Journal of Engineering Research and Reports

Volume 25, Issue 4, Page 66-78, 2023; Article no.JERR.101209
ISSN: 2582-2926

Effect of Silica Flour and Potasium Chloride as Additives in the Rhelogical Properties of High Temperature High Pressure Gas Well Cement Slurry

Amuah Freda Roli [a*], Ogbonna Joel [a,b] and Anthony John [a,b]

[a] African Center of Excellence, Center for Oilfield Chemicals and Research, University of Port Harcourt, Port Harcourt, Nigeria.
[b] Department of Petroleum and Gas Engineering, University of Port Harcourt, Port Harcourt, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2023/v25i4903

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/101209

Original Research Article

Received: 01/04/2023
Accepted: 03/06/2023
Published: 22/06/2023

ABSTRACT

This study explores the effects of silica flour and potassium chloride on the rheological properties of high temperature and pressure gas wells. Seven different materials were used as additives which includes: fresh water, dyckerhoff, silica flour, antifoam, extender, fluid loss, dispersant, retarder, anti-settling agent, gas control agent, dry viscosifier, potassium chloride and accelerator. Four recipes were prepared using these additives in different mixtures. Recipe four has all the additives including silica flour and potassium chloride. A series of flow tests was performed using an advanced shear-stress/shear strain controlled rheometer. Rheological properties of cement slurries were calculated from the resulting flow curves using the Bingham plastic model and the Herschel–Bulkley's model. Changes in shear stress–shear rate relationships, yield stress, plastic viscosity, and shear thinning/thickening behavior were found to be related to temperature and the type and

**Corresponding author: Email: amuah.freda@aceceforuniport.edu.ng;*

dosage of supplementary cementitious material. The four recipes were applied in 10 cases. Among the four different recipes tested for all the 10 cases, Recipe 4 has the best regression values for both temperature vs transit time and pressure vs transit time this can be attributed to the presence of silica flour and potassium chloride.

Keywords: Additives; slurry; rheology; temperature; pressure.

1. INTRODUCTION

Primary cementing is the process of placing cement between casing and formation or between casing and casing, the main objective is zonal isolation, and this is done by creating a hydraulic seal in the annulus which prevents the flow of wellbore fluids [1].

Cementing engineering technology is of utmost importance in exploration and development of any oil and gas field, this technology is what provides immediate and lifelong support to the wellbore, zonal isolation as well as protect casing from damage. [2] A bad cementing job leads to so many consequences like sustained casing pressure, remedial cementing job, casing collapse to mention but a few, this eventually leads to unwanted loss of time and revenue for clients. Over the lifetime of a well, it is important that zonal isolation is sustained and that after slurry placement, Cement Bond Log shows proper cement evaluation. [3] It is generally agreed that High Pressure High Temperature wells are wells with temperature above 149^{o}C and pressure above 15,000psi and that they pose threatening complications during design, execution and evaluation phases of cementing operations around the world. The first step to design a High Pressure High Temperature and gas well cementing job is to know the well construction. [4].

The use of additives in preparation of cement slurry has received increased attention over the last few decades. Mineral and chemical additives play an important role in controlling the physical and chemical properties of fresh and hardened cement systems. Partial replacement of cement using Supplementary additives is increasingly perceived as a sustainable solution. It reduces the cement factor thus reducing carbon IV oxide emission from cement production, and mitigates disposal of various industrial by products. A large number of industrial and naturally occurring materials including fly ash, volcanic ash, ground granulated blast furnace slag, silica fume, Zeolite, diatomaceous earth, metal powder, and rice husk ash can be used as partial replacement for cement. Due to differences in their chemical and physical properties, Supplementary additives have diverse effects on the rheological, mechanical and long-term durability performance of cementitious systems. For the particular case of the petroleum industry, cement slurries are pumped to several thousand meters into the ground to anchor and seal the casing to the borehole of oil or gas wells. Thus, an advanced characterization of the rheology of high temperature and high pressure gas well cement slurries is critical. However, the investigation of gas well cement slurry rheology is more complicated than that of cement paste. In order to contend with the bottom-hole conditions (wide range of pressure and temperature), various additives are usually used in the slurry composition.

2. RHEOLOGY

Rheology of cement slurry is critical to ensure mixability and pumpability of cement slurry, effective and efficient mud removal and friction pressure determination. Rheology is the science of flow and the deformation of matter. Denis and Guillot [5] showed that, with some cement slurry formulations, reasonable agreement can be obtained between a pipe viscometer and a specific coaxial cylinder viscometer, provided the rheological data are not affected by wall slip. However, when cement slurries are characterized with the standard oilfield viscometer, the results often differ from those obtained with pipe viscometers, even when using large-diameter pipes to minimize the effects of apparent wall slip [5]. Sound knowledge of rheology of cement slurry is required for the following reasons [6]; Appraisal of cement slurry mixability and pumping pressure required to displace mud in the annulus of the Casing, to estimate the effect of borehole temperature profile on placement of slurry, to estimate the pressure-depth relationship during and after cement slurry placement and for Predicting the flow distribution and profile of cement slurry. Borehole temperature also plays a key role in determining the slurry rheology and the extent of its role is also determined by the cement type and additives present.

Existing empirical and time-independent rheological models (e.g., Bingham, Herschel–Bulckley, Modified Bingham, Casson, etc.) allow fitting shear stress, shear rate, and viscosity data to specific trends using rheologicall data analysis software. However, no model is free from statistical error. The estimated rheological properties can vary significantly when calculated using various models [7].

3. RESEARCH ON CEMENTING IN HIGH PRESSURE HIGH TEMPERATURE (HPHT) GAS WELLS

Below are six cases of research work carried out on cementing in high temperature high pressure gas wells.

3.1 Case One

Boma and Babs in their paper "HPHT Well Integrity and Cement Failure", studied critical issues and factors such as high temperatures, high pressures, hole angles to mention but a few, affecting well integrity in HPHT wells as part of an ongoing research in Robert Gordon University, presenting an analytical model of the interactions between the casing, cement sheath and rock formation, focusing on the pay zone and limiting the research to Oil wells. The model generated, had verified results using finite element simulations, analytical results from open literature and live well data but failed to incorporate Gas migration which was later concluded to be part of a future research.

3.2 Case Two

Abdullah et al presented and in-depth paper studying gas migration in gas wells titled "Optimum Practices to Mitigate Gas Migration Problems in Deep Gas Wells". Focusing on cement density rheology and shrinkage and running three main tests which include, rheology, thickening time and compressive strength. The temperature ranged used here was quite small 275 to 300^{o}F and no specific pressure range was defined since the focus was on density, the conclusion showed that even though optimizing spacer, drilling fluids and centralizers as well as adding latex to the lead and tail slurries would improve the current cementing formular for cementing deep gas wells in that region, the critical static gel strength was recommended to be incorporated in further studies.

3.3 Case Three

In the Arabian gulf, a study was carried out to understand casing-casing annulus (CCA) pressure buildup prevention as well as well integrity in the region in a paper titled "Well Integrity Improvement: CCA Preventive Actions in HPHT Offshore Gas Wells in the Arabian Gulf". Alsubhi et al considered cementing strategies such as the use of resin-based cement and mechanical isolation strategy by replacing staging tools with high differential pressure tieback liner hangers. For the laboratory procedure considered here, they focused on the ductility of the resin-based cement and the increased compressive strength it would offer, cement shrinkage, rheology, compressive strength and fluid loss where tackled. The conclusion suggested that further trial tests needed to be done.

3.4 Case Four

The paper "Ensuring Zonal Isolation in Cementing Jobs of Gas Well" optimizes the Cement Slurry design, incorporating AntiSettling and Strength Enhancer Additives for Prevention of annular Gas migration, Edgar et al hoped to improve the preflush systems for the purpose of avoiding the contamination interface and channelling interfluids. The focus of the paper was the Fluid Loss Control and free water control which they believed to be the most important factors contributing to gas migration in a wellbore as stated in this paper. For the project, a Fluid Loss Control less than 25 cc/30 min and 40 cc/30 min, for Lead and Tail Slurry and 0 % Free Water Control where achieved, the conclusions showed that mud removal was efficient when the spacer and washes alkaline were used, The Extenders, Loss Fluid Control and antifoam Agent. were factors important for improved bonding, reduction losses and higher cement tops but poor cement bonding still appeared at the interfaces of mud and cement.

3.5 Case Five

Gas Migration issue is one cementing issue that has so many faces to it, in Saudi Arabia, Khalid et al in the technical paper "Prevention of Shallow Gas Migration Through Cement", studied a field and discovered that Nitrogen was coming from depths around 400ft to 1000ft after casing cementing operations, to combat this issue, a change in the casing design, a conventional fluid loss slurry and a conventional gas migration slurry were tried out. Extensive tests were performed to refine and provide a low-density gas tight recipe with low fluid loss and minimal free water development. The final recipe, with a density of 11.5 lb/gal, included a dispersant, antifoam, and extender in addition to the low temperature gas BLOK additive (Schlumberger additive trade name available). This solution in itself failed, due to so many reasons but one was because the critical gel time wasn't paid attention to.

3.6 Case Six

Ashraf et al in their paper "Oil Well Cement Static Gel Strength Development Comparison Between Ultrasonic and Intermittent Rotational Measurement Methods", did a comparative laboratory- based study between two measurement devices commonly used in the industry to measure the CGSP which are ultrasonic and intermittent rotational measurement techniques. The 16 slurry systems selected for the study covers a density range of 11.5 to 18 lbm/gal US within the temperature range of 27 to 121 ^{o}C and additives like silica flour, extenders, retarders, fluid loss additives and class G cement. They used two placement times of ranges 3-4 hours and 7-8 hours, while several of the slurry systems satisfied the CGSP criterion when measured using ultrasonic, they did not meet the criteria when measured using the intermittent rotation approach. They came to a conclusion that the hydration kinetics of the cement system play a major role in the development of static gel strength. Apart from that, it is significantly dependent on the test condition's temperature and pressure as well as the impact of the additives employed within, and that in future, pressure variations be added to this experiment.

For this work, we will focus on increasing the temperature range used above and also add pressure variations where necessary.

4. MATERIALS AND METHODS

4.1 Materials

The materials used for this research are as follows: Antifoam/Defoamer, Fluid Loss Additive, Retarder, Gas Migration Control Additive, Fresh Water/Seawater, API Class "G" Cement, Extenders, Accelerators and Strength Retrogression Material. While the equipment/apparatus that were used includes: Syringes, Plastic Petri dishes, Automated Weighing Balance (Kern Model), Viscometer (Fann 35), Warring Blender, Atmospheric Consistometer (Fann Model 165 AT Consistometer), High Pressure High Temperature Consistometer (Chandler Model 7025 Dual Cell HPHT Consistometer), Multiple Analysis Cement System (MACS II), Multiple Analysis Cement System (MACS II).

4.2 Methods

4.2.1 Cement slurry selection

Cement slurries are usually selected based on well objectives and requirements. The following would be used for this study.

4.2.2 Preparation of cement slurry

The recommended cement slurry volume for laboratory testing is 600ml (API RECOMMENDED PRACTICE 10B-2). The preparation of cement slurries varies from that of classical solid/liquid mixtures due to the reactive nature of cement, shear rate and time at share are important factors in the mixing of cement slurry in the laboratory. Before any test is carried out, a laboratory calculation sheet is designed which shows the required volumes of the mix water and additives as well as specified temperature, pressure and time.

4.2.2.1 Weighing mix water

The Warring blender is placed on the scale and set to zero, then fresh water/seawater is added to the blender on top of the scale till it reaches the desired weight on the laboratory calculation sheet for each of the designed cement slurry.

4.2.2.2 Weighing liquid additives

Syringes are used to weigh liquid additives. It is recommended to use new syringes each time an additive is to be measured to ensure that there is no form of contamination. To measure the liquid additive, the syringe is used to siphon some product into it and emptied, the dead weight is measured by setting scale to zero and measuring this emptied syringe containing particles of the future fluid to be measured, then the desired volume of liquid additive from the laboratory calculation sheet is measured and kept aside till all liquid additive to be added to the mix water are measured and weighed. This pattern of measurement is done for all liquid measurement to be used per cement slurry.

Table 1. Properties of materials

Materials	Function	Specific gravity	Concentration	Units
Fresh Water	Mixing water	1.000	3.744	Gps
Dyckerhoff	Cement "G"	3.140	100.00	%
Silica Flour	Strength Retrogression	2.630	35.00	%
Antifoam	Foam Preventer	0.880	0.011	Gps
Extender	Extender	0.830	2.030	Gps
Fluid Loss	Fluid Loss	1.050	0.450	Gps
Dispersant	Dispersant HT	0.921	0.510	Gps
Retarder	Retarder MT	1.026	0.010	Gps
Anti-Settling	Extender	0.880	0.300	Gps
Gas Control Agent	Gas Control	0.902	2.800	Gps
Dry Viscosifier	Weighting Material	-	0.100	%
KCL	Salt	1.162	19.149	Kg/tonne

Table 2. Composition of cement slurry

Materials	Recipe 1	Recipe 2	Recipe 3	Recipe 4
Fresh Water	✓	✓	✓	✓
Dyckerhoff	✓	✓	✓	✓
Silica Flour	✕	✕	✕	✓
Antifoam	✓	✓	✓	✓
Extender	✕	✕	✓	✕
Fluid Loss	✓	✓	✓	✓
Dispersant	✓	✓	✓	✓
Retarder	✕	✓	✕	✓
Anti-Settling	✓	✕	✕	✓
Gas Control Agent	✓	✕	✕	✓
Dry Viscosifier	✕	✕	✕	✓
KCL	✕	✕	✕	✓
Accelerator	✓	✕	✕	✕

4.2.2.3 Weighing dry additives

Plastic petri dishes are cleaned and placed on the measuring scale which is then set to zero. The dry additive is then added to the plastic petri dish till the desired volume from the laboratory calculation sheet is reached. The dry additive is kept aside until it is time to be added to the mix water in the warring blender.

4.2.2.4 Mixing and blending of the cement slurry

The recommended API mixing and blending procedure would be followed:

1. The Warring blender containing only the mix water is placed in the mixing chamber.
2. The motor is turned on and kept at 4000 r/min ± 250 r/min mixing speed.
3. The liquid additives are added into the warring blender still on low speed in the specified order that they would be added on the field.
4. Add Cement into the mix water which now contains other liquid additives and ensure the addition doesn't exceed 15secs. (This is to cater for flash setting which is a factor of Time to Add Cement). Cover the warring blender.
5. Turn the speed on the motor to high speed 12000 r/min ± 250 r/min for not more than 35s ± 1s to get a vortex in the blender.
6. Stop the mixer after 35 secs and proceed with desired test.

4.3 Procedures for the Tests

4.3.1 Surface rheology test

The recommended API procedure for determining surface rheological properties would be followed:

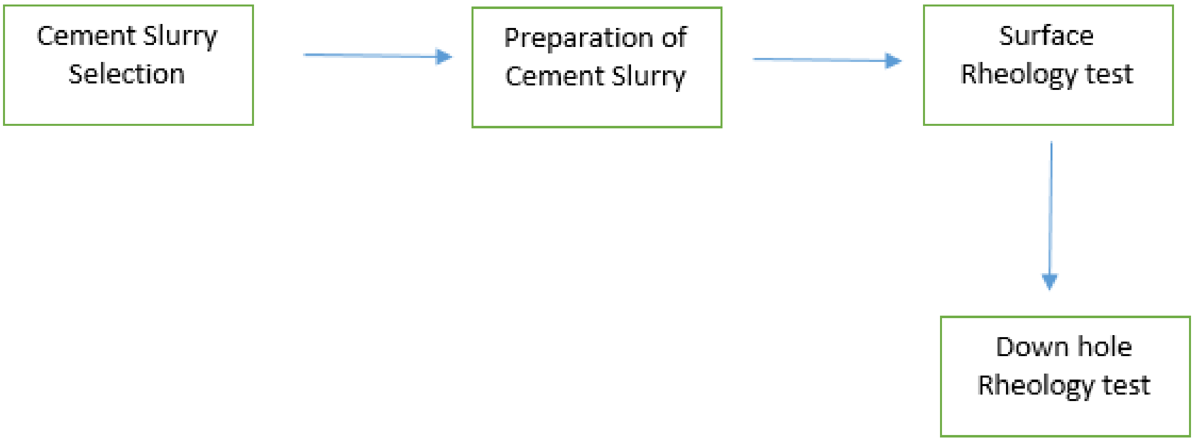

Fig. 1. Flow diagram

1. Ensure that the rotor and bob are clean and free from any form of debris.
2. The cement slurry is poured from the warring blender into the viscometer cup to a level adequate to raise the fluid to the scribed mark on the rotor without the rotor or bob touching the bottom of the cup.
3. Turn on rotor and ensure dial is at 3rpm, raise the cup till the cement slurry is on the scribed line on the rotor.
4. Take the initial reading still at 3rpm after about 10secs of continuous rotation of cement slurry.
5. Take upward reading after 10 secs for each rpm starting from 3rpm. Take downward reading after 10 secs for each rpm starting from 300rpm. The different rpm readings are 3,6,30,60,100,200,300 rpm respectively.
6. Calculate the ratio of the dial readings during ramp-up to ramp-down at each speed. This ratio would be used to help qualify certain fluid properties.

4.3.2 Down hole rheology test

The recommended API procedure for determining down hole rheological properties would be followed:

1. Condition the cement slurry to the specific temperature and pressure in the atmospheric consistometer.
   a. The cement slurry container would be placed in the heating bath or in the atmospheric consistometer with a paddle for rotational effect, preheated to the test temperature.
   b. This test temperature is held in the heating bath or in the atmospheric consistometer for 30 min ± 30 s to allow the test fluid temperature to reach equilibrium.
   c. After 30 minutes has elapsed, remove the paddle and stir the test fluid briskly with a spatula to ensure it is uniform. Continue with the desired test
2. Ensure that the rotor and bob are clean and free from any form of debris.
3. The cement slurry is poured from the conditioning cup into the viscometer cup to a level adequate to raise the fluid to the scribed mark on the rotor without the rotor or bob touching the bottom of the cup.
4. Turn on rotor and ensure dial is at 3rpm, raise the cup till the cement slurry is on the scribed line on the rotor.
5. Take the initial reading still at 3rpm after about 10secs of continuous rotation of cement slurry.
6. Take upward reading after 10 secs for each rpm starting from 3rpm. Take downward reading after 10 secs for each rpm starting from 300rpm. The different rpm readings are 3,6,30,60,100,200,300 rpm respectively.
7. Calculate the ratio of the dial readings during ramp-up to ramp-down at each speed. This ratio would be used to help qualify certain fluid properties.

5. RESULTS AND DISCUSSION

The result of the laboratory test carried out on the additives for the 10 cases studied are presented in Tables 3-6 at different temperature ranges.

Table 3. Laboratory test results for case 1-10 for recipe 1

Starting from 196^{o}F till 350^{o}Fwith stepwise increase

	Case/test carried out									
Recipes	1	2	3	4	5	6	7	8	9	10
Class G	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
antifoam (gal/sk)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
anti-settling (gal/sk)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
gas control (gal/sk)	1.2	1.4	1.6	1.8	2	2	2	2	2	2
fluid loss (gal/sk)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
dispersant (gal/sk)	0.11	0.11	0.11	0.1	0.09	0.09	0.08	0.05	0.05	0.05
accelerator (gal/sk)	0.1	0.1	0.1	0.05	0	0	0	0	0	0

Table 4. Laboratory test results for case 1-10 for recipe 2

Starting from 240^{o}F till 350^{o}Fwith stepwise increase.

	Case/test carried out									
Recipes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
class G (BWOC)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
antifoam (gal/sk)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
fluid loss (gal/sk)	0.32	0.5	1	1.5	2	2.5	2.6	2.7	2.7	2.7
dispersant (gal/sk)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
retarder (gal/sk)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Table 5. Laboratory test results for case 1-10 for recipe 3

Starting from 190^{o}F till 350^{o}Fwith stepwise increase.

	Case/test carried out									
Recipes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Class G	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
antifoam (gal/sk)	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
extender (gal/sk)	0.9	1	1	1	1	1.1	1.1	1.25	1.25	1.35
fluid loss (gal/sk)	0.36	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.7	0.7
dispersant (gal/sk)	0.293	0.3	0.31	0.32	0.32	0.32	0.32	0.32	0.32	0.32

Table 6. Laboratory test results for case 1-10 for recipe 4

Starting from 200^{o}F till 350^{o}Fwith stepwise increase.

	Case/test carried out									
Recipes	1	2	3	4	5	6	7	8	9	10
class G (BWOC)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
KCL (kg/ton)	19.149	19.149	19.149	19.149	19.149	19.149	19.149	19.149	19.149	19.149
Viscosifier	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
antifoam (gal/sk)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
gas control (gal/sk)	1	1.2	1.3	1.4	1.5	2	2	2	2	2
fluid loss (gal/sk)	0.3	0.31	0.31	0.31	0.32	0.32	0.31	0.31	0.32	0.31
dispersant (gal/sk)	0.13	0.15	0.17	0.18	0.18	0.18	0.17	0.17	0.18	0.2
retarder (gal/sk)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
silica	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%

Table 7. Static gel strenght analyzer and MACS II for recipe 1

Recipes 1	**Case**	**SGSA (hr:mn)**	**Transit time (mins)**	**Density (ppg)**	**Temp (degf)**	**Pressure (psi)**
	1	2:42-2:54	12	15.8	196	6312
	2	2:43-3:12	29	15.8	200	6312

Recipes 1	Case	SGSA (hr:mn)	Transit time (mins)	Density (ppg)	Temp (degf)	Pressure (psi)
	3	3:09-3:31	22	15.8	220	8000
	4	3:10-3:50	40	15.8	240	10000
	5	3:02-3:49	47	15.8	260	12000
	6	3:00-3:44	44	15.8	280	14000
	7	3:01-3:30	29	15.8	300	16000
	8	3:02-3:47	45	15.8	320	18000
	9	3:03-3:50	47	15.8	330	20000
	10	3:00-3:50	50	15.8	350	22000

Table 8. Static gel strenght analyzer and MACS II for recipe 2

Recipes 2	Case	SGSA (hr:mn)	Transit time (mins)	Density (ppg)	Temp (degf)	Pressure (psi)
	1	2:08-2:50	41	15.8	240	9000
	2	2:08-2:51	42	15.8	250	9000
	3	2:02-2:46	44	15.8	260	10000
	4	2:02-2:52	50	15.8	270	13000
	5	2:00-2:50	50	15.8	280	16000
	6	1:55-2:45	50	15.8	290	18000
	7	1:55-2:40	45	15.8	300	21000
	8	1:50-2:34	44	15.8	310	22000
	9	1:47-2:32	45	15.8	320	23000
	10	1:55-2:40	45	15.8	350	25000

Table 9. Static gel strenght analyzer and MACS II for recipe 3

Recipes 3	Case	SGSA (hr:mn)	Transit time (mins)	Density (ppg)	Temp (degf)	Pressure (psi)
	1	7:44-8:12	28	16.67	190	7000
	2	7:46-8:17	31	16.67	200	9000
	3	7:50-8:25	35	16.67	220	11000
	4	7:50-8:30	40	16.67	240	13000
	5	7:54-8:29	35	16.67	260	15000
	6	7:50-8:28	38	16.67	280	16000
	7	7:50-8:35	45	16.67	300	18000
	8	7:51-8:42	51	16.67	330	20000
	9	7:50-8:51	61	16.67	350	23000
	10	7:49-8:59	69	16.67	350	25000

Table 10. Static Gel Strenght Analyzer and MACS II for recipe 4

Recipes 4	Case	SGSA (hr:mn)	Transit time (mins)	Density (ppg)	Temp (degf)	Pressure (psi)
	1	13:36-14:16	40	16.8	200	15000
	2	13:40-14:17	37	16.8	220	17000
	3	13:45-14:10	35	16.8	240	18000
	4	13:58-14:29	31	16.8	260	19000
	5	14:04-14:32	28	16.8	280	20000
	6	14:07-14:31	24	16.8	300	21000
	7	14:09-14:27	18	16.8	310	22000
	8	14:15-14:32	17	16.8	320	23000
	9	14:19-14:35	16	16.8	340	24000
	10	14:27-14:36	9	16.8	350	25950

.

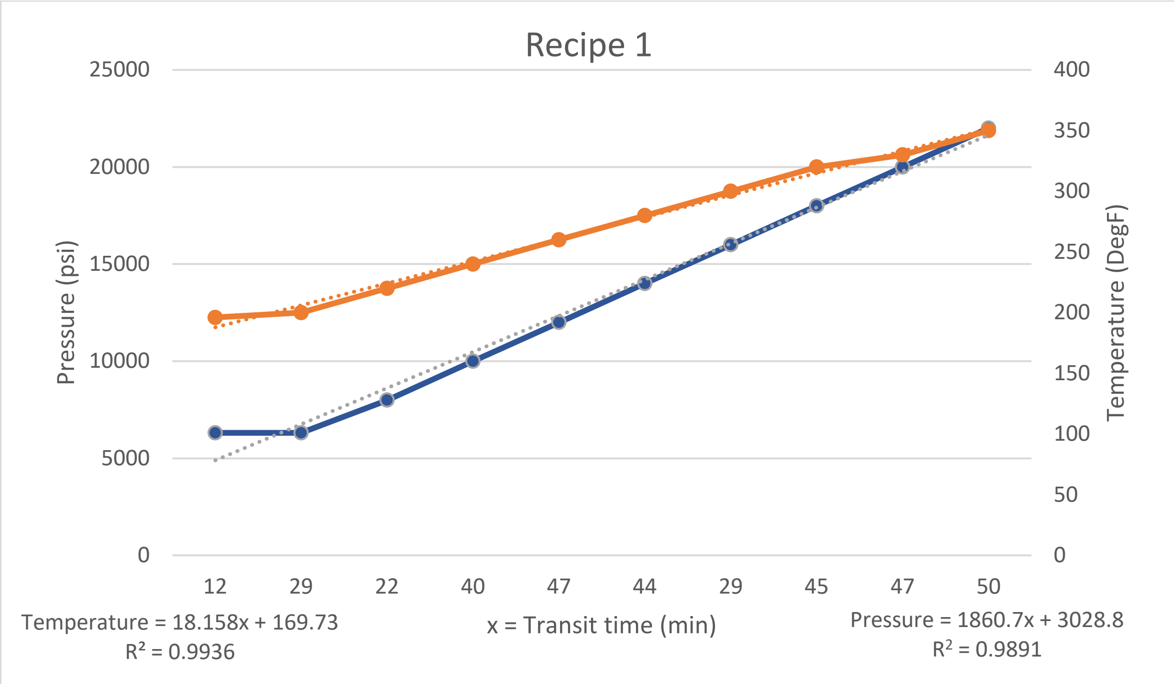

Fig. 2. Recipe 1 temperature and pressure vs transit time

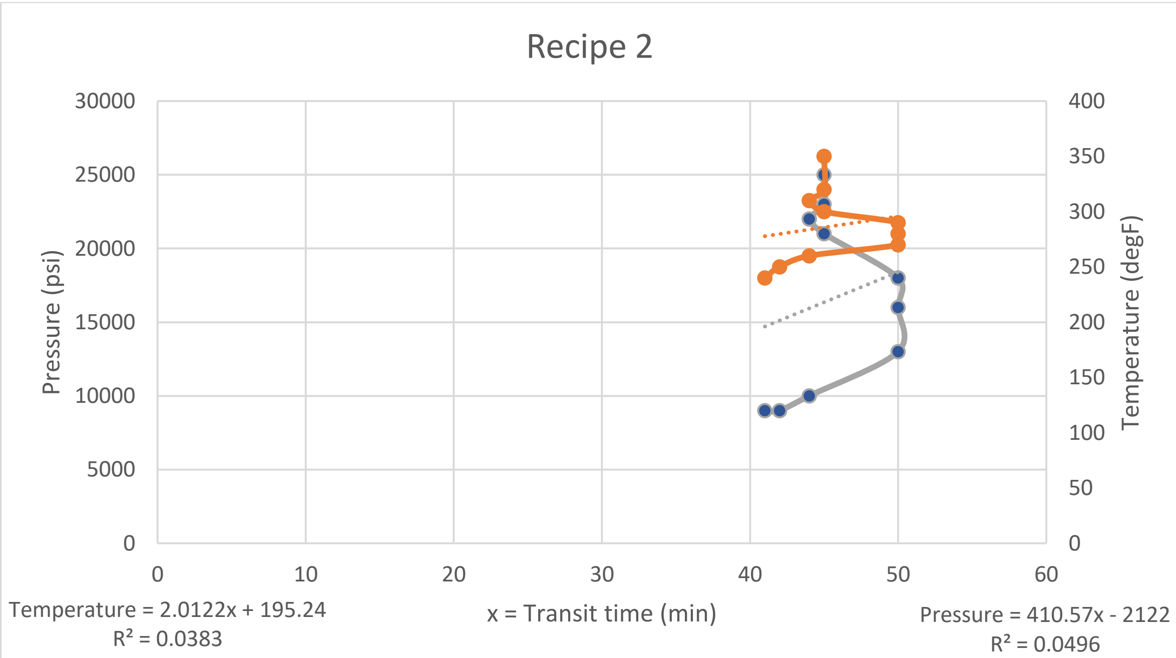

Fig. 3. Recipe 2 temperature and pressure vs transit time

Transition tests using Static Gel Strength Analyzer (SGSA) and MACS II using anti-settling agents in the recipes and strength retrogression materials.

The following results were obtained after this test for recipe 1-4.

5.1 Discussion

Table 3 shows the laboratory result for Recipe 1. This was for a plug job hence the use of accelerator but the accelerator was later removed as seen in case 5-10 because increasing concentrations of dispersant and gas control was leading to occurrence of flocculation in the mix fluid meaning the additives in the mix fluid where not dissolving properly in the mix water on a larger scale, this would meaning that if it is done on the field, the mix fluid would not be a proper representation of the intended design. This slurry was involved in this research as the only slurry recipe with accelerator to see the behavior with increasing temperatures and pressures. For Recipe 2, the results obtained are presented in Table 4. The slurry surprisingly had enough compressive strength to ensure for good bonding irrespective of the temperature and pressures and the absence of silica flour did not in any way deter the slurry properties but the transit time where relatively high as would be discussed in the transit time section below. The fluid loss additive here was used primarily as a fluid loss agent and at higher concentrations as gas control additive. To achieve the desired slurry density at the given temperatures and pressures, the extender additive needed to be increased sufficiently as well as the fluid loss additive concentrations. Table 5 shows results for Recipe 3, the slurry concentrations of fluid loss greater than 0.7 gal/sk would cause slurry to begin to retard and increase the time to get to 100 lbf/100ft^2 which was is not desired as a slurry which takes long to get to 100 lbf/100ft^2 would most likely have a long thickening time and with addition of a safety factor of 2 hours would mean undesired longer waiting on cement time. Silica flour and KCL were added in recipe 4 and used to increase the compressive strength of cement slurry and to prevent the potential damage that migration and swelling of clays platelets would cause to the cement as seen in Table 6.

Table 7 shows that the time for recipe 1 slurry to get to 100 lbf/100ft^2 was quite short meaning that thickening time may be quite low which is desirable but the time for cement slurry to move from 100 lbf/100ft^2 to 500 lbf/100ft^2 kept increasing with changing temperature and pressure going as high as 50 minutes for case 10 which was not even up to 25,000 psi, it shows that this slurry was struggling to stay between the API recommended boundary of 45 minutes which would not be advised because the lower the transit time the better for the cement bond log and future activities on the well. There is a steady linear progression for the transit time with increasing temperatures and pressures even though there are some outliers which may have occurred due to laboratory equipment inconsistencies. In Table 8, recipe 2 had all cases on the 45 minutes border and eve going higher, the increasing temperatures and pressures had little or no effect on the transit time but had effect on the time to reach 100 lbf/100ft^2 which would have been significant if the focus of this research was tilting towards thickening time as time to reach 100lbf/100ft^2 is significantly linked to thickening time but that is beyond the scope of this work. The result presented in table 9 for recipe 3 showed that the time to 100 lbf/100ft^2 is quite high at the varying temperatures, the varying temperature and pressures also shows that transit time keeps increasing to up to 1 hour, this time would expose the cement slurry after placement to formation pressures which could destabilize the slurry causing micro annuli and channeling leading to need for remedial cement job to be done after a cement bond log has been conducted [8-10].

The small concentrations of fluid loss additive could also be a determining factor in this cement slurry recipe because with presence of gas control agent in conventional cement slurry, there is high possibility of cement slurry to be unstable even if the rheologies and other important and critical set cement slurry properties are met. The slurry recipe 4 as seen in Table 10 delivered as desired but the time to get to 100 lbf/100ft^2 was too long this may imply that the thickening time would take longer depending on additives like accelerators or retarders as well as temperatures and pressures independently [11,12].

In Fig 1, The linear relationship between temperature and transit time is given as 18.158x+169.73, while the regression analysis shows 99.36% correctness, the linear relationship equation for pressure vs transit time gave 1860.7x + 3028.8 and a regression analysis value of 98.91%.

These relationships gave very high percentage of correctness when it comes to variation with transit time but the choice of slurry does not have strength retrogression properties, since it does not contain silica flour, it is a questionable slurry since it also has accelerators and was initially used for a kick off plug, the questions are, Would it be able to withstand formation pressure when placed in annulus?, Since kick off plugs are usually at the tail end of casing, what would be the reaction between this slurry and circulating formation temperatures?, Would this slurry experience shrinkage if set cement is placed in annulus? etc.

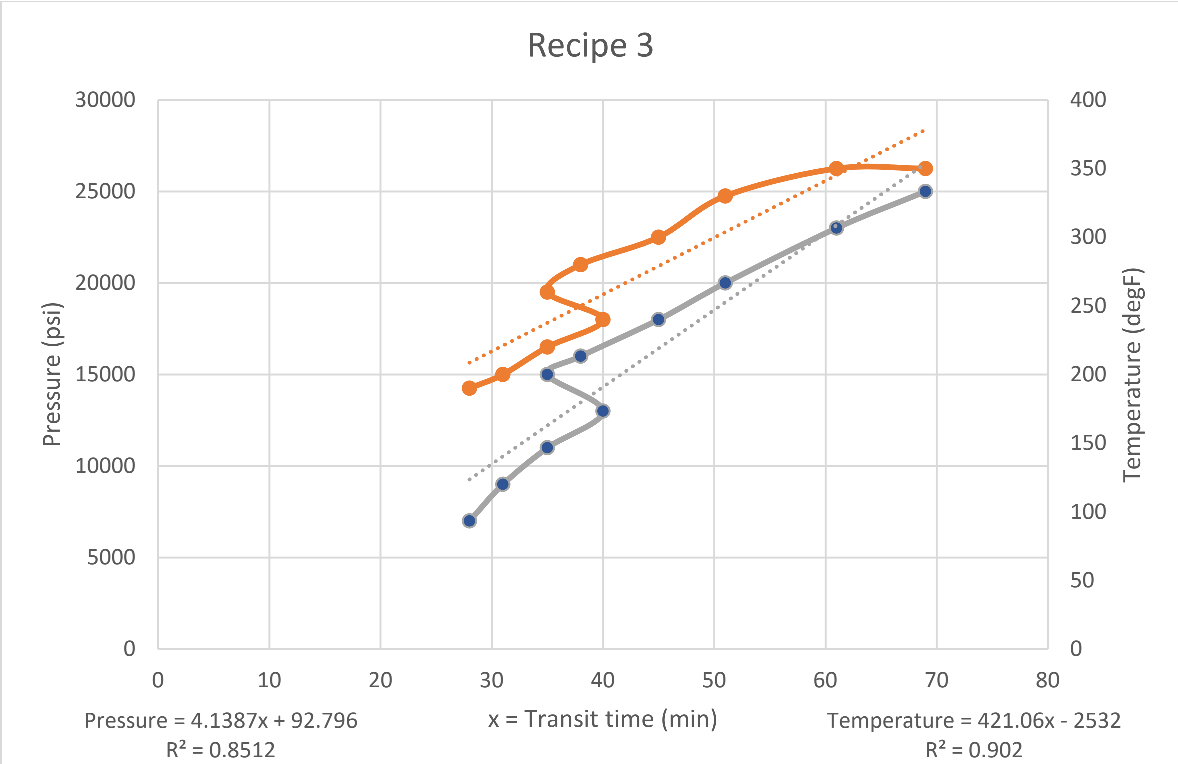

Fig. 4. Recipe 3 temperature and pressure vs transit time

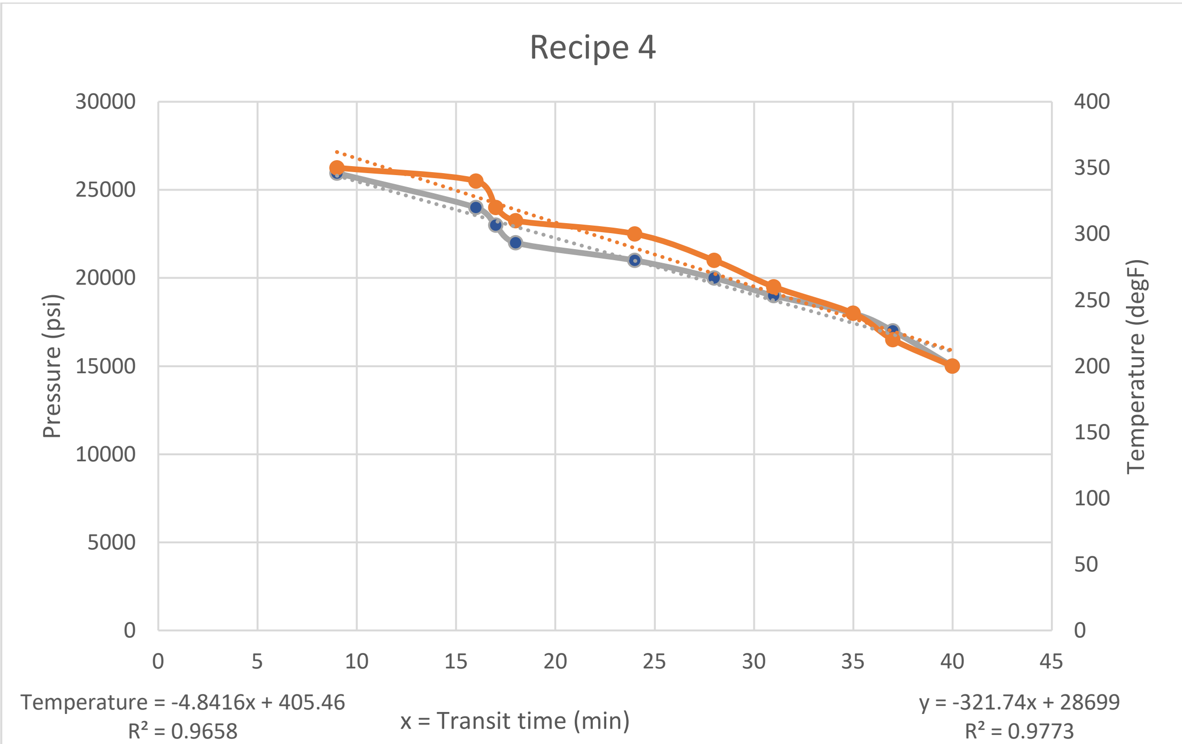

Fig. 5. Recipe 4 temperature and pressure vs transit time

The conclusion would likely be that while the regression analysis of both temperature and pressure showed good percentage of correctness, this slurry would be inefficient in meeting set cement placement in annulus. Fig. 2 showed that the linear relationship between temperature and transit time is given as 2.0122x+195.24, while the regression analysis shows 3.83% correctness, the linear relationship equation for pressure vs transit time gave 410.57x - 2122 and a regression analysis value of 4.96%. These relationships between pressure and transit time and between temperature and transit time have very low regression values and do not fit the purpose of this research. Fig. 3 also proved that the linear relationship between temperature and transit time is given as 4.1387x+92.796, while the regression analysis shows 85.12% correctness, the linear relationship equation for pressure vs transit time gave 421.06x + 2532 and a regression analysis value of 90.2% [13,14].

These relationships gave very high percentage of correctness when it comes to variation with transit time but the choice of slurry does not have strength retrogression properties, since it does not contain silica flour, it is a questionable slurry since it also does not have Gas Control agent and weighting agent considering the high density of 16.67 lb/gal.

Would this cement slurry be able to withstand formation pressure when placed in annulus? What would be the reaction between this slurry and circulating formation temperatures? Would this slurry experience shrinkage if set cement is placed in annulus? etc. If this slurry would be chosen as the optimized slurry to achieve the objectives of Designing a tailored slurry to cater for long zero gel time and short transition time thereby solving gas migration issues, Addressing fluid loss of cement using anti-settling agents in stabilizing conventional cement slurry system while varying temperature and pressure, Solving Strength retrogression issues that causes cement sheath failure, Dealing with flash setting and short thickening time of cement by designing a retarded slurry, then there would be so many unanswered questions that are beyond the scope of work for this project.

The conclusion would likely be that while the regression analysis of both temperature and pressure showed good percentage of correctness, this slurry would be inefficient in meeting set cement placement in annulus. The linear relationship between temperature and transit time is given as -4.8416x+405.46, while the regression analysis shows 96.58% correctness, the linear relationship equation for pressure vs transit time gave -321.74x + 28699 and a regression analysis value of 97.73%.

This recipe has the best regression values for both temperature vs transit time and pressure vs transit time, the recipe also met the objectives of designing a tailored slurry to cater for long zero gel time and short transition time thereby solving gas migration issues since the transit time kept on reducing with increasing temperatures and pressures, addressing fluid loss of cement using anti-settling agents in stabilizing conventional cement slurry system while varying temperature and pressure because of the presence of anti-settling and fluid loss additives present, solving Strength retrogression issues that causes cement sheath failure with the presence of KCL and silica flour to handle reduced strength retrogression and dealt with flash setting and short thickening time of cement by designing a retarded slurry with the presence of a retarder in the recipe as seen in Fig. 4.

6. CONCLUSION

The following conclusions can be deduced from this research work

1. Silica flour and potassium chloride are very important ingredient in the production of cement slurry.
2. The regression analysis of both temperature and pressure showed good percentage of correctness, slurry formed using recipe 1 would be inefficient in meeting set cement placement in annulus.
3. These relationships between pressure and transit time and between temperature and transit time in recipe 2 have very low regression values and do not fit for use in the industry.
4. For the slurry formed using recipe 3, while the regression analysis of both temperature and pressure showed good percentage of correctness, this slurry would be inefficient in meeting set cement placement in annulus.
5. Recipe 4 has the best regression values for both temperature vs transit time and pressure vs transit time.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Arash Shadravan, Mahmood Amani. HPHT 101 - What ever engineer or geoscintist should know about high pressure high temperature wells. SPE 163376. 2012:1-27.
2. Chike Nwagu. Case study: Planning and execution of a subsea HPHT well in Niger-Delta. SPE 178395 – MS. 2015:1-14.
3. Javier Urdaneta HS, Adi Wiriawan CI, Gabriel Barragan. Offline cementing technique. SPE/IADC International Drilling Conference and Exhibition (SPE/IADC-194186-MS). The Hague: SPE/IADC International Drilling Conference and Exhibition, The Hague, The Netherlands. 2019:6-7.
4. Kris Ravi, Richard Vargo H, Barbara Lasley BA. Succesful cementing case study in Tuscaloosa HPHT Wells. SPE Russia Oil and Gas Technical Conference and Exhibition. Moscow: SPE 115643. 2008:1-8.
5. Denis JH, Guillot D. SPE-16137-MS prediction of cement slurry laminar pressure drops by rotational viscometry. SPE/IADC Drilling Conference. New Orleans LA: Society of Petroleum Engineers; 1987.
6. Princewill MO. Effects of additive concentrations on cement rheology at different temperature conditions. International Journal of Engineering Works. Lagos NIgeria. 2019;6(03):50–70.
7. Umeokafor CJ. SPE 136973 modelling of cement thickening time at high temperatures with different retarder concentrations. Annual SPE International Conference and Exhibition. Calabar, Nigeria; 2010.
8. Abdullah AT. Optimum practices to mitigate gas migration problems in deep gas wells. SPE Russian Petroleum Technology Conference. Moscow, Russia; 2017.
9. Alsubhi AM. Well integrity improvement: CCA preventive actions in HPHT offshore gas wells in the Arabian gulf. SPE Middle East Oil & Gas Show and Conference. Manama, KIngdom of Bahrain; 2017.
10. Arpit Saxena SC, Pratush Tewari. Challenges in HPHT well: A case study. SPE Oil and Gas India Conference and Exhibition. Mumbai: SPE- 194633-MS. 2019:1-17.
11. Ashraf SH. Oil well cement static gel strength development comparison between ultrasonic and intermittent rotational measurement methods. SPE Asia Pacific Oil & Gas Conference and Exhibition. SPE Asia Pacific Oil & Gas Conference and Exhibition; 2016.
12. Boma WB. HPHT well integrity and cement failure. SPE-NAICE. Lagos, Nigeria: SPE-NAICE; 2016.
13. Edgar JEV. Ensuring zonal isolation in cementing jobs of gas well. SPE Latin American and Caribbean Petroleum Engineering Conference. Bogota, Columbia; 2020.
14. Khalid AK. Prevention of shallow gas migration through cement. IADC/SPE Asia Pacific Drilling Technology. Jakarta, Indonesia: IADC/SPE Asia Pacific Drilling Technology; 1998.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/101209