurry rheology data result

Temp,^{o}F	300 rpm	200 rpm	100 rpm	6 rpm	3 rpm	GS 10”	GS 10’	Plastic Viscosity, cP	Yield Point, lbf/100ft^2
95	116	83	50	22	19	24	36	99	17

4.2.4.1 Interpretation and Discussion

Determining the rheology models (bingham or power law) is not the scope of this project. However, it can be determined by plotting shear rate versus shear stress values in Cartesian and log scales. Bingham will give straight line in a Cartesian scale whereas power law fluid will result in straight line in log scale. Here we only make general conclusions about the flow behavior of the samples tested. Following the simple rule of thumb used in the field:

3 & 6 rpm < 5 = Solid settling
100 & 200 rpm > 20 = Gelation
300 rpm > 200 = Hard in mixing and pumping

Plastic Viscosity and Yield Point of the cement slurry was measured as a function of shear rate. These two parameters depend on the particle size, interparticle contact and surface interlocking.

Rheology of cement is important for achieving goals such:

- To understand the interactions between different ingredients in materials to get an insight into its structure.
- To control the quality of a raw material by measuring its rheological properties. The acceptance/rejection of a product can be determined based on rheological results.
- To evaluate the mixability and pumpability of a slurry.
- To determine the frictional pressure when a slurry flows in pipes and annuli.
- To evaluate the capability of a slurry or paste to transport large particles (e.g., some lost circulation materials and fibres).
- To evaluate how the surrounding temperature profile affects the placement of a slurry or paste.
- To design a processing equipment such as selecting the appropriate pump to provide sufficient power for a material to flow over a certain distance in pipelines. The relationship between the pump and flow in pipelines is governed by the rheological properties of the material.

4.2.5 Compressive Strength Test Result

Compressive strength test is the pressure takes to crush the set cement. The chamber was set for 24 hours curing time at 115 °F and 3000 psi pressure to stimulate the condition.

50	psi at 05:59 hrs:min
100	psi at 06:28 hrs:min
500	psi at 09:56 hrs:min
1000	psi at 17:19 hrs:min
665.1	psi at 12:00 hrs:min
1554.8	psi at 24:00 hrs:min

4.2.5.1 Interpretation and Discussion

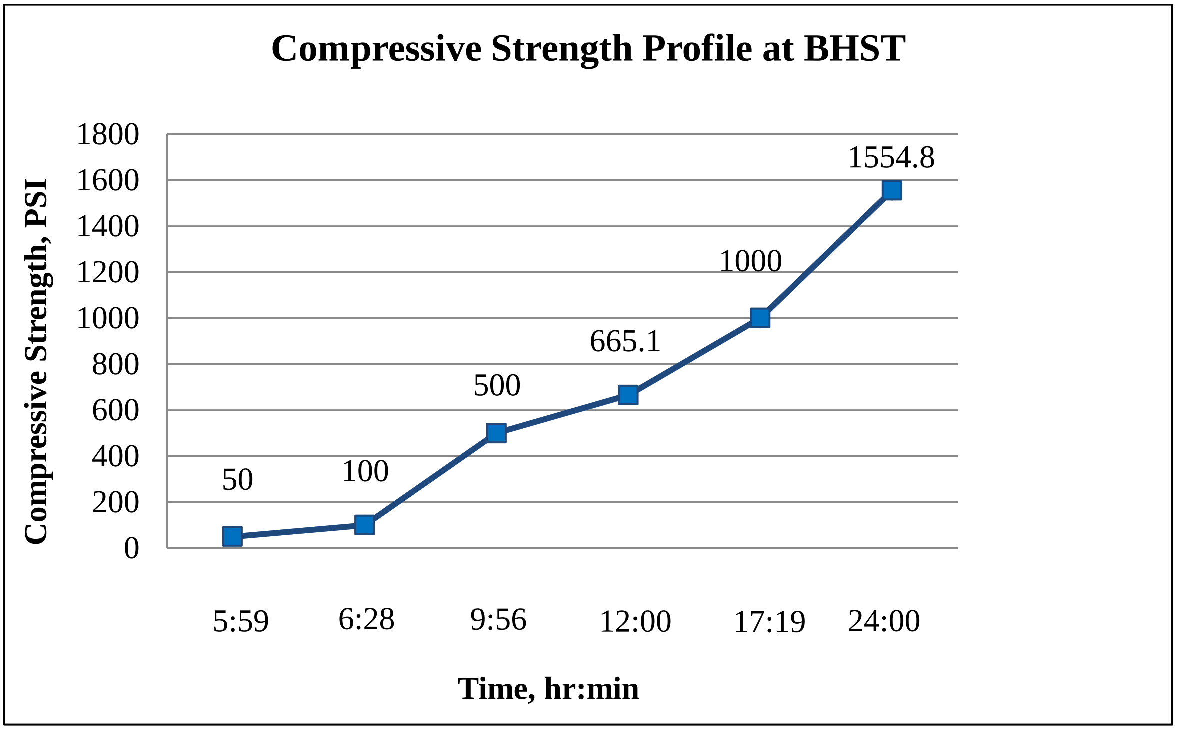

Figure 10: Graph of compressive strength result

Compressive strength of 50 psi was reached after 05:59 and 500 psi was reached after 09:56. In cement engineering 50 psi compressive strength is minimum gel strength (initial setting) and 500 psi is a minimum strength which needed to support the casing.

Crush test can withstand maximum up to 10 100 lbf.

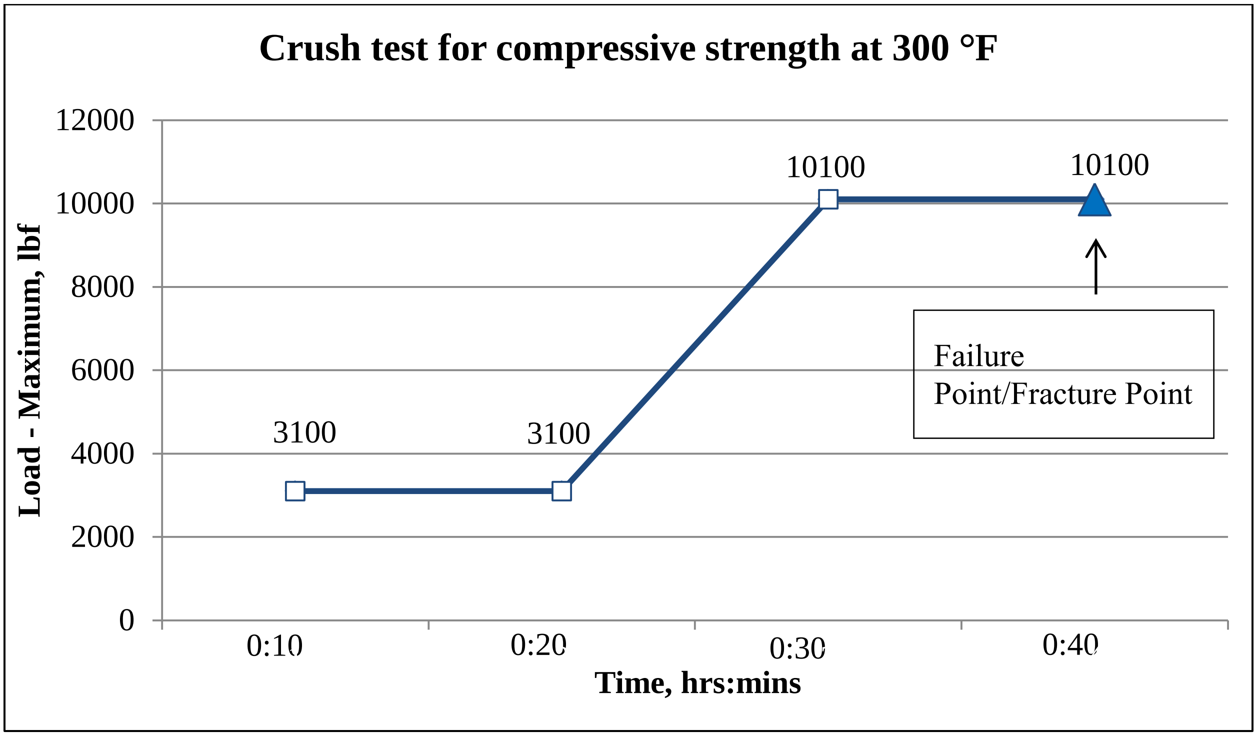

Figure 11: Graph of crush test for compressive strength

4.3 Discussion

4.3.1 Cement with Spherelite Cement Additive

When combined with the proper type of cement, Spherelite cement additive can provide slurry densities of 9.5 to 12 lb/gal. The 24-hour compressive strength of these slurries can range from 100 to 700 psi at curing temperatures of 28° to 140°F (-2.2° to 60°C)[14].

4.3.1.1 Features

Spherelite cement additive consists of hollow, fused, pressure-resistant mineral spheres that are competent up to a total exposure pressure of 12,000 psi. Lightweight slurries prepared with Spherelite cement additive generally have significantly higher 24-hour compressive strength development than equivalent density slurries prepared with bentonite, gilsonite, or silicate extenders. At any given pressure, the slurry density of a cement blend can be regulated by the quantity of Spherelite cement additive incorporated into the blend. Some of the hollow spheres are pressure-sensitive, and once the resistance of the individual spheres is exceeded, liquid is forced through the pores of the beads to fill the hollow interior space. This action gradually increases the slurry density as the total pressure on the slurry is increased [14].

4.3.1.2 Benefits

In addition to improving early compressive strength development, Spherelite cement additive slurries have very good thermal insulation properties and are good geothermal cementing applications as well. Set cements prepared with Spherelite cement additive also have improved heat insulation properties; the Spherelite cement additive functions as a lost-circulation aid. It also increases slurry volume yields because of its bulk density (25 lb/ft^3).

Spherelite give syntactic foam its light weight, low thermal conductivity, and a resistance to compressive stress that far exceeds that of other foams. Other than having low density properties, it also have excellent chemical stability, consistent distribution, free flowing, high compressive strength, high filler loading, low oil absorption, low thermal conductivity and low viscosity[17].

Spherelite has good elasticity and mechanical properties. These are the most crucial properties for long-term zonal isolation. Hollow microspheres cement exhibit improved ductility over conventional cements. This allows the microspheres cement to withstand higher hoop stresses from casing pressure and temperature cycling. This leads to lasting zonal isolation that means no sustained casing pressure, less produced water, fewer workovers and more efficient production. In addition, the capability of expanding gives very good zonal isolation and to give excellent bonding between casing-cement and formation-cement.

4.3.1.3 Hollow Microspheres Selection

Hollow Microspheres are selected based on function of cost versus performance and total risk. The physical and chemical properties should be taken into consideration. Taking slurry density as an example, the downhole slurry density should be designed using the specific gravity of the microspheres at the expected downhole pressure. The density should be verified (measured) in the laboratory by subjecting the slurry to the downhole pressure, thereby accounting for the crushing and breaking of the weakest microspheres. The average specific gravity of the microspheres and the slurry density at surface conditions will be lower than those at downhole condition. Therefore, the surface slurry density and slurry rheology should be also measured, before exposure to downhole pressure, in order to replicate surface mixing condition in the field.

4.3.1.4 Applications of Hollow Microspheres Cement

The hollow microspheres cement technology can be considered in most cement job operations all over the world, onshore and offshore. Although the microspheres operations can be very complex, hollow microspheres cement has many applications that can justify the increased complexity. These microspheres can be used in deep and high temperature wells, heavy oil wells and high pressure and high temperature wells. Some case studies are shown below on the usage of Hollow Microspheres Cement.

Case 1

Heavy oil well in Duri field, Indonesia uses cementing solution with Hollow Microspheres. Hollow Microsphere is used in steam injected field.

Case 2

Hollow Microspheres used in drilling fluid to control hole enlargement during drilling in Permafrost (permanently frozen ground, is ground, either soil or rock that remains at or below 0 ^{o}C (32 ^{o}F) for two or more years. Hole enlargement leads to lost circulation. Irregular and unstable holes also affect the quality of cement jobs. The temperature generally higher in permafrost formation which causes a heat transfer. The ice particles binding the sediments will also start to melt. This paper proposes to minimize this problem with a low thermal conductivity fluid by using hollow microspheres [18].

4.3.2 Cement Slurry without Spherelite Cement Additive

Cement Slurry without Spherelite cement additive cannot provide reliable sealing of the annular. It is caused by heightened water loss, low sedimentation stability, contraction and shrinkage strain during solidification. These factors lead to formation of channels able to conduct formation fluid both along cement stone body and its contact zones (cement stone-formation, cement stone-casing string). This will lead to bigger stress contact with the casing. Subsequently, these will affect and cause poor cement rheology, thickening time, free water, fluid loss and compressive strength.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The targeted objectives have been successfully achieved:

- To investigate the Low Density Cement on high temperature and high pressure well. Hollow Microspheres shows good physical and chemical properties over conventional cement.

- To analysis the effects Hollow Microspheres on the compressive strength, fluid loss, free water time thickening, and slurry rheology of cement. Cement composition with Hollow Microspheres content showed good compressive strength and thickening time values which are higher than the field requirements.

5.2 Recommendations

There is still much work that can be done on this project. The following are some of the recommendations that should be taken into account for any future research:

1. The chemical reaction between the Portland cement Class G and the spherelite additive should be determined before the field use. Presence of weak components in the cement samples would have potential to degrade in high temperature and high pressure environments.

2. The cement slurry should be further tested at HPHT simulated conditions.

3. Ultra hollow microspheres can improve lightweight cement performance in high temperature and high pressure wells and should be further tested.

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APPENDIX

Formula

1. $BHP = 0.052 * d * TVD$

   Where BHP = Bottom Hole Pressure in psi

   d = Density of Cement slurry in lb/gal

   TVD = True Vertical Depth in ft.

2. Gradient ($^{o}F/100ft$) = $(BHST – 80) / TVD$

   Where Gradient = Change in Temperature per given depth

   BHST = Bottom Hole Static Temperature in ^{o}F

   TVD = True Vertical Depth in ft.

3. Fluid Loss at $Q_{30mins} = \frac{Qt * 2 * 5.477}{\sqrt{T}}$

   Where Q_{30mins} = Quantity of fluid loss in 30mins.

   Qt = Quantity of fluid loss in time #

   T = Test Duration

4. Free Fluid = $\frac{\text{ml of Fluid} * 100\%}{250}$

5. Plastic Viscosity (PV) = 1.5 (300rpm-100rpm) reading

6. Yield Point (YP) = 300rpm reading – PV

7. Compressive Strength (Psi) = $\frac{\text{Force (lb)}}{\text{Area}}$

8. Heat- up Rate = $\frac{BHCT - 80}{\text{Heat up time}}$

9. %bwoc = percentage by weight of cement

10. gal/sk = gallon per sack

11. cu.ft/sk = cubit feet per sack

12. ppm = parts per million

13. Ibs/gal = pounds per gallon

14. MD = measured depth

15. CP = centipoise

16. Bc = Bearden units of consistency