Flowrate Measurement Based on ECD Behavior in Cementing HPHT Well

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
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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.

MUHHAMMAD RAFIUDDIN BIN AZIZ

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ABSTRACT

Cementing in HPHT well is approach used by many players in the oil and gas industry nowadays. This is due to most of reserve is situated in deeper location compare with regular well drill before. In order to perform cementing process in this location, it is very challenging. This is because the HPHT well is high in reservoir temperature and pressure and narrow density window. Therefore, details study and analyze of well parameters should be taken into consideration in design and execute cementing process. This paper is objectively to measure the flow rate of slurry when cementing in HPHT well with regards the ECD behavior. This is being obtained through the cement design slurry by using Landmark software. The software used encompasses three module like COMPASS module, WELLPLAN module and OPTICEM module which well trajectory design through COMPASS module and cement design by using WELLPLAN module and OPTICEM module. Pertaining on that, the ECD behavior is tabulated. As a result, the optimum flow rate of the slurry is measured and recorded.

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ABBREVIATIONS AND NOMENCLATURES

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BHA	Bottomhole Assembly
BHCT	Bottomhole Circulating Temperature
BHST	Bottomhole Static Temperature
BML	Below Mean Sea Level
ECD	Equivalent Circulating Density
ERW	Extended Reach Well
FYP	Final Year Project
HPHT	High Pressure High Temperature
ID	Internal Diameter
MD	Measured Depth
MWD	Measurement While Drilling
OD	Outer Diameter
PSD	Particle Size Distribution
ROP	Rate of Penetration
SPE	Society of Petroleum Engineers
TOC	Top of Cement
TVD	True Vertical Depth
UTP	Universiti Teknologi Petronas
WWW	World Wide Web

CHAPTER 1

1.1 BACKGROUND STUDY

Oil and gas production are really important in the world industry as they being used as energy sources. For instance, agriculture basis like food preservatives and fertilizers, clothing and textiles basis like bracelets, shoe laces and sneakers, office equipments like ink and printer cartridges, sport and games basis like waterproof clothing and oil paints, and kitchen and household basis like detergents bottles and jars. All of these products could only be manufactured through extraction of oil and gas from well. If the platform is not safe or improperly designed, the production of hydrocarbon will not being optimized and even worse no production at all and leading to fatal like incident happen at Macondo Well, Gulf of Mexico. Prior to hydrocarbon production, the candidate well should properly design and monitor. One of the major steps in well design is cementing well.

Cementing refer to a process of effectively displace a drilling fluid with cement at certain vertical depth within wellbore and annulus for well control purposes. It is really important in order to hold the casing from collapse, provide zonal isolation, to prevent gas mitigation and others. The good cement design will lead to safe production of hydrocarbon from candidate well. There are many parameters should be taken into consideration in designing the cement. The cement engineer should analyze and measure the depth, cement volume, cement slurry properties, thickening time, transition time, types of cement and many more.

For deep well or High Pressure and High Temperature (HPHT) well, the cement process is really challenging because of the complexity of well behavior like density, temperature and pressure. It is even more challenging when dealing with narrow pore pressure and fracture pressure also known as ECD window. In order to design good cement at this condition, the cement engineer should study and measure the equivalent circulating densities (ECD) of the slurry. Pertaining on that, software known as OptiCem software could be used for achieving this purpose. Furthermore, the displacement rate or annular velocity could be measured by study and analyzing the ECD behavior.

Overall, this research will discuss on the measurement of optimum flowrate through designing cement slurry in HPHT well based on ECD behavior.

1.2 PROBLEM STATEMENT

1.2.1 Problem identification

Cementing in HPHT can be refer as new idea in oil and gas industry specifically in Malaysia. Recently, most players in oil and gas industry dealing with HPHT well. The problem of cementing in HPHT well is the environment of reservoir is not the same as the shallow well reservoir because of the high pressure and temperature value and complexity of well characteristics. These parameters give significant effect on the cement design. If the cement is not properly design it lead to well control problems like slurry lost into formation and kick.

Consideration of ECD behavior should be emphasized in cementing HPHT well. Based on the variation of pressure and temperature in HPHT well, it gives significant effect on ECD behavior. Good cement design signify the density of the cement is not less than pore pressure and not exceeded the fracture pressure of the interest hole section. The

HPHT well encompasses narrow ECD window which make the cement design become more complex.

There are several factors affecting ECD behavior like rheology of slurry, hole cleaning and surge pressure through tripping. By manipulation these factors, the ECD is being analyze. Nevertheless, this project emphasize on the change of flowrate value in order to obtain the optimum flowrate or annular displacement of slurry.

Therefore, measuring the optimum flowrate by study and analyzing the ECD behavior should be conducted in order to design suitable and economical cement.

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1.2.2 Significant of the project

This paper is regarding on the simulation basis for the purpose of obtaining optimum flowrate by designing cement slurry using software that used by HALLIBURTON. The software used is LANDMARK. In HPHT well it is hard to design the suitable slurry. Therefore, this project is focusing on the design cement slurry by getting the displacement rate or annular velocity through analyzing ECD behavior.

1.3 OBJECTIVE

The main objective of the project is to determine the optimum displacement rate and annular velocity of cement slurry by using the Landmark software. The objectives to be achieved are:

i. To determine the ECD behavior from different hole sections
ii. To study and analyze the effect of ECD behavior on cementing HPHT well
iii. To determine the optimum flowrate or annular velocity for designated cement slurry at each hole section

1.4 SCOPE OF STUDY

Throughout the project of designing cement slurry for different hole sections by determining the optimum annular velocity, the scope of study involve conducting simulation using Landmark software. Below are the scopes of work which are related with the successful of the finding.

i. Well parameter and characteristic

   For cementing, do research by defining the important parameters and characteristics for design the suitable cement. The important indicators should be studied are knowing the depth of the target well location, the wellbore geometry like hole dimension, the temperature of the well like bottom hole circulating temperature (BHCT), bottom hole static temperature (BHST), the formation pressure or pore pressure, fracture pressure and rock characteristics and lastly, the formation characteristic like the fluids pressure, present of corrosive gas and PH value.

ii. Design cement using Landmark software

   Using the software to design well trajectory and cement design. The data which related to well and cement design are used. The design will lead to determining the suitable design of cement slurry for different interest hole section. The project will focusing on the finding of optimum flowrate by analyze the ECD behavior for different hole section. Then, any graph or result based on the finding is recorded and tabulated.

iii. Analyze the result from Landmark

   The result for each hole section is recorded, tabulated and analyze. By analyzing the result, it will lead to obtaining the optimum annular velocity or displacement rate of cement slurry. This final finding is really important for achieving the objective of this project.

1.5 RELEVANCY OF THE STUDY

This project is focusing on getting cement slurry optimum flow rate or annular velocity and best slurry density by designing cement slurry based on ECD behavior for different hole section in HPHT well. Recently, the cementing in HPHT well can be consider as a new thing as this process was being applied and practices by oil and gas players around the world. Pertaining on that, the design of cement slurry is conducted based on the first HPHT well drill in Malaysia which the research being publish on SPE paper on 2012. This revelation proves that the Malaysia currently practices drilling HPHT well. Through completing this project, the author could understand the cementing job process in HPHT well specifically in measure the optimum annular velocity and slurry density based on ECD behavior.

1.5.1 Feasibility of the project within the scope and time frame

The project started with literature review by gathering information in order to understand the concept of cementing, cementing in HPHT well and ECD. This information are gather through reading articles, research paper on SPE, lecture notes, textbooks and World Wide Web (WWW) or internet. Apart from that, the author attending Landmark class conducted by Petroleum Engineering department that being deliver by one of the HALLIBURTON engineer. The class gives exposure on Landmark software and the way to use it. In order to have better understanding on the software, the author also learns from author’s friend. The further work includes designing the cement slurry based on different hole sections selected. Pertaining on that, any available real field data is input into the software and simulate the cementing job, then, analyze the result show by the software. Next, proper analysis, comparison, recommendation and conclusion were recorded regards on the finding that resulting on getting the optimum slurry density and optimum annular velocity. Then the final step is preparing report and presentation. All of the process of the project completion directed within time frame given by Universiti Teknologi Petronas (UTP).

CHAPTER 2

2.1 LITERATURE REVIEW

2.1.1 Designing model using Landmark Software

Landmark software is software own by Halliburton company. The software is intended to assist any oil and gas engineer to make decision toward any problems regarding on the well for hydrocarbon production. There are several module inside Landmark like WellPlan for provides accurate BHA design and selection in complex drilling scenarios, WellCat for provides precise solutions for both wellbore analysis and integrated casing and tubingdesign, Profile for enables engineers to create and document planned completions designs and also review current and historical equipment installation and configuration in completed wellbores and StressCheck for trial and error out of designing casing, liner and tubing strings and minimizes the cost of well tubular.The software can be used to design well trajectory, design casing, assist in drilling process and many more. Pertaining on that, the software is really reliable and applicable to be used by engineer and student in order to do simulation or getting well data or any data prior to production of hydrocarbon.

For the Final Year Project (FYP) purposes, there are several researches which have been conducted by using Landmark Software. According to Sin. C. W. (2012) hole cleaning analysis for underbalanced drilling can be measure using Landmark. Based on the research, the author used Landmark software to calculate the pressure gradient of hole section in order to measure the optimum nozzle size for different drilling condition. By using Landmark, the author design hole cleaning session and analyzing the result by plotting total force area vs rate of penetration (ROP). The result get from the Landmark software is being compared with Beggs and Brill calculation and experimental setup.

Although the research is not related to cementing, the research give an idea on what is Landmark software is capable of in analyze and assisting getting data from various well problems and it also gives more exposure on the author to have better understanding using Landmark software to achieve objective set for this project.

2.1.2 Cementing

Cementing is one of the vital steps in well completion. Cementing refer to fills and seals an annulus between the casing string and drilled hole. According to Frittela et al (2009) stated that cementing can provide zonal isolation and casing support, whilst at the same time being able to tolerate massive changes of temperature and pressure. Apart from that, Yetunde and Ogbonna (2011) mention on the function of cementing which are providing structural integrity, provide continuous impermeable hydraulic seal in the annulus, preventing uncontrolled flow of reservoir fluids behind the casing and provide zonal isolation. Based on the function emphasize by these papers it is explain that the cementing process is really an important step in production of hydrocarbon from a well.

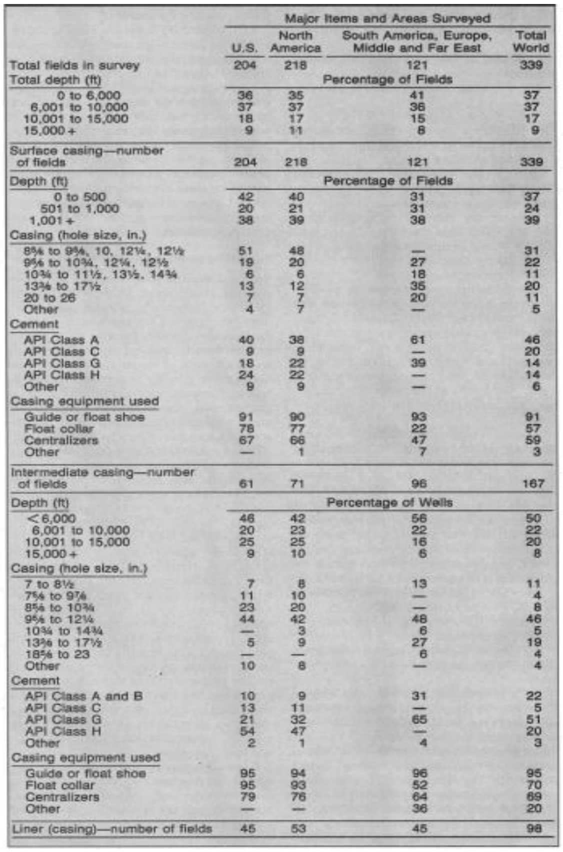
There are many criteria or parameters should be applied in order to design cement slurry. Some of the criteria are:

i. API cement class
ii. Displacement rate
iii. Casing eccentricity
iv. Flowrate, viscosity, rheology, depth, volume and etc.

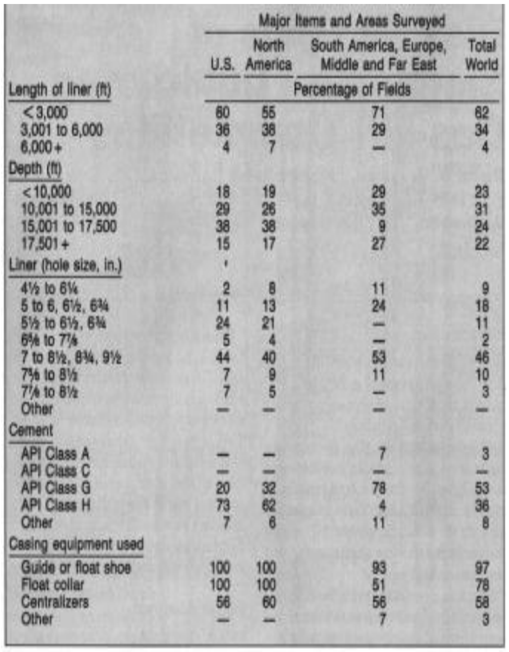
2.1.2.1 API cement class

Based on the location selected, the software will suggested the most suitable cement and drilling fluids regarding on the cement class and API standard. According to Morgan, the specification for oil-well cements can be useful to the oil and gas companies, the service companies and the cement manufacturers in classifying, identifying, and specifying Portland cement. This article explain on seven classes in regular and high sulfate-resistant types which are class A, B, C, N, D, E and F. each class intended for certain well depth and characteristic.

According to Calvert and Smith (1990), the national API committee adopted standards for six classes of cements used in oil and gas well cementing operations. The first tentative standard in 1953, designed API Std. 10A, was entitled API specification for oil well cement. The standards for sic classes of well cements covered chemical requirements, determined by ASTM procedures, and physical requirement, determined in accordance with procedures outlines in API RP 10B and ASTM. API committee surveyed 339 fields located throughout active drilling areas of the world. Because more than 70% of this drilling activity is in North America, a greater response was received from the US and Canada. Depth, casing/hole relationship, cements and casing equipment are expressed as percentage in each area for surface, intermediate, production or liner operation.



	Major Items and Areas Surveyed			
	U.S.	North America	South America, Europe, Middle and Far East	Total World
Total fields in survey	204	218	121	339
Total depth (ft)			Percentage of Fields	
0 to 6,000	36	35	41	37
6,001 to 10,000	37	37	36	37
10,001 to 15,000	18	17	15	17
15,000 +	9	11	8	9
Surface casing—number of fields	204	218	121	339
Depth (ft)			Percentage of Fields	
0 to 500	42	40	31	37
501 to 1,000	20	21	31	24
1,001 +	38	39	38	39
Casing (hole size, in.)				
8⅝ to 9⅝, 10, 12¼, 12½	51	48	—	31
9⅝ to 10¾, 12¼, 12½	19	20	27	22
10¾ to 11½, 13½, 14¾	6	6	18	11
13⅜ to 17½	13	12	35	20
20 to 26	7	7	20	11
Other	4	7	—	5
Cement				
API Class A	40	38	61	46
API Class C	9	9	—	20
API Class G	18	22	39	14
API Class H	24	22	—	14
Other	9	9	—	6
Casing equipment used				
Guide or float shoe	91	90	93	91
Float collar	78	77	22	57
Centralizers	67	66	47	59
Other	—	1	7	3
Intermediate casing—number of fields	61	71	96	167
Depth (ft)			Percentage of Wells	
< 6,000	46	42	56	50
6,001 to 10,000	20	23	22	22
10,001 to 15,000	25	25	16	20
15,000 +	9	10	6	8
Casing (hole size, in.)				
7 to 8½	7	8	13	11
7⅝ to 9⅞	11	10	—	4
8⅝ to 10¾	23	20	—	8
9⅝ to 12¼	44	42	48	46
10¾ to 14¾	—	3	6	5
13⅜ to 17½	5	9	27	19
18⅝ to 23	—	—	6	4
Other	10	8	—	4
Cement				
API Class A and B	10	9	31	22
API Class C	13	11	—	5
API Class G	21	32	65	51
API Class H	54	47	—	20
Other	2	1	4	3
Casing equipment used				
Guide or float shoe	95	94	96	95
Float collar	95	93	52	70
Centralizers	79	76	64	69
Other	—	—	36	20
Liner (casing)—number of fields	45	53	45	98



	Major Items and Areas Surveyed			
	U.S.	North America	South America, Europe, Middle and Far East	Total World
Length of liner (ft)			Percentage of Fields	
< 3,000	60	55	71	62
3,001 to 6,000	36	38	29	34
6,000 +	4	7	—	4
Depth (ft)				
< 10,000	18	19	29	23
10,001 to 15,000	29	26	35	31
15,001 to 17,500	38	38	9	24
17,501 +	15	17	27	22
Liner (hole size, in.)				
4½ to 6¼	2	8	11	9
5 to 6, 6½, 6¾	11	13	24	18
5½ to 6½, 6¾	24	21	—	11
6⅝ to 7⅞	5	4	—	2
7 to 8½, 8¾, 9½	44	40	53	46
7⅝ to 8½	7	9	11	10
7⅞ to 8½	7	5	—	3
Other	—	—	—	—
Cement				
API Class A	—	—	7	3
API Class C	—	—	—	—
API Class G	20	32	78	53
API Class H	73	62	4	36
Other	7	6	11	8
Casing equipment used				
Guide or float shoe	100	100	93	97
Float collar	100	100	51	78
Centralizers	56	60	56	58
Other	—	—	7	3

FIGURE 1: Summary of worldwide drilling and completion, Calvert and Smith (1990**)**

2.1.2.2 Displacement rate

Richard and Ronald (1979) stated that effective displacement of drilling fluid by cement is a critical factor in successful completion of oil and gas wells. Failure of doing so will lead creating channels of drilling fluid by-passed by the cement in the annulus. In this paper, the authors mention several factors which influence displacement in a vertical wellbore which are condition of the drilling fluid, pipe movement, pipe centralization, flow rate, amount of fluids flowed part a particular interval and difference in density between the two fluids.

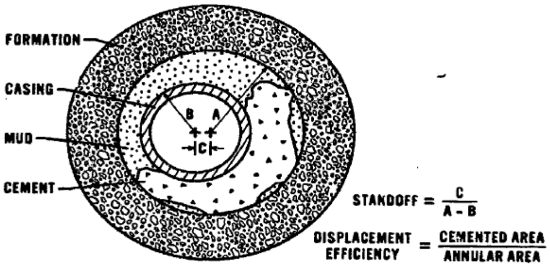


FIGURE2 : Definition of standoff and displacement efficiency. Richard and Ronald (1979)

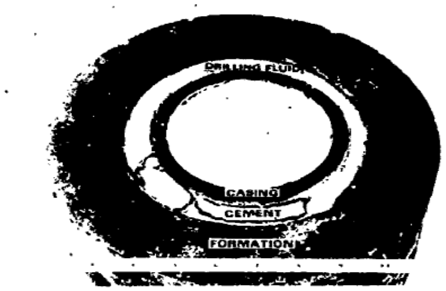


FIGURE3: Typical mud/cement displacement result. Richard and Ronald (1979)

2.1.2.3 Casing eccentricity

According to Zhaoguang et al (2012) stated that casing centered in the hole without any cementing complications is the perfect case. This is also referring to 100% standoff. Casing eccentricity and cement channel usually happen simultaneously. Cross section area fluid flow velocity is different during cementing could be happened if the casing is not centered. This may lead to the cement channel problem in lower clearance area. This wills gives effect to von misses stress in the casing where Von Mises stress is sensitive to cement Young’s modulus and formation Young’s modulus. Through the paper, the authors mention the casing eccentricity usually depends on wellbore angle, the number of casing centralizers and wellbore dimension. When casing is off centered, the fluid flavors the path of least resistance and flow more rapidly on the wide side than on the narrow side of the geometry. This is resulting in annulus may be left with long strip of inefficient cementing displacement of the slurry.

TABLE 1 : Casing cement maximum von mises stress distribution for different void cases. Zhaoguang et. al (2012)

	Brittle Cement		Elastic Cement	
	Casing Von Mises Stress (psi)	Cement Von Mises Stress (psi)	Casing Von Mises Stress (psi)	Cement Von Mises Stress (psi)
Casing Centered in the Hole	49,598	15,418	46,246	14,658
Rectangle Void in the Center of Cement	53,010	47,234	46,770	28,878
Circle Void in the Center of Cement (0.1 in. radius)	50,559	39,592	49,314	34,542
Circle Void in the Center of Cement (0.15 in radius)	53,035	44,455	51,685	39,899
Circle Void in the Center of Cement (0.2 in. radius)	56,925	48,378	55,414	43,872

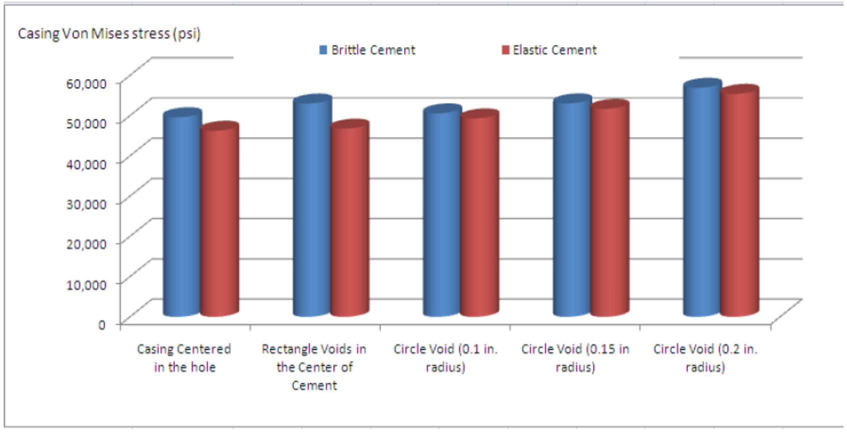


FIGURE4: Maximum Von Mises Stress in Casing. Zhaoguang et. al (2012)

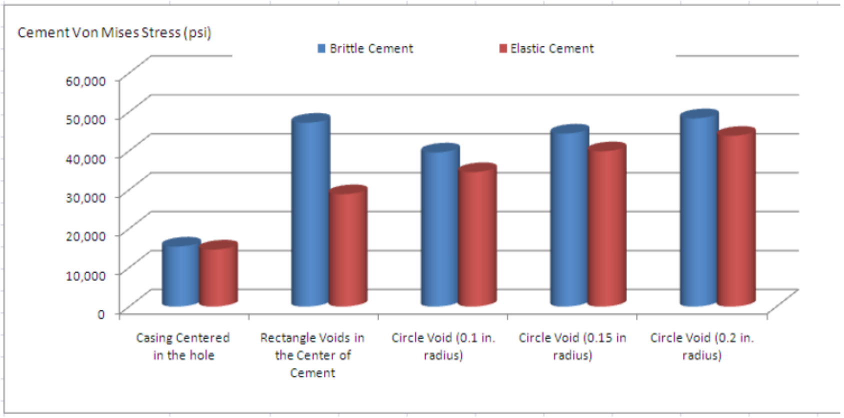


FIGURE5 : Maximum Von Mises Stress in Cement. Zhaoguang et. al (2012)

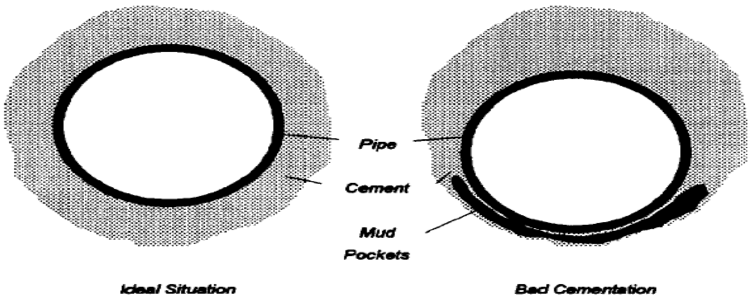


FIGURE6: Cementation based on cement eccentricity. Holger and Thomas (1997)

2.1.2.4 Flowrate, viscosity, rheology, depth, volume and etc

There are other factors that design engineer should take into consideration when designing cement slurry. There are slurry viscosity and density, volume, rheology and others. These factors are really important for preparing good cement. Below is the case study of some cementing process in Malaysia which mentioning several parameters of cement slurry in order to safely production of hydrocarbon from candidate wells.

2.1.2.5 Case study of cementing in Malaysia region

Pertaining on the software development, it is focusing on Malaysia region. Based on Abdul Rahman and Chong (1997), latex cement was used primarily for gas migration control to successfully cement the first multilateral well with cemented junction in the Asia-Pasific. Latex cement is a cement system that utilizes latex polymer dispersion as its main component. A styrene/butadiene ratio of 60:40 is a good balance of properties. To further enhance the chemical and physical stability of the dispersion, a high concentration of anionic surfactant can be added to the dispersion. Besides, the journal stresses on the compressive strength were actually reduced with increasing latex dispersion concentration.

At concentration of 2.5 gps of latex dispersion, the slurry started to increase in Pv and Yp beyond the ideal properties. The thickening times were decreased with increasing latex dispersion concentration.

According to Hampshire, et al. (2004) explains on solution-oriented approach to design and execution of a cement job for deepwater operation in the South China Sea. They suggest using non-foamed, engineered particle-size-distribution (PSD) slurries for cementing the surface casing strings in deepwater exploratory wells.

Based on that, the article included case histories. First at the Kikeh-5 well at block K, Offshore Sabah, East Malaysia, the water depth is 4380 ft, 36 in casing jetted to 322 ft below mean sea level (BML), 20 in section cased to 2297 ft BML. The volume of excess slurry designed was 100% of the annular volume for 24-in open hole. For the second case history regarding on the Kakap-1 well at block K, offshore Sabah, East Malaysia, the water depth is 3166 ft, 36 in casing jetted to 270 BML, 20 in section cased to 2297ft BML. This well experienced a shallow-water flow while drilling. To stop the flow and the remainder of the 24-in, hole was drilled using a mixture of 16-lbm gal mud and seawater. The differences between foamed cement and PSD slurry can be illustrated by figure 7 and figure 8.

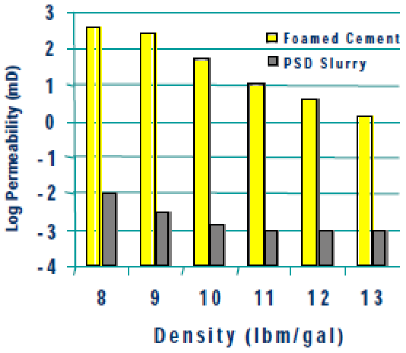


FIGURE 7: Permeability vs density. Hampshire, et al. (2004)

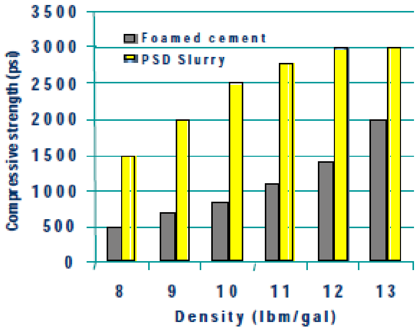


FIGURE 8: Compressive strength vs density. Hampshire, et al. (2004)

2.1.3 Cementing in HPHT well

Bruice Craigh (2008) claimed that the deep well is well which have depths of 25000ft (7620m). As the depth increases, the pressure and temperature also increases which temperatures and pressure at the bottom of the well exceed 300 to 350 ^{o}F (149 to 177 ^{o}C) and 10000 psi (69MPa) respectively. The deep well or HPHT well is wells with pressures that exceed 15000 psi and temperature that exceed 300^{o}F which the depth located at depth greater than 15000 ft stated by Yutunde and Ogbonna (2011)

As cementing in deep well might also happen in deep water well, there are special criteria need to be taken into considerations. Based on Frittella and Babbo (2009) a job cement design in HPHT well should have the following information to getting a laboratory report or recommendation.

i. Well description
ii. Temperature
iii. Mud characteristics
iv. Pore pressure and fracture pressure
v. Information about previous offset wells

The authors stated depth, hole size, casing hardware and deviation are the basic parameters required to start a design. Besides, for deep wells, mud weights ranging from 1.8kg/l (15.0 ppg) to 2.5 kg/l (20.9) are typically required for drilling. Apart from that, pore and fracture pressure information are other important consideration for the successful planning of HPHT cementing jobs. These pressures could be determined using wireline or MWD petrophysical data and effective stress calculations. In order to successfully implementing cementing jobs for a HPHT well, the engineer should have a functional tools and equipments.

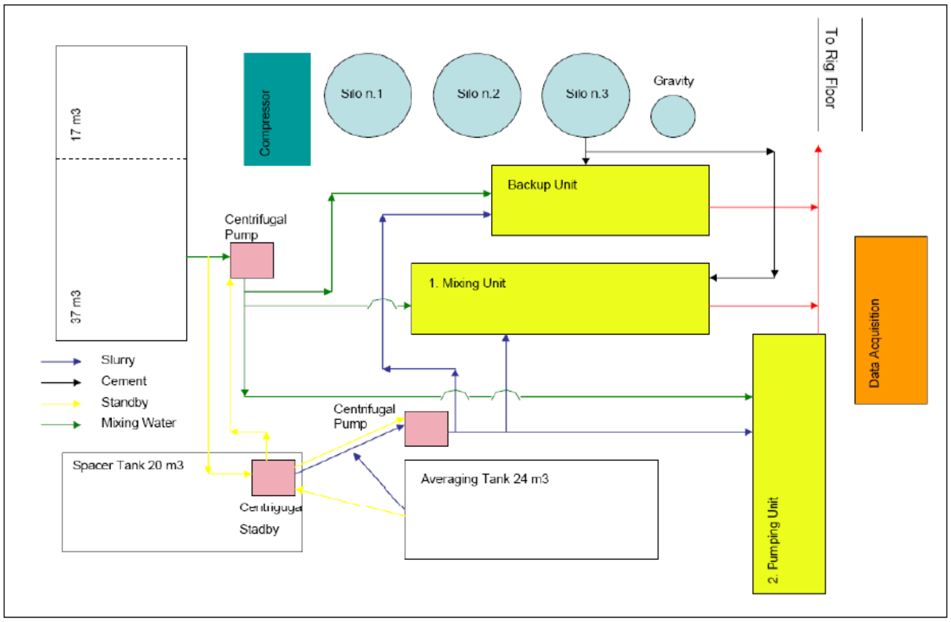
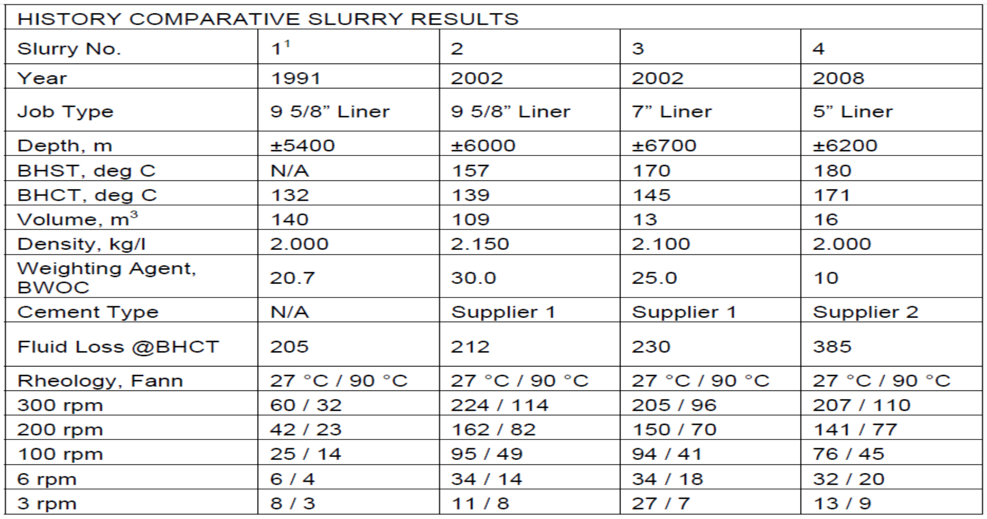


FIGURE9: Typical Layout of large volume HPHT cementing jobs. Frittella and Babbo (2009)

TABLE 2 : History comparative slurry results. Frittella and Babbo (2009)



HISTORY COMPARATIVE SLURRY RESULTS				
Slurry No.	1[1]	2	3	4
Year	1991	2002	2002	2008
Job Type	9 5/8" Liner	9 5/8" Liner	7" Liner	5" Liner
Depth, m	±5400	±6000	±6700	±6200
BHST, deg C	N/A	157	170	180
BHCT, deg C	132	139	145	171
Volume, m^3	140	109	13	16
Density, kg/l	2.000	2.150	2.100	2.000
Weighting Agent, BWOC	20.7	30.0	25.0	10
Cement Type	N/A	Supplier 1	Supplier 1	Supplier 2
Fluid Loss @BHCT	205	212	230	385
Rheology, Fann	27 °C / 90 °C	27 °C / 90 °C	27 °C / 90 °C	27 °C / 90 °C
300 rpm	60 / 32	224 / 114	205 / 96	207 / 110
200 rpm	42 / 23	162 / 82	150 / 70	141 / 77
100 rpm	25 / 14	95 / 49	94 / 41	76 / 45
6 rpm	6 / 4	34 / 14	34 / 18	32 / 20
3 rpm	8 / 3	11 / 8	27 / 7	13 / 9

Table 2, show that the comparative slurry result based on case history of several cementing operation have been performed in Italy. Below are several parameters that stated by the authors which need to take into consideration in cement job design.

TABLE 3 : Cement job considerations. Frittella and Babbo (2009)

Cement	•Regulated by the API Specification 10A / ISO 10426-1 •High cementing jobs are generally performed with API class G or class H cement
Fluid loss control	•The maximum casing or liners, the maximum fluid loss should be between 40 and 100 ml in 30 min. •Liquid fluid loss additive is often chosen
Retarder	•Small temperature change around 5^0 C (10^0F) can result in a large change in thickening time •High temperature retarder or synthetic high temperature retarder is usually used
Weighting agent	•Used heavy mud systems with density above 2.0 kg/l (16.5ppg) requires weighting agent •Dry blending a weighting agent into the bulk volume cement is difficult to mantain a consistent slurry density •Manganese Tetraoxide is preferable weighting agent
Spacer	•Heavy spacer help to minimise overbalanced pressure •Best mud removal can be achieved through annular velocity greater than 80 m/min (262 ft/min) •At least 200 m of spacer should be pumped ahead of the cement slurry and 50 m behinf to mantain seperation from displacement and avoid slurry contimination
Cementing simulator	•Calculate flow behavior, flow rate/ annular velocity and differential pressure •Predict ECD, displacement efficiency, standoff value, job operation time for proper thickening and Reynolds numbers.

According to Mishra (2006), several challenges might be faced for cementing surface casing in deep water well. Large diameter surface casings are set unconsolidated formations, with narrow pore fracture pressure window and high potential for shallow flow hazards. This problem is further aggravated due to a very low temperature found at the seabed and first few hundred meters below mud line. The recommended slurry is;

- High performance light weight slurry
- Low slurry weight in the range of 11-12ppg
- Controlled fluid loss less than 50 c.c
- Low transition time
- Low permeability
- Ability to set and attain good compressive strength at very low temperature
- Zero shrinkage
- Ductile cement system which can withstand cyclic loading

Youssef and Beggah (2013) mention deep water drilling with shallow water flows and lost circulation is a major challenge that becomes more critical as the water depth increases. To overcome this, dual-density drilling is used. In deep water drilling, the fracture pressure of the soft sediment on the seafloor is roughly equal to overburden pressure. The long column of drilling fluid in the riser helps to control water flows just below the casing shoe, but as the open hole is deepened, any increase in drilling fluid density to control the deeper and more pressures water flow will cause lost circulation at casing shoe.

Apart from that, cementing in HPHT well faced many challenges. Due to that, Yetunde and Ogbonna (2011) highlighted in their research the challenges and remedy for cementing in HPHT wells. The challenges and remedy is tabulate as per Table 4 and Table 5.

TABLE 4 : Cementing challenges and remedy. Yetunde and Ogbonna (2011)

The effect of temperature

- At high temperature, thickening time of slurry higly redused, so cement set faster
- Affect rheological properties of cement which plastic viscosity (PV) and Yield viscosity (YV) decrease in temperature increase

The effect of pressure

- Pressure not been properly estimated will invariably lead to collapse and resulting in kick
- Weighting agent used to create the minimum over balance will reduce pumpbility of the cement and lead to accelerating the development of premature compressive strength

Small ECD window

- Increase hydrostatic head causes an increase in ECD
- Increase in temperature cause decrease in ECD

The degradation of post set cement

- Expansion and contracting of casing and plastic formation like salt causes cracks in the already set cement

Large stress on post-cement

- High load in deep wells compression sets in and destroys the cement shealth by compacting of matrix porosity
- Cause by mechanical failure and create cracks in the cement matrix which lead to create pathway for migration of gas from the formation to the surface

Migration of gas

- Al-Yami et al (2009) pointed out approximately 80% of wells in Gulf of Mexico have gas transmitted to surface through cementing casing

Retrogression strength

- Cement will attain maximum strength after one fortnight is exposed to temperature exceeding 230^{0}F
- When cement is set, it contain complex calcium silicate hydrate called tobermorite which converted to a weak porous structure at temperature around 250^{0}F

Accurate estimation of temperature and monitoring downhole condition

- Estimated bottomhole circulating and static temperature using simulator

Efficient slurry design

- construct well that ensures a means of safe and economic production of hydrocarbon by considering engineering analysis, cement slurry design and testing, and cement slurry palcement and monitoring respectively

Stabilizing of cement system and stopping of strength retrogression

- Silica flour or silica sand is commonly used to prevent strentgh retrogression by modifying the hydration chemistry and it can used with all clasess Portland cement

Antigas migration slurry design for HPHT wells

- Hydrostatic pressure of cement column and mud above it must be greater than pore pressure of gas-bearing to prevent fluid invasion and must not exceeding fracture pressure of formation to prevent losses

Use expansion additive for improved cement bond

- Used Burnt Magnesium Oxide (MgO) as expansion additive as it can increase shear bond strenth but will reduce compressive strength although still higher than recommended minimum value

Efficient displacement of mud

- Used spacers and flushes as they are effective displacement aids because they separate unlike fluid such as cement and drilling fluid, and enhance the removal of gelled mud allowing a better cement bond

Casing design

- Chosen casing which have high MAWP to withstand high pressure in order to prevent a burst due to heavy cement being pumped through the casing string or collapse due to pore pressure

Besides, Youssef and Amor (2013) explained deepwater drilling with shallow water flows and lost circulation is a major challenge that becomes more critical as the water depth increase. Dual- density drilling has evolved as solution to this problem.

For API cement class for cementing HPHT well, Peters and Schindler (2001) pointed fluid loss control and lightweight lead slurries are required for cementing the deep surface casing strings. Intermediate and production casing strings require low permeability set cements to prevent deterioration in the extended life of the well. Gas invasion and migration must be prevented when cementing the deep intermediate and production casing. Properly designed annular pressure control may be required during deep cement jobs, and high temperatures may require the use of Class H oil well cement instead of the commonly used construction quality Class A.

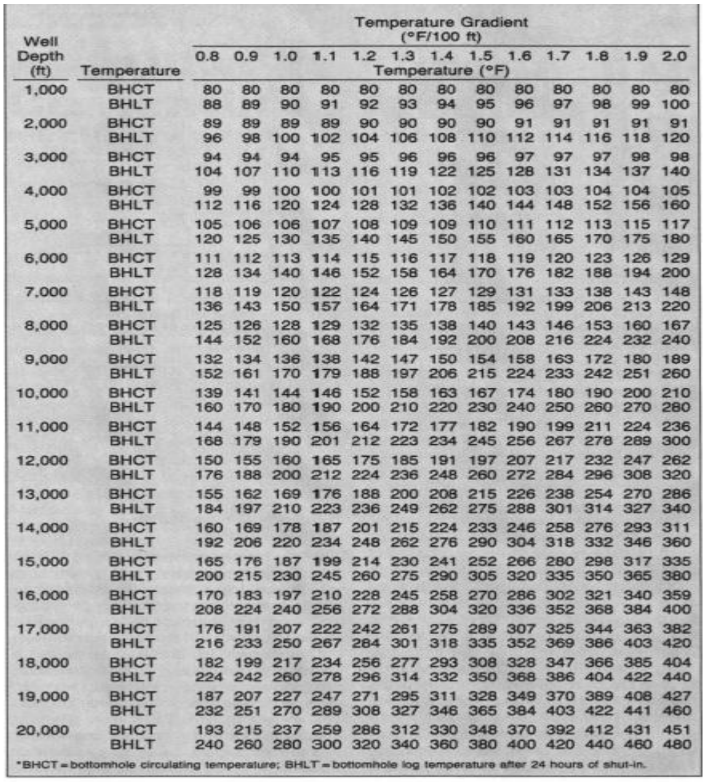
Apart from that, Nasvi et al. (2012) find that the optimum curing temperature for higher strength of geopolymer and class G cement lies in the same range (50-60 ^{o}C). However, G cement possesses higher strength at ambient conditions, whereas geopolymer has higher strength at elevated temperatures. Generally, class G cement will be good as well cement up to a depth of 1 km, whereas geopolymer will be suitable at depth of more than 1 km. Besides, at lower curing temperatures, G cement shows higher values of Young’s modulus and geopolymer has higher values at elevated curing temperatures. This means G cement is stiffer at ambient conditions compared to geopolymer, while geopolymer is stiffer at elevated temperatures.

Apart from that, to cement at HPHT well the temperature should be taken into consideration. Based on Wooley et al. (1984) highlighted on one important factor for cementing a deep well production liner, or any casing string, is cement temperature while pumping down and while waiting on cement to set. The inaccuracies in methods of determining cementing temperature are dramatized for deep well applications. It is also lack of sufficient measured data for deep well and errors that increase with depth. Apart from that, Calvert and Griffin (1998) explained when cementing oil and gas wells, the engineer require the temperature of the well to be able to properly design the cement slurries. Several temperatures are recognized and are used in testing the slurries.

They are the bottomhole static temperature (BHST) and the bottombole circulating temperature (BHCT). Normally, the BHST is used for testing to determine the strength or its rate of development. The BHCT is used to determine the thickening time, fluid loss andother properties.

According to Calvert and Smith (1990), the API has developed relationship between bottom-hole cementing temperature and pseudo-bottomhole static temperature for temperature gradients of 0.9 to 1.9^{o}F/100ft and for depth to 20,000ft. UP to 230^{o}F, increasing temperature increase strength, however at higher temperature, strength decreases. API industry survey revealed most companies routinely add 35% silica to cement at static temperature 230^{o}F and above to stabilize the cement against losses at this high temperature during placement and settling.

TABLE 5 : Bottomhole cementing temperature by depth, Calvert and Smith (1990)



Well Depth (ft)	Temperature	Temperature Gradient (°F/100 ft)												
		0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
		Temperature (°F)												
1,000	BHCT	80	80	80	80	80	80	80	80	80	80	80	80	80
	BHLT	88	89	90	91	92	93	94	95	96	97	98	99	100
2,000	BHCT	89	89	89	89	90	90	90	90	91	91	91	91	91
	BHLT	96	98	100	102	104	106	108	110	112	114	116	118	120
3,000	BHCT	94	94	94	95	95	96	96	96	97	97	97	98	98
	BHLT	104	107	110	113	116	119	122	125	128	131	134	137	140
4,000	BHCT	99	99	100	100	101	101	102	102	103	103	104	104	105
	BHLT	112	116	120	124	128	132	136	140	144	148	152	156	160
5,000	BHCT	105	106	106	107	108	109	109	110	111	112	113	115	117
	BHLT	120	125	130	135	140	145	150	155	160	165	170	175	180
6,000	BHCT	111	112	113	114	115	116	117	118	119	120	123	126	129
	BHLT	128	134	140	146	152	158	164	170	176	182	188	194	200
7,000	BHCT	118	119	120	122	124	126	127	129	131	133	138	143	148
	BHLT	136	143	150	157	164	171	178	185	192	199	206	213	220
8,000	BHCT	125	126	128	129	132	135	138	140	143	146	153	160	167
	BHLT	144	152	160	168	176	184	192	200	208	216	224	232	240
9,000	BHCT	132	134	136	138	142	147	150	154	158	163	172	180	189
	BHLT	152	161	170	179	188	197	206	215	224	233	242	251	260
10,000	BHCT	139	141	144	146	152	158	163	167	174	180	190	200	210
	BHLT	160	170	180	190	200	210	220	230	240	250	260	270	280
11,000	BHCT	144	148	152	156	164	172	177	182	190	199	211	224	236
	BHLT	168	179	190	201	212	223	234	245	256	267	278	289	300
12,000	BHCT	150	155	160	165	175	185	191	197	207	217	232	247	262
	BHLT	176	188	200	212	224	236	248	260	272	284	296	308	320
13,000	BHCT	155	162	169	176	188	200	208	215	226	238	254	270	286
	BHLT	184	197	210	223	236	249	262	275	288	301	314	327	340
14,000	BHCT	160	169	178	187	201	215	224	233	246	258	276	293	311
	BHLT	192	206	220	234	248	262	276	290	304	318	332	346	360
15,000	BHCT	165	176	187	199	214	230	241	252	266	280	298	317	335
	BHLT	200	215	230	245	260	275	290	305	320	335	350	365	380
16,000	BHCT	170	183	197	210	228	245	258	270	286	302	321	340	359
	BHLT	208	224	240	256	272	288	304	320	336	352	368	384	400
17,000	BHCT	176	191	207	222	242	261	275	289	307	325	344	363	382
	BHLT	216	233	250	267	284	301	318	335	352	369	386	403	420
18,000	BHCT	182	199	217	234	256	277	293	308	328	347	366	385	404
	BHLT	224	242	260	278	296	314	332	350	368	386	404	422	440
19,000	BHCT	187	207	227	247	271	295	311	328	349	370	389	408	427
	BHLT	232	251	270	289	308	327	346	365	384	403	422	441	460
20,000	BHCT	193	215	237	259	286	312	330	348	370	392	412	431	451
	BHLT	240	260	280	300	320	340	360	380	400	420	440	460	480

*BHCT = bottomhole circulating temperature; BHLT = bottomhole log temperature after 24 hours of shut-in.

Pertaining on cementing in deep well, Ilyas, et al. (2012) mention on cementing in deep well almost the same as those in shallow well. However, some of the key points that need to be taken into consideration are:

- Improving density and friction pressure hierarchy
- Effective mud removal
    - Mud properties
    - Pre-job circulation
    - Improving circulation efficiency
    - Casing reciprocation/rotation
- Casing centralization
- Designing top cement
- Used of plug in large casing volumes
- Defining temperature gradient

2.1.4 Equivalent Circulating Density (ECD)

Based on oilfield glossary, ECD refer to the effective density exerted by circulating fluids against the formation that takes into account the pressure drop in the annulus above the point being considered. It is occurred when pumps are turn on. ECD can be derived from formula which consists of variables including mud weight, rheological properties of slurry pump and frictional pressure drop in the annulus.

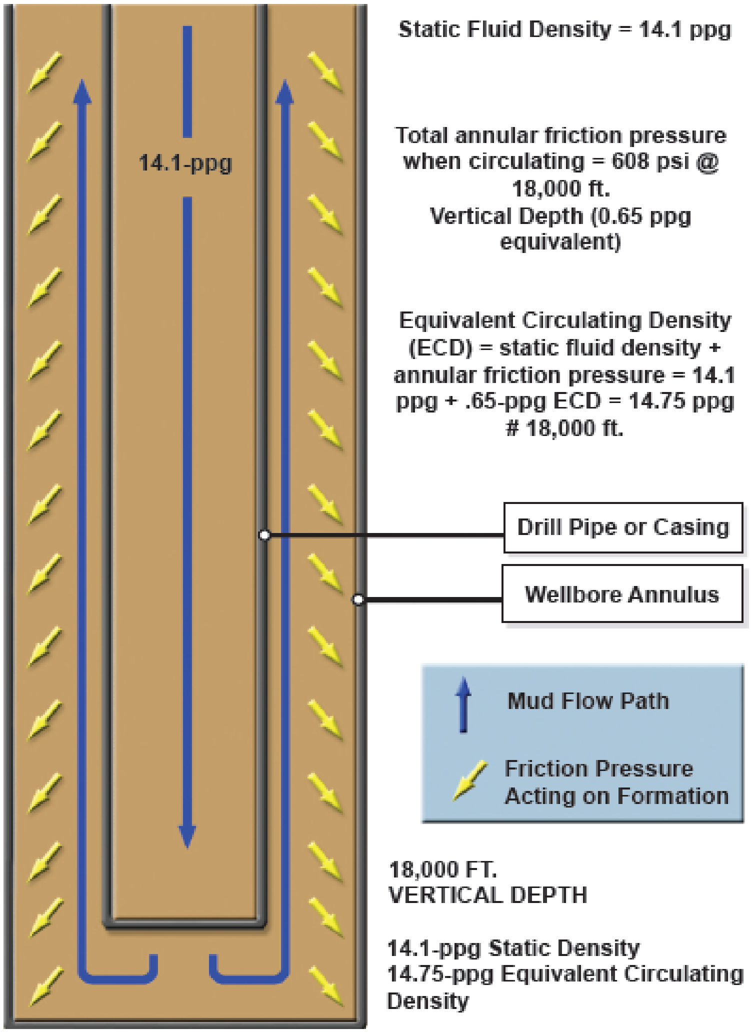


FIGURE10: Equivalent circulating density in a well. Transocean textbook (n.d.)

According to Naganawa and Okatsu (2008), ECD is one of the key issues in designing and drilling extended reach well (ERW). High ECD experienced while drilling a long highly inclined or horizontal section increases risks of drilling problems such as lost circulation, formation failure and consequently formation damage. Besides, insufficient hole cleaning and negative effects on torque and drag can occurred in reduction in mud flow rate in when controlling ECD.

Harris (2004) defined ECD as sum of the hydrostatic head of the fluid column and the pressure loss in the annulus due to fluids flow. The increased hydrostatic head causes increase in ECD due to compression whereas increase in temperature resulting in reduced the ECD due to thermal expansion. The ECD formula is

$$\rho_{ecd} = \frac{1}{0.052h} \left(\Delta P_{hydrostatic} + \Delta P_{friction}\right)$$

Where,

ρ_{ecd} = equivalent circulating density (lb/gal)

$\Delta P_{hydrostatic}$ = hydrostatic head of fluid column (psi)

$\Delta P_{friction}$ = pressure drop due to friction in the annulus

Based on Transocean deepwater horizon rig incident investigation into the facts and causation (2010) explained hydrostatic pressure is the pressure exerted by a fluid due to the force of gravity. The paper mentions pressure at any point in fluid column is generated by height of liquid above that point and higher density or heavier fluid in cylinders of the same height generates more pressure than a lighter fluid. The hydrostatic formula is

Hydrostatic pressure = fluid density x fluid height x gravity

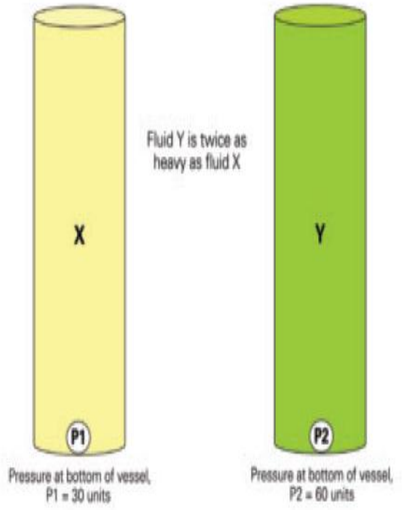


FIGURE11: Pressure different for different fluids density. Transocean deepwater horizon rig incident investigation into the facts and causation (2010)

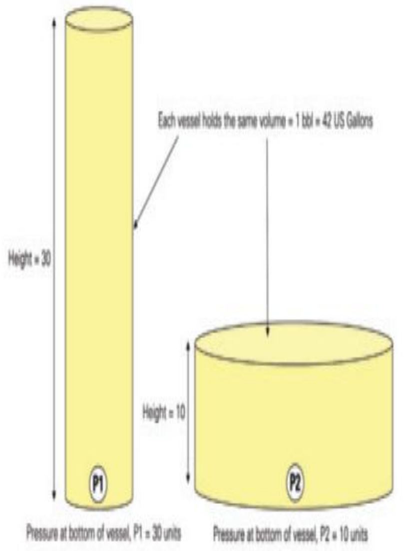


FIGURE13: Pressure different for same volume of fluid. Transocean deepwater horizon rig incident investigation into the facts and causation (2010)

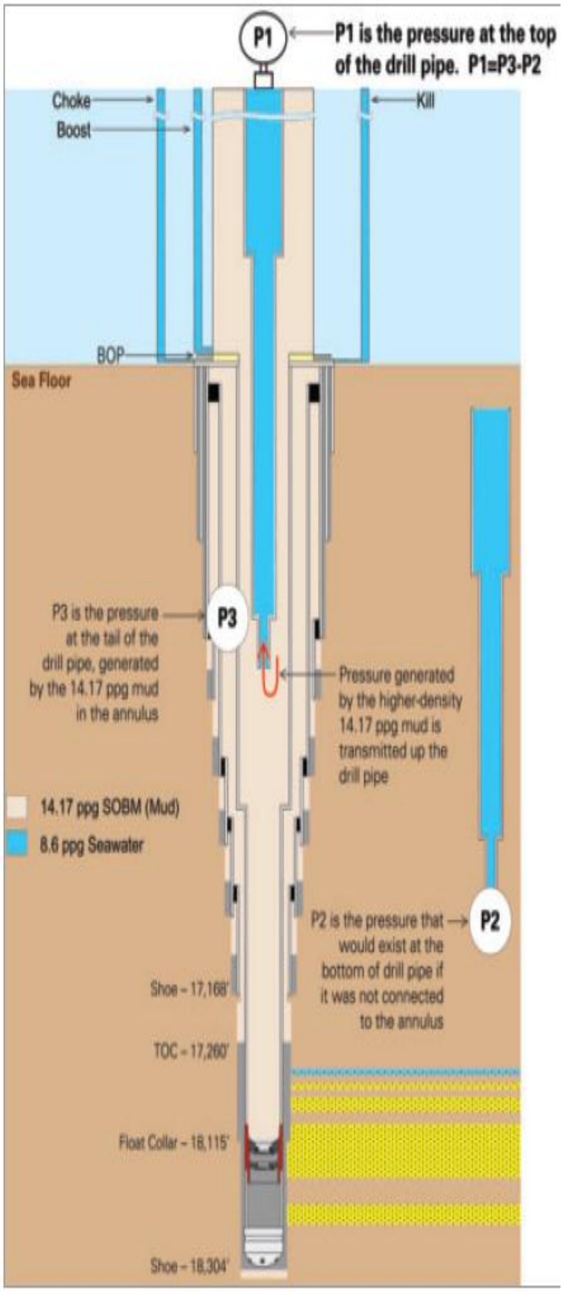


FIGURE 12: Pressure transmission through connected fluid columns. Transocean deepwater horizon rig incident investigation into the facts and causation (2010)

Harris (2004) also pointed out the pressure loss is the loss in pressure during fluid flow due to contact between the fluid and the walls of the fluids conduit. The associated pressure loss is directly proportional to the length of the fluids conduit, the fluid density, the square of the fluid velocity, and inversely related to the conduit diameter. The equation of the pressure loss is

$$\Delta P_{friction} = \frac{2f\rho v^2}{D}\Delta L$$

Where,

$\Delta P_{friction}$ = frictional pressure loss

f = Fanning friction pressure

ρ = fluid density

v = fluid velocity

D = pipe diameter

ΔL = conduit length

Fanning friction factor refer to the ratio between the force exerted on the walls of a fluid conduit as a result of fluid movement, and the product of the characteristic area of the flow conduit and the kinetic energy per unit volume of the fluid. Apart from that, rheological parameters affect pressure losses during flow as fluid rheology is dependent on variation of temperature and pressure. Fluid rheology referred to the study of the deformation and flow of fluid. Relationship between shear stress and shear rate characterize flow behavior of rheological model. There are three types of fluids which are Newtonian non-Newtonian and visco-elastic.

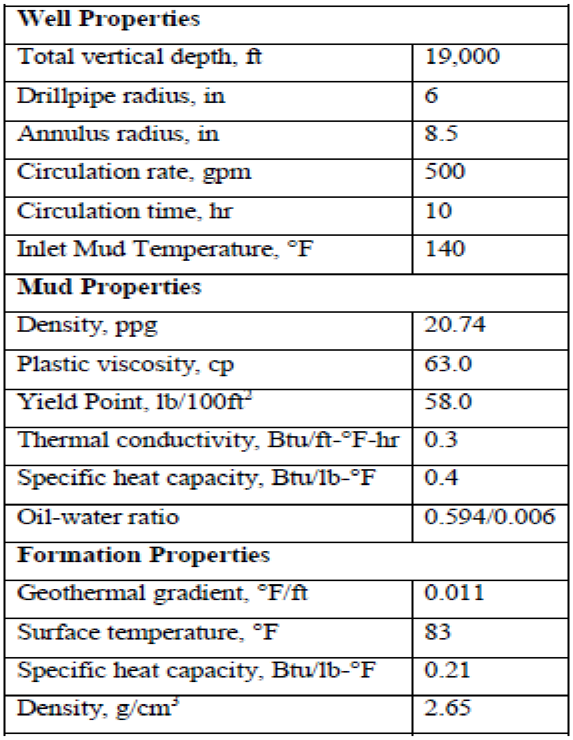
The non-Newtonian fluid can be stimulated using various models which are:

i. Bingham Plastic Model
ii. Power Law Model
iii. Herschel-Bulkley Model
iv. Casson Model
v. Ellis Model
vi. Carrreau Model

2.1.4.1 Case history prediction ECD model

Aidi Aiman (2012) predicting ECD in HPHT wells in order to determine well control issue. The author did simulation at Bearmbang-1 well by using Macro in Microsoft Excel.

TABLE 6 : Parameters for Berambang-1 well, Aidi Aiman (2012)



Well Properties	
Total vertical depth, ft	19,000
Drillpipe radius, in	6
Annulus radius, in	8.5
Circulation rate, gpm	500
Circulation time, hr	10
Inlet Mud Temperature, °F	140
Mud Properties	
Density, ppg	20.74
Plastic viscosity, cp	63.0
Yield Point, lb/100ft^2	58.0
Thermal conductivity, Btu/ft-°F-hr	0.3
Specific heat capacity, Btu/lb-°F	0.4
Oil-water ratio	0.594/0.006
Formation Properties	
Geothermal gradient, °F/ft	0.011
Surface temperature, °F	83
Specific heat capacity, Btu/lb-°F	0.21
Density, g/cm^3	2.65

The well is HPHT well as the bottom hole temperature is 292^0F at 19000 ft TVD and geothermal gradient of 0.001^0F/ft. The author explained the cooling effect of fluid is due to the heat being removed from the bottom of the wellbore to the surface as the temperature is reducing as increases in depth. By referring to the temperature data, the ECD was evaluated. The measured ECD is decreases with depth. This is due to the fluid constituents experience thermal expansion.

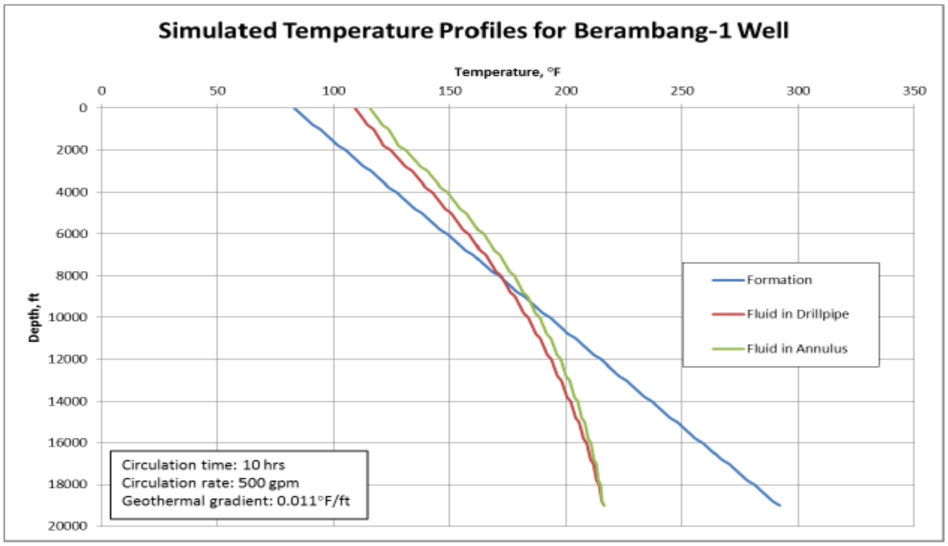


FIGURE14: Simulated wellbore temperature profile of Berambang-1 well. Aidi Aiman (2012)

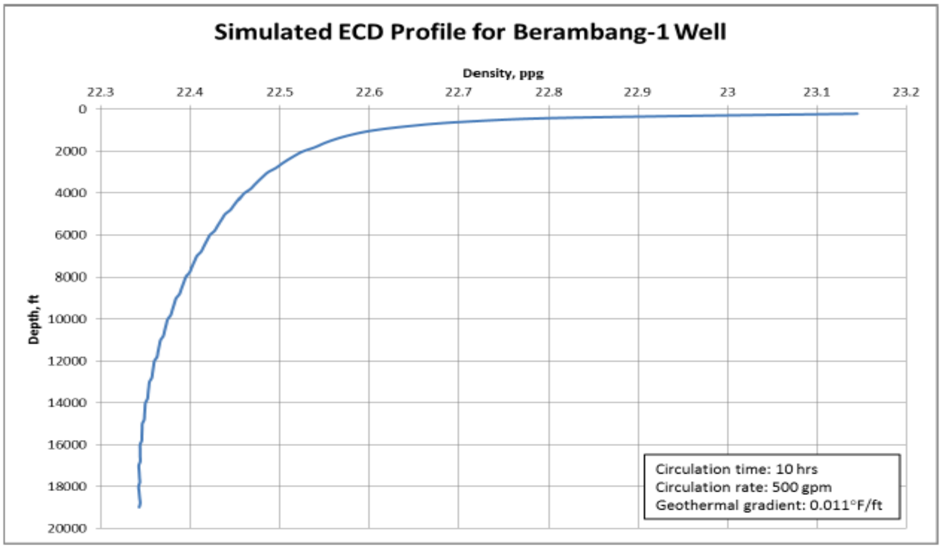


FIGURE15: Simulated ECD at Berambang-1 well. Aidi Aiman (2012)

CHAPTER 3

3.1 METHODOLOGY

The overall of the project research is illustrated in figure 16.

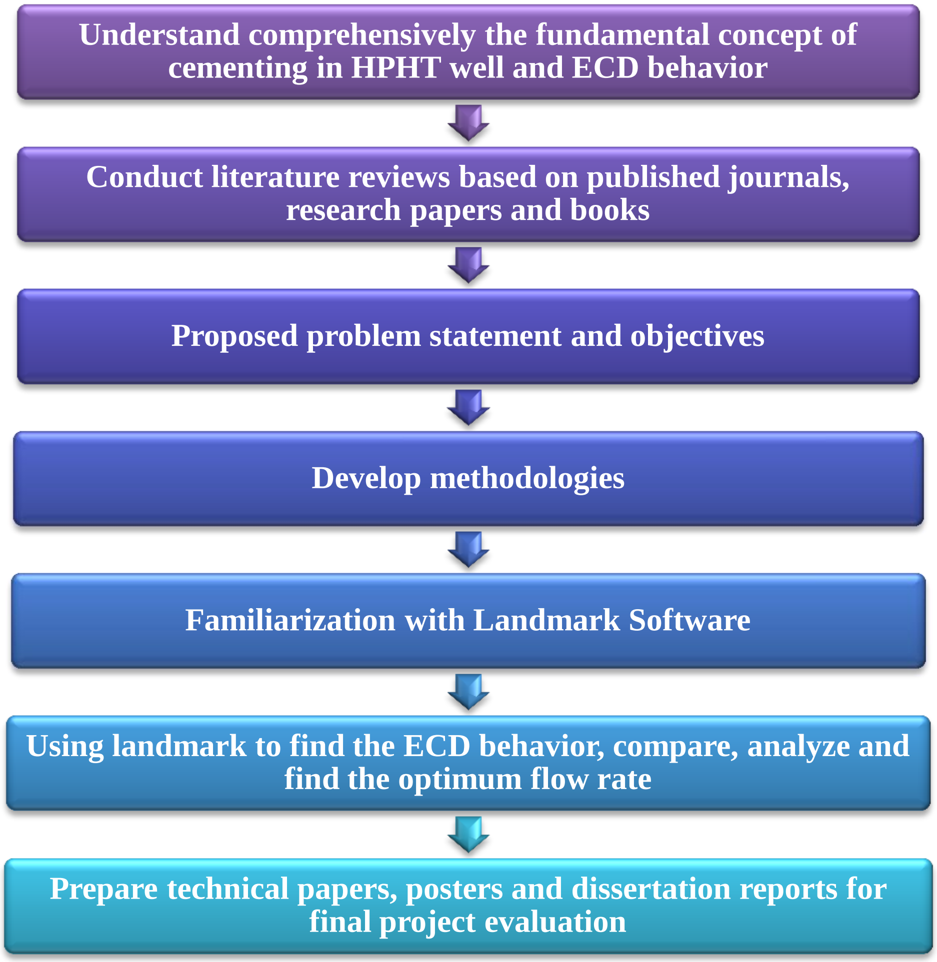
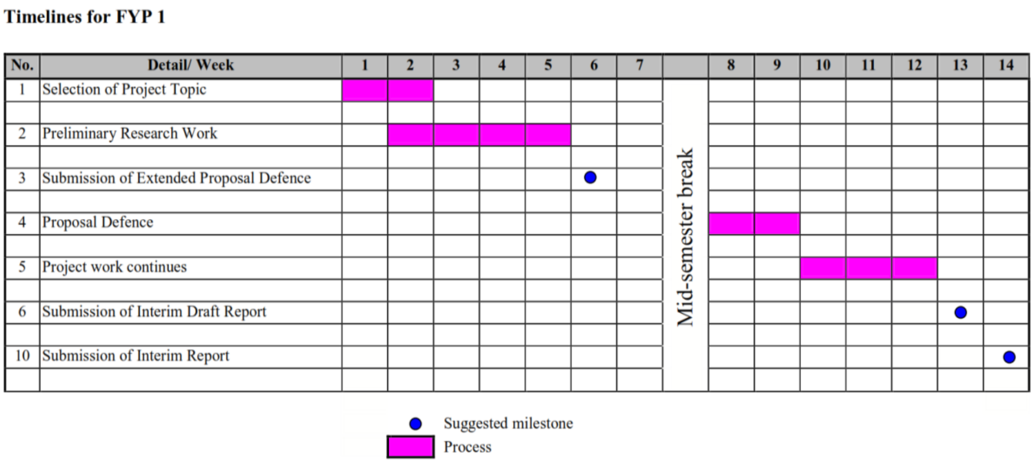


FIGURE16 :Overall research methodology

Based on the methodology, this project is highly concentrated on using Landmark software in order to measure the ECD behavior based on cementing in HPHT well. The details of the process and step in using Landmark software are explained in the project activities.

Before proceed with the software, the author need to gather data and have knowledge on the fundamental information of cementing, cementing in HPHT well and any information related with ECD. All of these data is really important in using the Landmark software later on. Any available data gather need to be defined into the software.

TABLE 7 : Gantt Chart for FYP 1

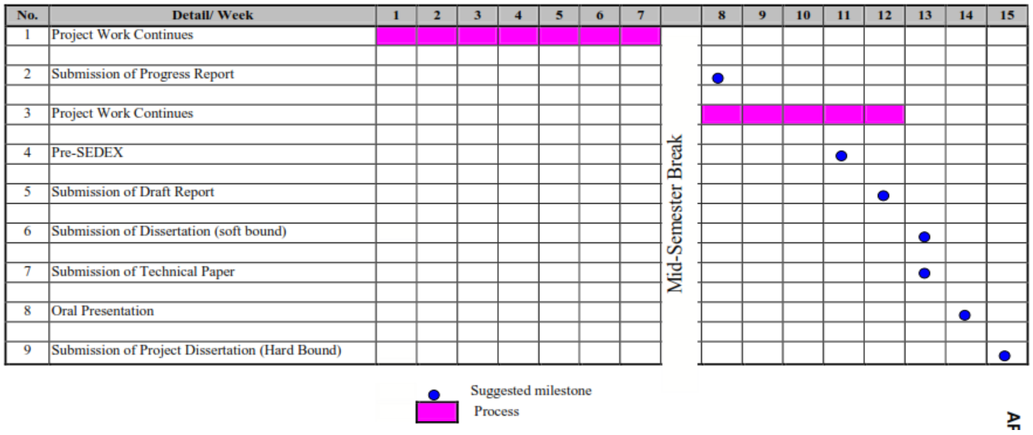


Timelines for FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	▨	▨						Mid-semester break							
2	Preliminary Research Work		▨	▨	▨	▨										
3	Submission of Extended Proposal Defence						●									
4	Proposal Defence									▨	▨					
5	Project work continues											▨	▨	▨		
6	Submission of Interim Draft Report														●	
10	Submission of Interim Report															●

● Suggested milestone
▨ Process

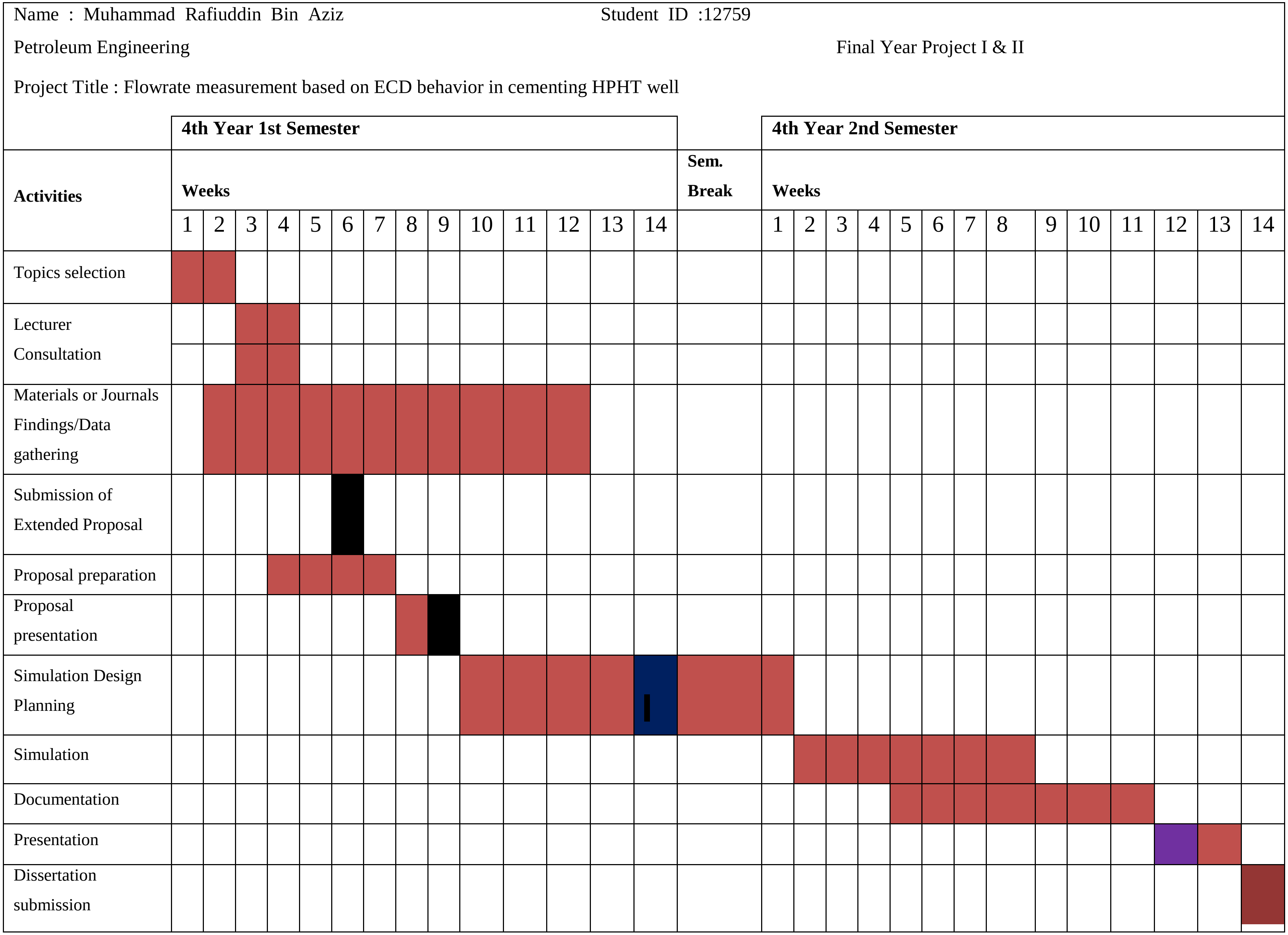
TABLE 8 : Gantt Chart for FYP 2



No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	▨	▨	▨	▨	▨	▨	▨	Mid-Semester 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)																●

● Suggested milestone
▨ Process

TABLE9: Gantt chart of technical process



Name : Muhammad Rafiuddin Bin Aziz Student ID :12759

Petroleum Engineering Final Year Project I & II

Project Title : Flowrate measurement based on ECD behavior in cementing HPHT well

	4th Year 1st Semester															**4th Year 2nd Semester**													
Activities	**Weeks**														**Sem. Break**	**Weeks**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topics selection	🟥	🟥																											
Lecturer Consultation			🟥	🟥																									
Materials or Journals Findings/Data gathering		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																	
Submission of Extended Proposal						⬛																							
Proposal preparation				🟥	🟥	🟥	🟥																						
Proposal presentation								🟥	⬛																				
Simulation Design Planning										🟥	🟥	🟥	🟥	🟦	🟥	🟥													
Simulation																	🟥	🟥	🟥	🟥	🟥	🟥	🟥						
Documentation																				🟥	🟥	🟥	🟥	🟥	🟥	🟥			
Presentation																											🟪	🟥	
Dissertation submission																													🟫

3.2 PROJECT ACTIVITIES

This research is focus on measuring the slurry flow rate based on the ECD behavior stimulated from Landmark software when cementing in HPHT well. In order to stimulate the ECD behavior using the software, the author need to design a well data. Due to that, the author used paper written by Noor Azree et al (2012) as the main reference. The author used this paper due to the paper provide three different hole section data. By using the Landmark software, the author stimulated cement design for each of the hole section.

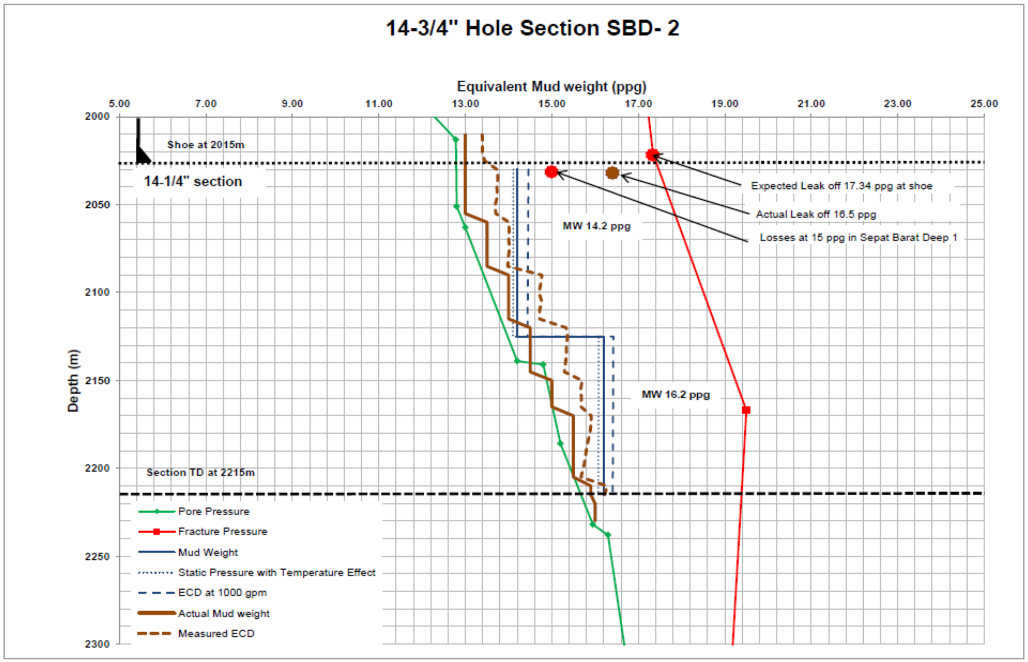


FIGURE17: 14-3/4 hole section data. Noor Azree et al (2012)

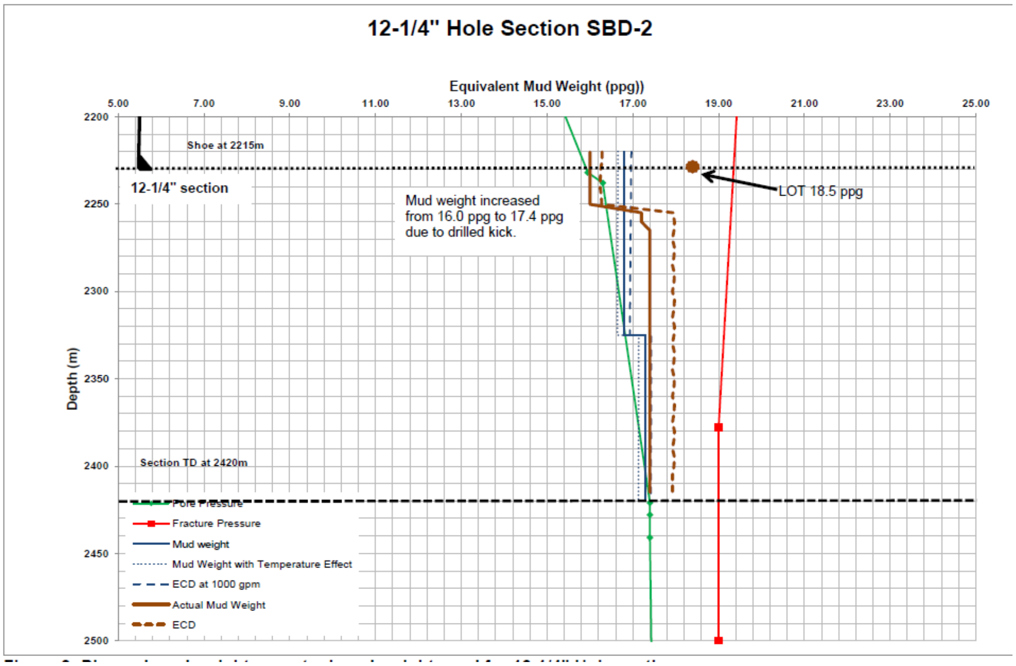


FIGURE18: 12-1/4 hole section data. Noor Azree et al (2012)

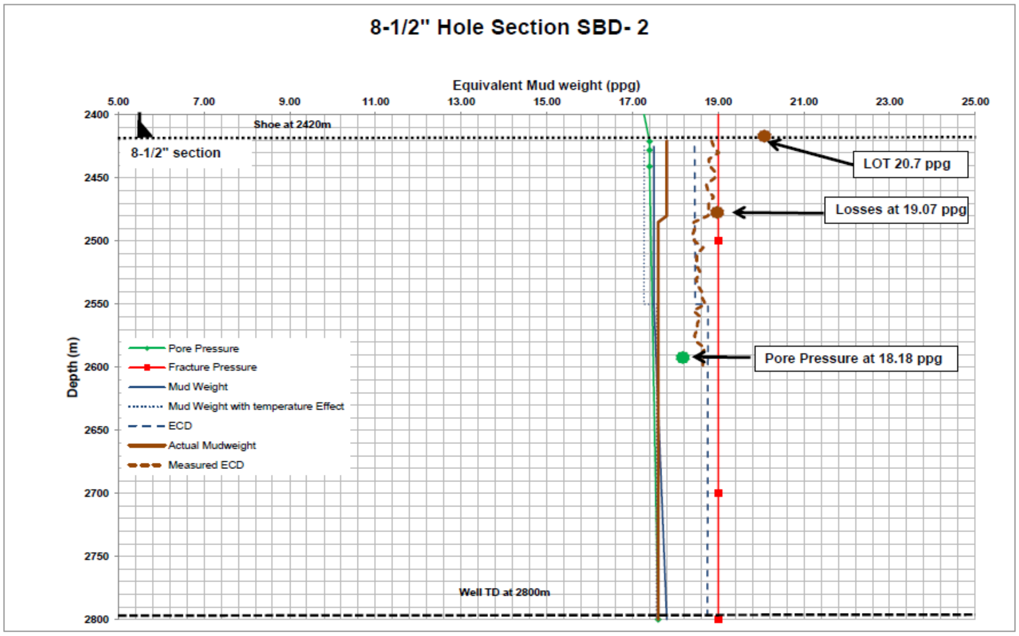


FIGURE19 : 8-1/2 hole section data. Noor Azree et al (2012)

3.2.1The step using Landmark software

3.2.1.1 Create wellbore directory using landmark software.

In order to design cement slurry in HPHT well, the first step is design a well trajectory. In order to doing so, the author used COMPASS module of Landmark software. COMPASS is capable in designing various well trajectories like vertical well, slanted well and horizontal well. The well trajectories design is based on the SPE paper written by Noor Azree et al (2012).

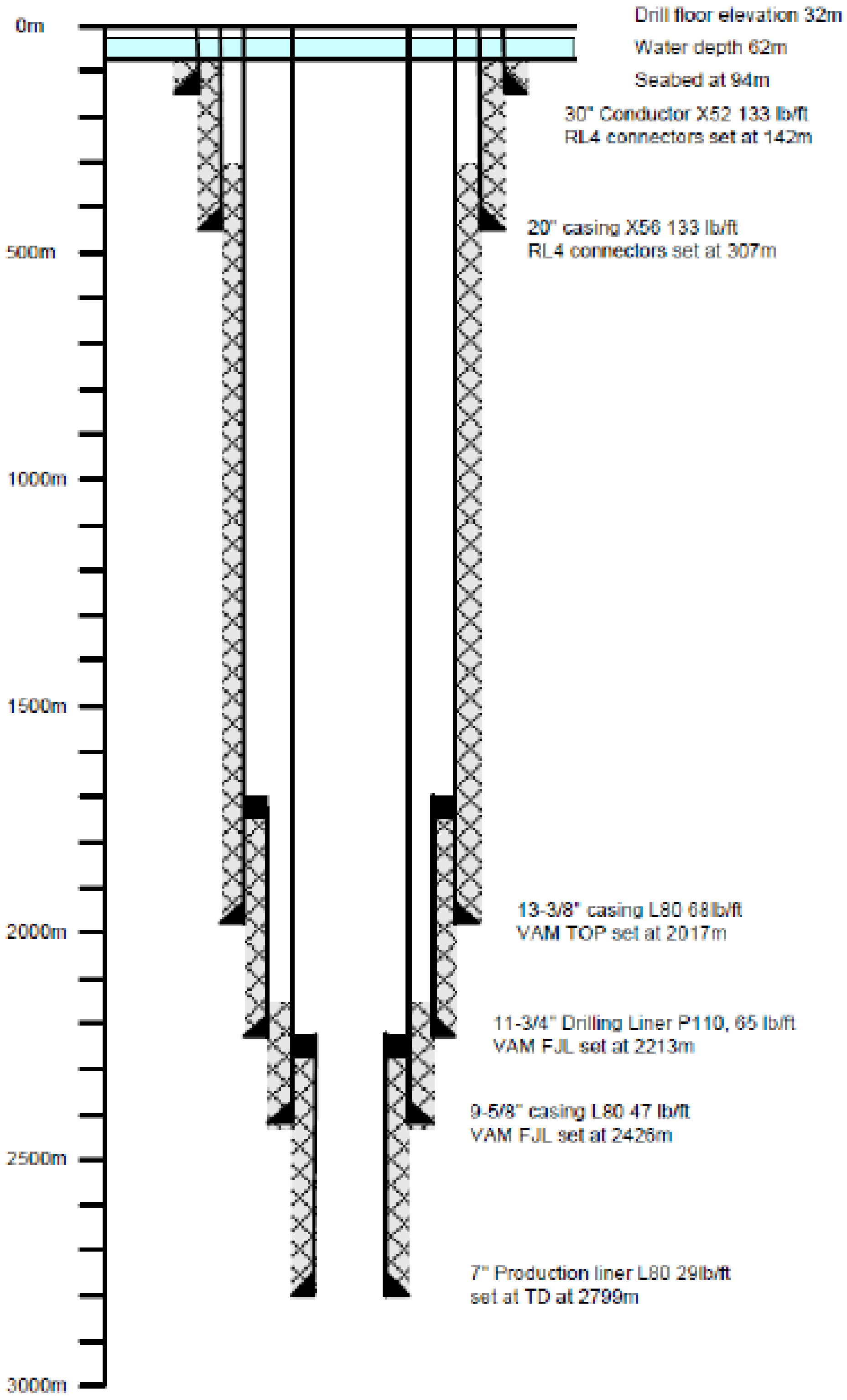


FIGURE20 :Well trajectory data. Noor Azree et al (2012)

The step of designing well trajectory is:

Step 1

Create new case or project for the design, then input the data regarding in the project properties. There are several important data should be input for this stage. The input data is;

i. Name of the project, location and description
ii. Defined project unit
iii. Defined the geographic reference system by selecting the geodetic system criteria, geodetic datum and map zone.

Step 2

Defined the site properties. For this stage, it is to precisely define the location of the site like the district, block and coordinates.

Step 3

Defined the well properties. The details of the well are defined in this step. This step is important in order to design the type of well either it is onshore, offshore or subsea. The input data is;

i. Defined details of the well name and location string
ii. Defined the depth reference for water depth and wellhead elevation if it is an offshore well, if it is onshore defined the ground elevation and wellhead elevation and defined the water depth and wellhead depth if it is subsea well.
iii. Defined the location of the well like coordinate if the data is available and provided.

Step 4

Defined the wellbore properties by input the wellbore descriptions like the name, location and type of wellbore.Then, defined the magnetic criteria if there is any declination and dip angle.

Step 5

Input data to define the plan design properties. The data should be input is based on general parameters of the plan design like name, description of the plan design and the depth reference information. Then, the other parameter which should be defined is tie-on properties, survey tool program, and vertical section data.

Step 6

Display the result of the wellbore trajectory and any related data.

3.2.1.2 Create the Cementing design using Opticem Module

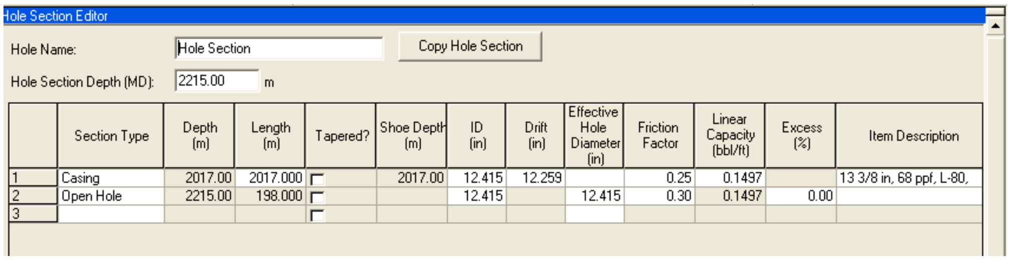
After complete with the wellbore design, used WELLPLAN module of Landmark software in order to design the cement. There are several parameters which could be calculated and measure through WELLPLAN module like drilling design by define the hydraulic, surge, bottom hole assembly, stuck pipe and others parameters. For cementing, the user needs to activate the Opticem module which being included inside WELLPLAN module. The process of cement design using Opticem module is;

Step 1

Used the well design did earlier which are using COMPASS module, then create new case for cementing purpose and name the case. Then activate the Opticem module.

Step 2

Defined the hole Section of the well. First, the user need to defined the hole name and the hole section depth. Then, input any section type data by choosing from the option given. For cementing casing purposes, select the casing and open hole section type. After selecting the section type, any data regarding on the section type need to be defined. For instance, the depth of the section, the length and shoe depth of the section, the internal diameter (ID) and excess. Some of the parameters are directly measured based on API standard of the section. But if there any contradiction with the actual design, this value could be changed.



Hole Name: Hole Section

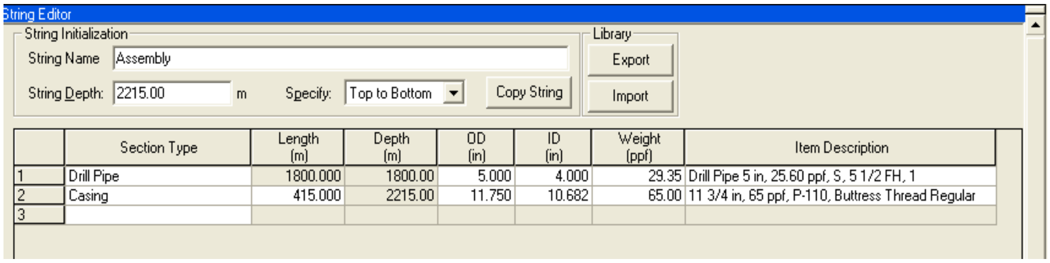
Hole Section Depth (MD): 2215.00 m

	Section Type	Depth (m)	Length (m)	Tapered?	Shoe Depth (m)	ID (in)	Drift (in)	Effective Hole Diameter (in)	Friction Factor	Linear Capacity (bbl/ft)	Excess (%)	Item Description
1	Casing	2017.00	2017.000	☐	2017.00	12.415	12.259		0.25	0.1497		13 3/8 in, 68 ppf, L-80,
2	Open Hole	2215.00	198.000	☐		12.415		12.415	0.30	0.1497	0.00	
3				☐								

FIGURE21: Hole section editor

Step 3

Defined the string of the well. First defined the name of the string name and depth and specify the string either the string is define from top to bottom or bottom to top. Then, defined the string section of the candidate hole section. Next, length, depth, outer diameter (OD), internal diameter (ID) and weight of the string section are defined. Some of the parameters of the string section are automatically measured by the module after selecting the string section type.



String Name: Assembly

String Depth: 2215.00 m

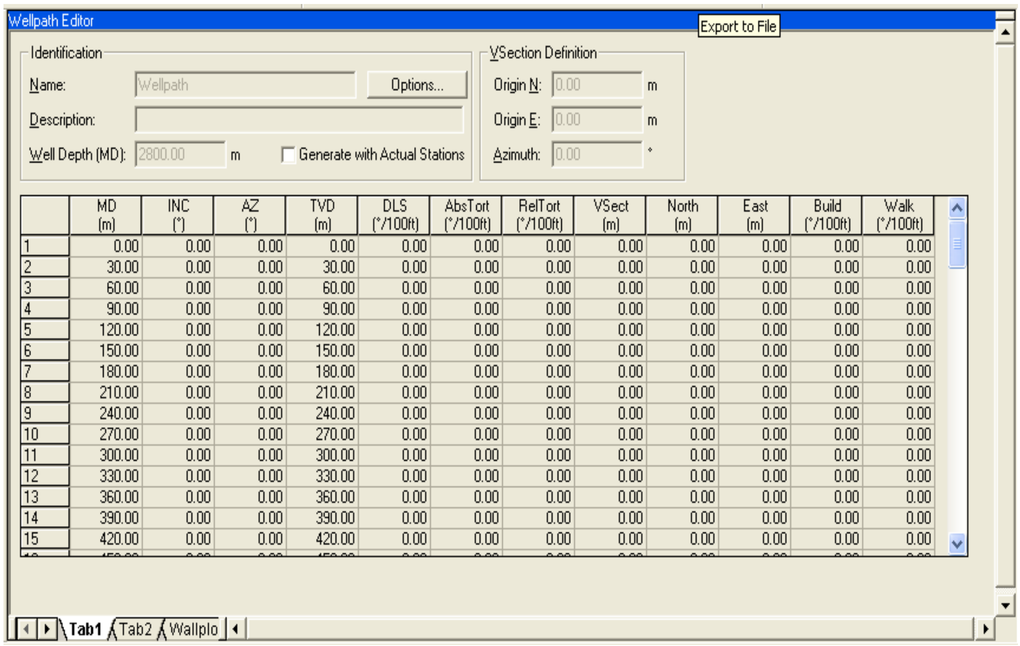
Specify: Top to Bottom

	Section Type	Length (m)	Depth (m)	OD (in)	ID (in)	Weight (ppf)	Item Description
1	Drill Pipe	1800.000	1800.00	5.000	4.000	29.35	Drill Pipe 5 in, 25.60 ppf, S, 5 1/2 FH, 1
2	Casing	415.000	2215.00	11.750	10.682	65.00	11 3/4 in, 65 ppf, P-110, Buttress Thread Regular
3							

FIGURE22: String editor

Step 4

Defined the wellpath of the well. This step is automatically defined by the module. It is based on the well trajectory module which has been design earlier. There is much information which could be getting from the wellpath data as it is tabulate the wellpath characteristic based on depth reference. As the project is design the cement on the vertical HPHT well, therefore not much information on the wellpath data.



Identification

Name: Wellpath

Description:

Well Depth (MD): 2800.00 m

☐ Generate with Actual Stations

VSection Definition

Origin N: 0.00 m

Origin E: 0.00 m

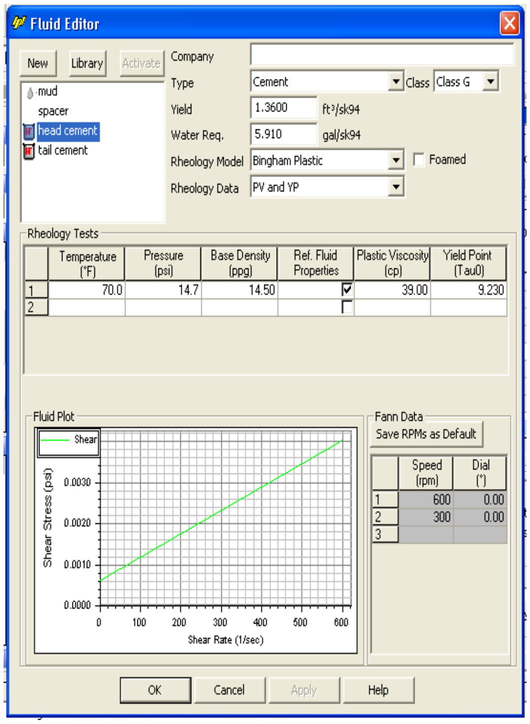
Azimuth: 0.00 °

	MD (m)	INC (°)	AZ (°)	TVD (m)	DLS (°/100ft)	AbsTort (°/100ft)	RelTort (°/100ft)	VSect (m)	North (m)	East (m)	Build (°/100ft)	Walk (°/100ft)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	30.00	0.00	0.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	60.00	0.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	90.00	0.00	0.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	120.00	0.00	0.00	120.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	150.00	0.00	0.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	180.00	0.00	0.00	180.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	210.00	0.00	0.00	210.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	240.00	0.00	0.00	240.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	270.00	0.00	0.00	270.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	300.00	0.00	0.00	300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	330.00	0.00	0.00	330.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	360.00	0.00	0.00	360.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	390.00	0.00	0.00	390.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	420.00	0.00	0.00	420.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FIGURE23: Wellpath editor

Step 5

Defined the fluid properties which involved the design process. First, select the new button to input the fluid involve in the design either it is non spacer, cement or spacer. Then, the parameter of the fluids like class of cement, rheology model and rheology data, temperature, pressure and others are defined. According to Frittella and Babbo (2009), high temperature cementing jobs are generally performed with API class G or class H cements.



Company

Type: Cement

Class: Class G

Yield: 1.3600 ft³/sk94

Water Req.: 5.910 gal/sk94

Rheology Model: Bingham Plastic

☐ Foamed

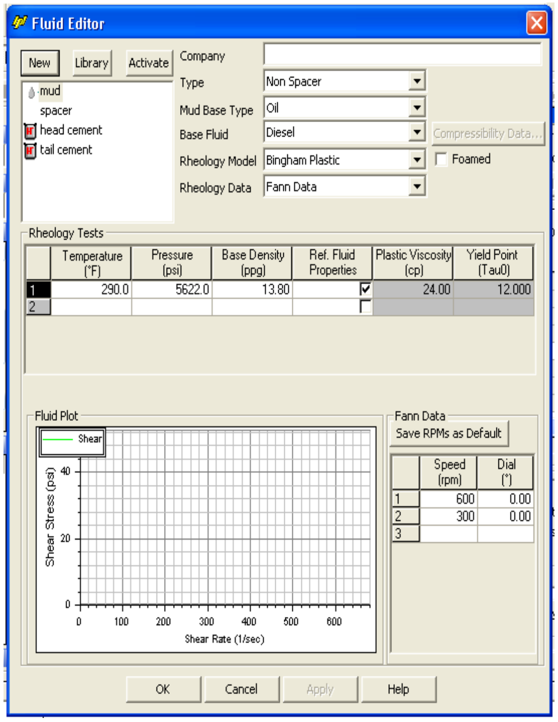
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	70.0	14.7	14.50	☑	39.00	9.230
2				☐		

Fann Data

	Speed (rpm)	Dial (°)
1	600	0.00
2	300	0.00
3		



Company

Type: Non Spacer

Mud Base Type: Oil

Base Fluid: Diesel

Rheology Model: Bingham Plastic

☐ Foamed

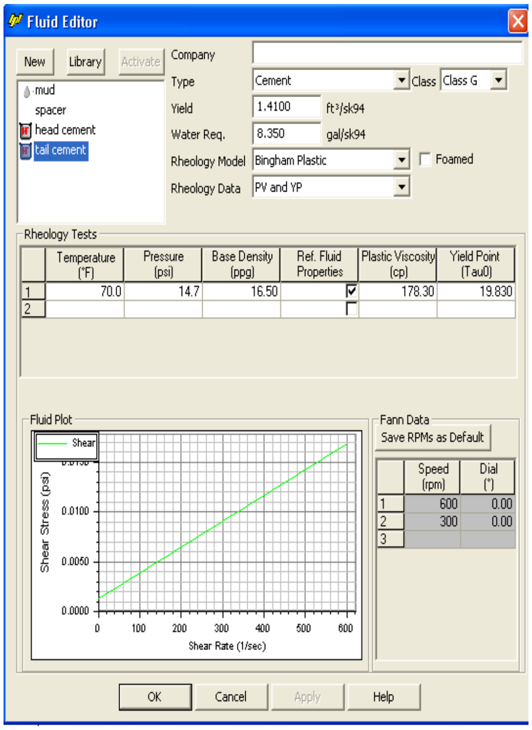
Rheology Data: Fann Data

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	290.0	5622.0	13.80	☑	24.00	12.000
2				☐		

Fann Data

	Speed (rpm)	Dial (°)
1	600	0.00
2	300	0.00
3		



Company

Type: Cement

Class: Class G

Yield: 1.4100 ft³/sk94

Water Req.: 8.350 gal/sk94

Rheology Model: Bingham Plastic

☐ Foamed

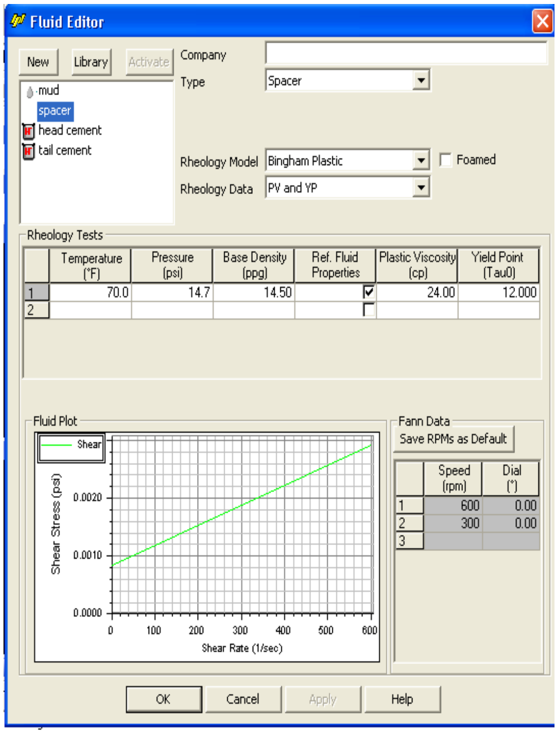
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	70.0	14.7	16.50	☑	178.30	19.830
2				☐		

Fann Data

	Speed (rpm)	Dial (°)
1	600	0.00
2	300	0.00
3		



Company

Type: Spacer

Rheology Model: Bingham Plastic

☐ Foamed

Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	70.0	14.7	14.50	☑	24.00	12.000
2				☐		

Fann Data

	Speed (rpm)	Dial (°)
1	600	0.00
2	300	0.00
3		

FIGURE24 :Fluid editor

Step 6

Defined the pore pressure and fracture gradient of the formation. This data is input into the module based on Noor Azree et al (2012).

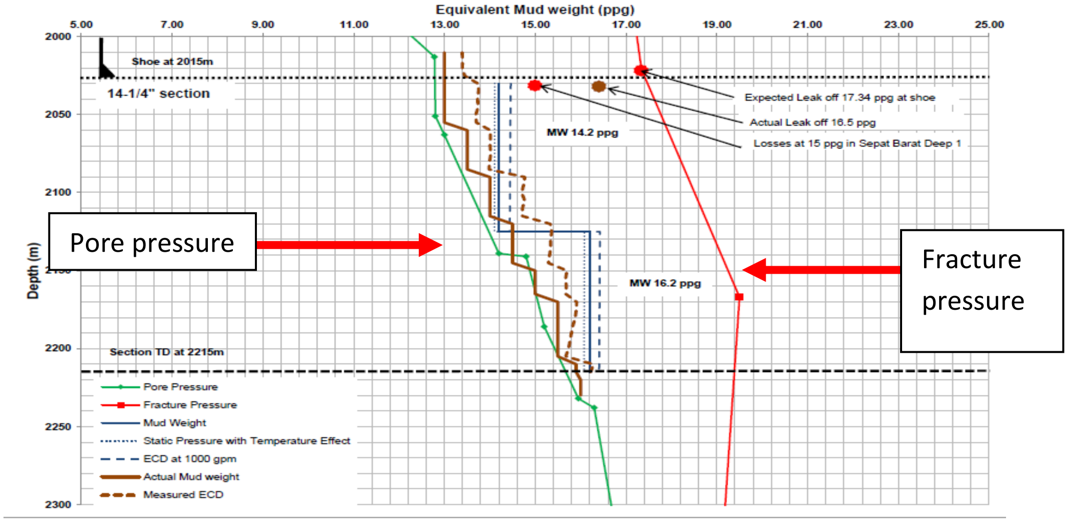
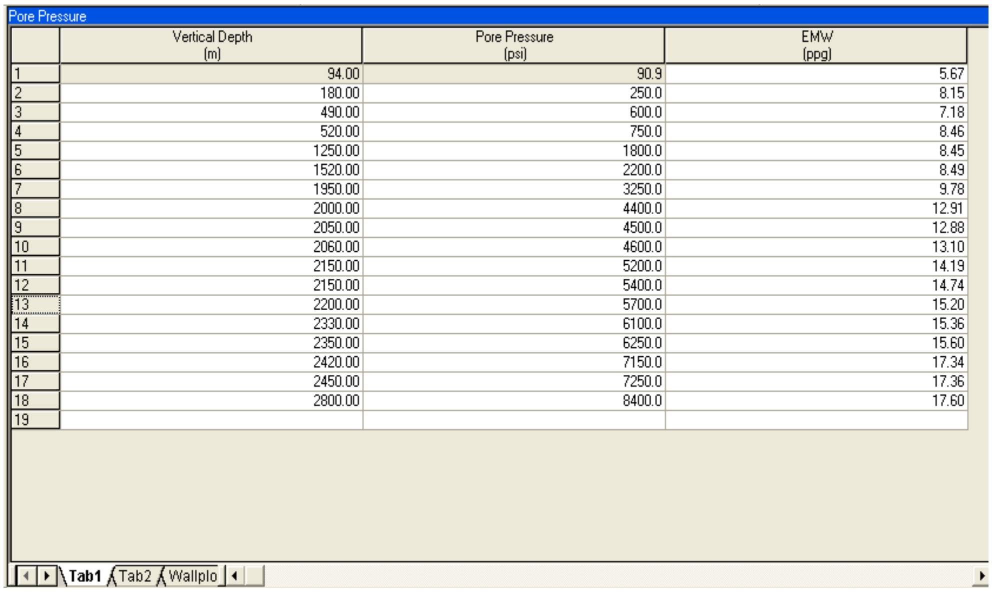
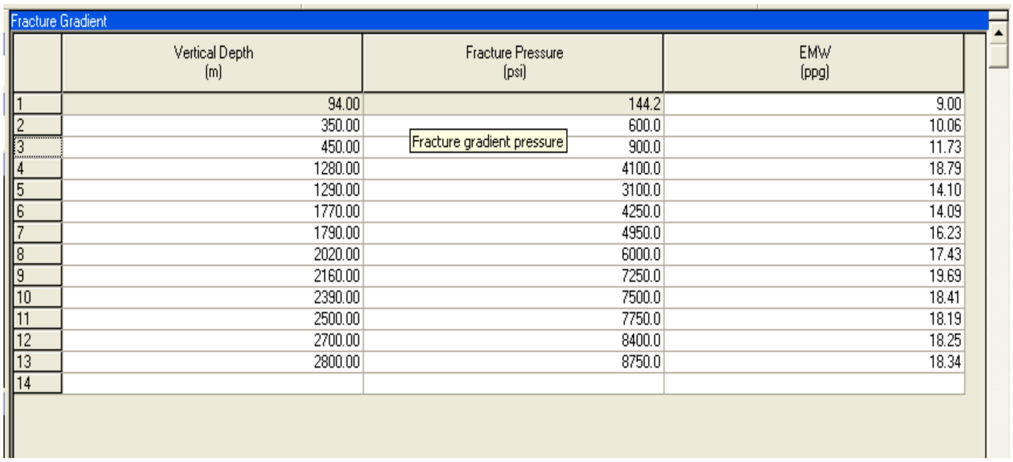


FIGURE25: Pore pressure and fracture pressure data



	Vertical Depth (m)	Pore Pressure (psi)	EMW (ppg)
1	94.00	90.9	5.67
2	180.00	250.0	8.15
3	490.00	600.0	7.18
4	520.00	750.0	8.46
5	1250.00	1800.0	8.45
6	1520.00	2200.0	8.49
7	1950.00	3250.0	9.78
8	2000.00	4400.0	12.91
9	2050.00	4500.0	12.88
10	2060.00	4600.0	13.10
11	2150.00	5200.0	14.19
12	2150.00	5400.0	14.74
13	2200.00	5700.0	15.20
14	2330.00	6100.0	15.36
15	2350.00	6250.0	15.60
16	2420.00	7150.0	17.34
17	2450.00	7250.0	17.36
18	2800.00	8400.0	17.60
19			

FIGURE26 :Pore pressure profile



Fracture Gradient

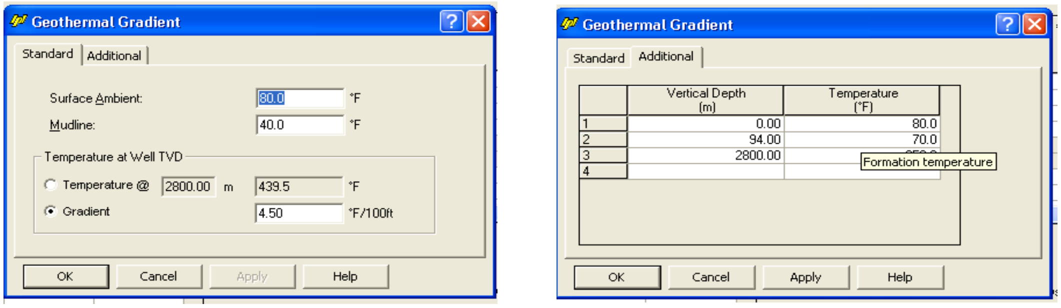
	Vertical Depth (m)	Fracture Pressure (psi)	EMW (ppg)
1	94.00	144.2	9.00
2	350.00	600.0	10.06
3	450.00	900.0	11.73
4	1280.00	4100.0	18.79
5	1290.00	3100.0	14.10
6	1770.00	4250.0	14.09
7	1790.00	4950.0	16.23
8	2020.00	6000.0	17.43
9	2160.00	7250.0	19.69
10	2390.00	7500.0	18.41
11	2500.00	7750.0	18.19
12	2700.00	8400.0	18.25
13	2800.00	8750.0	18.34
14			

Fracture gradient pressure

FIGURE27 :Fracture pressure profile

Step 7

Defined the geothermal gradient and cement circulating system.



Geothermal Gradient

Surface Ambient: 80.0 °F

Mudline: 40.0 °F

Temperature at Well TVD

○ Temperature @ 2800.00 m 439.5 °F

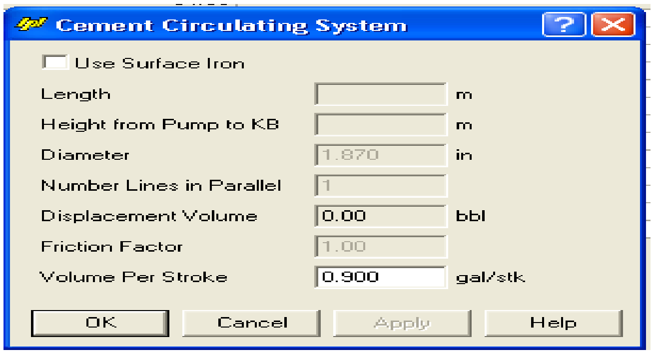
● Gradient 4.50 °F/100ft

Geothermal Gradient

	Vertical Depth (m)	Temperature (°F)
1	0.00	80.0
2	94.00	70.0
3	2800.00	[illegible]
4		

Formation temperature

FIGURE28: Geothermal gradient input data



Cement Circulating System

☐ Use Surface Iron

Length m

Height from Pump to KB m

Diameter 1.870 in

Number Lines in Parallel 1

Displacement Volume 0.00 bbl

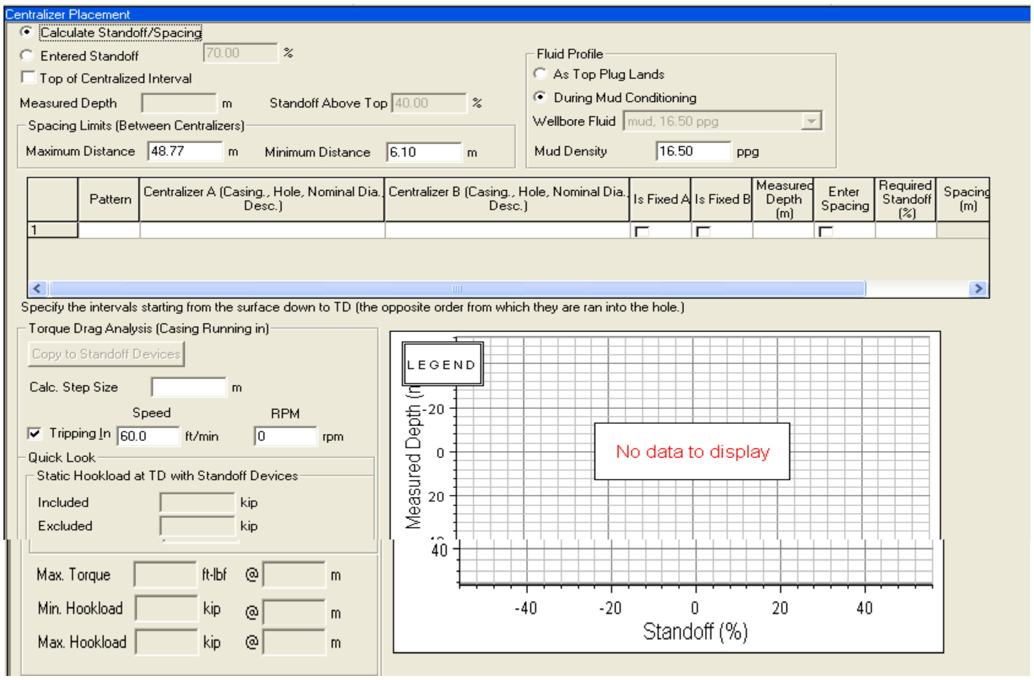
Friction Factor 1.00

Volume Per Stroke 0.900 gal/stk

FIGURE29 :Cement circulating system input data

Step 8

Defined the centralizer placement and standoff device if there is any.



Centralizer Placement

● Calculate Standoff/Spacing

○ Entered Standoff 70.00 %

☐ Top of Centralized Interval

Measured Depth m   Standoff Above Top 40.00 %

Spacing Limits (Between Centralizers)

Maximum Distance 48.77 m   Minimum Distance 6.10 m

Fluid Profile

○ As Top Plug Lands

● During Mud Conditioning

Wellbore Fluid mud, 16.50 ppg

Mud Density 16.50 ppg

	Pattern	Centralizer A (Casing., Hole, Nominal Dia. Desc.)	Centralizer B (Casing., Hole, Nominal Dia. Desc.)	Is Fixed A	Is Fixed B	Measured Depth (m)	Enter Spacing	Required Standoff (%)	Spacing (m)
1				☐	☐		☐		

Specify the intervals starting from the surface down to TD (the opposite order from which they are ran into the hole.)

Torque Drag Analysis (Casing Running in)

Calc. Step Size m

Speed RPM

☑ Tripping In 60.0 ft/min 0 rpm

Quick Look

Static Hookload at TD with Standoff Devices

Included kip

Excluded kip

Max. Torque ft-lbf @ m

Min. Hookload kip @ m

Max. Hookload kip @ m

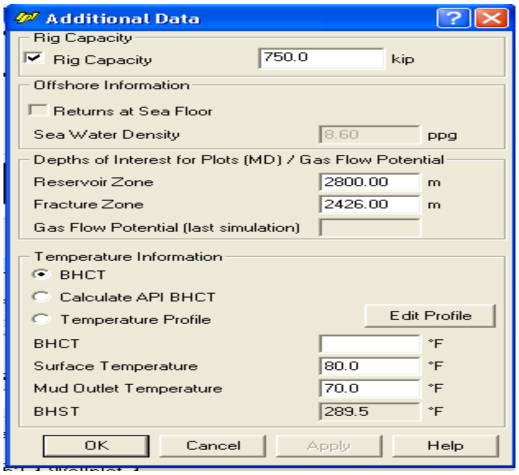
FIGURE30: Centralizer placement input data

The centralizer used to ensure that the casing in centralize position. In other word, the centralizer is used to ensure the casing is situated in the middle of the open hole. This can also refer to the eccentricity of the well. The position of casing can influence the slurry displacement. Cement slurry is the best being displaced when the casing is in the center of the hole or 100% standoff.

The pattern of the centralizer is choosing from the selected pattern which is already defined in the catalog.

Step 9

Input any additional data with regard with cementing design.



Rig Capacity
☑ Rig Capacity 750.0 kip

Offshore Information
☐ Returns at Sea Floor
Sea Water Density 8.60 ppg

Depths of Interest for Plots (MD) / Gas Flow Potential
Reservoir Zone 2800.00 m
Fracture Zone 2426.00 m
Gas Flow Potential (last simulation)

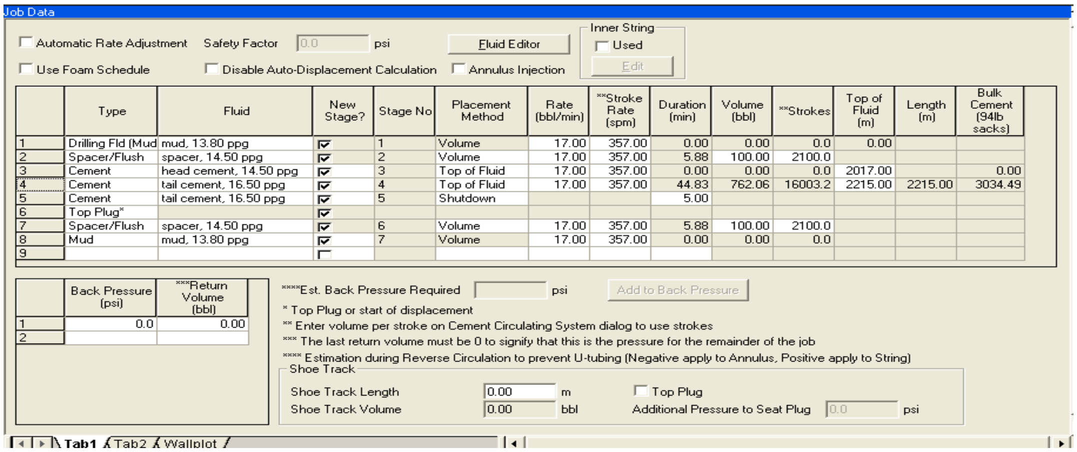
Temperature Information
● BHCT
○ Calculate API BHCT
○ Temperature Profile
BHCT °F
Surface Temperature 80.0 °F
Mud Outlet Temperature 70.0 °F
BHST 289.5 °F

FIGURE31: Input data text box for additional data

Base on the additional data dialog box, input data of the rig capacity, reservoir and fracture zone and temperature.

Step 10

Defined the job data and analysis data of the cement design.



☐ Automatic Rate Adjustment Safety Factor 0.0 psi
☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection
Inner String
☐ Used

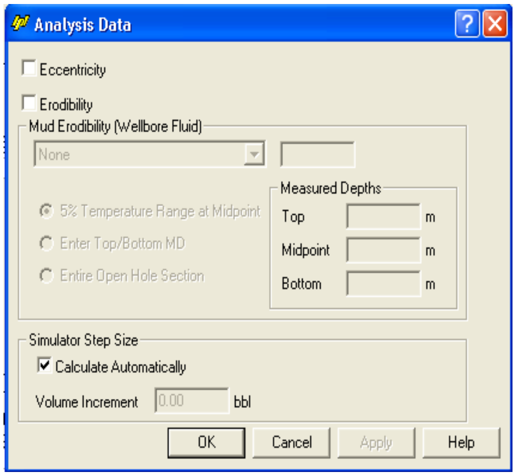
	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)	**Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud	mud, 13.80 ppg	☑	1	Volume	17.00	357.00	0.00	0.00	0.0	0.00		
2	Spacer/Flush	spacer, 14.50 ppg	☑	2	Volume	17.00	357.00	5.88	100.00	2100.0			
3	Cement	head cement, 14.50 ppg	☑	3	Top of Fluid	17.00	357.00	0.00	0.00	0.0	2017.00		0.00
4	Cement	tail cement, 16.50 ppg	☑	4	Top of Fluid	17.00	357.00	44.83	762.06	16003.2	2215.00	2215.00	3034.49
5	Cement	tail cement, 16.50 ppg	☑	5	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 14.50 ppg	☑	6	Volume	17.00	357.00	5.88	100.00	2100.0			
8	Mud	mud, 13.80 ppg	☑	7	Volume	17.00	357.00	0.00	0.00	0.0			
9			☐										

	Back Pressure (psi)	***Return Volume (bbl)
1	0.0	0.00
2		

****Est. Back Pressure Required psi
* Top Plug or start of displacement
** Enter volume per stroke on Cement Circulating System dialog to use strokes
*** The last return volume must be 0 to signify that this is the pressure for the remainder of the job
**** Estimation during Reverse Circulation to prevent U-tubing (Negative apply to Annulus, Positive apply to String)

Shoe Track
Shoe Track Length 0.00 m ☐ Top Plug
Shoe Track Volume 0.00 bbl Additional Pressure to Seat Plug 0.0 psi

FIGURE32: Data input text box


Analysis Data

☐ Eccentricity

☐ Erodibility

Mud Erodibility (Wellbore Fluid)

None

○ 5% Temperature Range at Midpoint
○ Enter Top/Bottom MD
○ Entire Open Hole Section

Measured Depths
Top m
Midpoint m
Bottom m

Simulator Step Size
☑ Calculate Automatically
Volume Increment 0.00 bbl

FIGURE33: Analysis data input text box

For the 11-3/4” liner the flowrate for all the fluids is initially set to be at 17bbl/min.13.8 ppg drilling mud reaches surface from MD of 1800 m. After that, 122m of 14.5ppg spacer is pumped followed by 248m (length) of 13.2 ppg cement lead. The TOC refer to depth the plug start to displace. The 16.5ppg cement tail is pumped after cement lead. Other information provided by this section is the amount of lead and tail cement required.

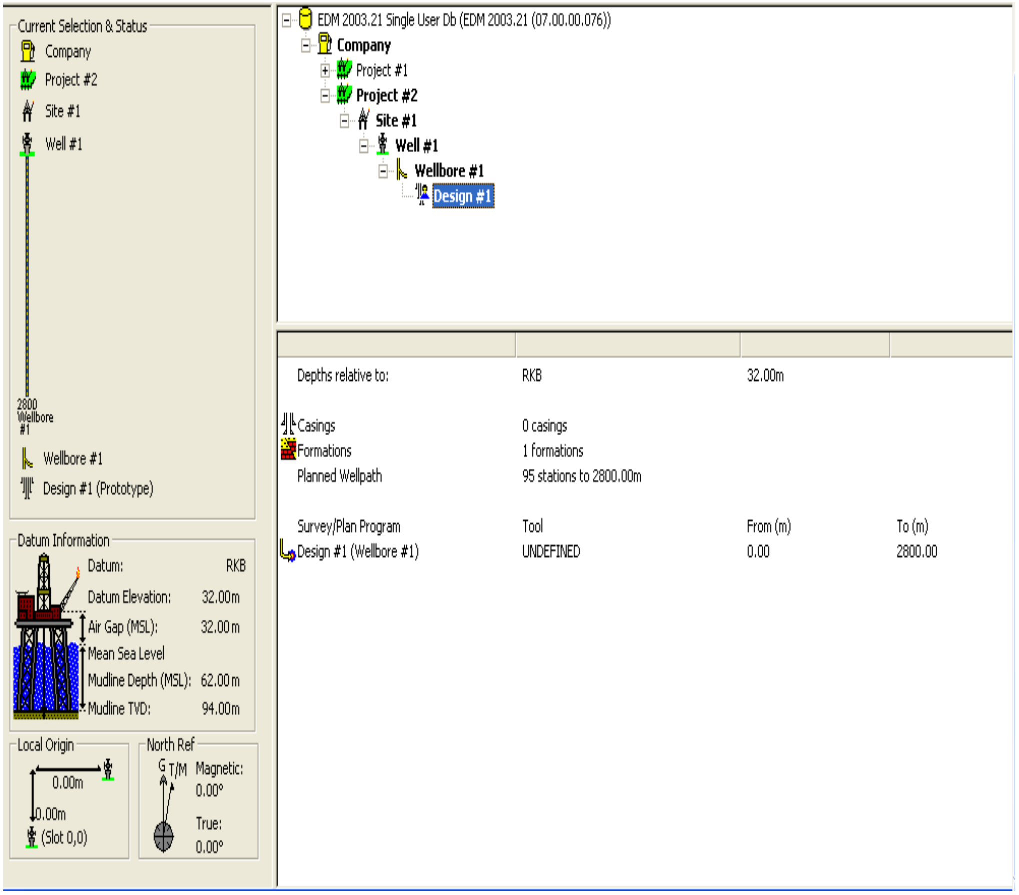
Step 11

Repeat the step for cementing 9-5/8” casing and 7” liner

CHAPTER 4

4.1 RESULT

4.1.1Wellbore directory using landmark software



Current Selection & Status
Company
Project #2
Site #1
Well #1
2800 Wellbore #1
Wellbore #1
Design #1 (Prototype)

Datum Information
Datum: RKB
Datum Elevation: 32.00m
Air Gap (MSL): 32.00m
Mean Sea Level
Mudline Depth (MSL): 62.00m
Mudline TVD: 94.00m

Local Origin
0.00m
0.00m
(Slot 0,0)

North Ref
G T/M
Magnetic: 0.00°
True: 0.00°

EDM 2003.21 Single User Db (EDM 2003.21 (07.00.00.076))
- Company
  - Project #1
  - Project #2
    - Site #1
      - Well #1
        - Wellbore #1
          - Design #1

Depths relative to:	RKB	32.00m	
Casings	0 casings		
Formations	1 formations		
Planned Wellpath	95 stations to 2800.00m		
Survey/Plan Program	Tool	From (m)	To (m)
Design #1 (Wellbore #1)	UNDEFINED	0.00	2800.00

FIGURE34: Analysis data input text box

Figure 34 illustrate the summary of the well trajectory design. The datum information show that the datum for the design using the rotary Kelly bushing instead of mean sea level. Beside the type of platform used is offshore platform design with datum elevation, air gap, mudline and total TVD is 32 m, 32 m, 62 m and 94 m respectively.

The plan design is illustrated by Figure 35. The well design is vertical well with the TVD is defined at 2800 m.

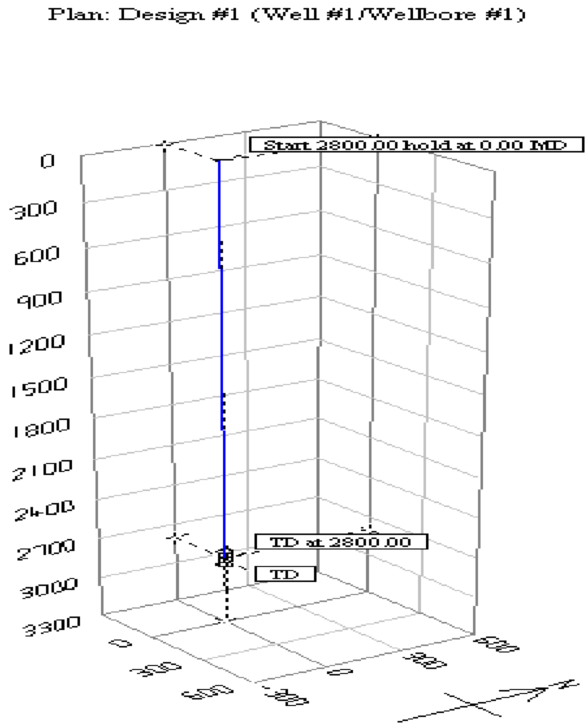
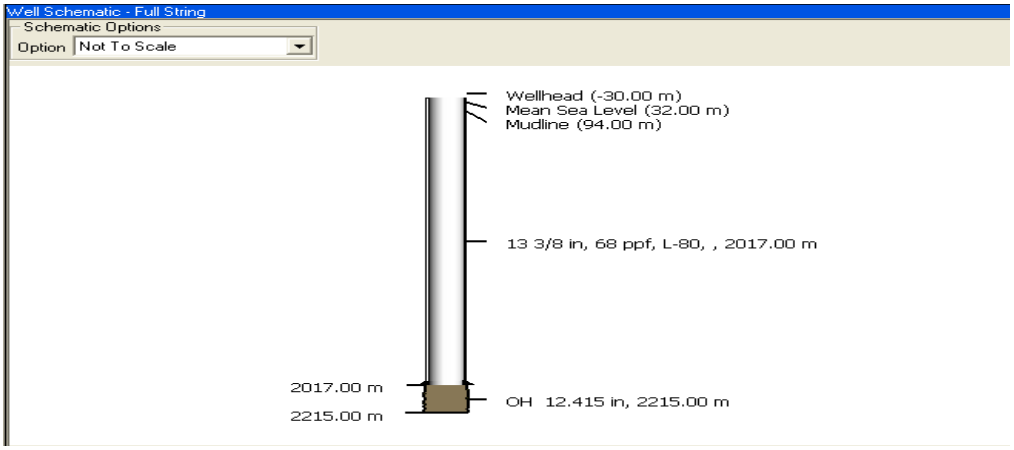


FIGURE35: Well trajectory design

4.1.2 Cementing liner 11-3/4” (13-5/8” hole section)

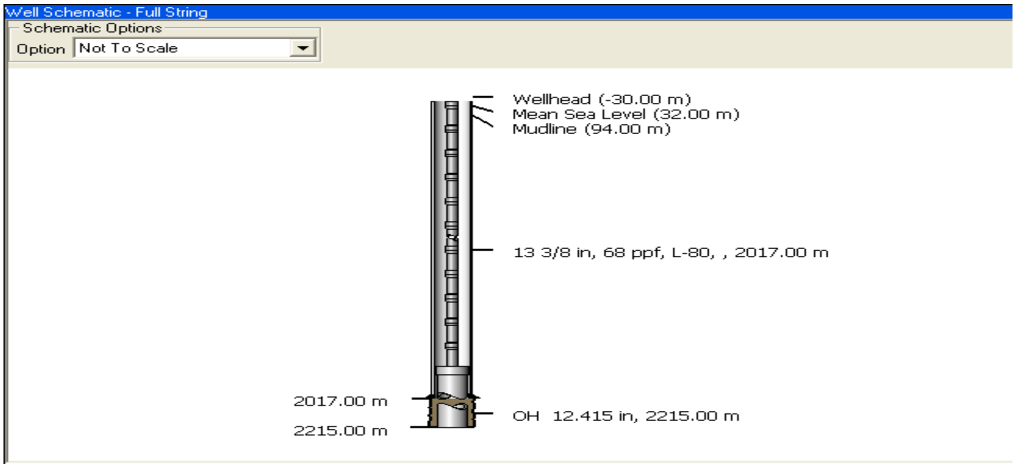
4.1.2.1 Well schematic


Well Schematic - Full String

Schematic Options

Option: Not To Scale

FIGURE 36: Well schematic for hole section for 14-3/4” hole section


Well Schematic - Full String

Schematic Options

Option: Not To Scale

FIGURE 37 : Well schematic after string section added for 14-3/4” hole section

Figure 36 and 37 illustrated the schematic diagram of the hole and string section. Based on that, the open hole is 12.415 inches starts at a depth of 2017 m. The liner is set above open hole and end at depth 2215 m.

4.1.2.2 Downhole pressure profiles

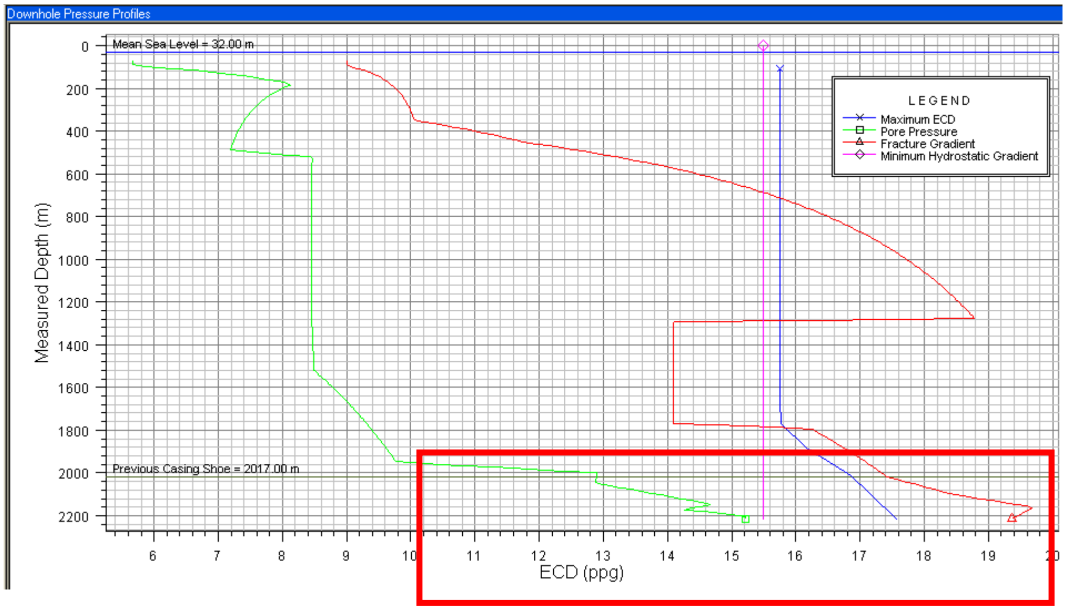


FIGURE38 : Downhole pressure profile for 11-3/4" liner cementing

Based on the Figure 38 the behavior of pore pressure, fracture pressure, ECD and hydrostatic pressure are plotted. For cementing the 11-3/4” liner, the interest zone is at the depth where the previous casing shoe set, 2017 meter to the target depth which for this cased is 2215 meter. The maximum ECD line and minimum hydrostatic line is within pore pressure and fracture pressure line. The behavior of the ECD and hydrostatic pressure can be seen clearly as illustrated in circulating pressure at fracture zone and circulating pressure at reservoir zone, Figure 39 and Figure 40 respectively.

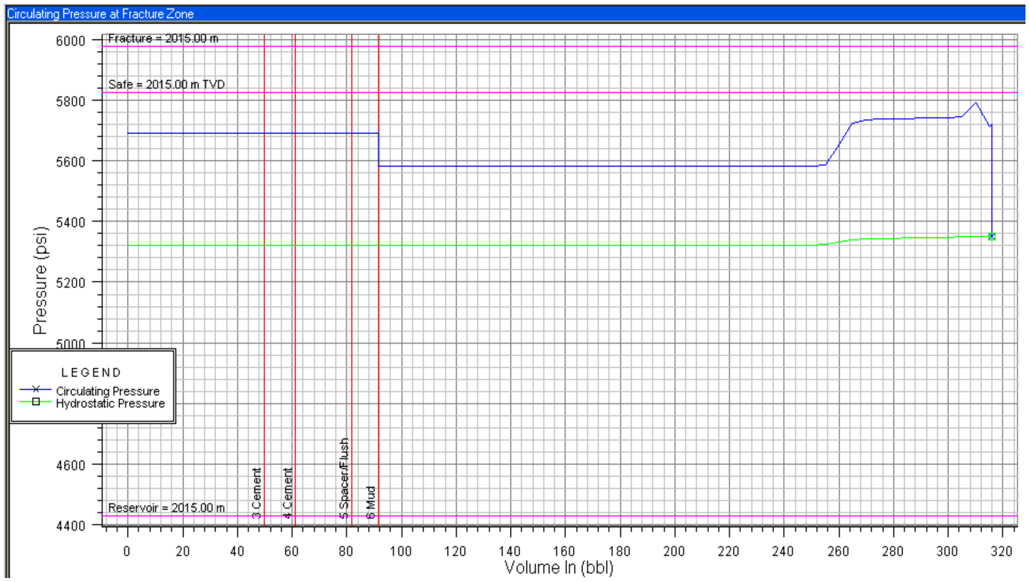


FIGURE 39 :Circulating Pressure profile at 11-3/4" liner at fracture zone

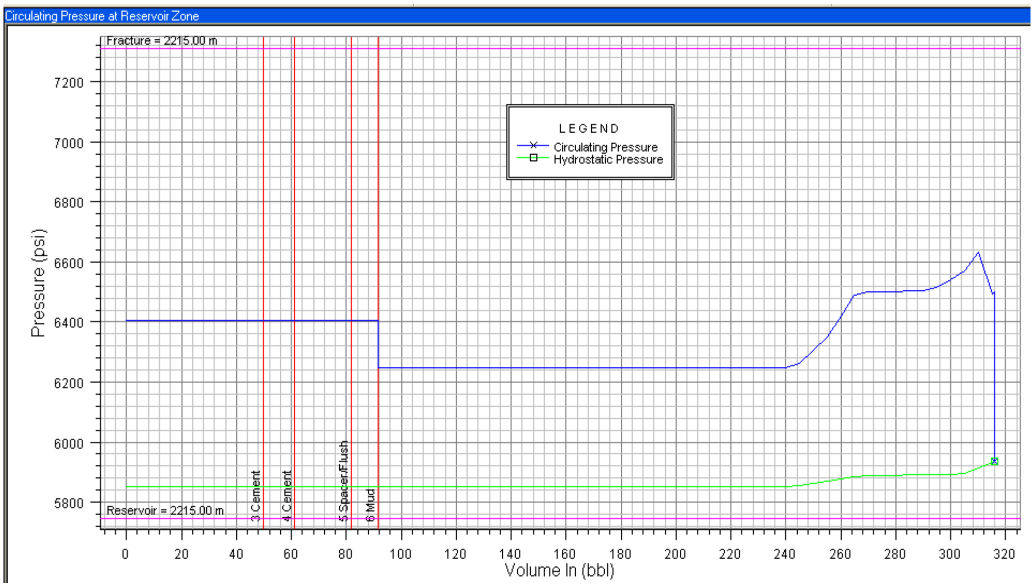
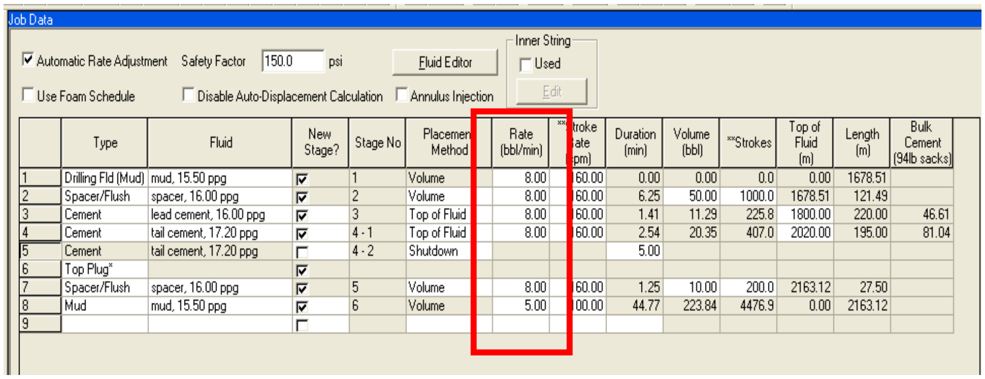


FIGURE 40: Circulating pressure profile for 11-3/4" liner at rezervoir zone

As plotted in both diagram, the ECD line and the hydrostatic line pressure are within the fracture pressure and pore pressure line. This indicates the cementing process is in the best and safe condition to be executed.

4.1.2.3Flow rate


Job Data

☑ Automatic Rate Adjustment   Safety Factor 150.0 psi   Fluid Editor

☐ Use Foam Schedule   ☐ Disable Auto-Displacement Calculation   ☐ Annulus Injection

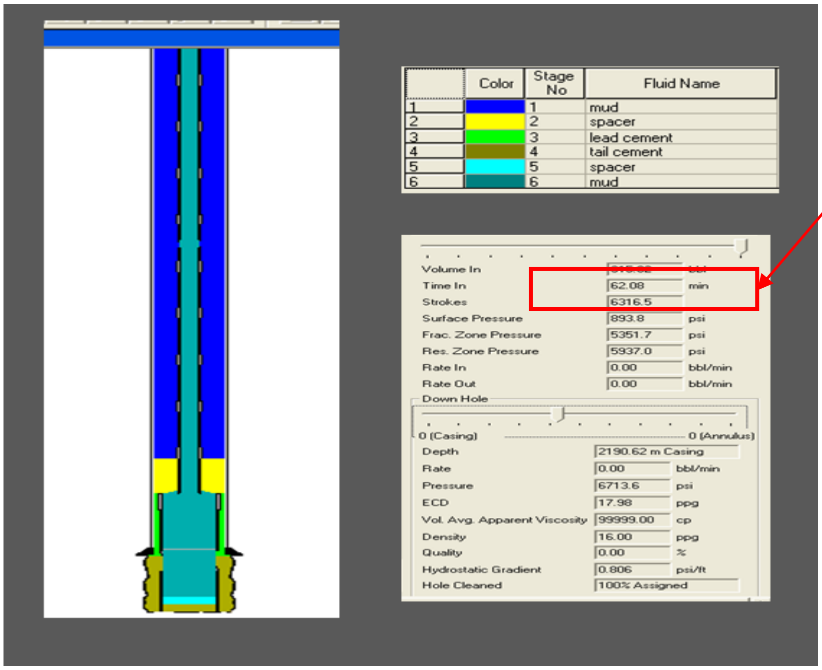
Inner String: ☐ Used   Edit

	Type	Fluid	New Stage?	Stage No	Placemen Method	Rate (bbl/min)	**troke ate pm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 15.50 ppg	☑	1	Volume	8.00	60.00	0.00	0.00	0.0	0.00	1678.51	
2	Spacer/Flush	spacer, 16.00 ppg	☑	2	Volume	8.00	60.00	6.25	50.00	1000.0	1678.51	121.49	
3	Cement	lead cement, 16.00 ppg	☑	3	Top of Fluid	8.00	60.00	1.41	11.29	225.8	1800.00	220.00	46.61
4	Cement	tail cement, 17.20 ppg	☑	4 - 1	Top of Fluid	8.00	60.00	2.54	20.35	407.0	2020.00	195.00	81.04
5	Cement	tail cement, 17.20 ppg	☐	4 - 2	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 16.00 ppg	☑	5	Volume	8.00	60.00	1.25	10.00	200.0	2163.12	27.50	
8	Mud	mud, 15.50 ppg	☑	6	Volume	5.00	00.00	44.77	223.84	4476.9	0.00	2163.12	
9			☐										

FIGURE41: Job data for 11-3/4" liner

Based on the project, the optimum flowrate for the cement slurry is 8 bbl/min. in order to ensure ECD pressure below the fracture pressure, the pre-flush mud rate at the line 8 is reduced to 5 bbl/min.

4.1.2.4 Fluid position frame


	Color	Stage No	Fluid Name
1	🟦	1	mud
2	🟨	2	spacer
3	🟩	3	lead cement
4	🟫	4	tail cement
5	🟦	5	spacer
6	🟦	6	mud

Volume In [illegible] bbl
Time In 62.08 min
Strokes 6316.5
Surface Pressure 893.8 psi
Frac. Zone Pressure 5351.7 psi
Res. Zone Pressure 5937.0 psi
Rate In 0.00 bbl/min
Rate Out 0.00 bbl/min

Down Hole
0 (Casing) 0 (Annulus)
Depth 2190.62 m Casing
Rate 0.00 bbl/min
Pressure 6713.6 psi
ECD 17.98 ppg
Vol. Avg. Apparent Viscosity 99999.00 cp
Density 16.00 ppg
Quality 0.00 %
Hydrostatic Gradient 0.806 psi/ft
Hole Cleaned 100% Assigned

Total time for execution of job

= 62.08 minutes

FIGURE42: Fluid position frame for 11-3/4" liner

The Figure 42 illustrates how the pump job cement at the target depth is done. The lead cement is indicates by green color with being set at the beginning depth of the liner set until the slightly down the casing shoe and the tail cement is set afterward up to the target depth. Apart from that, there is other parameter which could be obtained like volume of fluid in, time in, strokes, surface pressure and others along the pump process being conducted. Based on the research for this hole section, the time required for the cement to set at the planning elevation is 62.08 minutes.

4.1.3 Cementing 9-5/8” casing (12-1/4” hole section)

4.1.3.1 Well schematic

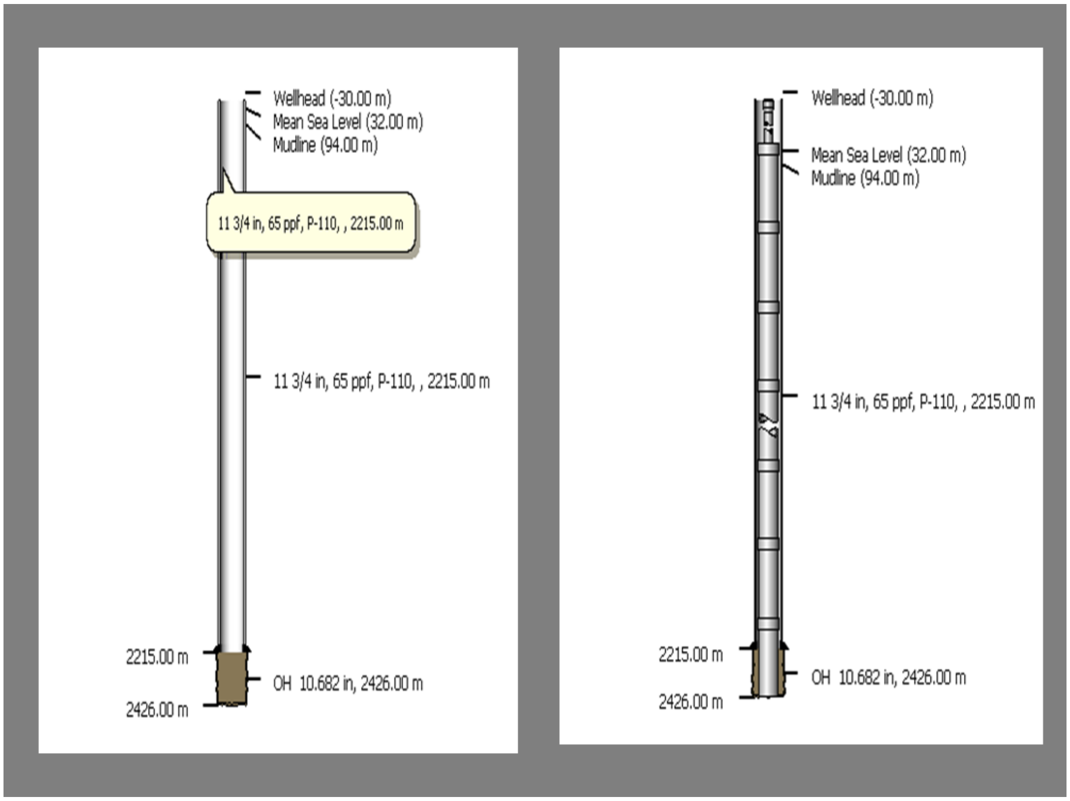


FIGURE43: Well schematic for hole and string section for 12-1/4” hole section

Figure 43 illustrated the schematic diagram of the hole and string section. Based on that, the open hole is 10.682 inches start at a depth of 2215 meter. The casing set start at sea level up to the target, 2426 meter.

4.1.3.2 Downhole pressure profiles

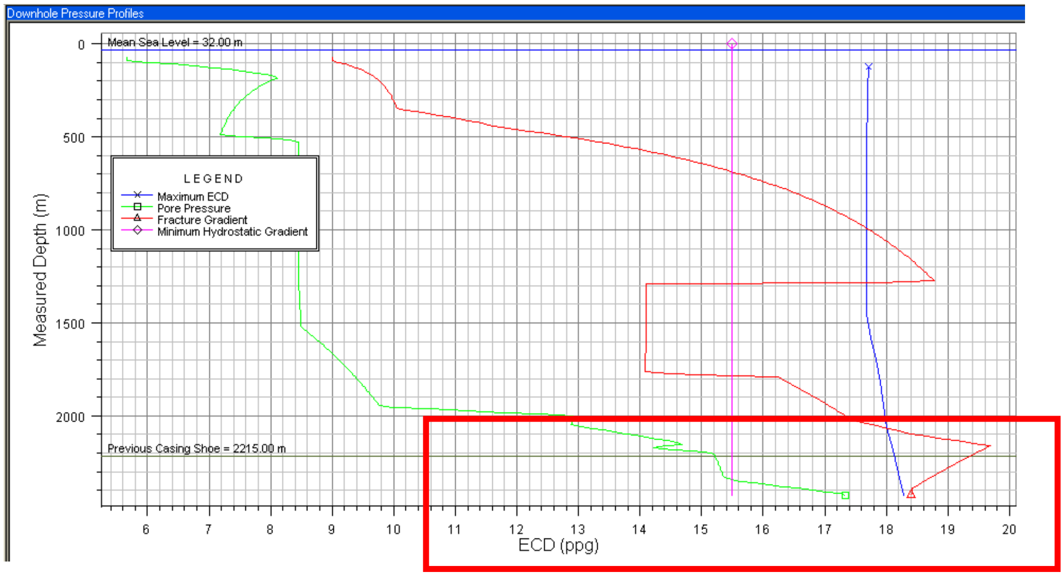


FIGURE44: Downhole pressure profile for 9-5/8" casing

Based on the Figure 44 the behavior of pore pressure, fracture pressure, ECD and hydrostatic pressure are plotted. For cementing the 9-5/8" casing, the interest zone is at the depth where the previous casing shoe set, 2215 meter to the target depth which for this cased is 2426 meter. The maximum ECD line is within pore pressure and fracture pressure line but the hydrostatic pressure line is below the pore pressure. This behavior could cause problems during cementing execution and the team must alter the properties of slurry for well control purposes in other to counter the problems like add sad additives to the slurry. The behavior of the ECD and hydrostatic pressure can be seen clearly as illustrated in circulating pressure at fracture zone and circulating pressure at reservoir zone, Figure 45 and Figure 46 respectively.

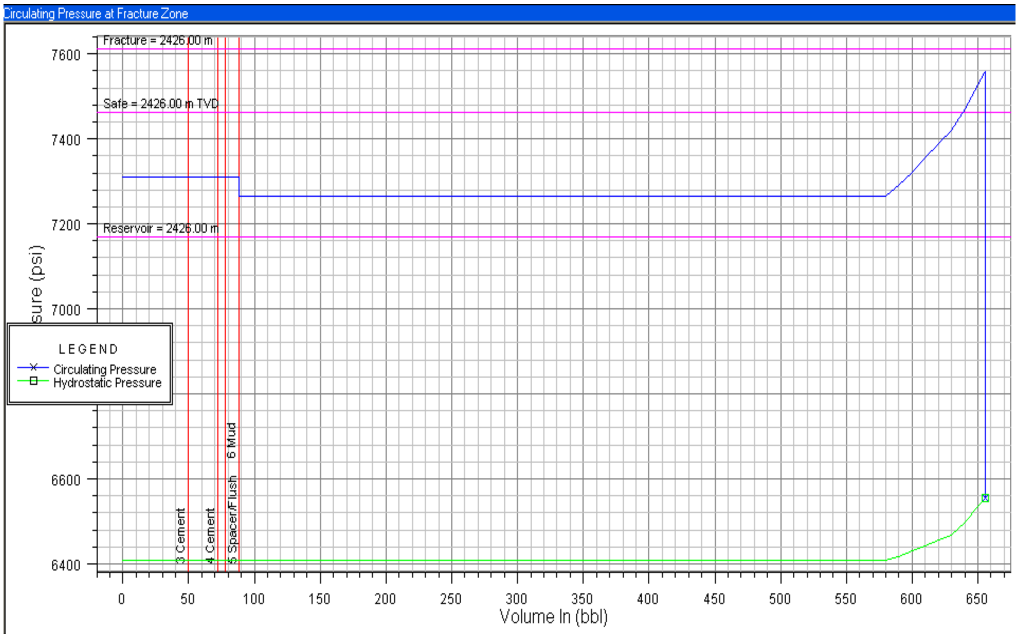


FIGURE45: Circulating pressure profile for 9-5/8” casing at fracture zone

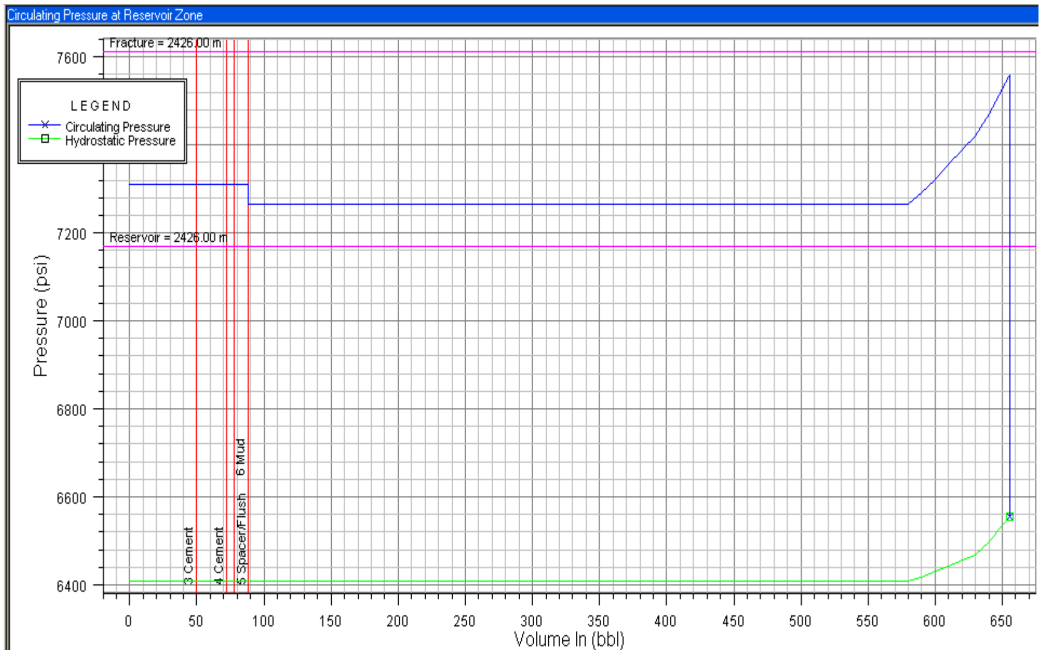
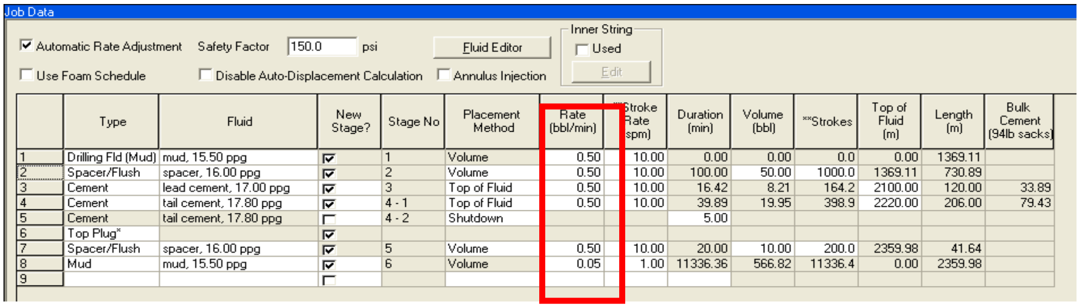


FIGURE46: Circulating pressure profile for 9-5/8" casing at reservoir zone

4.1.3.3 Flow rate


Job Data

☑ Automatic Rate Adjustment Safety Factor 150.0 psi Fluid Editor

☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection

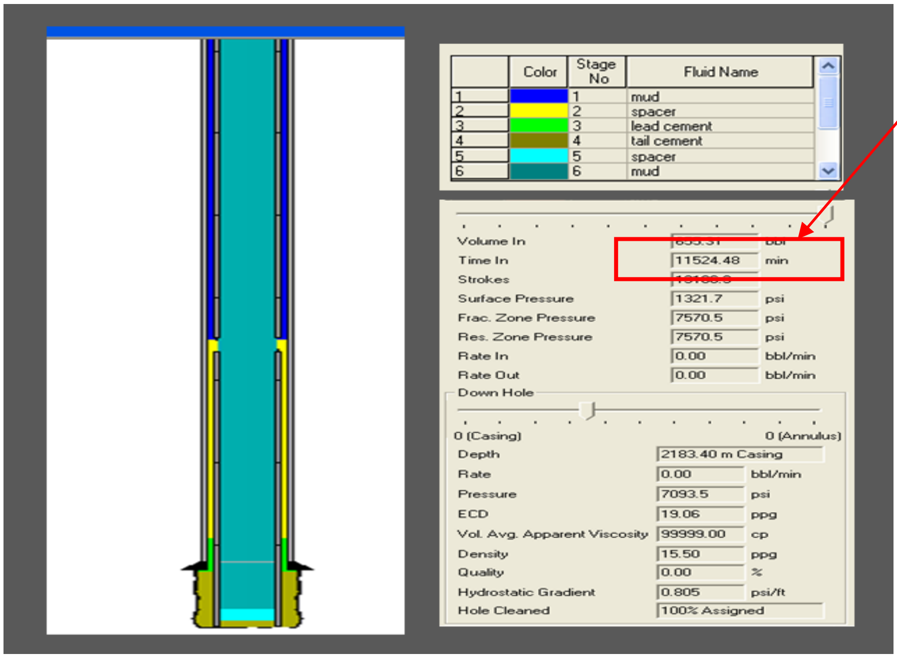
Inner String: ☐ Used Edit

	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)		***Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 15.50 ppg	☑	1	Volume	0.50		10.00	0.00	0.00	0.0	0.00	1369.11	
2	Spacer/Flush	spacer, 16.00 ppg	☑	2	Volume	0.50		10.00	100.00	50.00	1000.0	1369.11	730.89	
3	Cement	lead cement, 17.00 ppg	☑	3	Top of Fluid	0.50		10.00	16.42	8.21	164.2	2100.00	120.00	33.89
4	Cement	tail cement, 17.80 ppg	☑	4 - 1	Top of Fluid	0.50		10.00	39.89	19.95	398.9	2220.00	206.00	79.43
5	Cement	tail cement, 17.80 ppg	☐	4 - 2	Shutdown				5.00					
6	Top Plug*		☑											
7	Spacer/Flush	spacer, 16.00 ppg	☑	5	Volume	0.50		10.00	20.00	10.00	200.0	2359.98	41.64	
8	Mud	mud, 15.50 ppg	☑	6	Volume	0.05		1.00	11336.36	566.82	11336.4	0.00	2359.98	
9			☐											

FIGURE47: Job data for 9-5/8" casing

Based on the project, the optimum flowrate for the cement slurry is 0.5 bbl/min. in order to ensure ECD pressure below the fracture pressure, the pre-flush mud rate at the line 8 is reduced to 0.01 bbl/min.

4.1.3.4 Fluid position frame



	Color	Stage No	Fluid Name
1	🟦	1	mud
2	🟨	2	spacer
3	🟩	3	lead cement
4	🟫	4	tail cement
5	🟦	5	spacer
6	🟦	6	mud

Volume In [illegible] bbl
Time In 11524.48 min
Strokes [illegible]
Surface Pressure 1321.7 psi
Frac. Zone Pressure 7570.5 psi
Res. Zone Pressure 7570.5 psi
Rate In 0.00 bbl/min
Rate Out 0.00 bbl/min

Down Hole
0 (Casing) 0 (Annulus)
Depth 2183.40 m Casing
Rate 0.00 bbl/min
Pressure 7093.5 psi
ECD 19.06 ppg
Vol. Avg. Apparent Viscosity 99999.00 cp
Density 15.50 ppg
Quality 0.00 %
Hydrostatic Gradient 0.805 psi/ft
Hole Cleaned 100% Assigned

Total time for execution of job

= 11524.48 minutes

FIGURE 48: Fluid position frame for 9-5/8" casing

The Figure 48 illustrates how the pump job cement at the target depth is done for 9-5/8” casing. For this hole section, the time required for the cement to set at the planning elevation is 11524.48 minutes.

4.1.4 Cementing 7” liner (12-1/4” hole section)

4.1.4.1 Well schematic

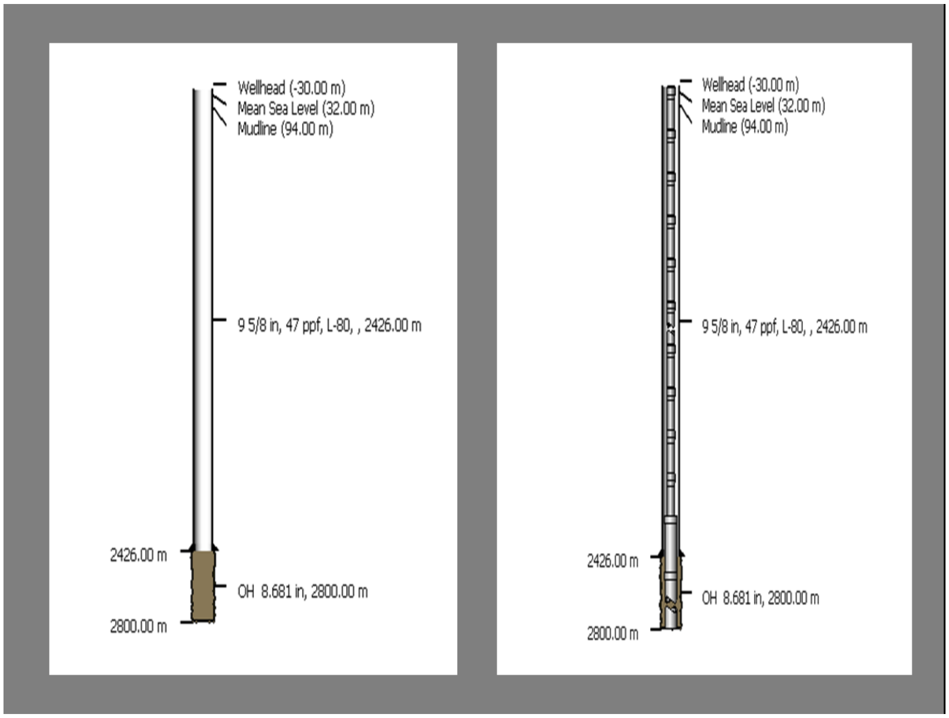


FIGURE49 : Well schematic for hole and string section for 8-1/2” hole section

Figure 49 illustrated the schematic diagram of the hole and string for 8-1/2” hole section. Based on that, the open hole is 8.681 inches start at a depth of 24226 meter. The liner set at 2426 meter up to the target, 2800 meter.

4.1.4.2 Downhole pressure profiles

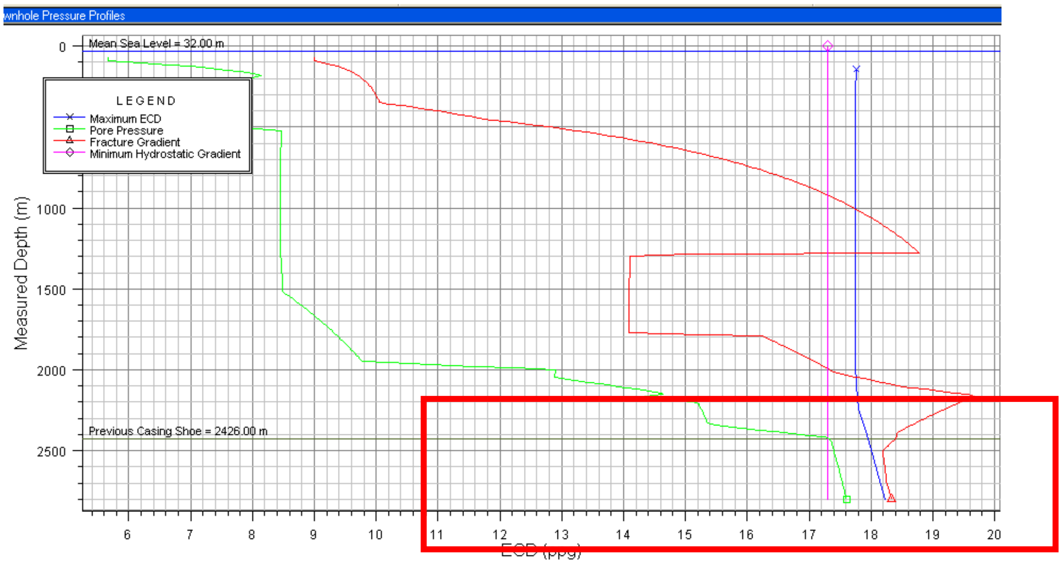


FIGURE50 : Downhole pressure profile for 7' liner

Based on the Figure 50 the behavior of pore pressure, fracture pressure, ECD and hydrostatic pressure are plotted. For cementing the 7” liner, the interest zone is at the depth where the previous casing shoe set, 2426 meter to the target depth which for this cased is 2800 meter. The maximum ECD line is within pore pressure and fracture pressure line but the hydrostatic pressure line is below the pore pressure. For this hole section, the cement design encounter the same problem with the 9-5/8” casing during cementing execution where the team must alter the properties of slurry for well control purposes. The behavior of the ECD and hydrostatic pressure can be seen clearly as illustrated in circulating pressure at fracture zone and circulating pressure at reservoir zone, Figure 51 and Figure 52 respectively.

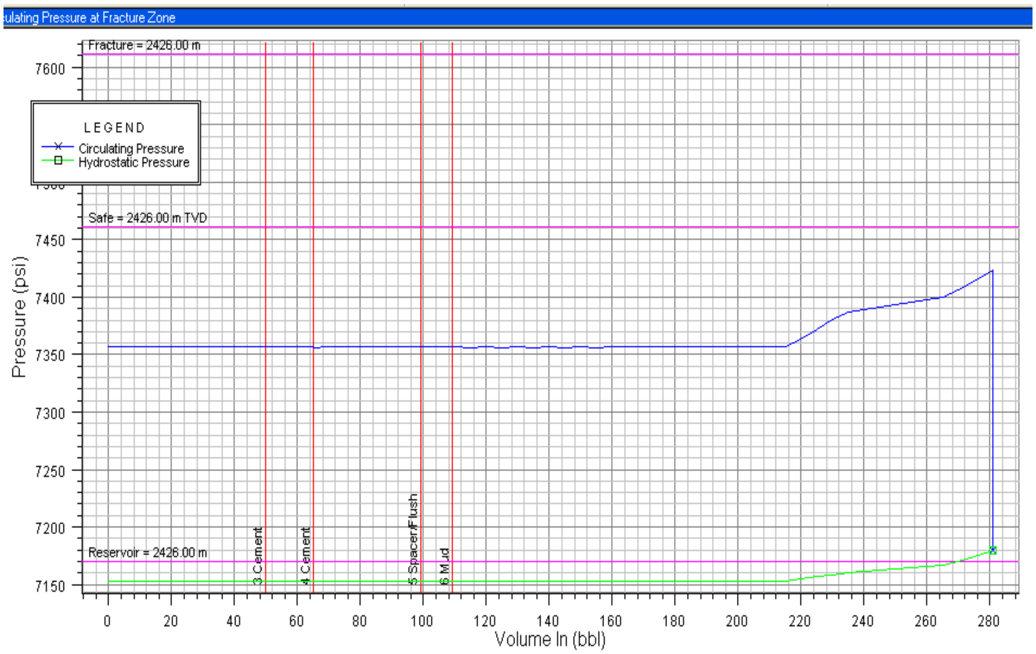


FIGURE51 :Circulating pressure profile for 7" liner at fracture zone

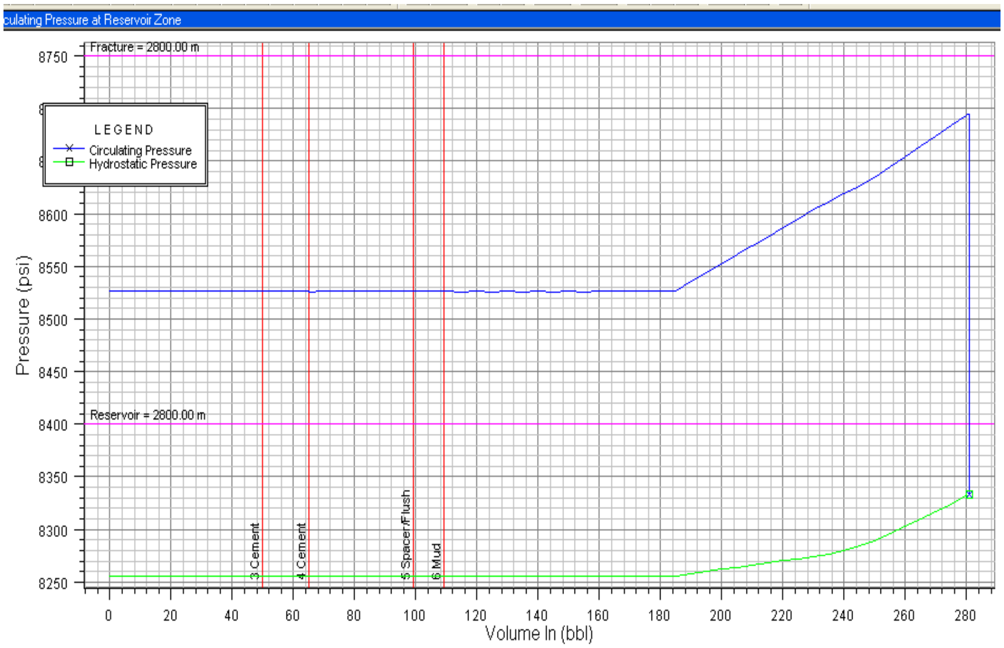
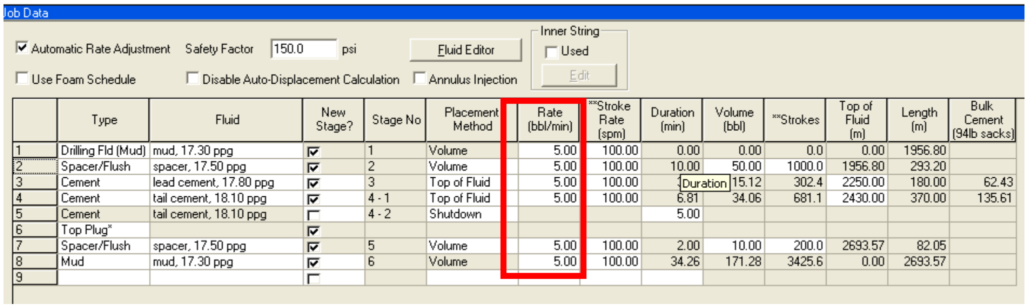


FIGURE52 :Circulating pressure profile for 7" liner at reservoir zone

4.1.4.3 Flow rate



☑ Automatic Rate Adjustment Safety Factor 150.0 psi

☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection

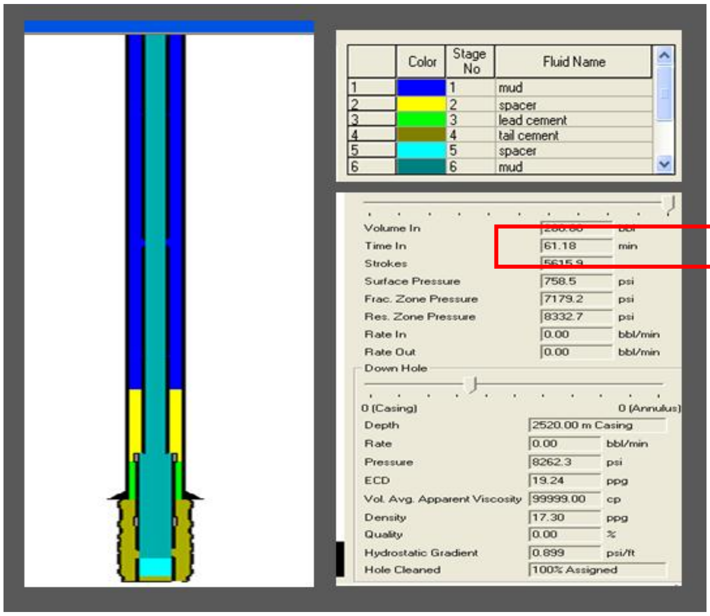
Inner String ☐ Used

	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)	**Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 17.30 ppg	☑	1	Volume	5.00	100.00	0.00	0.00	0.0	0.00	1956.80	
2	Spacer/Flush	spacer, 17.50 ppg	☑	2	Volume	5.00	100.00	10.00	50.00	1000.0	1956.80	293.20	
3	Cement	lead cement, 17.80 ppg	☑	3	Top of Fluid	5.00	100.00	[illegible]	15.12	302.4	2250.00	180.00	62.43
4	Cement	tail cement, 18.10 ppg	☑	4 - 1	Top of Fluid	5.00	100.00	6.81	34.06	681.1	2430.00	370.00	135.61
5	Cement	tail cement, 18.10 ppg	☐	4 - 2	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 17.50 ppg	☑	5	Volume	5.00	100.00	2.00	10.00	200.0	2693.57	82.05	
8	Mud	mud, 17.30 ppg	☑	6	Volume	5.00	100.00	34.26	171.28	3425.6	0.00	2693.57	
9			☐										

FIGURE53 : Job data for 7" liner

Based on the project, the optimum flow rate for the cement slurry is 0.5 bbl/min. in order to ensure ECD pressure below the fracture pressure, the pre-flush mud rate at the line 8 is reduced to 0.01 bbl/min.

4.1.4.4 Fluid position frame



	Color	Stage No	Fluid Name
1	🟦	1	mud
2	🟨	2	spacer
3	🟩	3	lead cement
4	🟫	4	tail cement
5	🟦	5	spacer
6	🟦	6	mud

Volume In [illegible] bbl
Time In 61.18 min
Strokes 5615.9
Surface Pressure 758.5 psi
Frac. Zone Pressure 7179.2 psi
Res. Zone Pressure 8332.7 psi
Rate In 0.00 bbl/min
Rate Out 0.00 bbl/min

Down Hole
0 (Casing) 0 (Annulus)
Depth 2520.00 m Casing
Rate 0.00 bbl/min
Pressure 8262.3 psi
ECD 19.24 ppg
Vol. Avg. Apparent Viscosity 99999.00 cp
Density 17.30 ppg
Quality 0.00 %
Hydrostatic Gradient 0.899 psi/ft
Hole Cleaned 100% Assigned

Total time for execution of job

= 61.18 minutes

FIGURE54: Fluid position frame for 7" liner

The Figure 54 illustrates how the pump job cement at the target depth is done for 7”liner. For this hole section, the time required for the cement to set at the planning elevation is 61.18 minutes.

CHAPTER 5

5.1 DISCUSSION

Cementing is an essential part of completion and its influences the future production of a candidate well. The cement design becomes more challenging in HPHT well due to the well complexity. For instance, narrow ECD window, high pressure and temperature profiles, rheology and others. Based on the research, the objective is to measure the optimum flowrate for three different hole section using Landmark software. Pertaining on that, the final result outcomes is the optimum flowrate measured is 8 bbl/min, 0.5 bbl/min and 5 bbl/min for 11-3/4” liner, 9-5/8” casing and 7” liner respectively. In order to reach the optimum flowrate, it is achieved by proposing the suitable and adequate cement design.

Through this research, it is quite challenging in come out with the final result as this research conducted in HPHT well. The author going through numbers of literature reviews, which included numerous research papers, patents, journals, articles, notes related with the cement design in HPHT well and lab data. These lead the author in achieving the best outcomes in flowrate measurement. Due to that, the author list out several issues faced prior to get the final finding.

5.1.1 Temperature

Prior to obtain the ECD pressure behavior, the temperature measurement is crucial as the cement strength is affected by temperature. As the temperature increase, the cement strength is increase, but at certain point, as the temperature increases its will lead to the decrease in cement strength. Therefore it is really important to measure the temperature along the target depth.

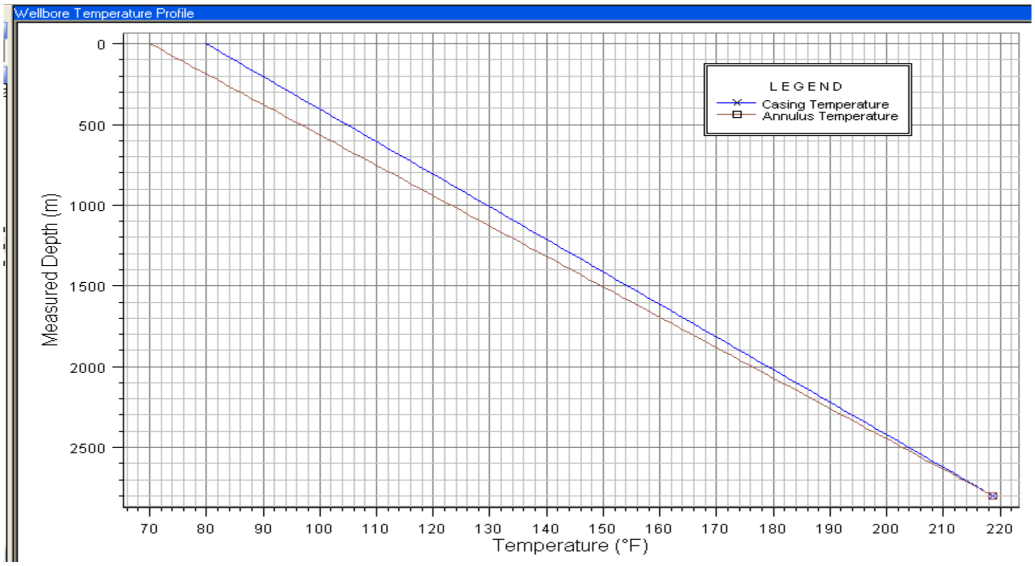
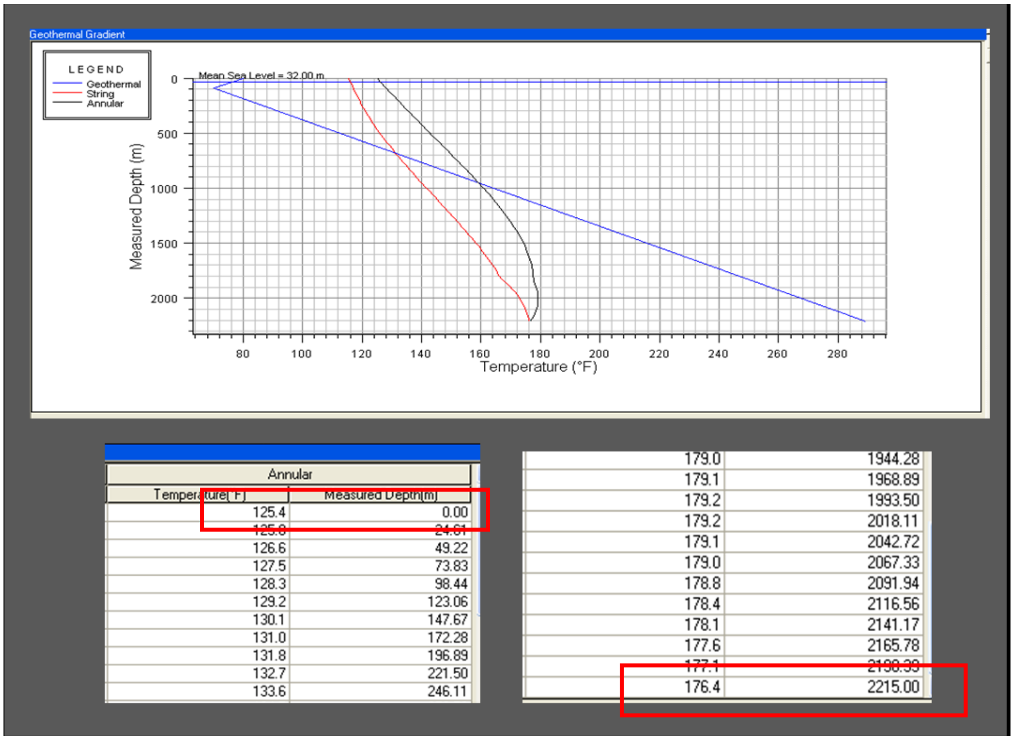


FIGURE55: Wellbore temperature profile along hole depth

Figure 55 illustrate the wellbore temperature profile for casing temperature and annulus temperature along the well to the target depth at 2800 meter. The graph shows both temperatures are increase as the depth increase which the casing temperature is slightly higher than the annulus pressure. The different is temperature is due to heat transfer.

Through physic concept, at first both the temperature can be assumed the same as the well temperature. Once the casing is set, there are barrier between the casing with annulus by casing wall. As the heat transfer concept, the heat will flow from hotter to cold area. Due to that, the heat from annulus is first to transfer to the surrounding and resulting in the reduced in temperature then follow by the heat from casing. As per depth increase, the different of temperatures is reduced. This is due to the temperature gradient between the casing, annulus and surrounding area is reduced. Therefore, this different reduces until reach equilibrium at the target depth.

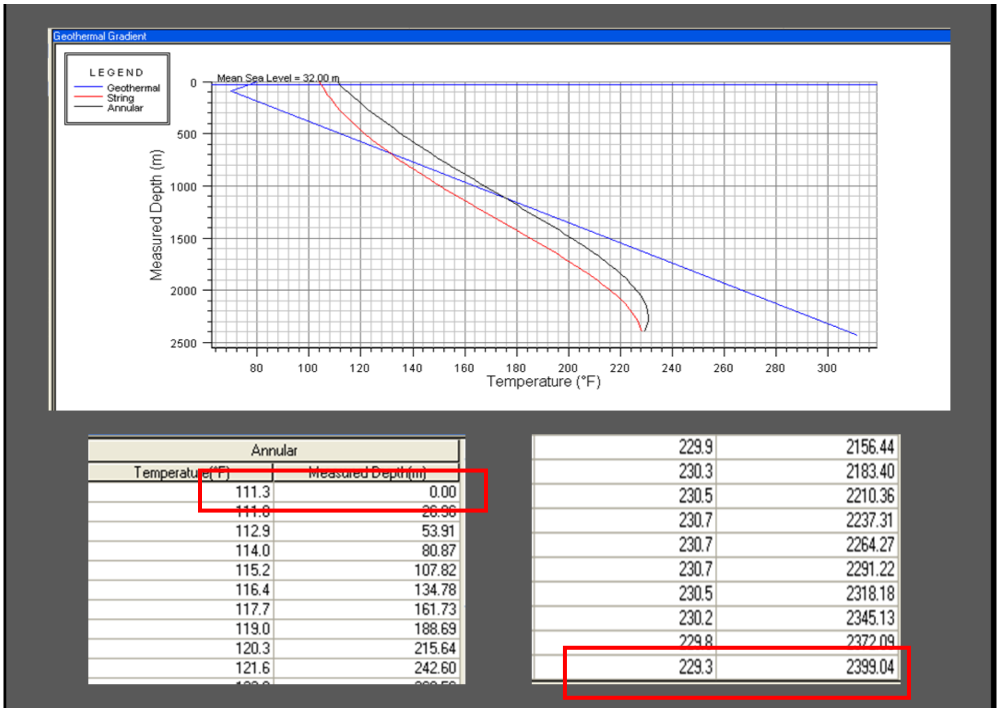
In order to conduct the research, the temperature for the each hole sections are measured. The temperature measured is on surface temperature, Bottomhole Static Temperature (BHST) and Bottomhole Circulating Temperature (BHCT).



Annular	
Temperature(°F)	Measured Depth(m)
125.4	0.00
125.8	24.61
126.6	49.22
127.5	73.83
128.3	98.44
129.2	123.06
130.1	147.67
131.0	172.28
131.8	196.89
132.7	221.50
133.6	246.11

179.0	1944.28
179.1	1968.89
179.2	1993.50
179.2	2018.11
179.1	2042.72
179.0	2067.33
178.8	2091.94
178.4	2116.56
178.1	2141.17
177.6	2165.78
177.1	2190.39
176.4	2215.00

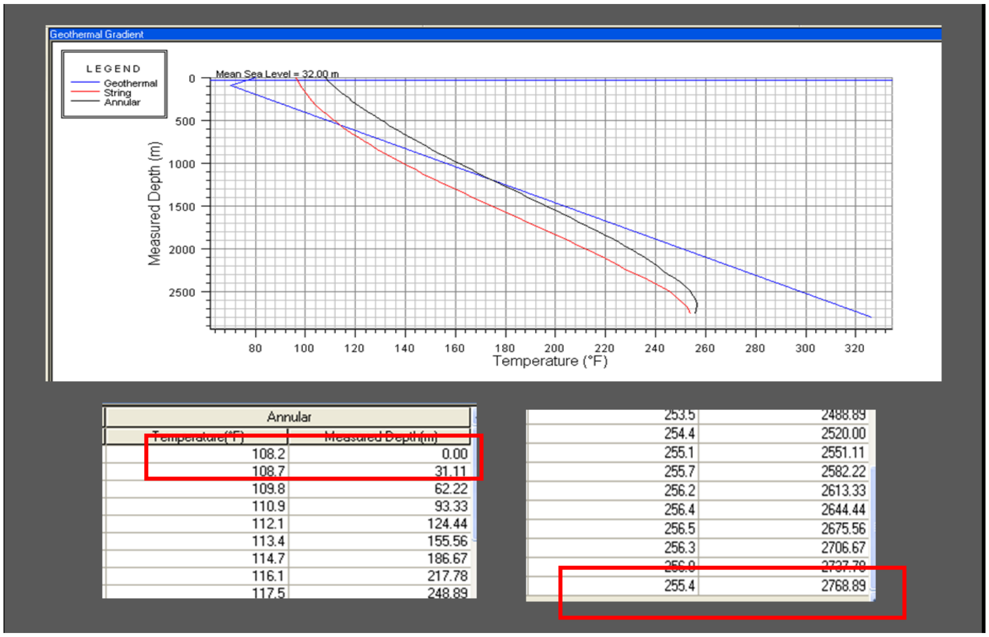
FIGURE56: Geothermal gradient for 14-3/4" hole section



Annular	
Temperature(°F)	Measured Depth(m)
111.3	0.00
111.8	26.96
112.9	53.91
114.0	80.87
115.2	107.82
116.4	134.78
117.7	161.73
119.0	188.69
120.3	215.64
121.6	242.60

229.9	2156.44
230.3	2183.40
230.5	2210.36
230.7	2237.31
230.7	2264.27
230.7	2291.22
230.5	2318.18
230.2	2345.13
229.8	2372.09
229.3	2399.04

FIGURE57: Geothermal gradient for 12-1/4" hole section



Annular	
Temperature(°F)	Measured Depth(m)
108.2	0.00
108.7	31.11
109.8	62.22
110.9	93.33
112.1	124.44
113.4	155.56
114.7	186.67
116.1	217.78
117.5	248.89

253.5	2488.89
254.4	2520.00
255.1	2551.11
255.7	2582.22
256.2	2613.33
256.4	2644.44
256.5	2675.56
256.3	2706.67
256.0	2737.78
255.4	2768.89

FIGURE58: Geothermal gradient for 8-1/2" hole section

The table below is the summary of the temperature profiles measured for each hole section.

TABLE 10 : Temperature profile summary for all hole sections

Temperature Profile	**14-3/4” hole section**	**12-1/4” hole section**	**8-1/2” hole section**
Surface temperature	138.4^{o}F	130.8^{o}F	119.4^{o}F
BHCT	150.4^{o}F	191.7^{o}F	218.7^{o}F
BHST	289.5^{o}F	311.3^{o}F	326.6^{o}F

The surface temperature and BHCT is measured through the hydraulic model of the fluid whereas the BHST is defined through the available temperature data gradient. By follow the rule of thumbs, the temperature value for BHST is higher than BHCT but this condition is not applicable for all well throughout the globe as at some location this phenomena act vice versa.

According to Peter Aird (n. d.), the proper estimation of the BHCT can provide several benefits like;

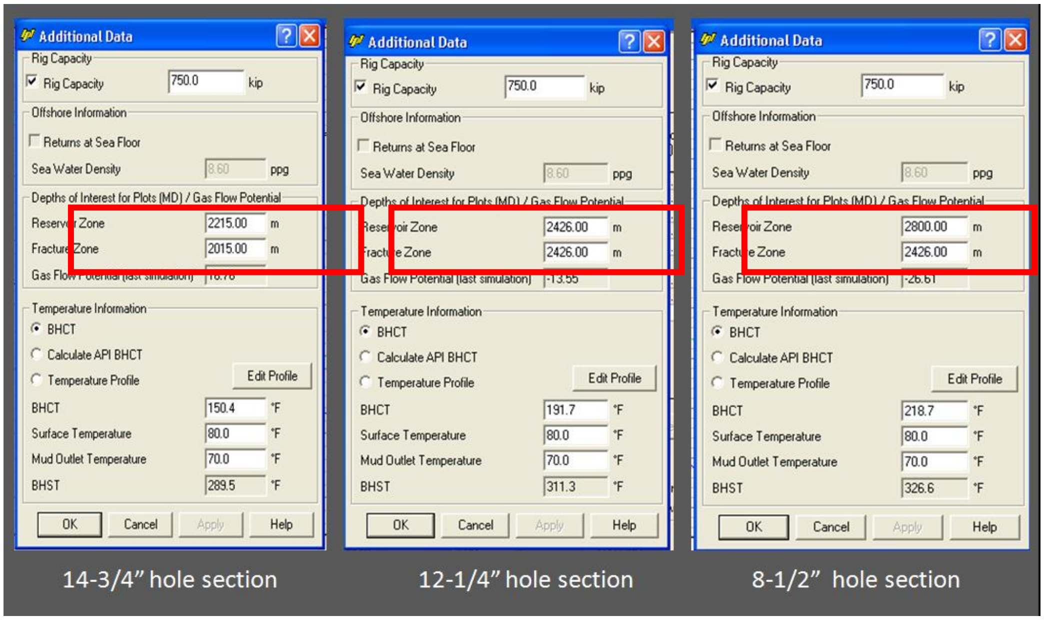
- Minimized waiting on cement
- Increased job safety
- Allows design to follow well conditions
- Optimizes circulating times and rates
- Eliminates risk of premature setting
- Aids in retarder selection

As the temperature concept is achieved, this project research is run with normal cementing procedure and process. If the BHST is lower than BHCT, some modification should be done to the cement slurry in order to change the properties of the so it could be set at the target elevation.Regarding on Bob (2011), typically 35% of silica is added to cement for temperature above 230^{o}F. This is due to increase in temperature, the cement retrogression is induced. Therefore, silica will act as an agent to strengthen the cement bonding. Apart from silica addition, retarder is need to be added to the cement in order to reduce the time for cement to set as the cement set time is fasten as the temperature increase.

5.1.2 Pressure profile at reservoir zone and fracture zone

Reservoir zone refer to the target depth where the slurry placement will be accomplished whereas the fracture zone for this design usually defined at the depth for the previous casing shoe. For 12-1/4" hole section the fracture zone and reservoir zone depth is the same. At first, the fracture zone is defined at the previous casing shoe, 2215 meter. The effect of the fracture zone and reservoir zone is set at same depth lead to the ECD line move toward fracture line.

As ECD increase, the displacement slurry process is optimized. The higher the ECD, the better the displacement process, but it must not exceeded the fracture pressure. Due to that, the depth is defined as the same. Nevertheless, the ECD should not be very close to the fracture pressure. Therefore, safety factor has been set for each of cement design. This safety factor consideration will adjust the ECD and create safety gap from fracture pressure.



14-3/4” hole section

Rig Capacity
☑ Rig Capacity 750.0 kip
Offshore Information
☐ Returns at Sea Floor
Sea Water Density 8.60 ppg
Depths of Interest for Plots (MD) / Gas Flow Potential
Reservoir Zone 2215.00 m
Fracture Zone 2015.00 m
Gas Flow Potential (last simulation) 16.76
Temperature Information
● BHCT
○ Calculate API BHCT
○ Temperature Profile
BHCT 150.4 °F
Surface Temperature 80.0 °F
Mud Outlet Temperature 70.0 °F
BHST 289.5 °F

12-1/4” hole section

Rig Capacity
☑ Rig Capacity 750.0 kip
Offshore Information
☐ Returns at Sea Floor
Sea Water Density 8.60 ppg
Depths of Interest for Plots (MD) / Gas Flow Potential
Reservoir Zone 2426.00 m
Fracture Zone 2426.00 m
Gas Flow Potential (last simulation) -13.55
Temperature Information
● BHCT
○ Calculate API BHCT
○ Temperature Profile
BHCT 191.7 °F
Surface Temperature 80.0 °F
Mud Outlet Temperature 70.0 °F
BHST 311.3 °F

8-1/2” hole section

Rig Capacity
☑ Rig Capacity 750.0 kip
Offshore Information
☐ Returns at Sea Floor
Sea Water Density 8.60 ppg
Depths of Interest for Plots (MD) / Gas Flow Potential
Reservoir Zone 2800.00 m
Fracture Zone 2426.00 m
Gas Flow Potential (last simulation) -26.61
Temperature Information
● BHCT
○ Calculate API BHCT
○ Temperature Profile
BHCT 218.7 °F
Surface Temperature 80.0 °F
Mud Outlet Temperature 70.0 °F
BHST 326.6 °F

FIGURE59: Reservoir zone and fracture zone depth for each hole section

TABLE 11 : Summary of reservoir zone and fracture zone depth for each hole section

	14-3/4” hole section	12-1/4” hole section	8-1/2” hole section
Reservoir zone	2215 meter	2426 meter	2800 meter
Fracture zone	2015 meter	2426 meter	2426 meter
Safety factor	150 psi	150 psi	150 psi

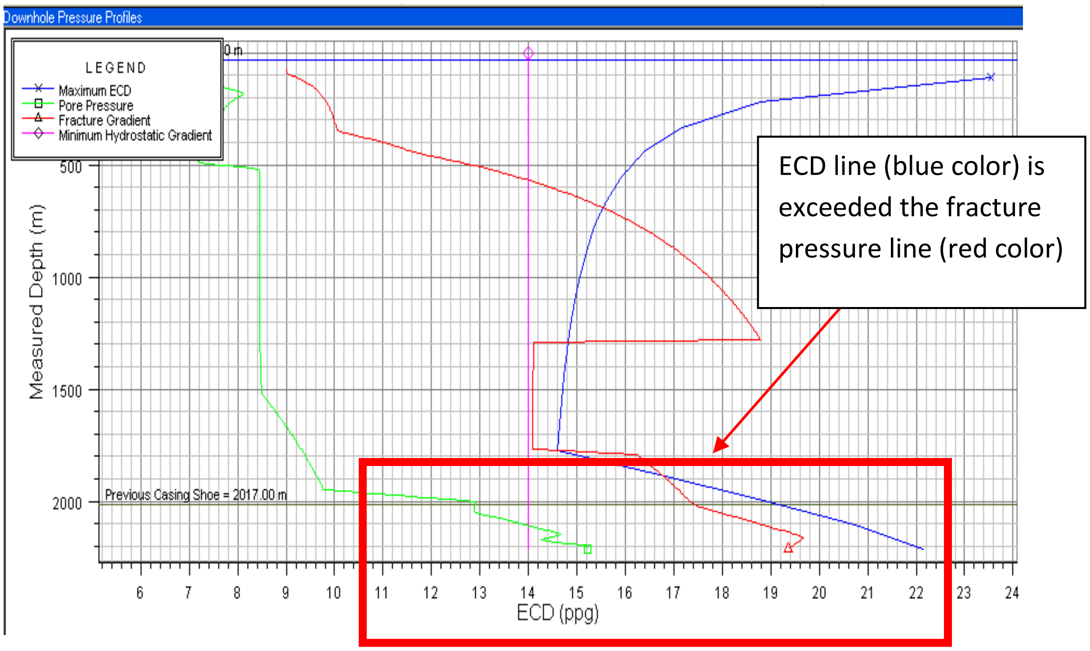
There are two pressure profiles in these zones which are circulating pressure and hydrostatic pressure. Both of these pressure profiles had been recorded in the result part. For the 11-3/4” liner, both of this profile within fracture and formation pressure at both reservoir zone and fracture zone. Therefore this hole section will not faced any well control problem during the placement at target depth.

The situation is contrary with the other two hole sections, 12-1/4" and 8-1/2" hole sections. Although the circulating pressure is within the fracture and formation pressure for both zones, the hydrostatic pressure is lower than formation pressure. This situation indicates that these hole section are in underbalanced differential pressure. Due to that, they might encounter with well control problems during placement process at the target depth. The most severe problem might occur is kick. For the 8/1/2", the hydrostatic pressure not very below the formation pressure. Hence, by applying back pressure this problem could be overcome. In contradict, the hydrostatic pressure for 12-1/4" hole section is really huge in different. This might lead really severe problem during slurry placement at target depth. Therefore, the proper and safety execution of cement should be done and prepared. For this purpose, there will need some adjustment to the fluid design like add retarder and additives adjust the flowrate and monitor the surface pressure so that the team will alert and take any action if there is any kick identification when the pressure being monitored change abruptly.

The reasons behind this situation is also can be refer to U-tube effect. In this effect, the concept is there are two differential density fluids in the tube. The heavier density fluid can be referring to the formation pressure whereas the lighter density fluid refers to the hydrostatic pressure. Due to that, the high density fluid will pushed the lighter fluid. This behavior explains why kick happen when dealing with hydrostatic pressure lower than formation pressure.

5.1.3 ECD

Pertaining on that, this behavior should be monitored to ensure no complication occur throughout the cementing execution. When the ECD exceeded the fracture pressure, the slurry will damage the formation and lead to slurry lost into formation whereas as the ECD below the pore pressure, kick will occur. Therefore, controlling the ECD is really crucial for successful cement job.



ECD line (blue color) is exceeded the fracture pressure line (red color)

FIGURE60 : ECD line exceed fracture pressure

For this project purpose, in order to overcome this problem, the flowrate of slurry is reduced.

The other complication which might be encounter when ECD line not within the ECD window is;

- Hole cleaning inefficiency as the higher flowrate increase the hole cleaning process which could be done when the value of ECD is low.
- Differential sticking of slurry which formed bridging at the pore at clogged the formation.
- Casing string inefficiency as the casing strings number can be reduced. It is an economical approach as the cost to set unnecessary casing strings can be cut or reduced.

Due to that, these problems could be overcome by;

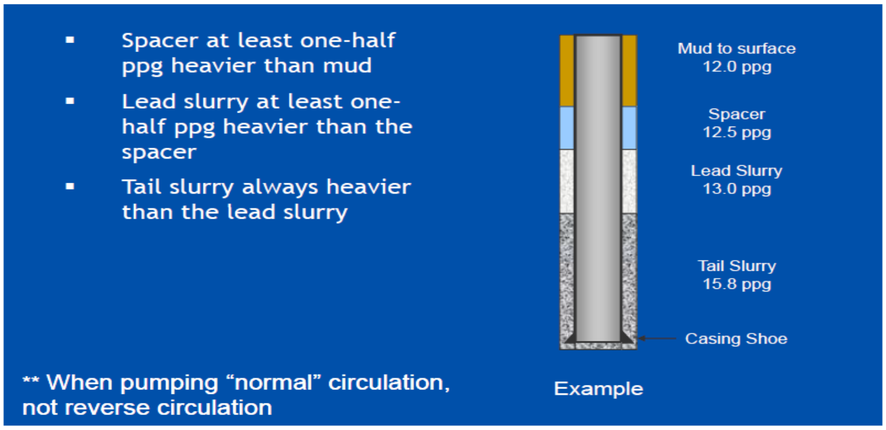
- Using low fluid rheologies like reduced the density of displace mud, spacer, lead cement and tail cement on order to reduce frictional losses.
- Using drill strings and casing strings that provide greater annular clearance.
- Allowing drilling fluids, spacer and cement to flow freely into the casing and up the annulus to avoid lost circulation, while providing excellent hole cleaning.
- Reducing flow rates to decrease frictional losses.(approach used in the project)
- Reducing penetration rates to reduce the amount of cuttings in the annulus

5.1.4 Flowrate

The flowrate values is different for each hole section. These differences due to the many factors like the rheology of slurry, temperature, pressure, fluid properties and pump flowrate. Based on this project, in order to achieve the desire and optimum flowrate, the pump flowrate is adjusted. The reason behind this is to ensure that the ECD line is within ECD window or lies within the pore pressure and fracture pressure gradient line. As explain earlier, the ECD is affected by the frictional losses, hence, the flowate reduces will result in the reduction of frictional losses, then automatically reduced the ECD.

Regarding on the project, the flowrates are 8 bbl/min, 0.05 bbl/min and 5 bbl/min for 11-3/4” liner, 9-5/8” casing and 7” liner respectively. As per result, the flowrate for 11-3/4” liner is higher than the other cases. This is due, the hole section is not as complex compare to the others. The ECD window is bigger and the pressure and temperature profiles for the elevation are not so high and still not exceeded 300^{o}F. Therefore, for this case, the liner can be considered as normal well. In contrary, the 9-5/8” casing and 7” liner are both HPHT well. For the 9-5/8” casing, the flowrate is adjusted to 0.05 bbl/min. The value is quite unreasonable, but the increment of flowrate higher than 0.05 bbl/min will lead to ECD line exceeded fracture pressure line and resulting in well control problem. For the 7” liner case, the flowrate is reduces to 5 bbl/min and this flowrate is appropriate as the ECD is within pore pressure and lower than fracture pressure.

Apart from that, the flowrate is also influenced by the slurry density design. The heavy the fluids, the higher the ECD profile. Based on this project, there are four types of fluids is defined for each hole section which are mud, spacer, lead cement and tail cement. The mud density is can be set higher that pore pressure value for previous casing string and the tail cement is set below the fracture pressure for design casing string. The spacer and lead cement density are set based on standard used by Chevron ETC drilling and completion (2010).



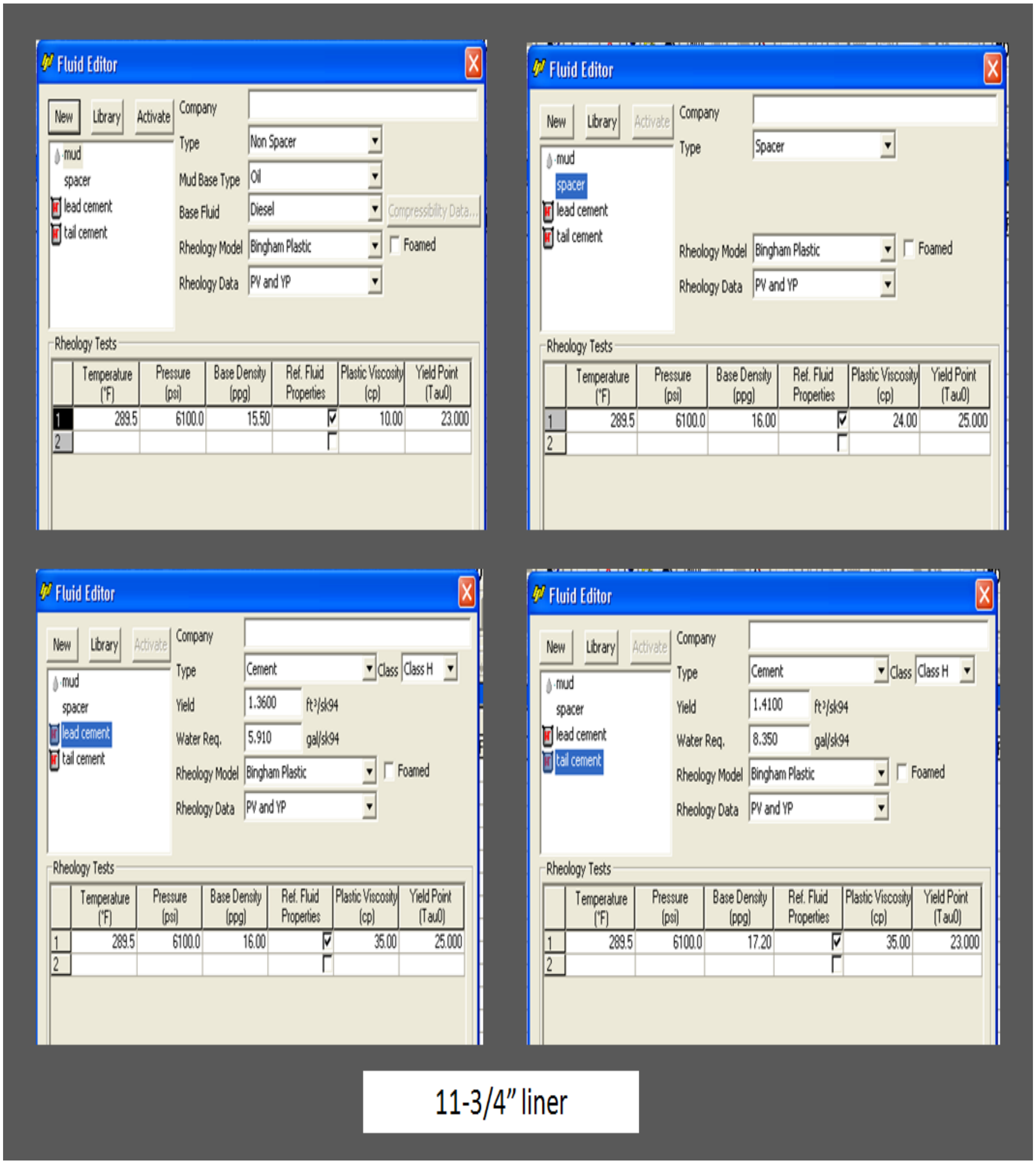
- Spacer at least one-half ppg heavier than mud
- Lead slurry at least one-half ppg heavier than the spacer
- Tail slurry always heavier than the lead slurry

** When pumping “normal” circulation, not reverse circulation

FIGURE61 : Slurry density hierarchy selection**.** Chevron ETC drilling and completion (2010).

Based on the Figure 61, the density selection is only applicable for 11-3/4” liner and 9-5/8” casing but the 7’ liner is not applicable since the ECD window is narrow. Therefore, for the 7” liner, the fluids are design such by following the rule of thumbs which the density of mud lower than spacer, the spacer less than lead cement and the lead cement is lower than tail cement.

The summary of the fluids density design for each hole section is;



mud
spacer
lead cement
tail cement

Company
Type: Non Spacer
Mud Base Type: Oil
Base Fluid: Diesel
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	289.5	6100.0	15.50	☑	10.00	23.000
2				☐		

mud
spacer
lead cement
tail cement

Company
Type: Spacer
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	289.5	6100.0	16.00	☑	24.00	25.000
2				☐		

mud
spacer
lead cement
tail cement

Company
Type: Cement Class: Class H
Yield: 1.3600 ft³/sk94
Water Req.: 5.910 gal/sk94
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	289.5	6100.0	16.00	☑	35.00	25.000
2				☐		

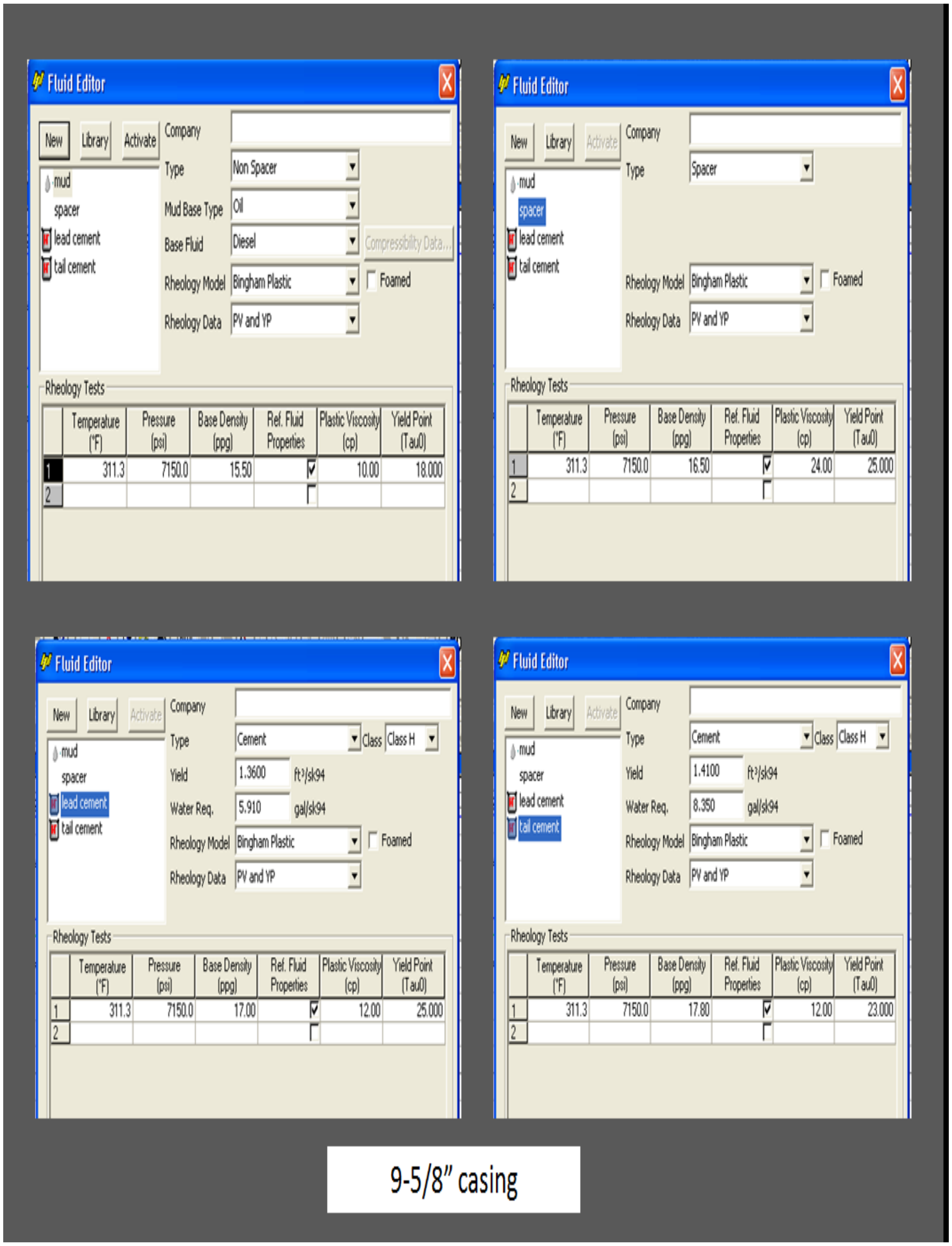
mud
spacer
lead cement
tail cement

Company
Type: Cement Class: Class H
Yield: 1.4100 ft³/sk94
Water Req.: 8.350 gal/sk94
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	289.5	6100.0	17.20	☑	35.00	23.000
2				☐		

FIGURE62 : Fluid density selection for 11-3/4" liner



Company:
Type: Non Spacer
Mud Base Type: Oil
Base Fluid: Diesel
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	311.3	7150.0	15.50	☑	10.00	18.000
2				☐		

Company:
Type: Spacer
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	311.3	7150.0	16.50	☑	24.00	25.000
2				☐		

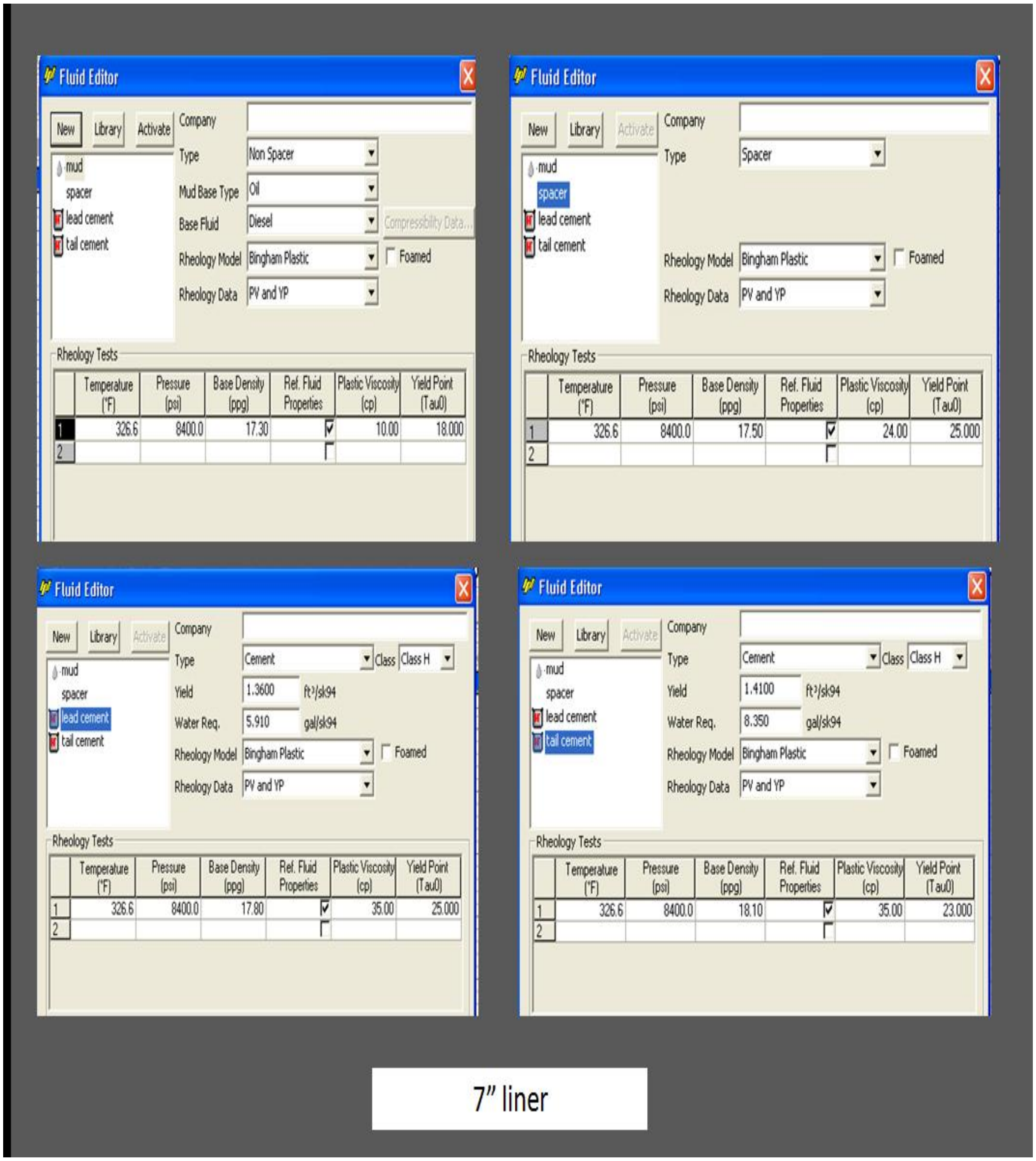
Company:
Type: Cement Class: Class H
Yield: 1.3600 ft³/sk94
Water Req.: 5.910 gal/sk94
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	311.3	7150.0	17.00	☑	12.00	25.000
2				☐		

Company:
Type: Cement Class: Class H
Yield: 1.4100 ft³/sk94
Water Req.: 8.350 gal/sk94
Rheology Model: Bingham Plastic ☐ Foamed
Rheology Data: PV and YP

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	311.3	7150.0	17.80	☑	12.00	23.000
2				☐		

FIGURE 63 : Fluid density selection for 9-5/8"casing



Company:
Type: Non Spacer
Mud Base Type: Oil
Base Fluid: Diesel
Rheology Model: Bingham Plastic
☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	326.6	8400.0	17.30	☑	10.00	18.000
2				☐		

Company:
Type: Spacer
Rheology Model: Bingham Plastic
☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	326.6	8400.0	17.50	☑	24.00	25.000
2				☐		

Company:
Type: Cement
Class: Class H
Yield: 1.3600 ft³/sk94
Water Req.: 5.910 gal/sk94
Rheology Model: Bingham Plastic
☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	326.6	8400.0	17.80	☑	35.00	25.000
2				☐		

Company:
Type: Cement
Class: Class H
Yield: 1.4100 ft³/sk94
Water Req.: 8.350 gal/sk94
Rheology Model: Bingham Plastic
☐ Foamed
Rheology Data: PV and YP

Rheology Tests

	Temperature (°F)	Pressure (psi)	Base Density (ppg)	Ref. Fluid Properties	Plastic Viscosity (cp)	Yield Point (Tau0)
1	326.6	8400.0	18.10	☑	35.00	23.000
2				☐		

FIGURE64 : Fluid density selection for 7" liner

TABLE 12 : Summary of fluid density selection for each hole section

	11-3/4” liner	9-5/8” casing	7” liner
Mud	15.5 ppg	15.5 ppg	17.3 ppg
Spacer	16.0 ppg	16.5 ppg	17.5 ppg
Lead cement	16.5 ppg	17.0 ppg	17.8 ppg
Tail cement	17.2 ppg	17.8 ppg	18.1 ppg

Based on Cementing Services and Product by Schlumberger (n.d.) stated for harsh environment like HPHT well, special resistance properties are required. Hence, some components are added to increase the cement resistance in order to avoid it from mixing with other chemical during placement. The types of special cement used by Schlumberger are;

- Acid-resistant cement
- Carbon dioxide-resistant cement
- Synthetic cement

The cement used in this project is cement API class H. based on Peter Aird (n.d.), for HPHT cementing coursework, cement API class G or H is being used. The other minimum additives required stated by Peter Aird are;

- Add silica (sand or flour)
- Weighting agent (Hematite or Manganese Oxide)
- High temperature Fluid loss additive
- De-foamer
- Water

5.1.5 Problems encounter using landmark

5.1.5.1 The pore pressure and ECD lines are not show in the downhole pressure profile graph.

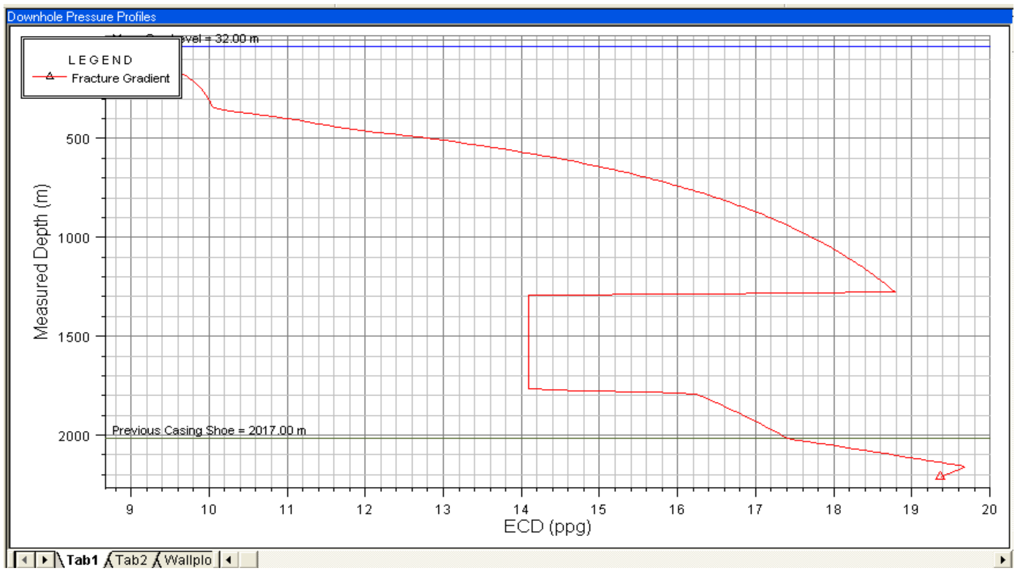


FIGURE65 : Downhole pressure profile not showing pore pressure, ECD and hydrostatic pressure

Without these lines, there are difficult to analyze the ECD behavior which resulting in error in getting the optimum flow rate. There are several factors which contributed to this outcome.

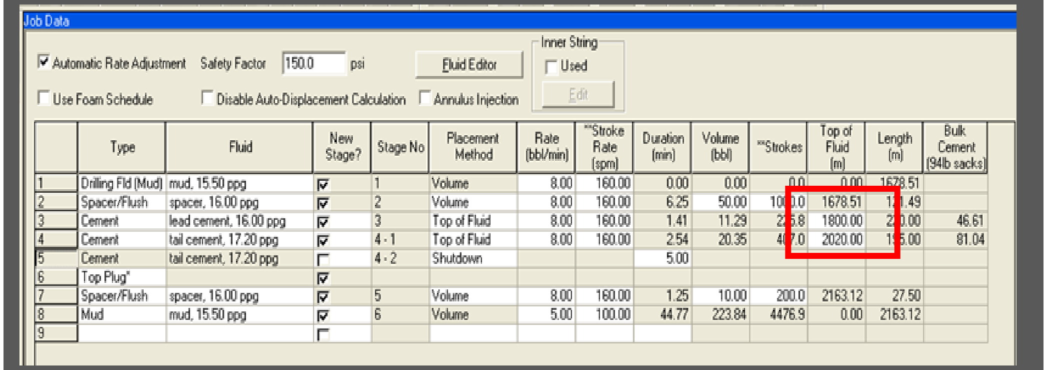
5.1.5.2 Pore pressure line

This line is unavailable due to redundancy in the pore pressure relative to the depth. Pertaining on that, the author input 4500 psi and 4600 psi for the pore pressure at 2050 meter. The module failed to generate the pore pressure line when there are redundancies in the value of pore pressure at same elevation. Due to that, the value of depth is changed where the pore pressure for 4500 psi is defined at the depth of 2050 meter and the 4600 psi is defined at the depth of 2060 meter.

5.1.5.3 ECD line

The ECD line is not visualized in the plot is due to some problem regarding on the error in defining fluids in fluid editor. The fluid used must parallel with the wellbore parameter at the measured elevation. Pertaining on that, an adjustment of temperature, pressure, spacer and slurry density should be redefined.

Next, in job data analysis, the top of fluid is redefined based on desire depth of cement should be set. Based on the cementing design for 11-3/4 inches liner, the top of lead cement and the tail cement are set at 2000 meter and 2200 meter respectively.



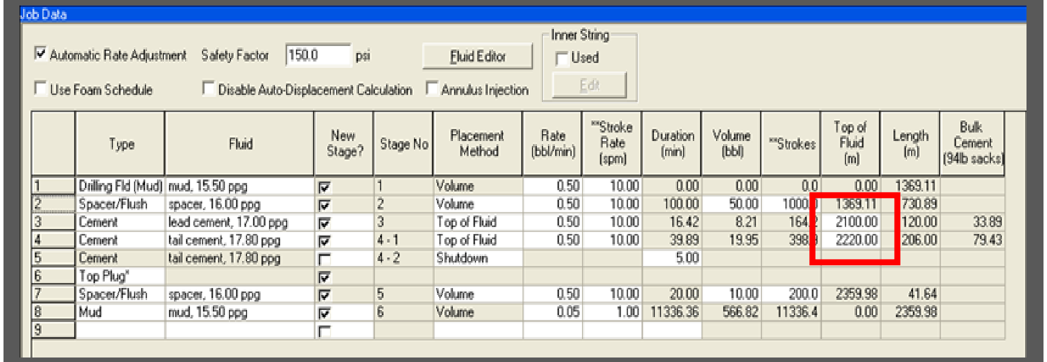
Job Data

☑ Automatic Rate Adjustment Safety Factor 150.0 psi Fluid Editor Inner String ☐ Used Edit

☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection

	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)	**Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 15.50 ppg	☑	1	Volume	8.00	160.00	0.00	0.00	0.0	0.00	1678.51	
2	Spacer/Flush	spacer, 16.00 ppg	☑	2	Volume	8.00	160.00	6.25	50.00	10[illegible]0.0	1678.51	1[illegible]1.49	
3	Cement	lead cement, 16.00 ppg	☑	3	Top of Fluid	8.00	160.00	1.41	11.29	2[illegible]5.8	1800.00	2[illegible]0.00	46.61
4	Cement	tail cement, 17.20 ppg	☑	4 - 1	Top of Fluid	8.00	160.00	2.54	20.35	4[illegible]7.0	2020.00	1[illegible]5.00	81.04
5	Cement	tail cement, 17.20 ppg	☐	4 - 2	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 16.00 ppg	☑	5	Volume	8.00	160.00	1.25	10.00	200.0	2163.12	27.50	
8	Mud	mud, 15.50 ppg	☑	6	Volume	5.00	100.00	44.77	223.84	4476.9	0.00	2163.12	
9			☐										

11-3/4" liner



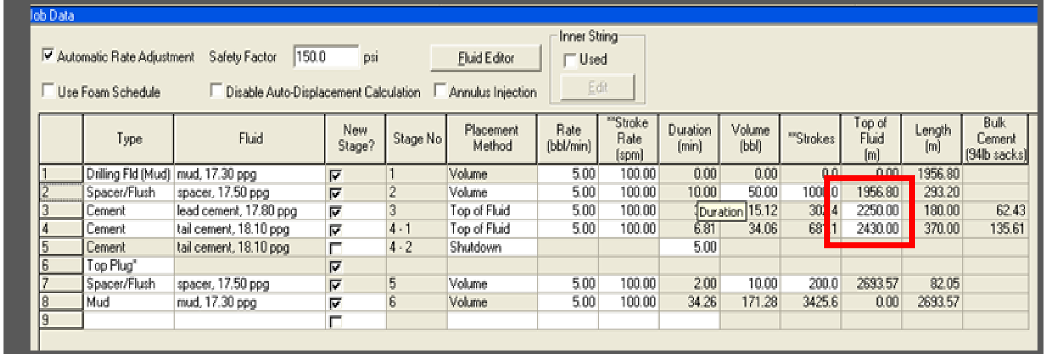
Job Data

☑ Automatic Rate Adjustment Safety Factor 150.0 psi Fluid Editor Inner String ☐ Used Edit

☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection

	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)	**Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 15.50 ppg	☑	1	Volume	0.50	10.00	0.00	0.00	0.0	0.00	1369.11	
2	Spacer/Flush	spacer, 16.00 ppg	☑	2	Volume	0.50	10.00	100.00	50.00	1000[illegible]	1369.11	730.89	
3	Cement	lead cement, 17.00 ppg	☑	3	Top of Fluid	0.50	10.00	16.42	8.21	164[illegible]	2100.00	120.00	33.89
4	Cement	tail cement, 17.80 ppg	☑	4 - 1	Top of Fluid	0.50	10.00	39.89	19.95	398[illegible]	2220.00	206.00	79.43
5	Cement	tail cement, 17.80 ppg	☐	4 - 2	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 16.00 ppg	☑	5	Volume	0.50	10.00	20.00	10.00	200.0	2359.98	41.64	
8	Mud	mud, 15.50 ppg	☑	6	Volume	0.05	1.00	11336.36	566.82	11336.4	0.00	2359.98	
9			☐										

9-5/8" liner



Job Data

☑ Automatic Rate Adjustment Safety Factor 150.0 psi Fluid Editor Inner String ☐ Used Edit

☐ Use Foam Schedule ☐ Disable Auto-Displacement Calculation ☐ Annulus Injection

	Type	Fluid	New Stage?	Stage No	Placement Method	Rate (bbl/min)	**Stroke Rate (spm)	Duration (min)	Volume (bbl)	**Strokes	Top of Fluid (m)	Length (m)	Bulk Cement (94lb sacks)
1	Drilling Fld (Mud)	mud, 17.30 ppg	☑	1	Volume	5.00	100.00	0.00	0.00	0.0	0.00	1956.80	
2	Spacer/Flush	spacer, 17.50 ppg	☑	2	Volume	5.00	100.00	10.00	50.00	100[illegible]0	1956.80	293.20	
3	Cement	lead cement, 17.80 ppg	☑	3	Top of Fluid	5.00	100.00	Duration	15.12	30[illegible]4	2250.00	180.00	62.43
4	Cement	tail cement, 18.10 ppg	☑	4 - 1	Top of Fluid	5.00	100.00	6.81	34.06	68[illegible]1	2430.00	370.00	135.61
5	Cement	tail cement, 18.10 ppg	☐	4 - 2	Shutdown			5.00					
6	Top Plug*		☑										
7	Spacer/Flush	spacer, 17.50 ppg	☑	5	Volume	5.00	100.00	2.00	10.00	200.0	2693.57	82.05	
8	Mud	mud, 17.30 ppg	☑	6	Volume	5.00	100.00	34.26	171.28	3425.6	0.00	2693.57	
9			☐										

7" liner

FIGURE66 : Top of fluid for lead cement and tail cement

The final result for bottom hole pressure profiles can be refer to Figure 38, 44 and 50 in result part where the pore pressure line, fracture pressure line and maximum ECD line for each hole section is shown.

5.2 RECOMMENDATION

Prior to well production, there are a lot of consideration and parameters should be study and analyze. Pertaining on that, collection of data is really important. Same goes to the measurement of the flowrate for the cementing design in HPHT well. There are many parameters in cementing design which should be input into the Landmark software prior to final result. The lack of data leads to inaccurate outcome. Based on this project, the flowrate measurement from HPHT well cementing design is measure by using data from Dynamic modeling of wellbore pressures allows successful drilling of a narrow margin HPHT exploration well in Malaysia written by Noor Azree et al. (2012). The data provided in this paper is insufficient for getting the final outcomes. Due to that, assumptions and additional data by referring to articles, journals, past papers and cementing practices data used by oil and gas players are needed. Some of these data are confidential to public. Therefore, in order to get the accurate final outcome, all the data start from acquisition data until prior to cementing process should be gathered and input into the software. This encompasses the lab data of cementing practices in HPHT well.

Pertaining on the project, the other recommendations for measured the flowrate using Landmark software are;

- Measure flowrate at different types of well trajectory, for instance slanting well and horizontal well as these types of well trajectory are widely used around the globe and the ECD behavior are really challenging.
- Used the current version of Landmark software as some of the parameters in precious Landmark software are not being updates in catalog.
- Measured the flowrate by change the variable, for instance modified rheology of slurry by adding on additive like silica instead of adjust the flowrate at job data dialog box.

CHAPTER 6

6.1 CONCLUSION

Cementing of well is really important process in production of hydrocarbon from a well. Without proper design and planning of cementing process this may lead to the failure of well. Apart from that, a well with fail cement with cause the well to face many problems like well collapse, mitigation of gas, loss of formation and even more cause fatal. Therefore, cement engineer and cement designer should highly analyze well parameters to prepare the best cement design and process.

Based on the project, the main objective is to measure the optimum flowrate or displacement velocity of the cement in HPHT well by take consideration of ECD behavior. For this project, the optimum flowarate for the each hole sections are 8 bbl/min, 0.05 bbl/min and 1.5 bbl/min for 11-3/4" liner, 9-5/8" casing and 7" liner respectively. The flowrate value is depends on the slurry rheology and adjustment of pump flowrate. The higher the slurry density, the higher the value of ECD and the flowrate is reduces so that ECD is within pore pressure and fracture pressure. Both of these situations should be taken into considerationto avoid well control problems later on.

The temperature of BHST and BHCT are also need to be defined. The temperature is affecting the slurry retrogression. As temperature increase, the strength of slurry increase but up until certain increase in temperature, it reduces the slurry strength. Therefore, an addition of additive like silica is needed. Besides, retarder is also important in order to lengthen the time thickening for HPHT well cementing.

Apart from that, the project has taught the author on Landmark software and the cementing process. This knowledge is really valuable because in the real working life in oil and gas industry, the author has to face with this situation when dealing with drilling operation specifically in well control process. Therefore, the author become more prepared to enter the real industry in the future.

As the conclusion, the objective of the project which is to determine the ECD behavior from different hole sections, to study and analyze the effect of ECD behavior on cementing HPHT well, to determine the optimum flow rate or annular velocity for designated cement slurry at each hole section are achieved.

6.2 REFERENCES

Abdul Rahman, R. and Chong, A. 1997.*Cementing Multilateral Well with Latex Cement*

Adamson. K, Birch. G, Gao. E, Hand. S, Macdonald. C, Mack. D, and Quadri. A. 1998. *High Pressure, High Temperature Well Contruction*

Aird. P. n.d. Msc Drilling Engineering. *HPHT cementing Coursework*

Bruce Craigh. 2008. *Deep Oil and Gas Well Construction*

Calvert, D. G. and Griffin, T.J. 1998. *Determination for cementing in wells drilled in deep water.*

Calvert, D.G. and Smith, D.K. 1990. *API Oilwell Cementing Practice*

Cook. J, Growcock. F, Guo. Q, Hodder. M and Oort. E. V. 2012. *Stabilizing the Wellbore to Prevent Lost Circulation*

Dalamarinis P. 2010 *An Easy to Use Well Design Software Package for Educational Training*, department of Mineral Resources Engineering, Technical University of Crete.

Dillenbeck. L. 2010. *The Impact of Cementing on Proper Well Control*

Elmarsafawi, Y., and Beggah, A. 2013. *Innovative Managed-Pressure-Cementing Operations in Deepwater and Deep Well Conditions*

Frittella, F., and Babbo, M. 2009.*Best practices and lessons learned from 15 years of experience of cementing HPHT wells in Italy*

Haidher. S, Kale. S, and Nair. S. K. 2006. *HP/HT Cement System Design-East Coast Case History*

Halliburton.Cementing. Retrieved February 21, 2013, from http://www.apastyle.org/learn/faqs/web-page-no-author.aspx?apaSessionKey=BA3FE059590098C5BB81CC38B6D59149

Hampshire,K., McFadyen, M., Ong, D., Mukoro, P. and Elmarsafawi, Y. (2004), *Overcoming Deepwater Cementing Challenges in South China Sea, East Malaysia.*

Harris, O. 2004.*Evaluation of equivalent circulating density of drilling fluids under high pressure-high temperature conditions*

Ilyas, M., Sadiq, N., Mughal, A.M., Pardawalla, H., and Noor, S.M.2012.*Improvement of Cementing in Deep Wells.*

Kinzel, H., and Koithan, T. 1997. *Planning the cementing job incorporates data management and technical expertise-a new software to calculate the optimum placement of mechanical cementing products*

Morgan, B.E.*API Specification for OIL-well Cements.*

Mishra, P.K.2006. *Ultradeepwater cementing: Challenges and Solutions*

Naganawa, S., and Okatsu, K. 2008.*Fluctuation of equivalent circulating density on extended reach drilling with repeated formation and erosion of cuttings bed*

Nasvi, Ranjit,P.G. and Sanjayan, J. 2012. *Comparison of mechanical behaviors of geopolymer and glass G cement as well cement at different curing temperatures for geological sequestration of carbon dioxide*

Noor Azree, N., Lawrence, U., IntanAzian, A., and Steve, N. 2012.*Dynamic modeling of wellbore pressure allows successful drilling of a narrow margin HPHT exploration well in Malaysia*

Ozbayoglu. E. M and Sorgun. M. 2010. *Frictional Pressure Loss Estimation of Non-Newtonian Fluids in Realistic Annulus with Pipe Rotation*

Razak. A. UTM Power Point Slide. Drilling Engineering.*Formation Pressure*

Schlumberger. Cementing Services and Products, *Materials*

Schlumberger.Drilling fluids. Retrieved February 21, 2013, from http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=drilling%20fluid

Transocean. 2010. *Deepwater Horizon Rig Incident Investigation into the Facts and Causation.*

Wooley, G.R, Giussani, A. P., and Wedlich, H.F. 1984. *Cementing Temperature for deep-well production lines*

Yuan, Z., Schubert, J., Teodoriu, C., and Gardoni, P. 2012. *HPHT gas well cementing complications and its effect on casing collapse resistance*

Yutende, S., and Ogbonna, J. 2011.*Challenges and remedy for cementing of HPHT wells in Nigerian operation*

6.3 APPENDIX

Additional information

Minimum pump rate = 475 gpm

Increment pump rate = 50 gpm

Maximum pump rate = 725 gpm

Average Pump rate = 400 gpm

Maximum surface pressure = 7500 psi

Maximum pump power = 2000 psi

Time of circulation = 9hour * mud temperature effect included

All is assume as 100% standoff

Tripping in = 60 ft/min

Rotation per Minute (RPM) = 5 rpm

Safety factor = 150 psi

Additional pressure to seat plug = 100 psi

11-3/4” liner

Mud

- Plastic Viscosity (cp) = 10
- Yield Point (TauO) = 23

Spacer

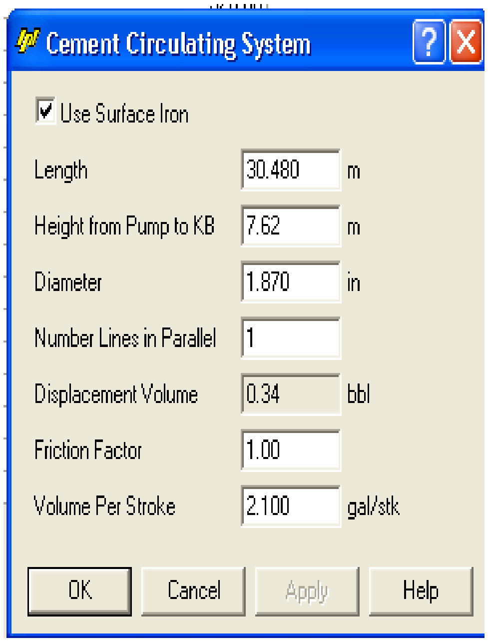
- Plastic Viscosity (cp) = 24
- Yield Point (TauO) = 25

Lead cement

- Plastic Viscosity (cp) = 35
- Yield Point (TauO) = 25

Tail cement

- Plastic Viscosity (cp) = 35
- Yield Point (TauO) = 23



☑ Use Surface Iron

Length 30.480 m

Height from Pump to KB 7.62 m

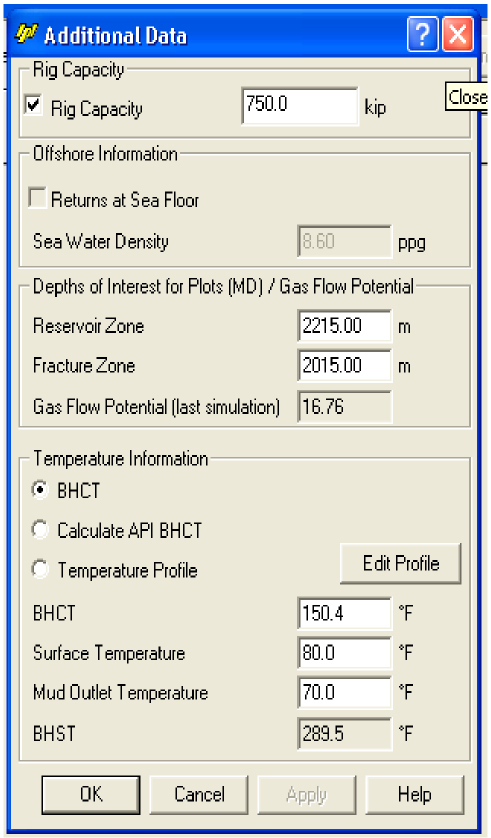
Diameter 1.870 in

Number Lines in Parallel 1

Displacement Volume 0.34 bbl

Friction Factor 1.00

Volume Per Stroke 2.100 gal/stk



☑ Rig Capacity 750.0 kip

☐ Returns at Sea Floor

Sea Water Density 8.60 ppg

Reservoir Zone 2215.00 m

Fracture Zone 2015.00 m

Gas Flow Potential (last simulation) 16.76

● BHCT

○ Calculate API BHCT

○ Temperature Profile

BHCT 150.4 °F

Surface Temperature 80.0 °F

Mud Outlet Temperature 70.0 °F

BHST 289.5 °F

9-5/8” casing

Mud

- Plastic Viscosity (cp) = 10
- Yield Point (TauO) = 18

Spacer

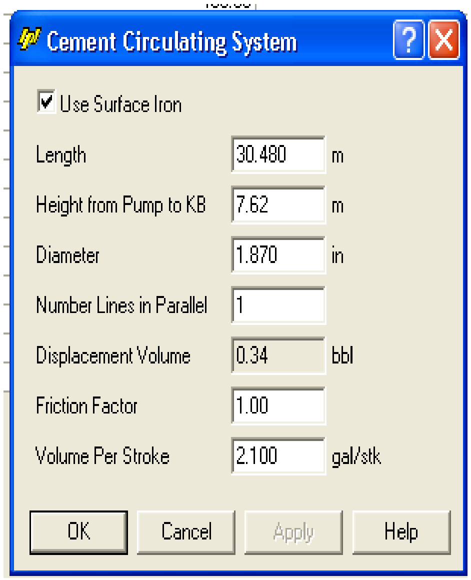
- Plastic Viscosity (cp) = 24
- Yield Point (TauO) = 25

Lead cement

- Plastic Viscosity (cp) = 12
- Yield Point (TauO) = 25

Tail cement

- Plastic Viscosity (cp) = 12
- Yield Point (TauO) = 23



Cement Circulating System

☑ Use Surface Iron

Length 30.480 m

Height from Pump to KB 7.62 m

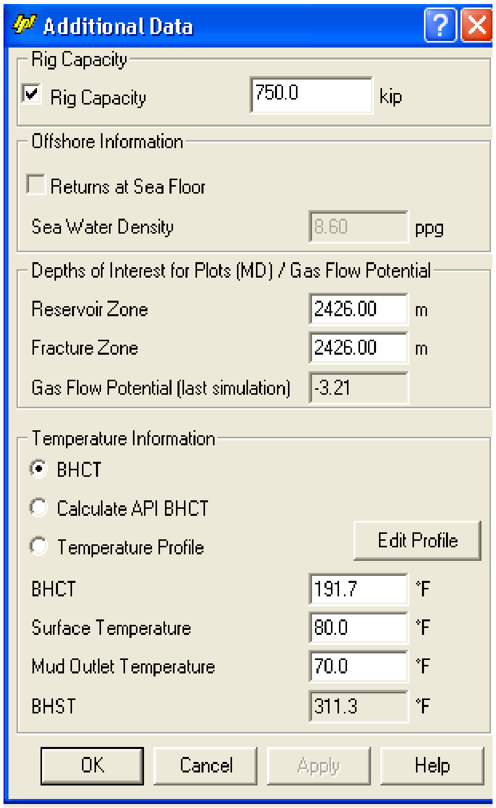
Diameter 1.870 in

Number Lines in Parallel 1

Displacement Volume 0.34 bbl

Friction Factor 1.00

Volume Per Stroke 2.100 gal/stk



Additional Data

Rig Capacity

☑ Rig Capacity 750.0 kip

Offshore Information

☐ Returns at Sea Floor

Sea Water Density 8.60 ppg

Depths of Interest for Plots (MD) / Gas Flow Potential

Reservoir Zone 2426.00 m

Fracture Zone 2426.00 m

Gas Flow Potential (last simulation) -3.21

Temperature Information

● BHCT

○ Calculate API BHCT

○ Temperature Profile

BHCT 191.7 °F

Surface Temperature 80.0 °F

Mud Outlet Temperature 70.0 °F

BHST 311.3 °F

7” liner

Mud

- Plastic Viscosity (cp) = 10
- Yield Point (TauO) = 18

Spacer

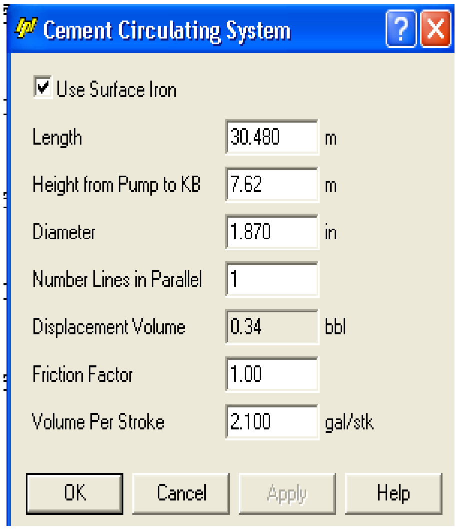
- Plastic Viscosity (cp) = 24
- Yield Point (TauO) = 25

Lead cement

- Plastic Viscosity (cp) = 35
- Yield Point (TauO) = 25

Tail cement

- Plastic Viscosity (cp) = 35
- Yield Point (TauO) = 23



Cement Circulating System

☑ Use Surface Iron

Length 30.480 m

Height from Pump to KB 7.62 m

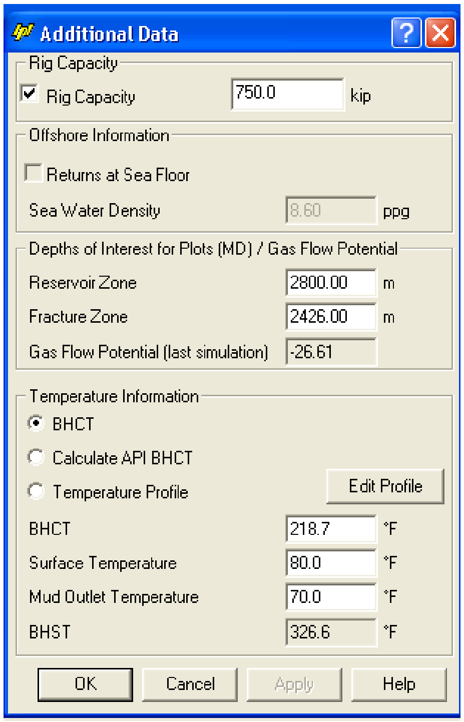
Diameter 1.870 in

Number Lines in Parallel 1

Displacement Volume 0.34 bbl

Friction Factor 1.00

Volume Per Stroke 2.100 gal/stk



Additional Data

Rig Capacity

☑ Rig Capacity 750.0 kip

Offshore Information

☐ Returns at Sea Floor

Sea Water Density 8.60 ppg

Depths of Interest for Plots (MD) / Gas Flow Potential

Reservoir Zone 2800.00 m

Fracture Zone 2426.00 m

Gas Flow Potential (last simulation) -26.61

Temperature Information

● BHCT

○ Calculate API BHCT

○ Temperature Profile

BHCT 218.7 °F

Surface Temperature 80.0 °F

Mud Outlet Temperature 70.0 °F

BHST 326.6 °F