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# Special Cement Slurry Design Consideration for High Temperature High Pressure Gas Well

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**ABSTRACT:** This study explores special cement slurry design consideration for 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. 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 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 1 gave a regression value of 52.19% correctness, 65.43% correctness for recipe 2, 23.72% for recipe 3 and 96.58% correctness for recipe 4. Recipe 4 has the best regression values for both temperature vs transit time and pressure vs transit time this can be accounted for the presence of both silica flour and potassium chloride salt.

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The basic goal of primary cementing is zonal isolation, which is achieved by forming a hydraulic seal in the annulus that stops the flow of wellbore fluids. Primary cementing is the process of inserting cement between casing and formation or between casing and casing. (Arpit 2019; Arash 2021). In the discovery and development of any oil and gas field, cementing engineering technology plays a crucial role in providing the wellbore with immediate and ongoing support, zonal isolation, and casing protection. (Chike, 2015) A poor cementing job has a number of negative effects, including casing collapse, remedial cementing work, and continuous casing pressure, to name a few. This ultimately causes clients to lose time and money. It's crucial that zonal isolation is maintained throughout a well's lifespan and that the Cement Bond Log following slurry application reflects an accurate cement evaluation (Javier *et al.*, 2019). It is commonly accepted that high pressure, high temperature wells are those that have temperatures and pressures above 149 oC and 15,000 psi, respectively, and that they provide dangerous challenges in the planning, carrying out, and evaluating stages of cementing operations all over the world. Knowing the well's construction is the first step in designing a high pressure, high temperature, and gas well cementing work (Kris 2008). Over the past few decades, the use of additives in the creation of cement slurry has drawn more attention. The physical and chemical characteristics of newly formed and hardened cement systems are significantly influenced by mineral and chemical additions. Using supplementary chemicals to partially replace cement is increasingly seen as a sustainable alternative. It lessens the cement factor, lowering the amount of carbon IV oxide emitted during the production of cement, and lessens the amount of industrial waste that

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needs to be disposed of. Cement can be partially replaced by a wide range of naturally occurring and industrial materials, including fly ash, volcanic ash, crushed granulated blast furnace slag, silica fume, Zeolite, diatomaceous. Supplemental additives have a variety of effects on the rheological, mechanical, and long-term durability performance of cementitious systems due to variances in their chemical and physical properties. Cement slurries are poured into the earth up to a few thousand meters in the case of the petroleum sector to anchor and seal the casing to the borehole of oil or gas wells.

The rheology of high temperature and high pressure gas well cement slurries must therefore be advanced characterized. However, compared to cement paste, the study of the rheology of gas well cement slurry is more challenging. Hence, the objective of this study is to provide a special cement slurry design consideration for high temperature high pressure gas well.

## MATERIALS AND METHODS

*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).

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 |

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

*Preparation of Cement Slurry:* For laboratory testing, a volume of 600 cc of cement slurry is advised (API Recommended Practice 10B-2). Due to the reactive nature of cement, the preparation of cement slurries differs from that of conventional solid/liquid mixes. Shear rate and time at share are significant parameters in the mixing of cement slurry in the laboratory. A laboratory calculation sheet is created before any test is run, and it includes the required amounts of the mix water and additives as well as the specified temperature, pressure, and duration. The slurry composition often includes a variety of additives that can withstand a wide range of pressure and temperature.

*Weighing Mix Water:* For each of the intended cement slurries, the Warring blender is set to zero and placed on the scale. Next, fresh water or seawater is added to the blender on top of the scale until it reaches the necessary weight.

*Weighing Liquid Additives:* Liquid additives are weighed using syringes. To guarantee there is no contamination, it is advised to use fresh syringes each time an ingredient needs to be measured. To measure the liquid additive, a syringe is filled with product and then emptied. The dead weight is then calculated by setting the scale to zero and weighing the empty syringe that contains the future fluid to be measured. Next, the desired volume of liquid additive from the laboratory calculation sheet is measured and set aside until all liquid additive that will be added to the mix water are measured and weighed. This pattern of measurement is used to determine the amount of each liquid to be utilized in the cement slurry.

*Weighing Dry Additives:* Clean plastic petri dishes are positioned on the measuring scale after it has been reset to zero. Once the appropriate volume from the laboratory calculation sheet is attained, the dry ingredient is next put to the plastic petri dish. When it's time to add the dry ingredient to the mix water in the warring blender, it is set aside.

*Mixing and Blending of the Cement Slurry:* The Warring blender containing only the mix water was placed in the mixing chamber. The motor was turned on and kept at 4000 r/min ± 250 r/min mixing speed. The liquid additives were added into the warring blender still on low speed in the specified order that they would be added on the field. Cement was addede 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). The warring blender was covered. The speed on the motor was turned to high speed 12000 r/min ± 250 r/min for not more than 35s ± 1s this is to get a vortex in the blender. The mixer was stopped after 35 seconds.

*Surface Rheology Test:* The rotor and bob were clean and free from any form of debris. The cement slurry was 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. The rotor was turned on ensuring dial is at 3rpm, the cup was raised till the cement slurry was on the scribed line on the rotor. The initial reading was taken at 3rpm after about 10secs of continuous rotation of cement slurry. The upward reading was taken after 10 secs for each rpm starting from 3rpm. The downward reading was taken after 10 secs for each rpm starting from 300rpm. The different rpm readings are 3, 6, 30, 60,100,200,300 rpm respectively. The ratio of the dial readings was calculated during ramp-up to ramp-down at each speed. This ratio would be used to help qualify certain fluid properties.

*Down Hole Rheology Test:* The cement slurry was conditioned to the specific temperature and pressure in the atmospheric consistometer. The cement slurry container was placed in the heating bath or in the atmospheric consistometer with a paddle for rotational effect, preheated to the test temperature. This test temperature was held in the heating bath or in the atmospheric consistometer for 30 min ± 30 s to allow the test fluid temperature to reach equilibrium. After 30 minutes has elapsed, the paddle was removed and the test fluid was stirred briskly with a spatula to ensure it is uniform.

*Thickening Time Test: Preparation of cement slurry for the Consistometer cup:* The threads of the consistometer cup are clean and free of debris. The paddle shaft, diaphragm, diaphragm support ring and back up support plate were assembled and secured in the cup sleeve with the flange ring, as well as the base and center plug and ensure that the paddle turns freely. The ends of the consistometer cup was greased to ensure for easy removal of set cement after test.
The already prepared slurry was poured into the cup to the middle of the thread to cover the cup and all entrained air was removed. The body of the cup was cleaned before putting the cup in the High Pressure High Temperature Consistometer.

*Preparing cup for the High Pressure High Temperature Consistometer:* The filled slurry container was placed on the drive table in the pressure vessel, the slurry container was rotated, and the paddle shaft drive bar was engaged with the potentiometer mechanism or other suitable device for measuring consistency. The vessel was filled halfway with oil. The threads were partially engaged by inserting the thermocouple through its fitting. The thermocouple threads were tightened when the pressure vessel is entirely filled with oil. The test commenced after inputting the details in the equipment computer.

*Programming and running the test on the High Pressure High Temperature Consistometer Computer:* After the consistometer cup has been placed in the Consistometer, the ramp time, temperature and pressure was set up and the test was monitored to ensure that it is going as planned. Stopping the High Pressure High Temperature Consistometer.

*Transition Time Tests:* Multiple Analysis Cement System (MACS II) slurry cup was cleaned and freed from debris. Cement slurry was prepared to specification. Multiple Analysis Cement System (MACS II) cup was filled with cement slurry. It was ensured that no air was trapped in the cup. Multiple Analysis Cement System (MACS II) cup was put in the Multiple Analysis Cement System. The Desired Ramp up and End Time and Gel Strength was set up and the output on the attached computer system was monitored.

## RESULTS AND DISCUSSION

The result of the laboratory test carried out on the additives for the 10 cases studied are presented in table 3-6 at different temperature ranges. For recipe 1, as seen in table 3, the concentrations of Gas control used kept changing because at the test temperature and pressures, it was recommended that those concentrations would give optimal results with the corresponding fluid loss additive, dispersants, and retarder concentrations. The fluid loss and gas control additive combination in the mix water can lead to highly viscous mix fluid which could cause the cement to be unmixable and even unpumpable as seen in the warring blender when performing the test in the laboratory hence the reduction of the fluid loss while gas control was increased. This slurry interestingly had too much solid volume fraction which was over 20% (the recommended solid volume fraction), the weighting agents were added based on available silica flour which was 7% as against the recommended 35%, the concentrations of the fluid loss was optimized to act as both fluid loss and gas control as well as the dispersant which was optimized to avoid a slurry that would be too viscous or unpumpable as seen in table 4 for recipe 2.

**Table 3:** Laboratory test results for case 1-10 for Recipe 1 Starting from 239ºF till 350ºFwith 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% |
| silica (BWOC) | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% |
| 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) | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| gas control (gal/sk) | **0.1** | **0.5** | **1** | **1.2** | **1.4** | **1.6** | **1.8** | **2** | **2** | **2** |
| fluid loss (gal/sk) | 0.5 | 0.5 | 0.5 | **0.4** | **0.4** | **0.4** | **0.4** | **0.3** | **0.2** | **0.1** |
| dispersant (gal/sk) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | **0.1** | **0.2** | **0.2** | **0.2** | **0.2** |
| retarder (gal/sk) | 0.05 | 0.05 | 0.05 | 0.05 | **0.03** | **0.03** | **0.01** | **0.01** | **0.01** | **0.01** |

**Table 4:** Laboratory test results for case 1-10 for Recipe 2; Starting from 140ºF till 350ºFwith 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% |
| silica (BWOC) | 7% | 7% | 7% | 7% | 7% | 7% | 7% | 7% | 7% | 7% |
| Weighting agent (Barite) | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% |
| Weighting agent (Hematite) | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| antifoam (gal/sk) | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| extender (gal/sk) | **1.2** | **1.2** | **1.25** | **1.25** | **1.3** | **1.3** | **1.35** | **1.35** | **1.35** | **1.35** |
| fluid loss (gal/sk) | **0.42** | **0.5** | **0.55** | **0.56** | **0.56** | **0.56** | **0.56** | **0.56** | **0.56** | **0.56** |
| dispersant (gal/sk) | **0.3** | **0.3** | **0.35** | **0.35** | **0.4** | **0.4** | **0.45** | **0.45** | **0.5** | **0.5** |

**Table 5:** Laboratory test results for case 1-10 for Recipe 3. Temperature @ 400 DegF.

| | **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% |
| silica (BWOC) | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% | 35% |
| Viscosifier (BWOW) | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% |
| Gas Control (gal/sk) | **1.50** | **1.50** | **1.50** | **1.7** | **1.7** | **1.7** | **1.9** | **1.9** | **1.9** | **1.9** |
| antifoam (gal/sk) | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** | **0.05** |
| extender | **5%** | **5%** | **5%** | **5%** | **5%** | **5%** | **5%** | **5%** | **5%** | **5%** |
| fluid loss (gal/sk) | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1** | **1.1** | **1.2** |
| retarder (gal/sk) | **0.7** | **0.6** | **0.5** | **0.4** | **0.3** | **0.3** | **0.3** | **0.3** | **0.3** | **0.3** |

**Table 6:** Laboratory test results for case 1-10 for Recipe 4. Starting from 200ºF till 350ºFwith 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% |

For Recipe 3 as shown in table 5, A viscosifier was added to increase the thickness of the slurry to achieve the desired rheology, considering the concentration of the gas control agent was relatively low, fluid loss and gas control was increased relatively to meet the minimum required concentrations to be used the specified temperature and pressures. This slurry produced the best case of reduced transit time as low as 1 minute. For recipe 4, KCL was 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. Looking at Recipe one above and the subsequent cases 1-10 in table 7, increasing temperature has adverse effect on the transition time because increasing the temperature caused the transition time to increase though not linearly, when we look at adverse effect of pressure, transition time continuously increases which is not a desired. Referencing API standard of transit time to be 45 minutes and below, this tests results showed that even though the compressive strength was achieved micro-channeling could still occur leading to the need for a remedial cementing job and loss of revenue or even occurrence of non-productive time.

**Table 7:** Static Gel Strength Analyzer and MACS II for recipe 1 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.

| Recipes | Case | SGSA (hr:mn) | transit time (mins) | Density (ppg) | Temp (degF) | Pressure (psi) |
|---|---|---|---|---|---|---|
| 1 | 1 | 3:18-3:28 | 10 | 15.8 | 239 | 8799 |
| | 2 | 3:18-3:35 | 17 | 15.8 | 240 | 8799 |
| | 3 | 3:45-3:59 | 14 | 15.8 | 250 | 9000 |
| | 4 | 3:00-3:55 | 55 | 15.8 | 260 | 9500 |
| | 5 | 2:43-3:25 | 42 | 15.8 | 270 | 10000 |
| | 6 | 4:00-4:37 | 37 | 15.8 | 280 | 12000 |
| | 7 | 4:02-4:44 | 42 | 15.8 | 290 | 15000 |
| | 8 | 4:12-4:43 | 31 | 15.8 | 300 | 18000 |
| | 9 | 4:21-5:09 | 48 | 15.8 | 310 | 20000 |
| | 10 | 4:23-5:20 | 57 | 15.8 | 350 | 25000 |

**Table 8:** Static Gel Strength Analyzer and MACS II for recipe 2

| Recipes | Case | SGSA (hr:mn) | Transit Time (mins) | Density (ppg) | TEMP (degF) | Pressure (psi) |
|---|---|---|---|---|---|---|
| 6 | 1 | 5:47- 6:07 | 20 | 15.8 | 140 | 6309 |
| | 2 | 5:40- 6:05 | 25 | 15.8 | 150 | 6309 |
| | 3 | 5:47- 6:23 | 36 | 15.8 | 160 | 7000 |
| | 4 | 5:25- 6:10 | 45 | 15.8 | 180 | 9000 |
| | 5 | 5:21- 6:17 | 56 | 15.8 | 200 | 12000 |
| | 6 | 5:17- 6:12 | 55 | 15.8 | 230 | 15000 |
| | 7 | 5:15- 6:01 | 46 | 15.8 | 260 | 17000 |
| | 8 | 5:15- 6:14 | 59 | 15.8 | 300 | 20000 |
| | 9 | 5:13- 6:15 | 62 | 15.8 | 320 | 25000 |
| | 10 | 5:17- 6:13 | 56 | 15.8 | 350 | 25000 |

**Table 9:** Static Gel Strength Analyzer and MACS II for recipe 3

| Recipes | Case | SGSA (hr:mn) | Transit time (mins) | Density (ppg) | Temp (degF) | Pressure (psi) |
|---|---|---|---|---|---|---|
| 7 | 1 | 4:24-4:25 | 1 | 16.2 | 400 | 18000 |
| | 2 | 4:20-4:24 | 4 | 16.2 | 400 | 19000 |
| | 3 | 4:18-4:22 | 4 | 16.2 | 400 | 20000 |
| | 4 | 4:15-4:18 | 3 | 16.2 | 400 | 21000 |
| | 5 | 4:15-4:19 | 4 | 16.2 | 400 | 21500 |
| | 6 | 4:14-4:16 | 2 | 16.2 | 400 | 22000 |
| | 7 | 4:13-4:15 | 2 | 16.2 | 400 | 22500 |
| | 8 | 4:12-4:13 | 1 | 16.2 | 400 | 23000 |
| | 9 | 4:11-4:12 | 1 | 16.2 | 400 | 24000 |
| | 10 | 4:12-4:13 | 1 | 16.2 | 400 | 25000 |

**Table 10:** Static Gel Strength 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 |

Increasing temperatures and Pressures caused the transit time to increase significantly going as high as 1 hour or close to for most case, this result is not desired, but it could also be due to the changing concentrations of extender, fluid loss and dispersant or could be because of the presence of hematite and barite as weighting agents making the slurry drag while trying to gain gel strength.

Weighting materials have poor gas migration control characteristics because of sedimentation issues that could occur, this slurry did not cater for settling or possible sedimentation at higher temperatures and pressures by adding anti-settling agents. Anti-settling agents would have significantly reduced the effect of the weighting materials present in this slurry while still retaining the set cement slurry properties for recipe two as shown in table 8.

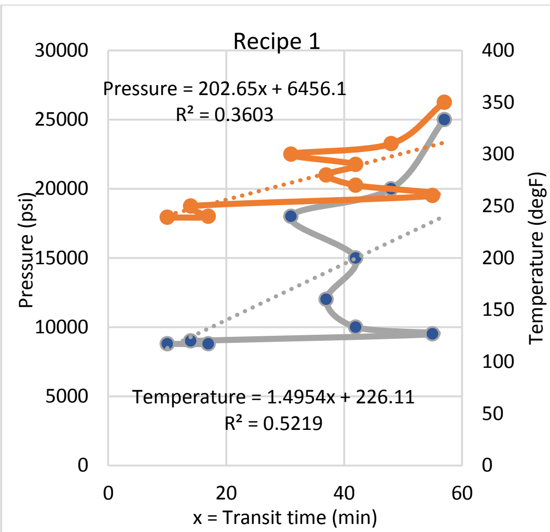


**Fig 1:** Recipe 1 Temperature and Pressure vs Transit time

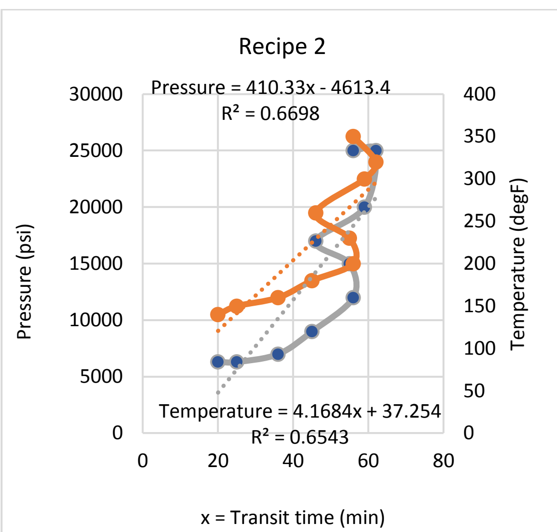


**Fig 2:** Recipe 2 Temperature and Pressure vs Transit time

From the results above, this recipe 3 gave the best results desired in this research work with low time to 100 lbf/100ft$^2$, 4 hours and some minutes for each case, the temperature was kept constant due to the laboratory equipment standard but the pressures where varied to show changes.

The equation of line and regression analysis would be done to show relationship of cement slurry recipe with density, transit time, pressures, and temperature. The presence of viscosifier helped in aiding the cement slurry recipe to reach desired transit time and helped it gain gel strength quickly. For recipe 4, this slurry recipe 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.

In fig 1, the linear relationship between temperature and transit time is given as 1.4954x + 226.11, while the regression analysis shows 52.19% correctness which is too small and cannot be used , the linear relationship equation for pressure vs transit time gave 202.65x + 6456.1 and a regression analysis value of 36.03%.

In fig 2, the linear relationship between temperature and transit time is given as 4.1684x+37.254, while the regression analysis shows 65.43% correctness, the linear relationship equation for pressure vs transit time gave 410.33x – 4613.4 and a regression analysis value of 66.98%. The regression values for both temperature vs transit time and between pressure vs transit time are not strong enough as they are far from 1/100% and are therefore not acceptable.

In fig 3, The linear relationship between temperature and transit time is not given since they temperature is just one value, the linear relationship equation for pressure vs transit time gave -795.03x + 23429 and a regression analysis value of 23.72%. This slurry recipe would not be used for obvious reasons as it does not consider varying temperatures.

In fig 4, 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.

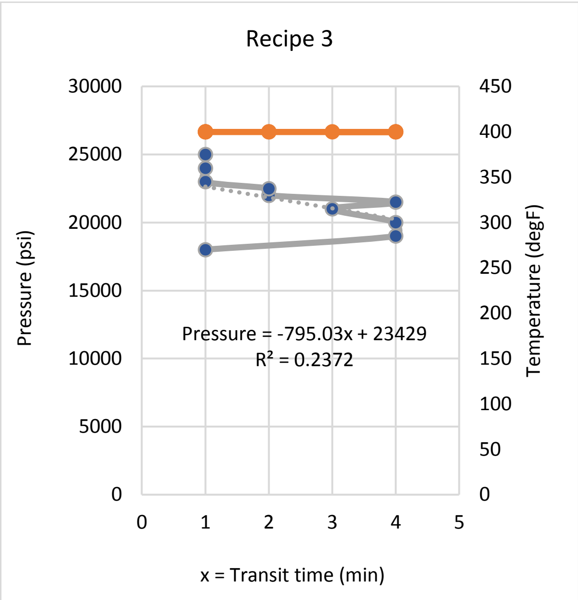


**Fig 3:** Recipe 3 Temperature and Pressure vs Transit time

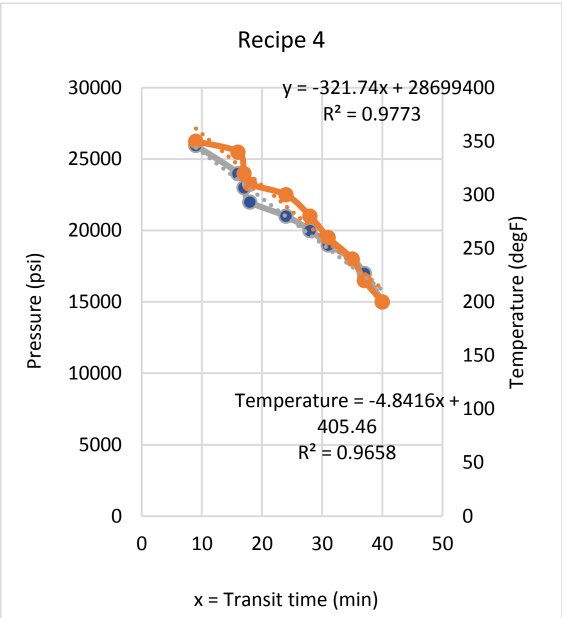


**Fig 4:** Recipe 4 Temperature and Pressure vs Transit time

*Observations from Temperatures and pressures vs Transit time:* Recipe1 showed good regression signs most likely there is a good link between the transit time and temperatures and pressures but the issue here would be that there are so many factors that need to be considered before the best recipe can be select from this tests, the factors include but are not limited to the kind of formation, the availability of equipment to laboratory test and also perform the cement blending in the bulk plant as well as equipment and trained personnel to pump the job on the field. Recipe 2 has good regression but would be able to achieve the API standard for 45 minutes transit time as temperature and pressure increases. Recipe 3 has low transit time values which are desired, but the test was done at just one temperature, so a regression analysis would not be performed since there is no varying temperatures, but the cement additives used here can achieve the objectives of this research seeing that silica flour is present and in the accepted blend volume. Recipe 4 had the best acceptable slurry recipe design, regression values and reduced transit time with increasing temperatures and pressures, it also met the objectives of this project which are to design a tailored slurry to cater for long zero gel time and short transition time thereby solving gas migration issues, address fluid loss of cement using anti-settling agents in stabilizing conventional cement slurry system while varying temperature and pressure, solve Strength retrogression issues that causes cement sheath failure and to deal with flash setting and short thickening time of cement by designing a retarded slurry.

*Conclusion:* Silica flour and KCl are very important ingredient in the production of cement slurry. Recipe1 showed good regression signs. There is a good link between the transit time and temperatures and pressures. Recipe 2 would be able to achieve the API standard for 45 minutes transit time as temperature and pressure increases. Cement additives used in recipe 3 can achieve the objectives of this research seeing that silica flour is present and in the accepted blend volume. Recipe 4 has the best regression values for both temperature vs transit time and pressure vs transit time.

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