MAJOR PROJECT REPORT

"HYDRAULIC FRATURING FLUID DESIGN"

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UNDER THE ABLE GUIDANCE OF

Prof. R.P.Soni

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CERTIFICATE

This is to certify that the work contained in this project titled **"HYDRAULIC FRACTURING FLUID DESIGN"** has been carried out by **AMRITANSH TRIPATHI (R820211004), NISHANT (R820211020) & PRABUDDHA PUNETHA (R820211023) students of B.Tech Applied Petroleum Engineering - Gas (2011-2015) during August 2014-April 2015** under my/our supervision and has not been submitted elsewhere for a degree.

Prof. R.P.Soni

ABSTRACT

The project aimed at conniving hydraulic fracturing fluid which depends on the following key parameters: fluid type, viscositychuck, fluid rheology, fluid economics , laboratory information on the formation, objects accessibility & proppant assortment. The most frequent base gel & cross-linker used in the industry are guar &borax respectively. The fracturing fluid remains viscous until a breaking agent is introduced to break the cross-linker.

The effectiveness of any fracturing treatment depends on achieving desired fracture geometry, proper proppant placement and finally, an efficient clean-up. The clean-upprocess is achieved by plummeting the fluid viscosity using chemical additives called breakers. There are different types of breakers which are used nowadays in the production, & can be generally divided into two categories: oxidizers & enzymes. Breaker performance depends on the bottom-hole temperature, breaker concentration & polymer loading. Various breakers, used at different concentrations & temperatures, give different kind of break results. Therefore, the amount of unbroken gel & residue generated is also different for each one of them.

The Experiments have been conducted to measure the variation in viscosity of fracturing fluid with increasing loading of gelling agent and a relation between viscosity and polymer concentration has been established. The experiments also aimed to measure the variation in viscosity with and without cross linkers with increasing temperature. Through this experiment, the effect of cross linkers on the viscosity with change in temperature have been identified as well as the variation of viscosity with temperature at different concentration of breakers have been developed which would provide with an idea of what concentration of breakers is suited for a given temperature.

The project provided a clear perceptive of the various gelling agents, cross linking and breaker systems that could be used in the industry, while conniving fracturing fluid systems in order to optimize the breaker performance and achieve a better, cleaner and efficient break to minimize the formation damage caused by polymer degradation.

ACKNOWLEDGEMENT

The project bears the imprints of the efforts extended by many people to whom we are deeply indebted.

We would like to express our gratitude towards our mentor Prof. R.P.Soni under whose able guidance we gained the insights and ideas, without which the project could not have seen the light of the day. His suggestions have been valuable and his teachings during the course of our discussions would continue to be a guiding principle in our works in the future as well.

We would also like to thank Mr. VisheshNath, Drilling Fluid Department, ONGC Dehradun and Mr.Himanshu Pant, Well Stimulation Engineer, Baker Hughes for lending their unparalleled guidance and support throughout this time.

We would also like to take this opportunity to acknowledge the technical assistants of Nanotechnology Lab for helping us out in performing the practical experiments conducted in this project and Shraddha Associates for providing us with the chemicals needed to develop our fluid.

Finally we would like to thank Mr. C. H. Varaprasad, Activity Coordinator, Dept of Chemical Engineering and the University for providing us an opportunity to apply our technical knowledge and see it materialize in the form of this project.

Executive Summary

The main objective of this research was to perform a comprehensive study of the various chemicals used in hydraulic fracturing fluid design and the variation of viscosity as a function of temperature and time. An extensive testing was done for guar based linear gel, borax based cross linked fluid and APS as breaker. Their response in terms of viscosity by varying temperature was recorded and viscosity measurements were done to identify the chemical activity of the chemicals. The cross linking and breaker analysis was restricted to a temperature up to 176^0F since it was the maximum temperature the rheometer could attain thereby putting a constraint on the maximum temperature range in which the cross linker remains active. The rheometer used was Anton Paar viscometer present in the nanotechnology lab. The software used for measurements was Rheolab QC plus.

Due to the unavailability of the enzyme breaker, the breaking analysis of the developed fluid was restricted only to oxidative breaker. The time spent in the sourcing of the chemicals restricted the fulfillment of the scope of project. Also the presence of only a single rheometer in the lab posed a great challenge in the execution of the conducted experiments since a number of other R&D projects were being conducted on the same rheometer.

The project provided a better perceptive of the various gelling agents, cross linking & breaker systems that could be used in the industry, while designing fracturing fluid systems in order to optimize the breaker performance and achieve a better, cleaner and efficient break to minimize the formation damage caused by polymer degradation.

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Chapter 1: Introduction

1.1 Hydraulic Fracturing

Hydraulic fracturing isprincipally a well stimulation procedure. The reason to stimulate a well is simple i.e. a low production rate. Therefore, a well stimulation is a procedure performed to increase the production of a well. There could be a number of reasons that can cause a low production rate. These include:

- Low permeability
- Low reservoir pressure
- High bottom hole pressure
- High fluid viscosity
- High skin

1.2: Fracturing Fluids

Fracturing fluid is one of the most important components of a hydraulic fracturing treatment. Fracturing fluids are used for three main purposes:

- Creating the fracture
- Transporting proppant into the fracture
- Placing the proppant inside the fracture

To accomplish the above tasks, the fluid has to be designed carefully. The performance of a fracturing fluid and its efficiency in achieving the desired results depends on its chemical composition. The rheological properties, most significantly viscosity, dictates the fluid performance, though, viscosity is not the only rheological property of importance. Other properties like elasticity also play a momentous part. The fracturing fluid should be designed in such a way that:

- It is easy to pump offering low friction, and therefore, less wear & tear to the pumping equipment
- Maintains adequate viscosity in the fracture
- Exhibits good characteristics for controlling the fluid leak-off

- Breaks quickly once pumping stops and is easy to flowback
- It is cost-effective

Due to this special type of behavior that is requisite of the fracturing fluids, i.e., to be thin-enough at the surface to pump easily,then gain viscosity to carry the proppantand then break and turn into almost water-like after fracturing is complete for the ease of clean up.

1.3:Types of Fracturing Fluids

As discussed in the previous section, many different types of fracturing fluids have been developed and used over the years starting with oil-based fluids. These types are:

- Oil-based
- Water-based
- Multiphase fluids like foams and emulsions
- Unconventional fluids like Viscoelastic Surfactants (VES)

This project focuses on the most frequently used type of fracturing fluids, i.e., water based fluids, particularly, guar-based fluids. Therefore, a brief discussion follows on water-based fluids and then anin depth account is presented on guar-based fluids, their composition and chemistry.

1.3.1: Water-Based Fracturing Fluids

Water-based fluids are the most commonly used fracturing fluids in the industry and it is not without fine reason. These fluids are cheap compared to others, deliver good results and are safer to use. Water is an abundant source, available throughout the world. They can be linear or cross linked guar-based fluids. They could be a simple amalgamation of water and a friction reducer like polyacrylamide, or it could be just plain water. The linear gels, used without cross linking and water-friction reducer combinations are commonly used for shale gas fracturing applications.

The subsequent section presents an account on the different components of guar-based fracturing fluids, their structure and chemistry.

Chapter 2:Fracturing Fluid Design

Guar-based fluids, which consist of guar and its derivatives, are the most common type of fracturing fluids used in the industry. Theygenerate good results& are safe to transport & offer excellent economic value. They induce good proppant transport distinctiveness, which is one of the most important jobs of a fracturing fluid & can be used in the form of linear gels, which implies only guar & water are mixed together, or cross linked form, by using special chemicals that change its structure and increase its viscosity. This made them versatile fluids that can be designed and used according to the job constraint. A typical guar-based fluid contains:

- Water
- Guar or guar derivative as gelling agent
- Cross linking agent to augment viscosity
- Buffer
- Breaker to reduce viscosity after pumping stops
- Biocide to kill bacteria
- Clay stabilizers to avert clay swelling and fines migration
- Surfactant to alter surface tension and wettability

An example of a typical gel formulation for a 45 lb per 1000 gallon system is provided in Table 2.1

Component	Amount	Remarks
Polymer	0.54 cm^3	Guar gum
Surfactant	0.2 cm^3	
Gel Breaker (Oxidizer)	0.5 cm^3	Sodium bromate ($NaBrO_3$)
Gel Stabilizer	0.29 cm^3	
Bactericide	0.05 cm^3	
KCl	25 g	Clay control
*Crosslinker	0.45 g	Boric acid (H_3BO_3)
HT delay agent	1.5 g	Sodium gluconate ($C_6H_{11}NaO_7$)
Stabilizer	0.1 cm^3	60-100% Alcanolamine
Activator	0.9 g	Sodium hydroxide to control the pH (9-12)
Water	98.32 cm^3	

Table 2.1 - Guar Gel Formulation (45 lb/1000 gal) (Nasr-El-Din et al., 2007)

2.1: Guar Gum

Guar gum is the gellant or viscosifying agent in fracturing fluids. It is a polysaccharide produced from guar bean plant. This plant is grown in abundance in Pakistan, India and southern United States. When guar is mixed with water, it swells and forms a viscous gel. This has sufficient viscosity & elastic properties desired to carry proppants into the fracture & good leak-off control. But certain additives can make it even more viscous and, therefore, augment its performance appreciably.

2.1.1: Structure of Guar

Guar has a linear structure which consists of two different kinds of sugars i.e. mannose & galactose. It consists of a long chain or backbone made of mannose units linked to each other by -1, 4 acetal linkages. This backbone is attached to isolated units of galactose by -1, 6 acetal linkages. These mannose and galactose units exist in a ratio of 1.5:1 to 2:1. The linear structure of guar polymer is shown in Figure 2.1

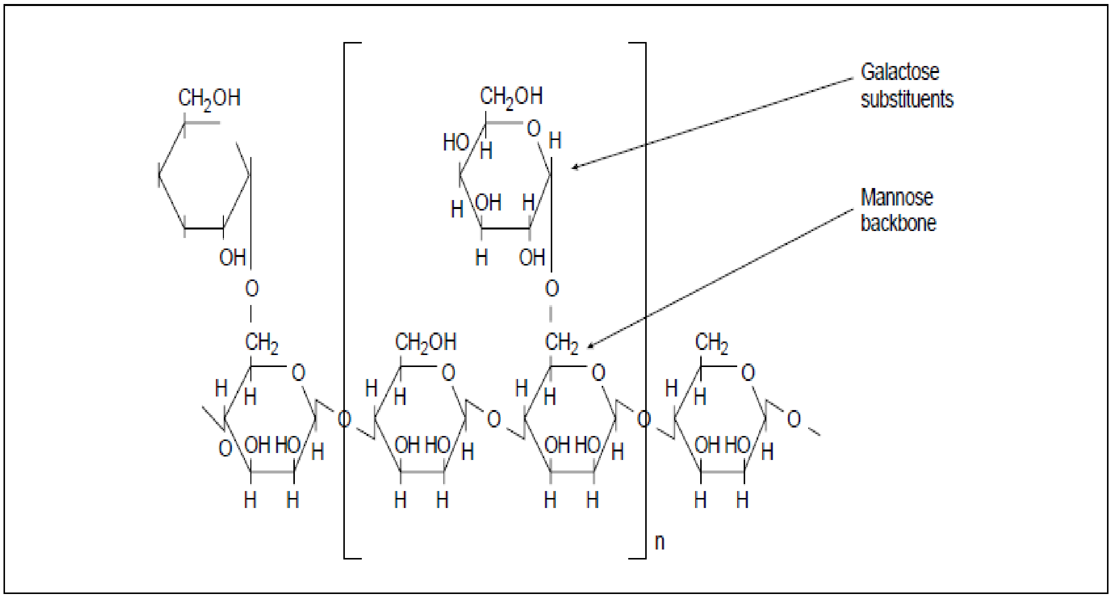

Figure 2.1: Structure of Guar

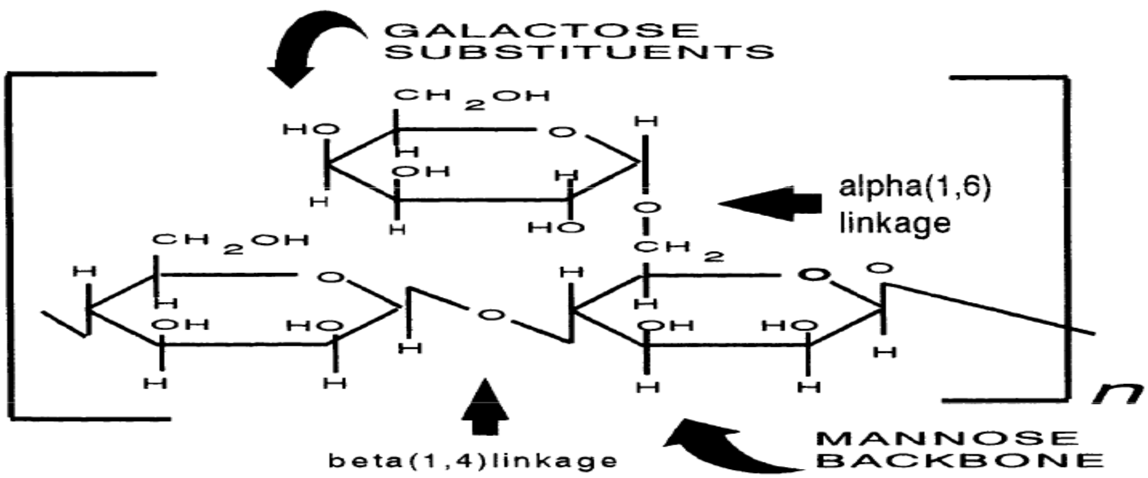

Figure 2.2- A single repeating unit of guar

2.1.2: Guar Derivatives

Guar gum is produced from a plant. There is some natural waste residue in this guar, which comes from the plant material. This residue is of no use and does not help in escalating the viscosity of the guar gel in any way. Natural guar has about 5% to 10% of this residue. When this residue gets pumped along with the guar gel, it inflicts damage to the formation. In order to avoid the formation damage caused by this residue, guar is chemically treated with various chemicals to reduce this waste material and clean the guar. This practice creates guar derivatives, which contain less amount of the waste material and also amplify the working temperature range of guar.

When guar is treated with propylene oxide, it forms hydroxypropyl guar (HPG). HPG contains 2% to 4% residue by mass. A dual treatment, with propylene oxide and chloroacetic acid, results in carboxymethylhydroypropyl guar (CMHPG), with even smaller amounts of residue i.e. about 1% - 2%. These chemical treatments cost money, & therefore, make these derivatives more expensive compared to the un-derivatized guar.

These derivatised guar were very popular during the 1970s & 80s, but then some new studies and observations shifted the industry back towards the use of natural, un-derviatized guar. Studies showed that the damage caused by HPG and natural guar was not very unlike. Another reason was the study showing that although natural guar contains more percentage of residual material by mass, still it compares well with derivatised guars on volume percentage basis, Figure 2.3. Also, the improvement of guar-borate cross linked systems which increased their working temperature range was also a factor. This was achieved by using gel stabilizers like sodium thiosulfate. And the most imperative reason was cost. Considering all these factors, un-derivatised guar still remains the most popular choice.

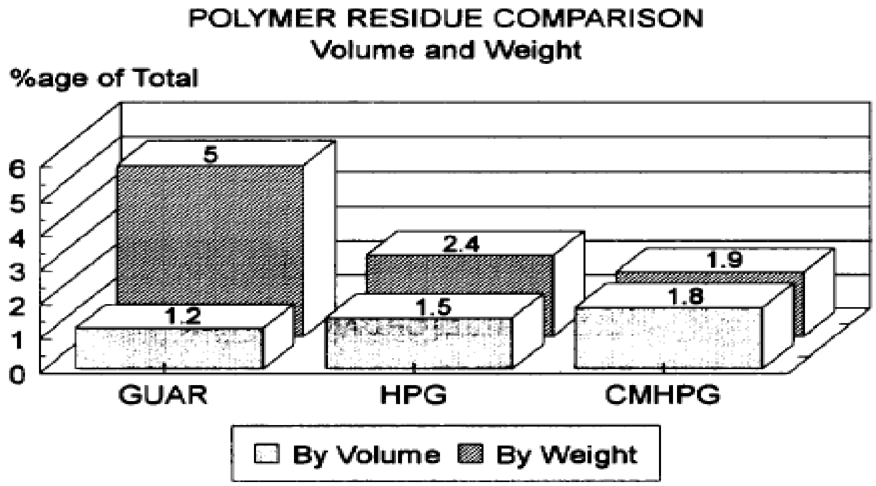

Figure 2.3- A comparison between guar and its derivatives

Over the years, improved techniques have helped produce better quality guar. Natural guar produced these days can have residue amounts as low as 2% or less, with derivatised guars now containing 0.5%.

2.2: Rheological Properties of Fracturing Fluids

Mostly the fracturing fluids are non-newtonian fluids, which mean that their viscosity depends on the shear rate. The rheology of fracturing fluids is defined by the power law model, shown in Equation 2.1

$$\tau = K\,\gamma^{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

where τ is the shear stress having units of lbf/ft2, γ is the shear rate in sec-1, K is the consistency index having units of lbf-sec/ft2 and n is the dimensionless flow behavior index. The values of n and K are calculated by plotting a log-log chart of shear stress against shear rate. The slope of the straight-line part of this plot gives n and K is the value of the shear stress at shear rate of 1 s-1.

The fluid properties are generally measured using rotational viscometers with cylindrical geometries. Thus, the parameters obtained are geometry dependent and are represented as n and Kv. These parameters have been calculated for all the viscosity tests conducted in this study.

2.3: Fracturing Fluid Additives

2.3.1: Cross linkers

Cross linkers are chemical agents used to increase the viscosity of the fracturing fluid. They were developed to diminish the amount of polymer loading in fracturing fluids and still maintain good proppant carrying abilities. There are various cross linking agents used in the industry like borates, aluminates, zirconates, organictitanates etc. Every cross linker has a particular working range which includes temperature, pH and the type of polymer. The pH ranges for various types of cross linkers are shown in Figure 2.4 and the temperature ranges are shown in Figure 2.5.

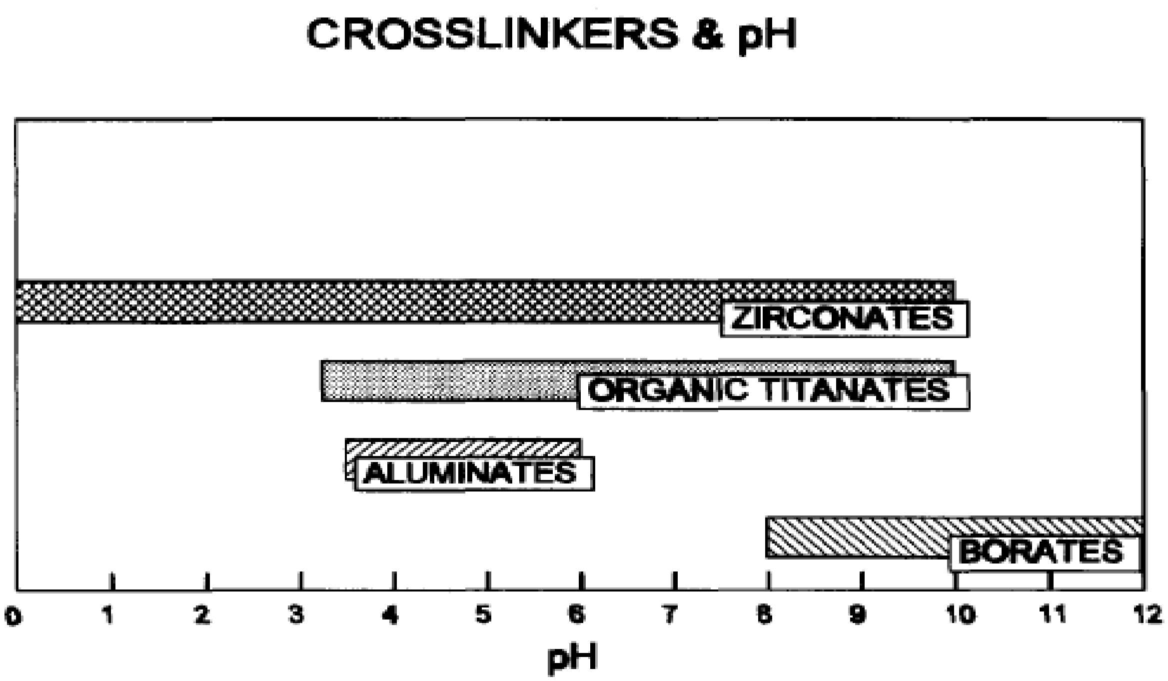

Figure 2.4: pH ranges for various cross linking agents

Delayed cross linking systems are used because of the high viscosities of cross linked fluids. Highly viscous fluid will create high friction while pumping and increase the pressure and power required to pump it. Therefore, a delayed crosslink can reduce the pressure and power requirements at the surface making it easier to pump, and then increases the viscosity to provide the necessary proppant carrying ability.

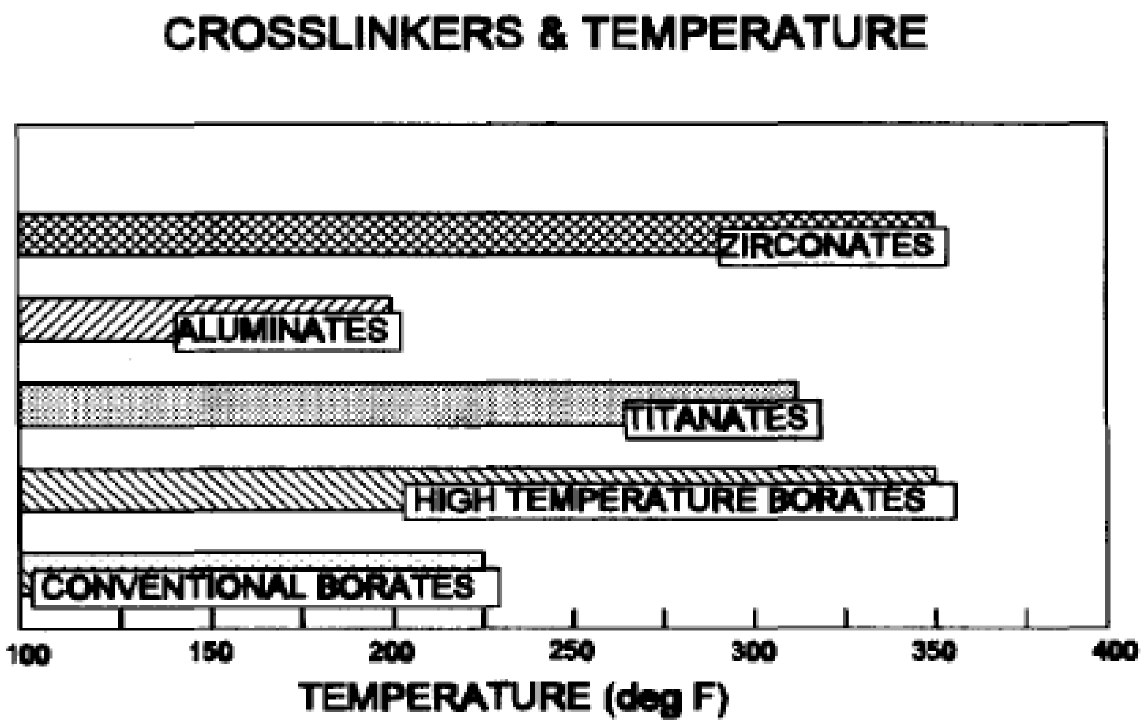

Figure 2.5: Temperature ranges for various cross linking agents

One of the most widely used cross linking agents for guar based fluids is borate. Borates are added to the fracturing fluid in the form of borate salts or boric acid. They are basically a source of monoborate ions which are considered to be the cross linking agents. For example, borax or sodium tetraborate produces monoborate ions in water as shown in Equation 2.2

Na2B4O7 + 10H2O → 2Na+ + 2B(OH)3 + 2B(OH)4- + 3H20………….(2.2)

Monoborate ion is also produced when boric acid undergoes hydrolysis as shown in Equation 2.3

B(OH)3 + 2H2O → B(OH)4- + H3O+ …………………….(2.3)

At pH values greater than 8.5, this monoborate ion creates complex structures by combining with the cis-hydroxyl groups present in the guar polymer chain as shown in Figure 6. The generation of monoborate ions is a function of pH and temperature. The concentration of monoborate ions increases with increasing pH, which causes further cross linking to occur. An increase in temperature causes pH to fall, and therefore reduces the crosslink as shown in Figure 2.6.
.
At higher temperatures, using greater concentration of borates to account for the low pH can cause a phenomenon called "synersis". Elevated concentrations of monoborate ions cause excessive cross linking or over-cross linking. The polymer forms a clump and releases the water, making it useless forproppant transport. Therefore, the pH of the borate cross linked fluid should always be maintained at high level, around (10-12). At higher temperatures, using organo borates or low solubility borates (calcium or calcium sodium borate) can prevent synersis by producing

low monoborate ion concentration early and then generating greater concentration at high temperature later.

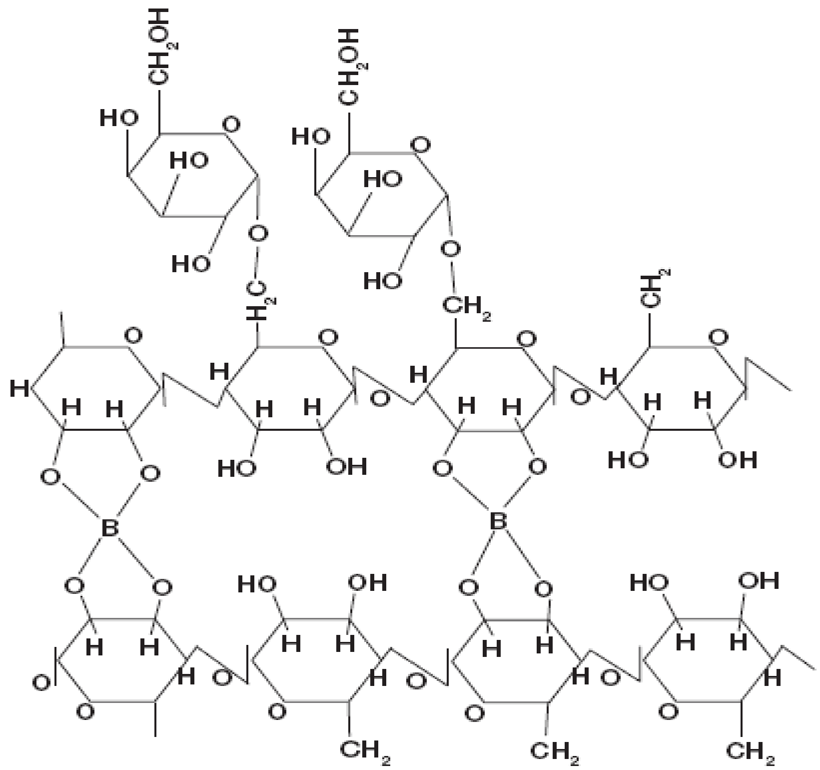

Figure 2.6- Structure of borate cross linked guar

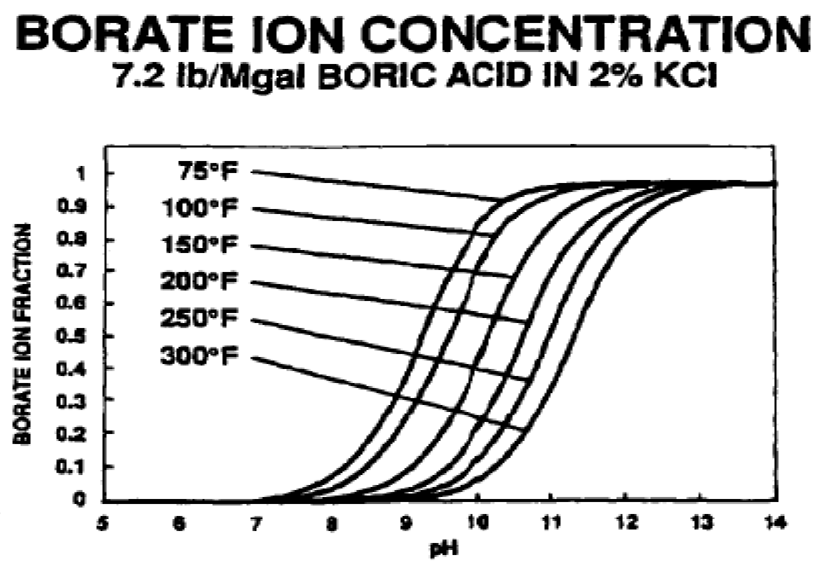

Figure 2.7- Dimensionless monoborate ion concentration vs pH for various temperatures

2.3.2: Buffers

Buffers are used to maintain the pH of the fluid for cross linking purposes. They are also used as dispersants for polymer particles to prevent the polymer from forming small clumps or fish eyes when mixed with water. They are produced from the reaction of weak acids with strong bases. There are many different buffers used in the industry, depending on the pH requirement. Some examples include sodium acetate, sodium carbonate, sodium bicarbonate, sodium silicate & the same salts for potassium.

2.3.3: Breakers

Breakers are the main objects of study in this project. They are chemical agents used to reduce the viscosity of the fracturing fluids after proppant has been delivered inside the fracture. This is required to make it easy to flow the fluid back to the surface & also to prevent the thick fracturing fluid from plugging the formation or reducing the proppant pack permeability. Unbroken gel or residue can be a cause of formation damage & reduced productivity, making the whole fracturing process ineffective or at least significantly decreasing its effectiveness.

Breakers reduce the viscosity of the polymer by breaking the polymer backbone into smaller fragments. This decreases the molecular weight & thus, decreases the viscosity. Breakers can be divided into two main categories

1. Oxidizers

2. Enzymes

2.3.4: Oxidizers

Oxidizers or oxidative breakers generate free radicals which react at certain sites on the polymer backbone to break the polymer chain. These radicals which are highly reactive are created through thermal decomposition of the oxidizer. There are 18 places that are available on a single guar repeating unit where these radicals can react, shown in Figure 2.8.

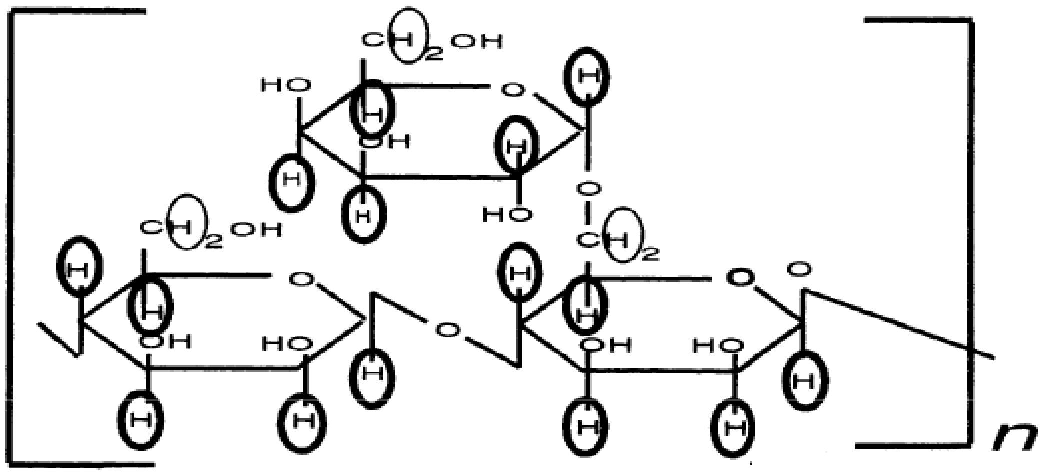

Figure 2.8: Radical reaction sites available on a single repeating unit of guar

One of the most common types of breakers is persulfate (S2O82-) salts of ammonium, sodium and potassium. Persulfate decomposes due to temperature and yields two free radicals as show in Equation 2.4.

$O_3S\text{-}O\text{:}O\text{-}SO_3^- \rightarrow .SO_4^{-1} + .SO_4^{-1}$ ……………………..…….(2.4)

These two radicals can attack any of the 18 sites available on the guar repeating unit. Of these 18 sites, the two best sites to degrade the polymer are the -1, 4 acetal linkages between the mannose units. But these two sites are less acidic than the rest and therefore have lesser affinity toward a reaction with the radicals. The ideal breaking would be if the radicals break the polymer chain at the center creating two equal polymer fragments and then more radicals break these fragments at the center, and so on. If the chain is broken closed to one end instead of the center, it will create a smaller fragment and a larger fragment, and the molecular weight reduction will be less effective.

Oxidizers are highly reactive at high temperatures (>140^{0}C). As the temperature is increased, they become more & more reactive & the reaction rate between the free radicals & the polymer also increases. They decrease the viscosity of the fracturing fluid very quickly. Persulfate at 200 ^{0}F has a half-life of about 20 minutes & at 225 ^{0} F it reduces further to less than five minutes. Therefore, they should be carefully used at high temperatures, increasing the concentration too much can cause fluid to break too soon & lose its proppant carrying ability before the proppant has been transferred into the fracture.

Encapsulated breakers can be used at very high temperatures to delay the break. This helps in using high oxidizer concentrations while preventing the risk of the fluid breaking prematurely, before the pumping is stopped. The encapsulated breaker is the same oxidizer, e.g. persulfate, coated with a synthetic material like PVC, nylon etc.

2.3.5: Enzymes

Enzymes or enzymatic breakers are catalysts which accelerate chemical reactions produced from living cells. They are biodegradable & therefore considered environmentally friendly. Initially there were only thought to be effective for low pH (3.5 – 8) and temperatures (<150 ^{0}F). Modern day enzymes can go up to 350 ^{0}F. Enzymes are mostly reactive at room temperature and therefore they immediately start degrading the polymer as soon as they are introduced.

2.3.6: Biocides

Biocides are used to kill bacteria. Bacteria like to eat the natural polymers present in the fracturing fluids. Therefore they can reduce the viscosity of the fracturing fluid and make it lose its proppant carrying ability. In addition to this, bacteria can also make the reservoir fluids produce hydrogen sulfide and turn sour, which can be a huge problem. Therefore biocides are added to the mixing tanks of fracturing fluids. One of the most common examples of biocides is Gluteraldehyde which provides very good protection against sulfate reducing bacteria (SRB).

2.3.7: Clay Stabilizers

Clay stabilizers are salts like ammonium chloride or potassium chloride which are added to water-based fracturing fluids to prevent the swelling of clays in water-sensitive formations, i.e., formations that contain clays that can be mobilized when introduced to water.

2.3.8: Surfactants

Surfactants are used to reduce surface and interfacial tensions, & change the wettability of the fluids for easier recovery from the formation. Reduction of surface tension can make the recovery of the fluid easy after the fracturing process is completed. Reducing the interfacial tension between reservoir fluids and water protects from emulsions forming and reducing permeability. Changing the wettability of the fracturing fluid by changing its contact angle of leak-off into the formation makes it easier to flowback.

2.4: Formation Damage Caused by Fracturing Fluids

Fracturing fluids can cause damage to the formation. Unbroken gel or polymer can cause severe reduction in proppant pack permeability and has an adverse effect on fracture conductivity. Fracturing fluid that is leaking-off into the formation can cause damage to the fracture face. This decreases the permeability of the formation outside the fracture.

A lot of research has been conducted and is still going on to improve the fracturing fluids so that it does not cause formation damage. This research project is also a part of this effort, in order to study the breaking system to provide maximum degradation and minimize the amount of unbroken gel in the fracture.

Chapter 3: Economics of Fracturing Fluids

To fully appreciate the life cycle costs of fluids used for hydraulic fracturing – including water, one needs to observe the total costs of fluid acquisition, management and its disposal. Typically, these costs are distributed between various groups within an operator's organization (i.e., completions and production), with budgeting emphasis on the acquisition costs during the completions process.

3.1: The True Cost of Water

Hydraulic fracturing represents the largest demand for water in drilling and completions (orders of magnitude greater than drilling).It is estimated that 2.5 million to 5 million gallons of water are used *per well* in hydraulic fracturing. For example, one operator reports it averages 4.5 million gallons of water for each well to fracture its deep shale gas wells. In addition, produced water (post-flowback) tends to increase as the well deteriorates, with reported water-to-oil ratios increasing from 1:1 early in the life of a well to 15:1 late in life. Accordingly, the wastewater volumes recovered from hydraulic fracturing varies from 10% to 70%, depending upon the geologic formation. That means, for a 5 million gallon hydraulic fracturing job, recovery rates could mean anywhere between 500,000 and 3.5 million gallons of fluid returned to the surface.

The cost to acquire, transport, store, use, treat, recover, reuse & recycle, or dispose off water represents a noteworthy investment for energy producers & service companies. The water cycle cost includes water acquisition, chemical mixing & site supervision, well construction, injection, flowback & produced water management, wastewater treatment & disposal. It is important to adopt the water life cycle evaluation for hydraulic fracturing fluids to fully appreciate the cost of water as well as alternative methods to reduce the overall total costs. Recent estimates put the yearly cost of water management for oil and gas industry in the $51 billion range. Factors that contribute to driving up water costs include supply constraints and increasing competing demands outside of the industry. The motivating factors to amend include: the scale and demand of well programs in some unconventional plays; public perception; and municipal demands for water that are projected to continue to outpace supply.

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Chapter 4: Experimental Procedures, Results and Discussions

4.1: Apparatus

4.1.1: REMI 5MLH Magnetic stirrer

Magnetic stirrer was used at various rpm to mix the fracturing fluid solution in the lab. It consists of stainless steel top housing & is quite squashed. The Permanent Magnet DC motor gives soaring torque at lower speeds and maintains rate stability in spite of viscosity or volume alterations. The stirrer also contains a hot plate but was not required during mixing as all the solutions were prepared at ambient temperature. During linear gel mixing around 600 rpm was used and for cross linked fluids approximately 200rpm was used for mixing.

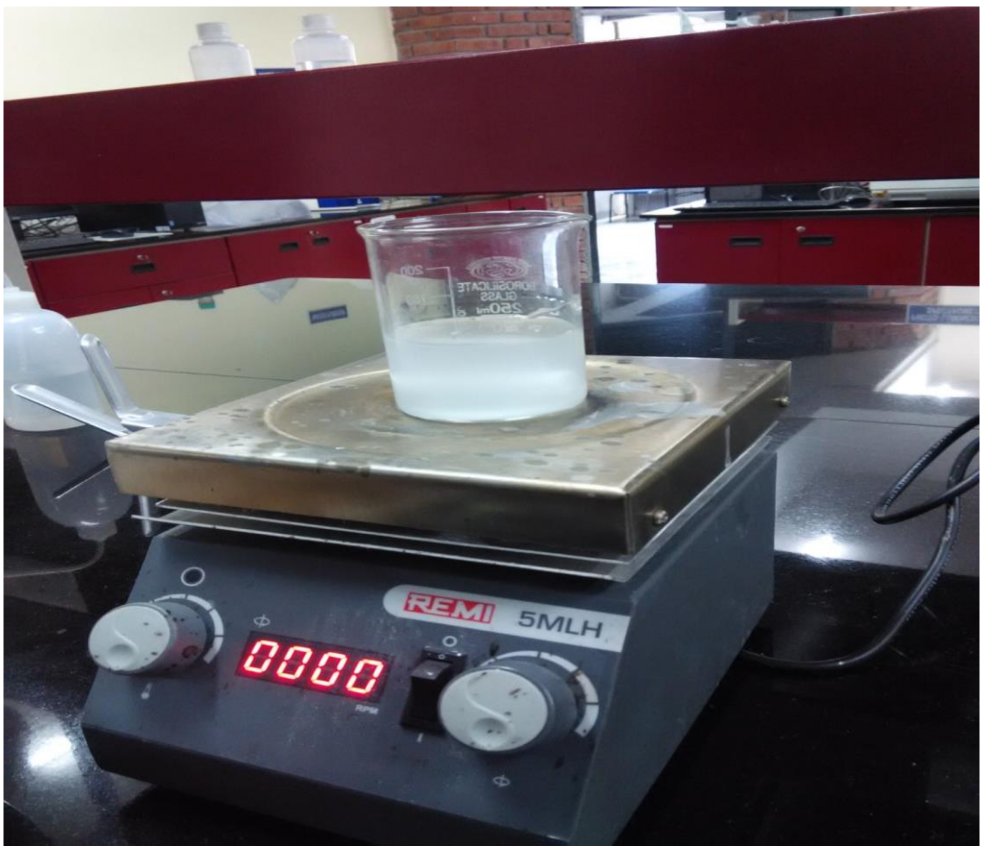


Figure4.1: REMI 5MLH Magnetic stirrer

4.1.2: Anton Paar QC Lab Viscometer

Anton Paar viscometer was used for viscosity measurement for all the experiments performed. The main module was connected to computer for digital recordings. External water bath was also connected to vary the temperature during measurements. Two types of probes were used for measurement: C-17 and C-39 each having a cylinder with 5ml and 70ml capacity respectively. For higher viscosities above 100cp C-17 probe was used and C-39 for lower viscosities. Maximum temperature at which the module could be safely used was 80°C.

Following physical variables can be measured using the viscometer:

- Dynamic viscosity
- Shear stress
- Shear rate
- Speed
- Torque
- Temperature
- Time
- Kinematic viscosity
- Yield stress
- Deformation
- Compliance

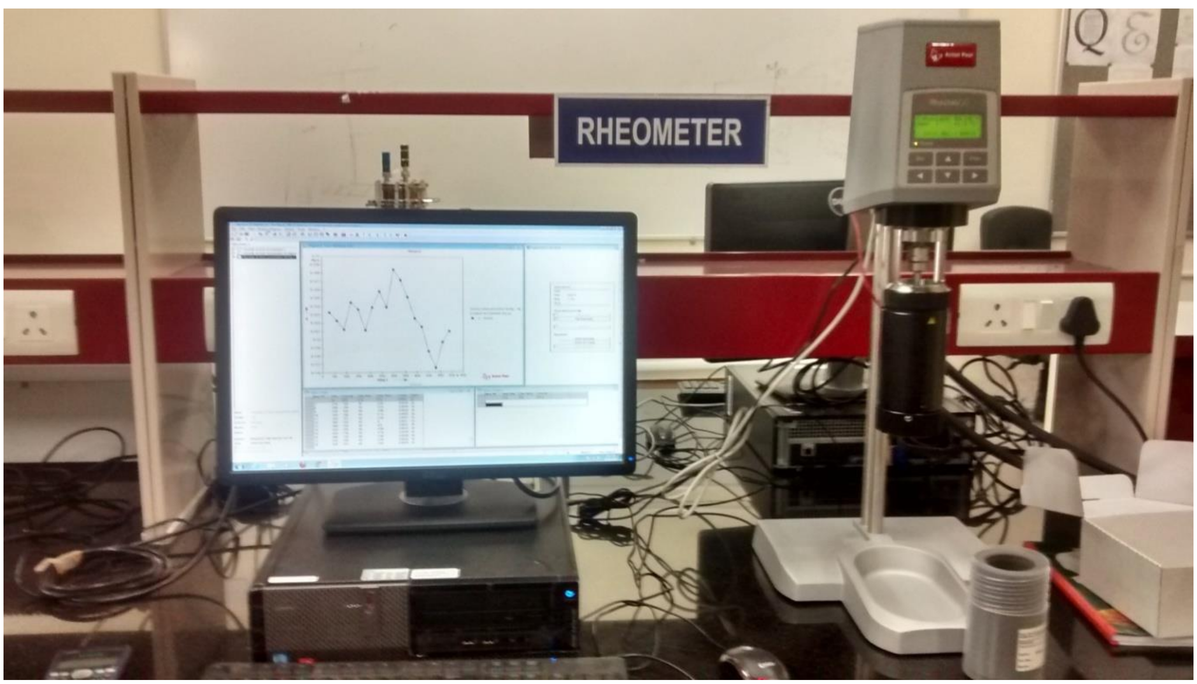


Figure 4.2: Anton Paar QC Lab Viscometer

Rheoplus software was used as an interface between the computer and equipment. Various technical advancements used in the equipment are given below.

Technical highlights:

It has a powerful, highly dynamic EC motor drive. It can be operated at wide speed and torque range. The controlled shear rate and controlled shear stress test settings makes it a reliable equipment to use. The operations could be controlled using software.

4.1.3: Mettler Toledo Analytical Balance

ME analytical weighing balance was used for accurately measuring the weight of the chemicals used in the experiments. It has an accuracy of .0001 gm and can weigh max of 220gm at a time.

Figure 4.3: Mettler Toledo Analytical Balance

4.2: Materials Used

All chemicals used in experiments were from Shraddha Associates, Ahmedabad (Gujarat) under the guidance of Prof. R. P. Soni.

Materials used in laboratory testing were:

- DM Water
- Guar polymer: Dry powder form and slurry form
- Oxidative breaker: Ammonium Persulfate(APS)
- Mineral Oil: Diesel
- Buffer Agent: NaoH
- Crosslinker: Borax
- Clay Stabilizer: KCl

4.3: Experimental Procedures

There were three different experimental procedures used in this study. The objective was to measure the viscosity changes with change in concentration and temperature of linear and cross linked gels as well as breaker. The step by step process to perform these tests follows starting with the mixing procedure to make the gel.

4.4: Gel Preparation Procedure:

4.4.1: Linear Gel

- Take 100 ml of distilled water in a beaker
- Add 2g of KCl in the solution
- Add various concentration of guar powder (add slowly), concentration varies from .25g/100ml to .72g/100ml
- Mix the solution at various RPM(600 RPM for lower concentration & higher RPM for higher concentration) using the Magnetic stirrer
- Add small quantity of diesel in the solution if fish-eyes are formed
- For high viscosity fluids C17-Anton Parr Q Lab probe having 5ml capacity & for low viscosity(below 100cp) C39 probe is used
- Vary the temperature from 20^0C to 80^0C using 20^0 intervals for 20 points at 30 seconds interval.

Figure 4.4: Linear gel preparation

4.4.2: Cross linked Gel

- Prepare a 30ppg linear gel as stated above with guar concentration of .36gm in 100 ml water
- Add 1.5ml of 0.2M NaoH Solution and check the pH to ensure it is above 10.
- Prepare a 200 ppt borax solution and add 5gpt of the borax to the linear gel.
- Mix at slow RPM using magnetic stirrer until crowning occurs (Fig 4.5) and vortex cannot be seen.
- To ensure further that the cross linking has been done Lip test is performed where the gel is suspended up to approximately 2mm from the beaker by tilting it.
- C17-Anton Parr Q Lab probe having 5ml capacity was used to measure cross linked gel viscosity at various temperatures.

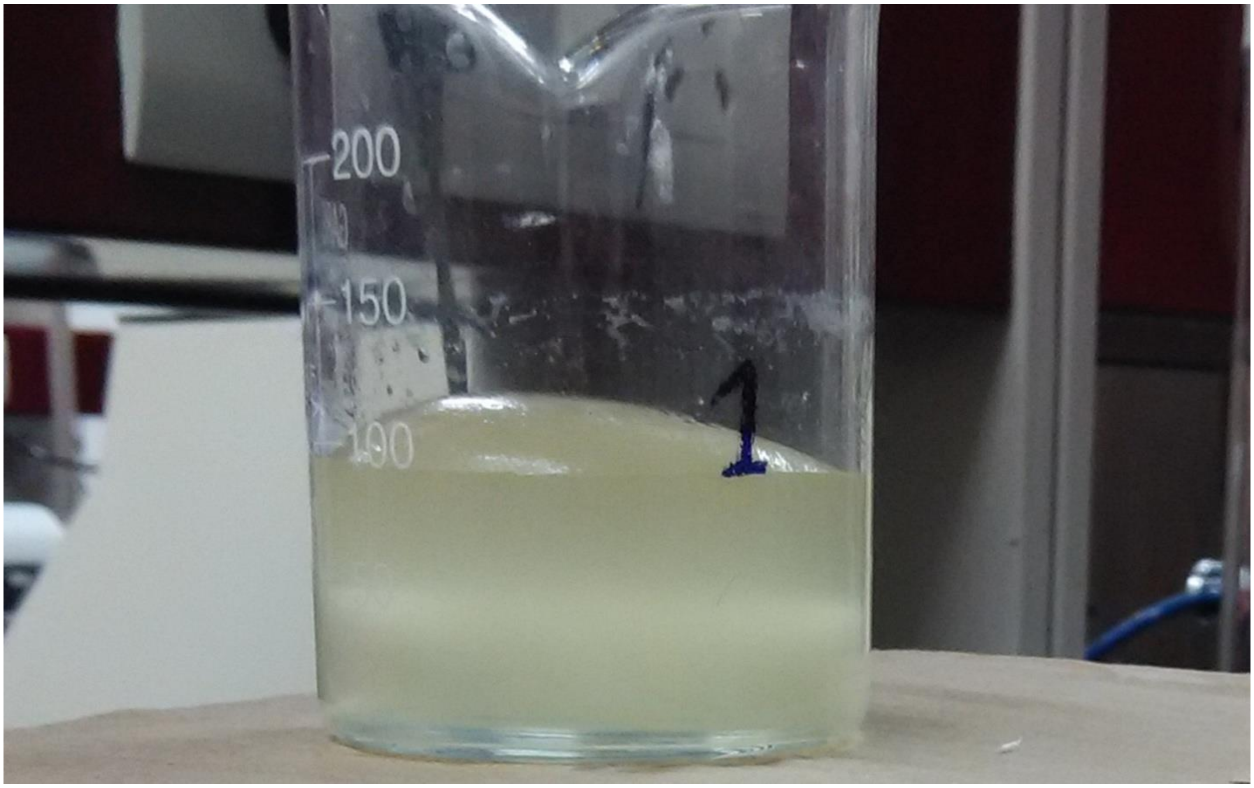


Figure 4.5: Crowning

4.4.3: Breaker Test Procedure

- Linear gel/cross linked was prepared as stated above and Ammonium Persulfate in various concentrations was added and viscosity was measured at different concentration.
- The breaker was added just before pouring the fluid in the measuring cylinder and mixed for 1 min using magnetic stirrer.

4.5: Viscosity Measurement

Major portion of this study involved viscosity measurement. This was performed using Anton Par QC-Lab viscometer which was connected to a water bath to vary the temperature. The viscosity of the gels was measured at temperatures ranging from 20°C to 80°C. Higher temperatures could not be tested due to temperature constraint of the equipment (Max 80°C). The readings were recorded directly onto computer using Rheoplus software of Anton Par which helped in instant evaluation of results. The viscometer had two types of measuring cylinder and probes. C17-Anton Parr Q Lab probe having 5ml capacity was used to measure for viscosity greater than 100cp. C39-Anton Parr Q Lab probe having 70ml capacity cylinder was used for low viscosities below 100cp.

For linear gel viscosity measurement, viscosity was measured at following concentration of guar 0.25gm, 0.36gm, 0.5gm, 0.72gm. Measurements were done at 20°C, 40°C, 60°C, 80°C. At each temperature 20 measuring points were taken at 30 sec intervals. The shear rate was fixed at 40cp for all the three experiments to simulate linear flow of fluid within the reservoir.

For cross linked gel, 5gpt Borax solution of 200ppt was added to linear gel. The pH of the gel was increased using NaoH above 10 and tested using pH paper. This ensured cross linking of the gel and was further tested by observing the crown during mixing and performing the lip test.

Breaker analysis was done by using APS at various concentration and generating viscosity temperature curves by continuously changing the temperature from 20°C to 80°C.

4.6: Results and Discussion

4.6.1: Linear Gel

The curves were generated on the basis of both temperature and concentration. Charts 1-4 and Charts 12-23 present the charts developed based on the concentration of Guar from 20°C to 80°C temperature. The Charts 12-23and readings for all charts are provided in the annexure from table 1-16.

It provides the baseline viscosity readings for guar at different concentrations of 0.25, 0.36, 0.5 and 0.72 at different temperatures as mentioned above. The focus of study was emphasized on 30ppt linear gel solution hence only .36gm guar concentration linear gel solution has been discussed here while the rest of the viscosity profiles are provided in the annexure.

While testing linear gel it was observed that as the temperature was increased, the rheological properties changes and viscosity is greatly reduced around 80°C. In most of the experiments the fluid broke down after first five minutes of 80 °C reading. It was also observed that the hydration time provided greatly affects the viscosity and significant viscosity increase was seen when hydration time was changed from half an hour to one hour during initial stages of experiments. Though in industry higher temperatures are also used, the temperature constraints of our apparatus restricted us to perform experiments only up to 80 °C.

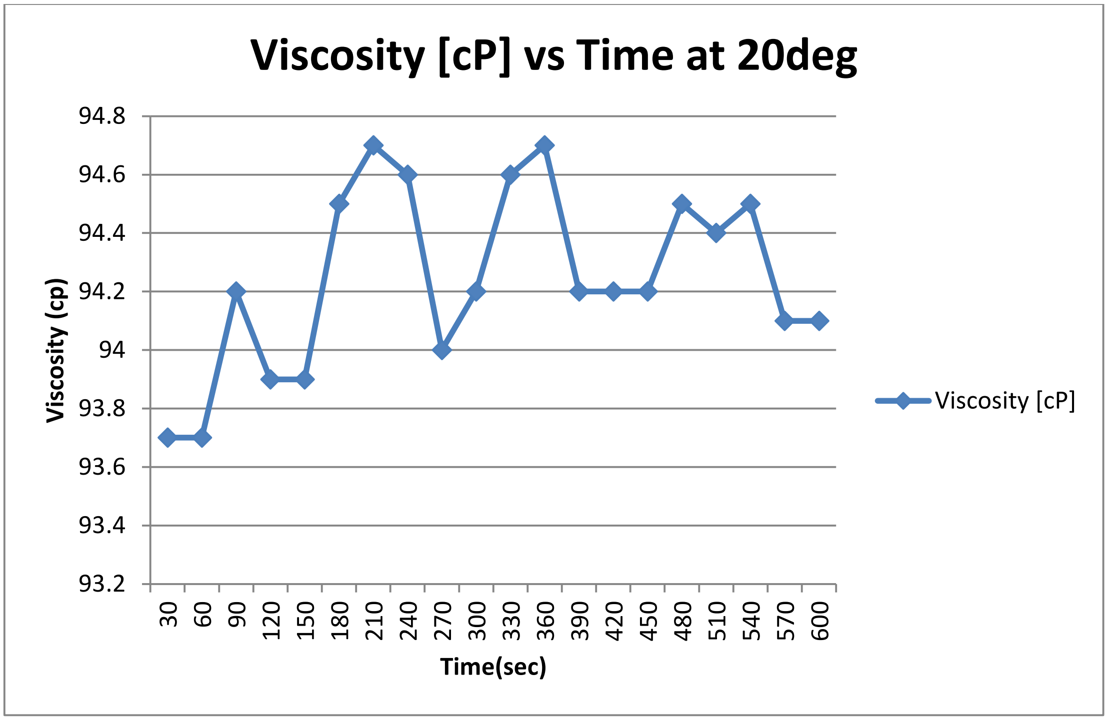


Chart 1: Viscosity profile for .36g Guar concentration (30ppt) at 20°C

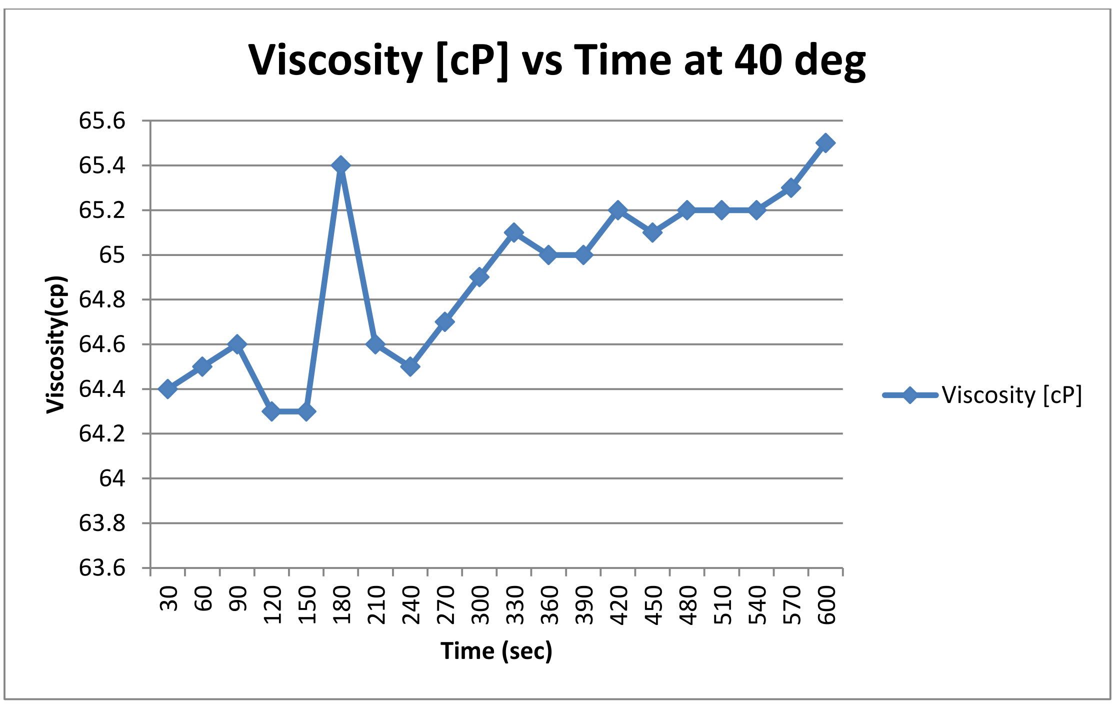


Chart 2: Viscosity profile for .36g Guar concentration (30ppt) at 40°C

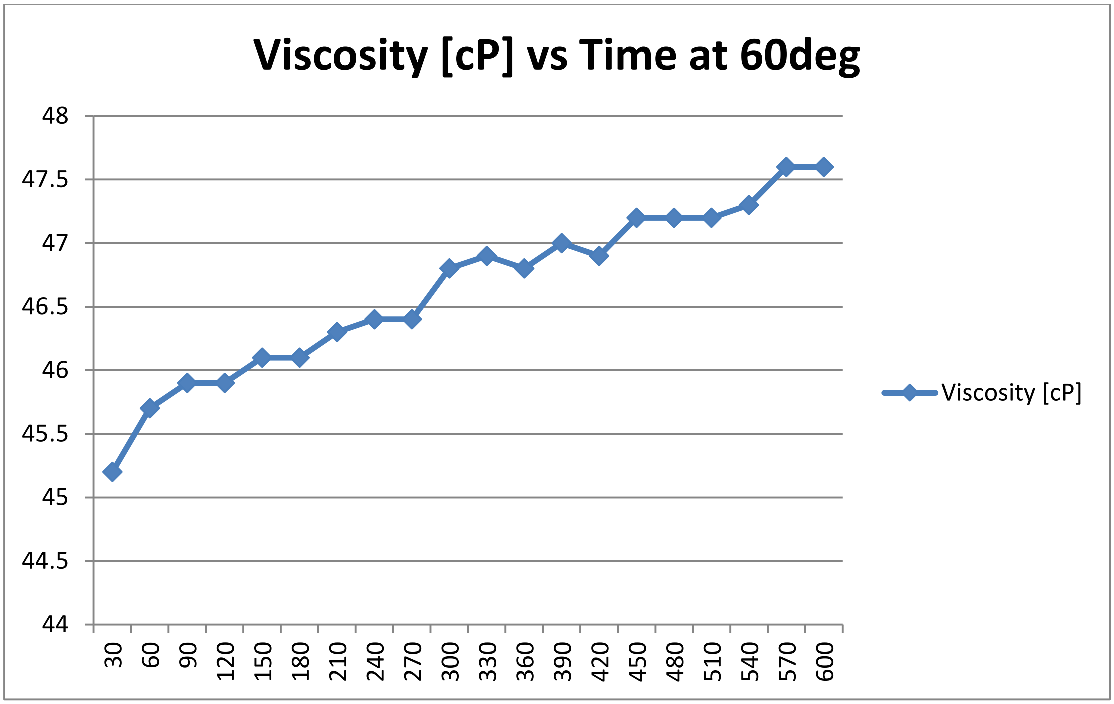


Chart 3: Viscosity profile for .36g Guar concentration (30ppt) at 60°C

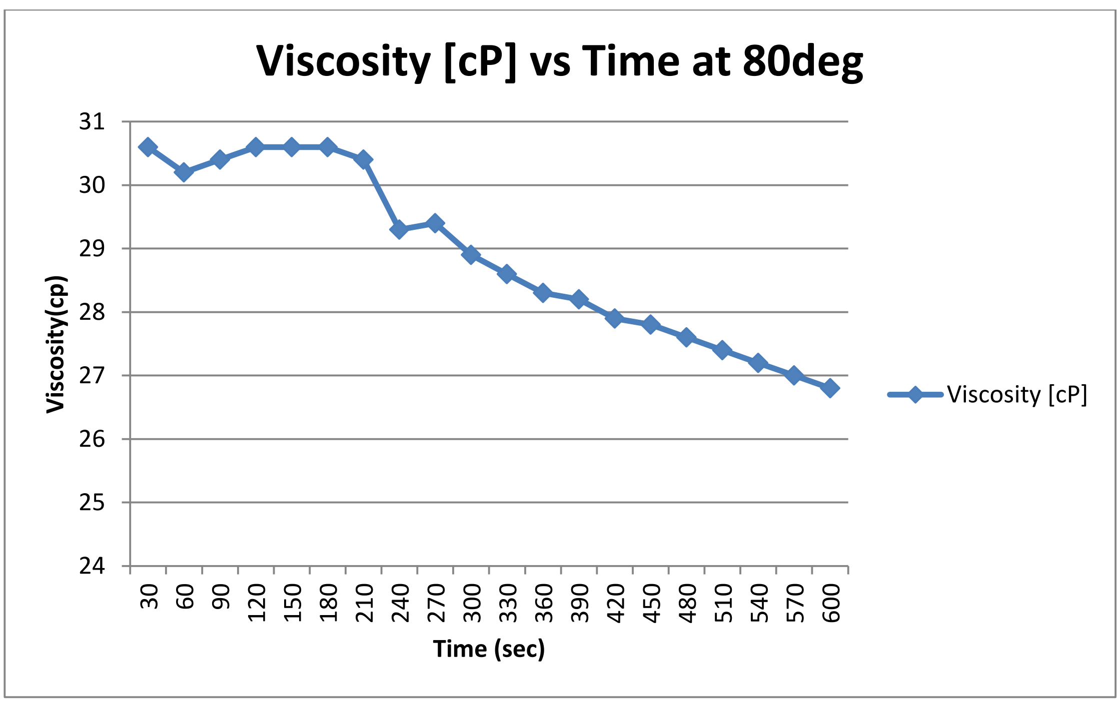
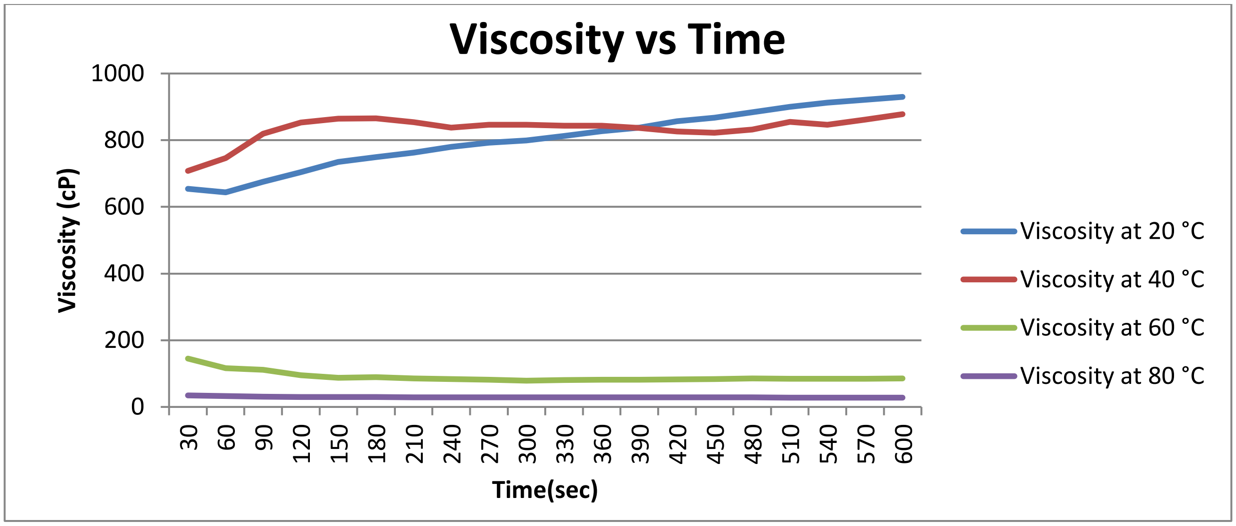


Chart 4: Viscosity profile for .36g Guar concentration (30ppt) at 80°C

4.6.2: Cross linked Gel

The experiment was initially started at 20°C and then periodically temperature was increased to 40°C, 60°C and 80°C. The readings that were obtained at 20°C and 40°C were consistent and rising at a satisfactory level. However at 50°C and above the fluid viscosity started to fall down and it completely degraded at 80°C.



Viscosity profile of Crosslinked gel at different temperatures

The reason for this early breakdown of cross-linked fluid at lower temperature was due to unsatisfactory quality of the chemicals provided. Further investigation of the cross linker was done by constantly varying the temperature from 20 °C to 70 °C to identify the point of breakdown. It was observed that the viscosity drastically reduced at 50 °C.

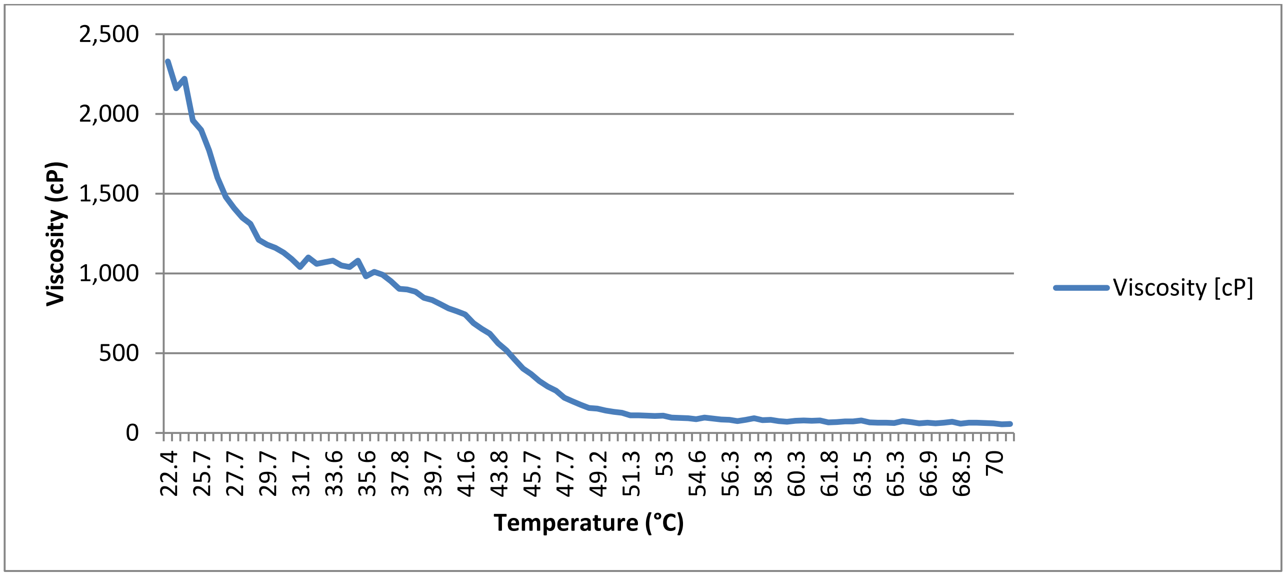


Chart 5:Crosslinked Gel (0.36g guar & 5 gpt borax) w/o APS

4.6.3: Breaker

The breaker test was aimed to identify the efficiency of Ammonium Per-Sulphate (APS) for breaking of 30 ppt linear and cross-linked gel. The breaker amount was varied from 1 ppt to 3 ppt for linear gel and 4 ppt& 6 ppt for cross-linked gel. The temperature was varied in a ramp fashion from 20°C to 80°C and viscosity (cP) was continuously recorded.

It was observed after repetitive experiments, that 1ppt and 2ppt concentration of APS in 30 ppt linear gel showed no effective breaking to drastically reduce the viscosity. When 3ppt breaker was used the viscosity was drastically reduced as compared to 1 and 2 ppt, however the rate of breaking in all the three cases was same as the slope was nearly constant. Following charts justify the above interpretation

For cross linked gel APS was used in 4 ppt and 6 ppt concentrations to perform the test. Along with viscosity measurement pH was also measured for the broken cross linked fluid to identify the extent of breakage. 4 ppt and 6 ppt concentrations both were able to reduce the viscosity but 6 ppt was observed to be more effective as the pH after addition of 6ppt was below 7 which was not the case with 4 ppt as its pH remained above 7 when tested with pH paper.

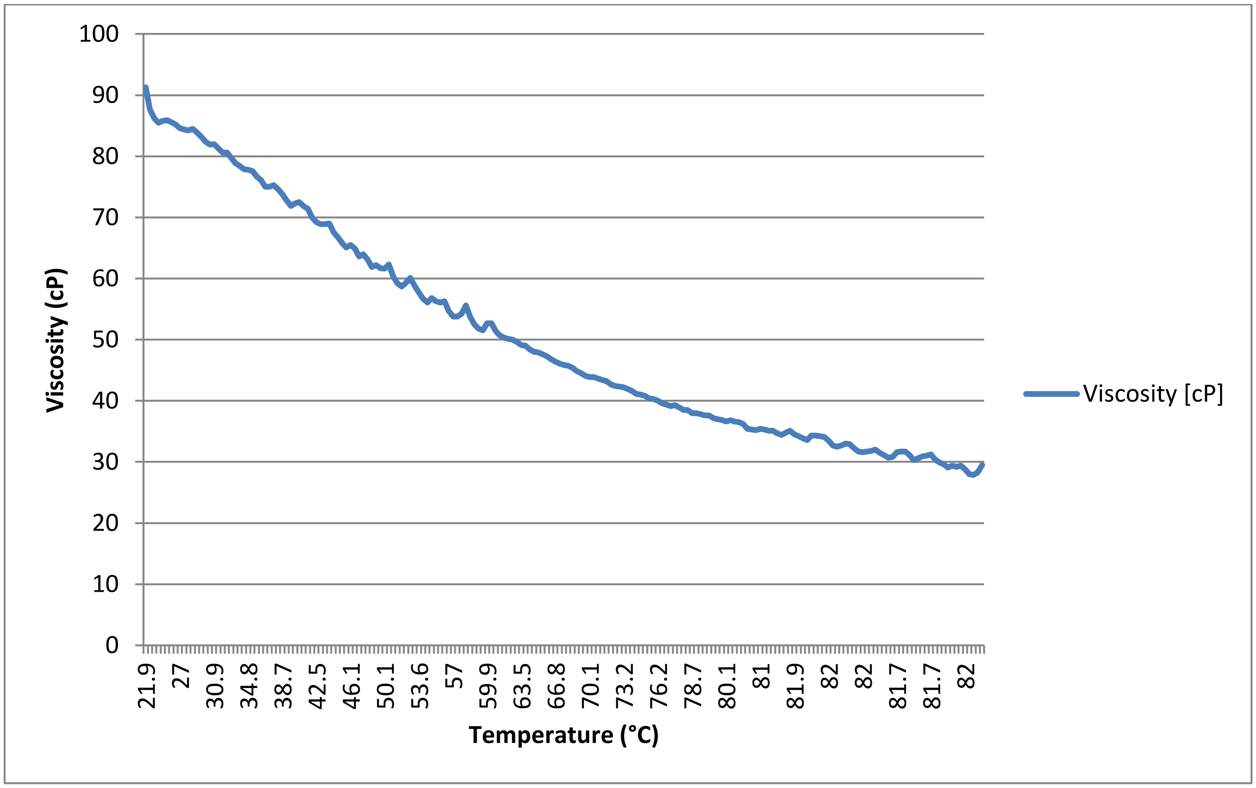


Chart 6: Linear Gel (0.36g guar) Breaking by APS (1ppt)

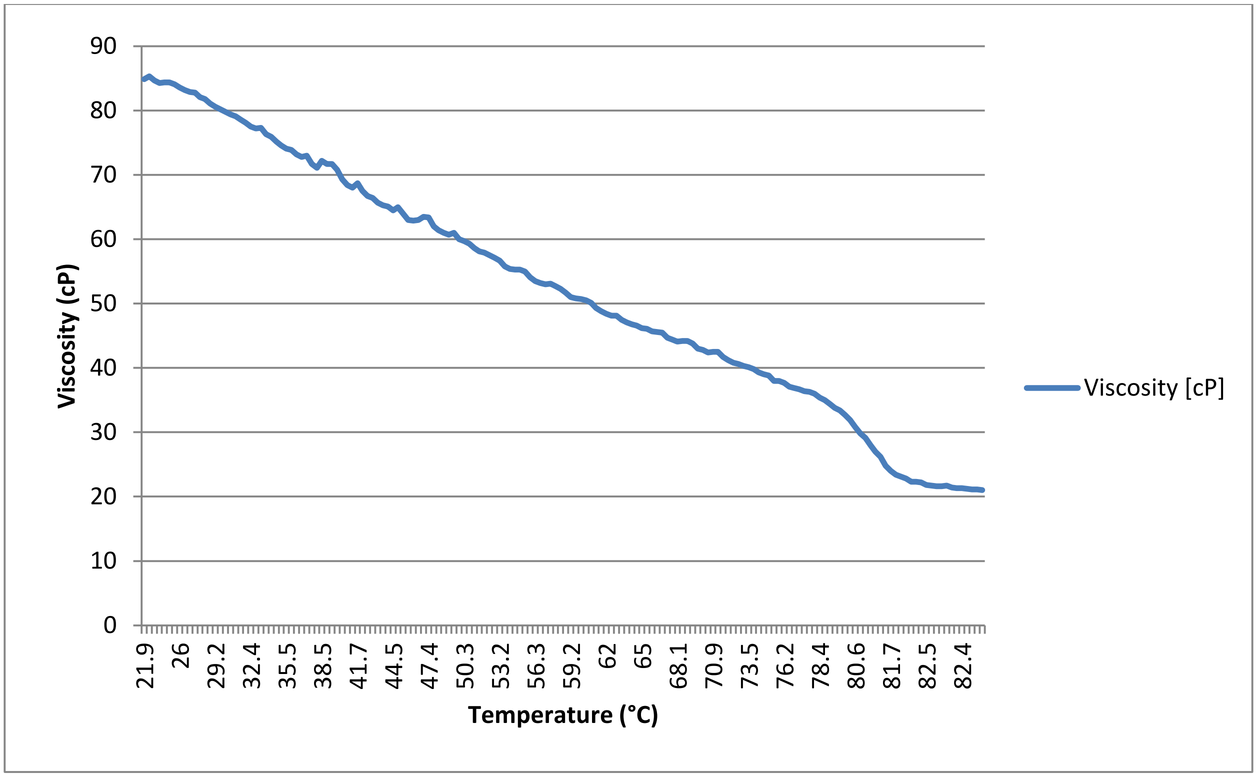


Chart 7: Linear Gel (0.36g guar) Breaking by APS (2ppt)

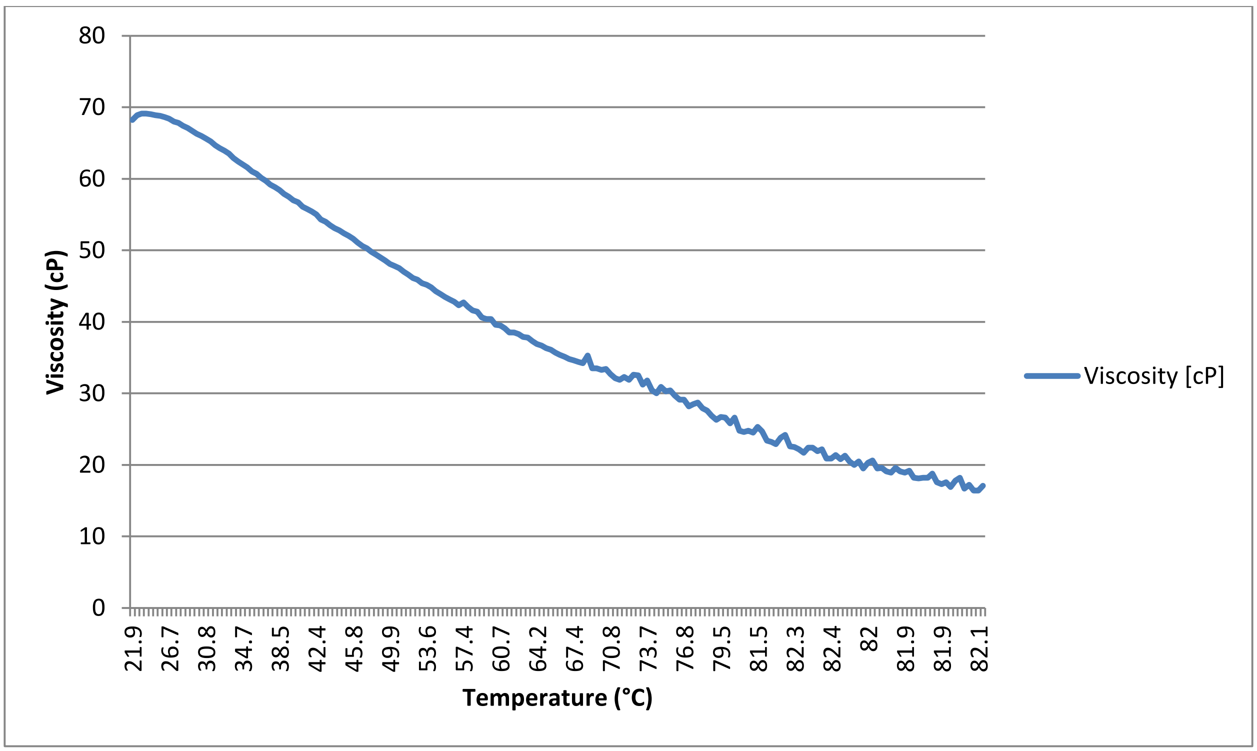


Chart 8: Linear Gel (0.36g guar) Breaking by APS (3ppt)

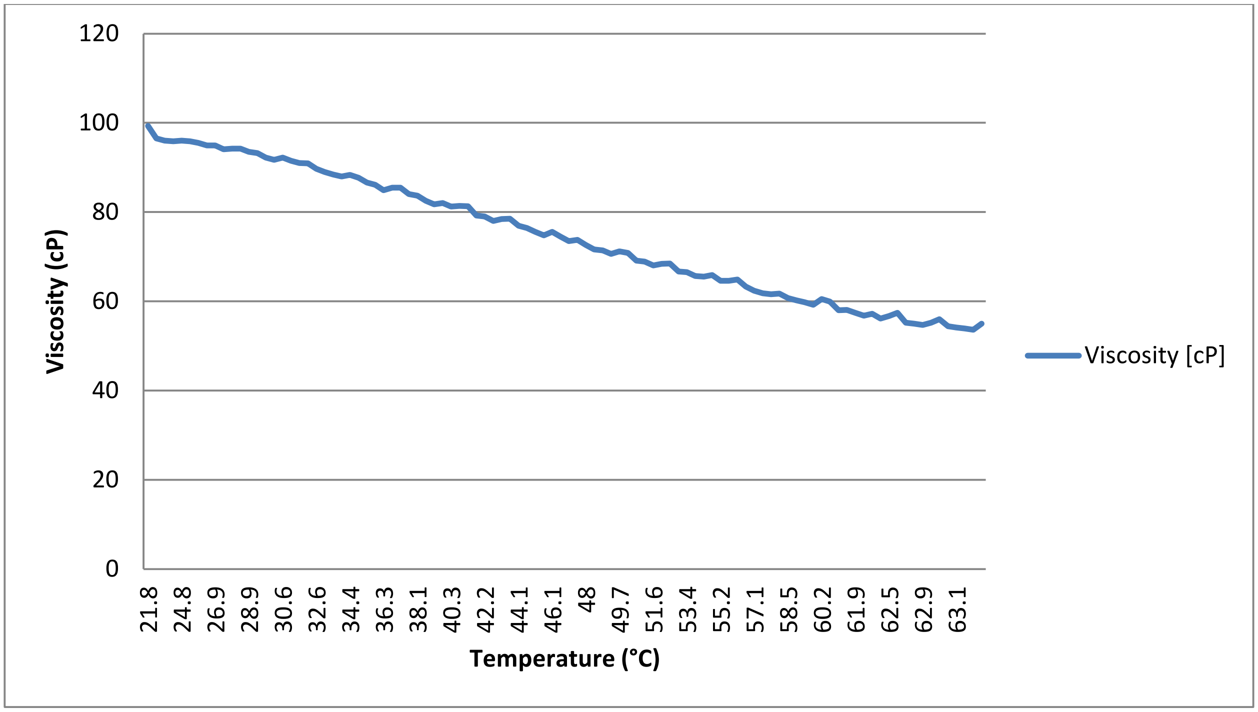


Chart 9 Cross-linked Gel (0.36g guar & 5gpt borax) Breaking by APS (4ppt)

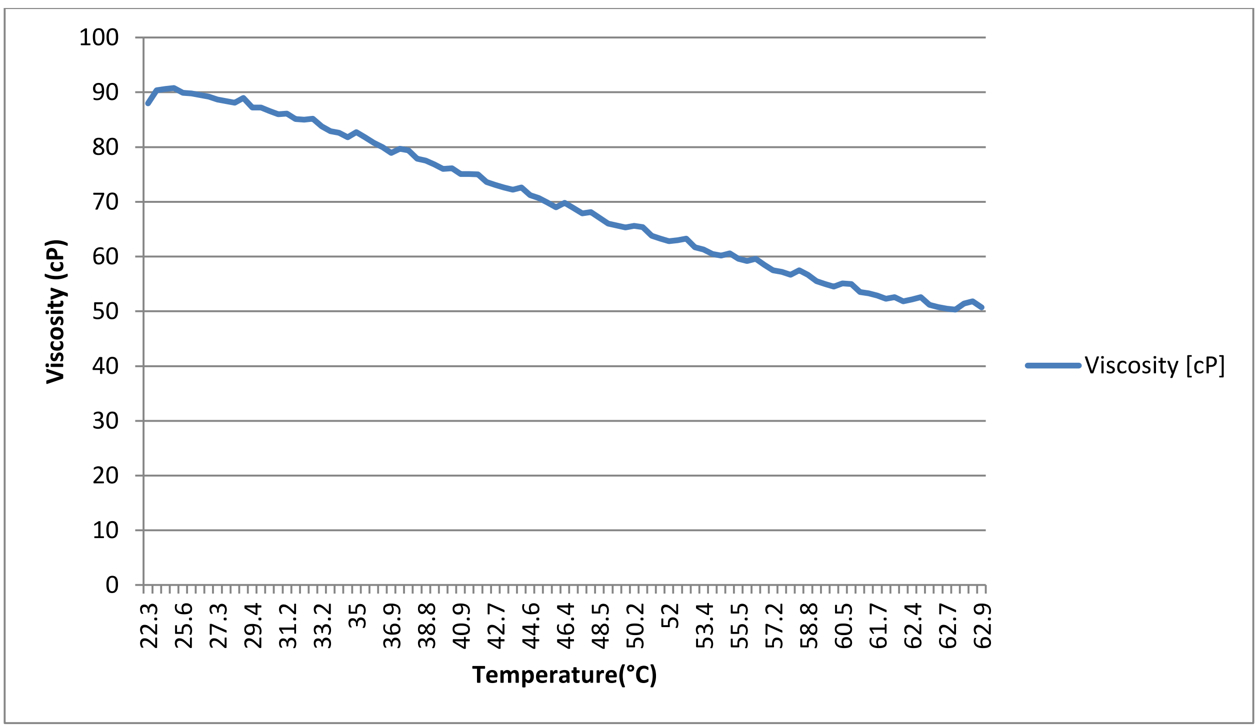


Chart 10 Cross-linked Gel (0.36g guar & 5gpt borax) Breaking by APS (6ppt)

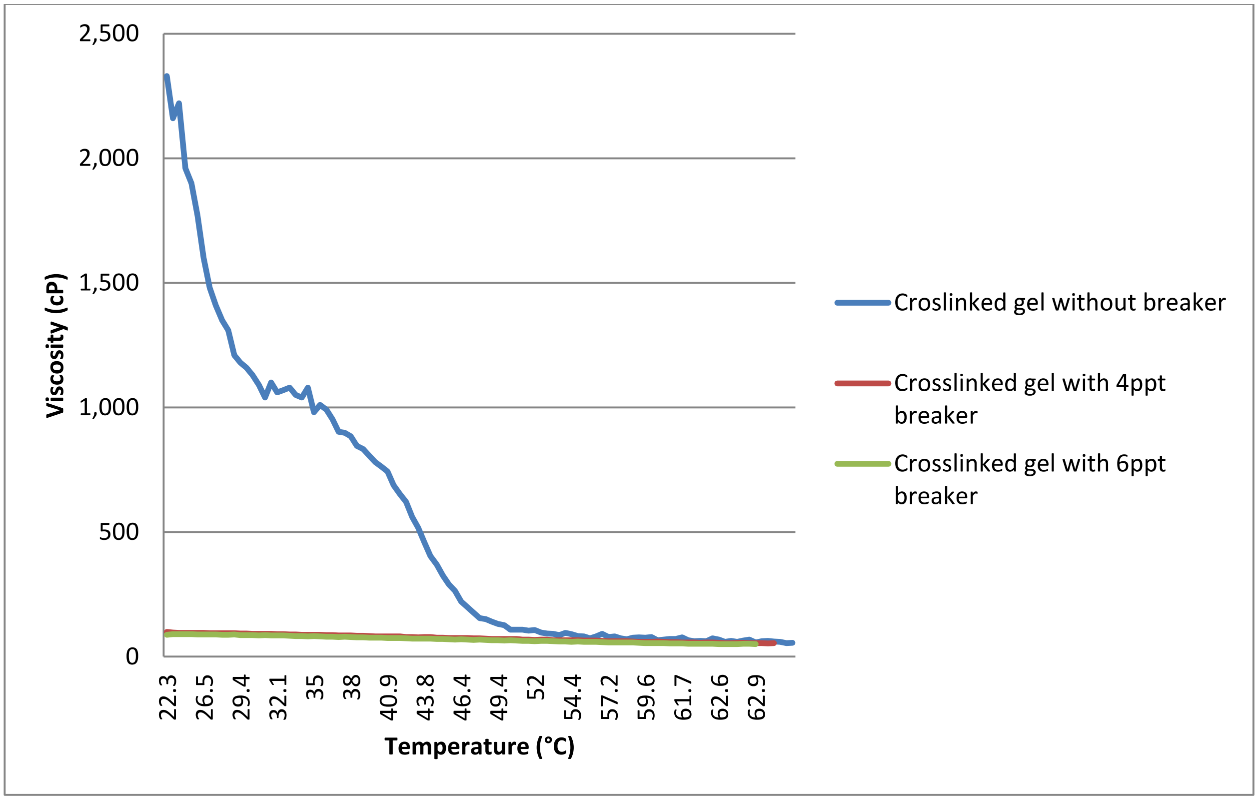


Chart 11: Cross linked gel w/o breaker and with APS (4 & 6 ppt)

Chapter 5: Conclusion and Recommendations

Main objective of this research was to perform a comprehensive study of the various chemicals used in hydraulic fracturing fluid design and their variation of viscosity as a function of temperature and time. An extensive testing was done for guar based linear gel, borax based cross linked fluid and APS as breaker. Their response in terms of viscosity by varying temperature was recorded using Anton Paar viscometer in the lab. Viscosity measurements were done to identify the chemical activity of the chemicals. Following conclusions are drawn from the study:

1. Viscosity profile has been developed for linear gel for different concentration of guar (0.25gm, 0.36gm, 0.5gm and 0.72gm) at 20 °C, 40 °C, 60°C and 80°C. These profiles help in chemical testing and provide a baseline viscosity for Hydraulic Fracturing Fluid Design.

2. The shear rate was set at 40 (1/sec) for all the experiments in order to replicate the reservoir flow conditions. The readings thus generated will provide viscosity measurements within the reservoir.

3. 200ppt Cross linked fluids were prepared by using 30 ppt linear gel solution. The viscosity measurements were done at 20 °C, 40 °C, 60 °C and 80°C. The borax received was not of proper quality, thus the gel would break above 50 °C. Below 50 °C the gel maintained its viscosity as desired and viscosity of around 600cp to 800cp was observed.

4. Breaker activity curves of linear and cross linked gels were generated. Ammonium Persulfate was used as breaker. For linear gel the concentration of breaker was varied from 1ppt to 3 ppt in which 3ppt proved to most effective providing the maximum breakage while the results from 1 and 2ppt were not satisfactory. For cross linked gel only 4ppt and 6 ppt concentration of breaker was used and though the difference between the two was not large, 6 ppt gave better results.

5. Each test was performed multiple times in order to generate a consistency in the readings which is used to substantiate the baseline viscosity profiles. It was essential to follow a set of procedure to achieve desired readings.

5.1 Constraint

1. Sourcing of the chemicals was a time taking task which restricted us from sticking to our desired timeline.

2. Breaker activity curve for Galactomannanase, Sodium Bromate and Magnisium peroxide was also desired to be performed but could not be initiated due **to non availability of chemicals**.

3. Turbulent flow readings for high shear rate were not performed due **non availability of the equipment**.

4. Nanotechnology lab viscometer was used, due to non availability of a working viscometer in the drilling fluid lab

5. **Only one viscometer was present** and multiple projects were being performed on the viscometer which led to non availability of the equipment at many instances thus restricting the scope of the research due to time contraint. In order to support such laboratory projects more focus is required by the department towards regular improvements of lab

6. Residue after test to identify the amount of unbroken gel after using breaker could not be performed due to excess time spent in the chemical sourcing. Conducting the basic rheology test also consumed a lot of time due to availability of single apparatus.

5.2 Recommendations

Inspite of having a full intent, the scope of the project could have been fully materialized but due to above constraints which restricted in performing some of the experiments as already stated. Further work can be performed on Hydraulic fracturing Fluid Design if the requirements are fulfilled and appropriate apparatus are available to perform the tests.

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Appendix

A.1: 0.25g Guar Concentration (20℃)

Sample Temperature:	20deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 12:09 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 1

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	36.9	40	1.48	21.1
2	60	36.9	40	1.48	21.3
3	90	37.5	40	1.5	21.3
4	120	37.2	40	1.49	21.3
5	150	37.4	40	1.49	21.1
6	180	37.3	40	1.49	21.1
7	210	37.5	40	1.5	21.1
8	240	37.5	40	1.5	21
9	270	37.5	40	1.5	21.1
10	300	37.8	40	1.51	21.1
11	330	37.5	40	1.5	21.1
12	360	37.7	40	1.51	21
13	390	37.7	40	1.51	21.1
14	420	37.8	40	1.51	21.1
15	450	37.7	40	1.51	21.2
16	480	37.7	40	1.51	21.1
17	510	37.7	40	1.51	21.1
18	540	37.7	40	1.51	21.1
19	570	37.9	40	1.52	21
20	600	37.8	40	1.51	21.3

A.2: 0.25g Guar Concentration (40 °C)

Sample Temperature:	40deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 12:31 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 2

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	23.2	40	0.926	41.6
2	60	23.4	40	0.936	41.5
3	90	23.5	40	0.94	41.7
4	120	23.6	40	0.943	41.7
5	150	23.5	40	0.939	41.7
6	180	23.5	40	0.938	41.9
7	210	23.6	40	0.943	41.7
8	240	23.4	40	0.937	41.8
9	270	23.5	40	0.942	41.8
10	300	23.5	40	0.941	41.6
11	330	23.6	40	0.946	41.7
12	360	23.6	40	0.944	41.7
13	390	23.5	40	0.939	41.8
14	420	23.6	40	0.943	41.7
15	450	23.6	40	0.946	41.8
16	480	23.7	40	0.947	41.6
17	510	23.7	40	0.949	41.7
18	540	23.8	40	0.951	41.7
19	570	23.7	40	0.948	41.7
20	600	23.7	40	0.95	41.9

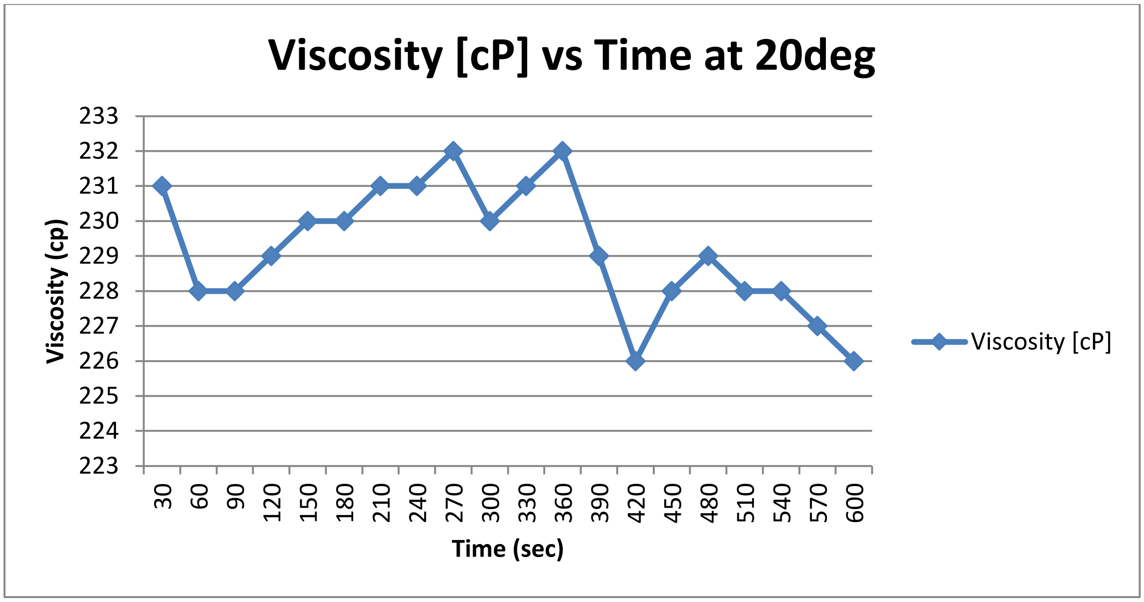

Chart 12: Viscosity profile for .25g Guar concentration at 20°C

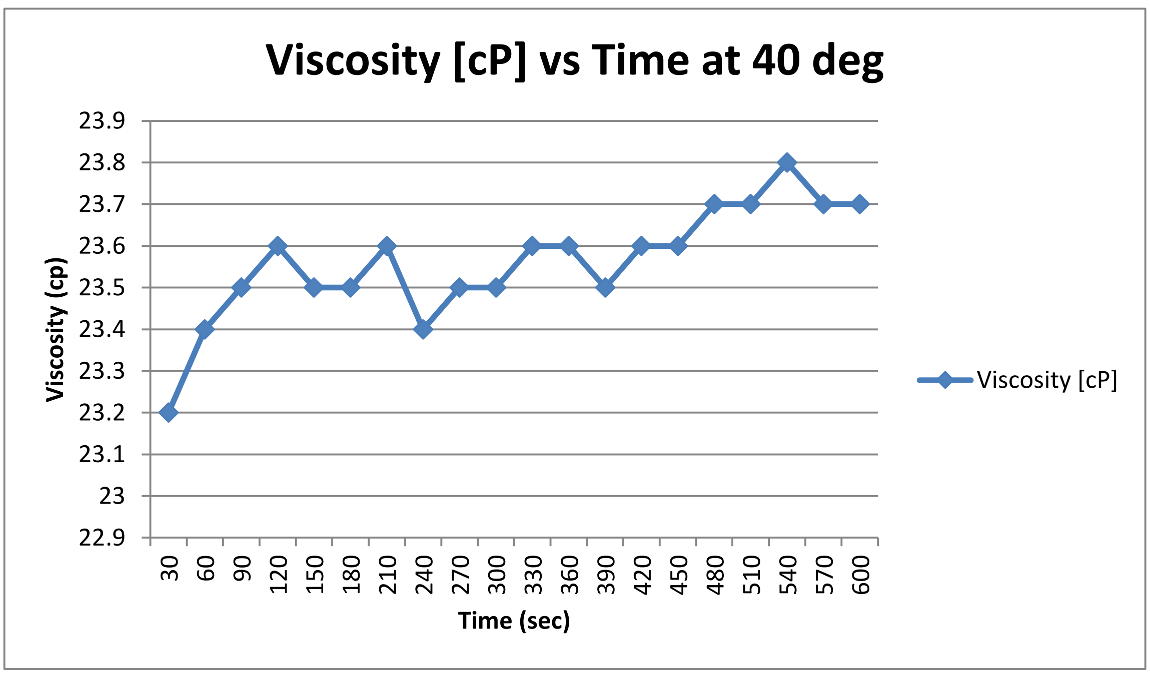

Chart 13: Viscosity profile for .25g Guar concentration at 40°C

A.3: 0.25g Guar Concentration (60 ℃)

Sample Temperature:	60deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 12:57 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 3

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	15.2	40	0.61	61.6
2	60	15.4	40	0.614	61.4
3	90	15.4	40	0.615	61.5
4	120	15.2	40	0.608	61.6
5	150	15.3	40	0.613	61.4
6	180	15.5	40	0.622	61.4
7	210	15.6	40	0.624	61.7
8	240	15.5	40	0.622	61.7
9	270	15.3	40	0.612	61.7
10	300	15.6	40	0.623	61.6
11	330	15.7	40	0.629	61.7
12	360	15.7	40	0.629	61.8
13	390	15.8	40	0.631	61.6
14	420	15.6	40	0.625	61.7
15	450	16	40	0.638	61.6
16	480	15.9	40	0.637	61.6
17	510	16	40	0.638	61.7
18	540	15.9	40	0.635	61.7
19	570	16.1	40	0.644	61.6
20	600	16.2	40	0.649	61.5

A.4: 0.25g Guar Concentration (80 ℃)

Sample Temperature:	80deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 1:19 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 4

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	9	40	0.369	81.8
2	60	9	40	0.371	82
3	90	9	40	0.371	81.9
4	120	9	40	0.374	81.9
5	150	9	40	0.373	81.9
6	180	9	40	0.371	82
7	210	9	40	0.372	82
8	240	9	40	0.369	81.9
9	270	9	40	0.365	81.9
10	300	9	40	0.371	81.8
11	330	9	40	0.363	81.9
12	360	9	40	0.35	81.9
13	390	8	40	0.338	81.8
14	420	9	40	0.345	81.9
15	450	8	40	0.339	82
16	480	8	40	0.337	81.9
17	510	8	40	0.324	82
18	540	8	40	0.324	81.9
19	570	8	40	0.33	82
20	600	8	40	0.324	81.9

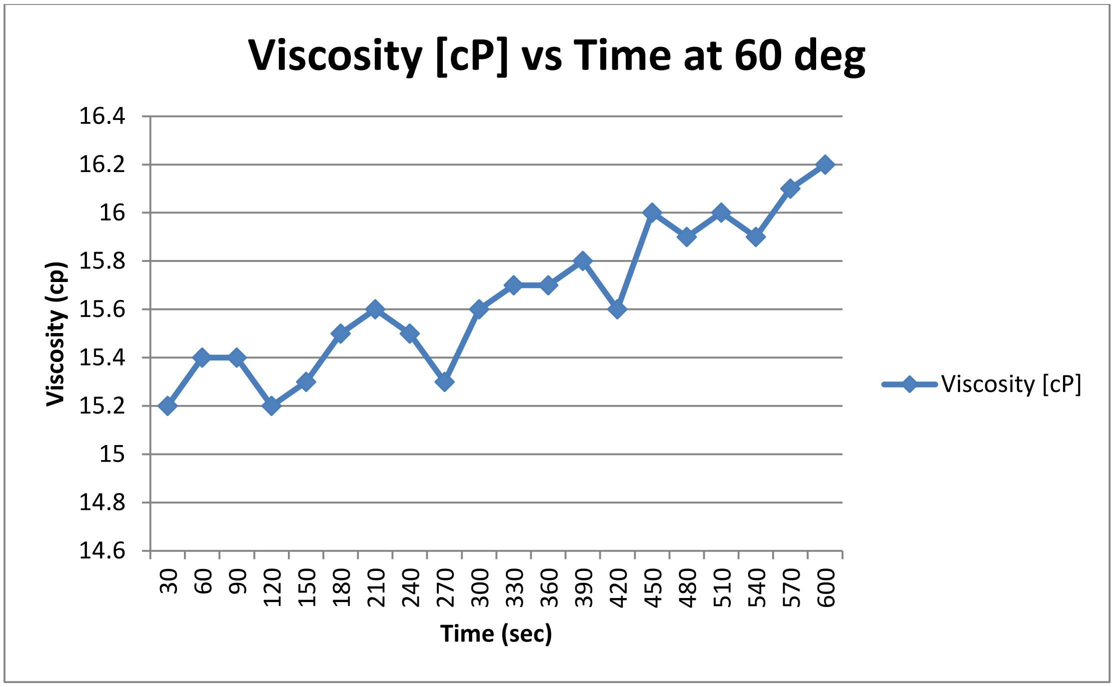

Chart 14: Viscosity profile for .25g Guar concentration at 60°C

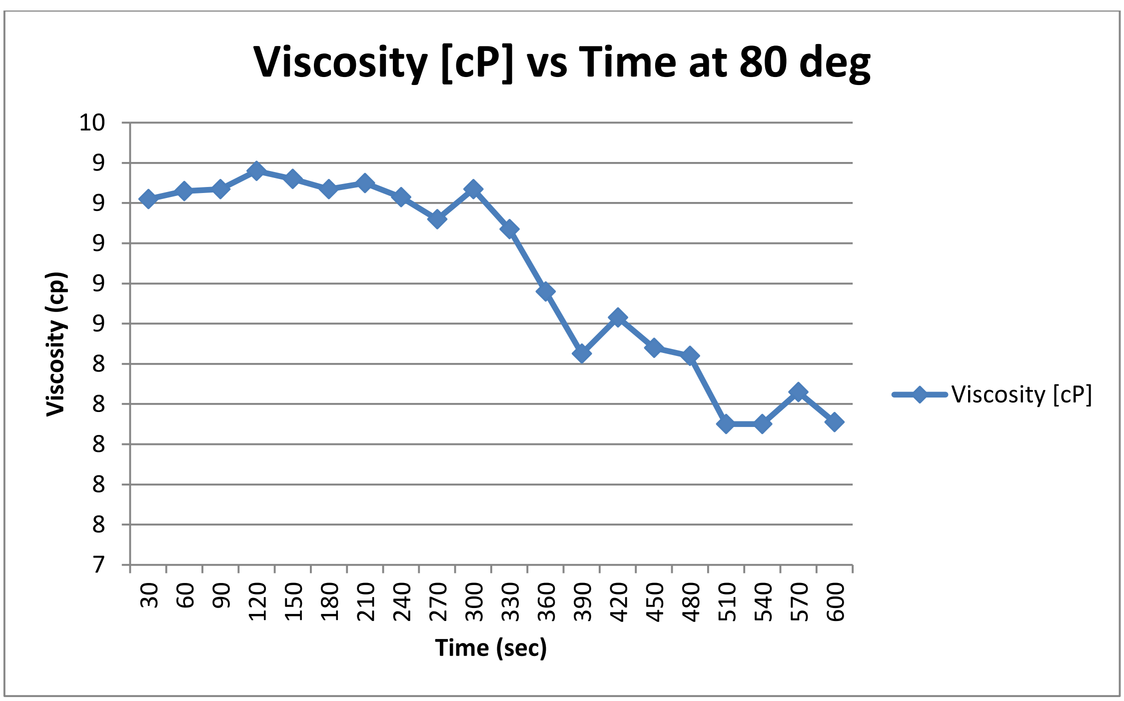

Chart 15: Viscosity profile for .25g Guar concentration at 80°C

A.5: 0.36g Guar Concentration (20 °C)

Sample Temperature:	20deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 12:20 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 5

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	93.7	40	3.75	20.1
2	60	93.7	40	3.75	20.1
3	90	94.2	40	3.77	20.1
4	120	93.9	40	3.76	20.2
5	150	93.9	40	3.76	20.1
6	180	94.5	40	3.78	20.2
7	210	94.7	40	3.79	20.2
8	240	94.6	40	3.78	20.1
9	270	94	40	3.76	20.1
10	300	94.2	40	3.77	20.3
11	330	94.6	40	3.78	20.2
12	360	94.7	40	3.79	20.2
13	390	94.2	40	3.77	20.3
14	420	94.2	40	3.77	20.1
15	450	94.2	40	3.77	20.3
16	480	94.5	40	3.78	20.1
17	510	94.4	40	3.78	20.1
18	540	94.5	40	3.78	20.2
19	570	94.1	40	3.77	20.3
20	600	94.1	40	3.76	20.3

A.6: 0.36g Guar Concentration (40 °C)

Sample Temperature:	40deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 12:43 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 6

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	64.4	40	2.58	41.4
2	60	64.5	40	2.58	41.3
3	90	64.6	40	2.58	41.4
4	120	64.3	40	2.57	41.3
5	150	64.3	40	2.57	41.3
6	180	65.4	40	2.62	41.3
7	210	64.6	40	2.59	41.3
8	240	64.5	40	2.58	41.3
9	270	64.7	40	2.59	41.3
10	300	64.9	40	2.6	41.4
11	330	65.1	40	2.6	41.2
12	360	65	40	2.6	41.4
13	390	65	40	2.6	41.3
14	420	65.2	40	2.61	41.3
15	450	65.1	40	2.6	41.5
16	480	65.2	40	2.61	41.4
17	510	65.2	40	2.61	41.5
18	540	65.2	40	2.61	41.3
19	570	65.3	40	2.61	41.3
20	600	65.5	40	2.62	41.3

A.7: 0.36g Guar Concentration (60 °C)

Sample Temperature:	60deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 1:11 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 7

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	45.2	40	1.81	62
2	60	45.7	40	1.83	61.8
3	90	45.9	40	1.84	61.7
4	120	45.9	40	1.83	61.7
5	150	46.1	40	1.84	61.7
6	180	46.1	40	1.85	61.7
7	210	46.3	40	1.85	61.7
8	240	46.4	40	1.85	61.7
9	270	46.4	40	1.86	61.7
10	300	46.8	40	1.87	61.7
11	330	46.9	40	1.88	61.7
12	360	46.8	40	1.87	61.9
13	390	47	40	1.88	61.9
14	420	46.9	40	1.88	61.8
15	450	47.2	40	1.89	61.8
16	480	47.2	40	1.89	61.8
17	510	47.2	40	1.89	61.8
18	540	47.3	40	1.89	61.7
19	570	47.6	40	1.9	61.7
20	600	47.6	40	1.9	61.8

A.8: 0.36g Guar Concentration (80 °C)

Sample:	80deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 1:32 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 8

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	30.6	40	1.22	82.4
2	60	30.2	40	1.21	82.2
3	90	30.4	40	1.22	82
4	120	30.6	40	1.22	81.8
5	150	30.6	40	1.22	81.8
6	180	30.6	40	1.22	81.7
7	210	30.4	40	1.21	81.7
8	240	29.3	40	1.17	81.7
9	270	29.4	40	1.18	81.8
10	300	28.9	40	1.16	81.8
11	330	28.6	40	1.14	81.8
12	360	28.3	40	1.13	81.9
13	390	28.2	40	1.13	82
14	420	27.9	40	1.11	81.9
15	450	27.8	40	1.11	81.9
16	480	27.6	40	1.11	81.8
17	510	27.4	40	1.1	81.9
18	540	27.2	40	1.09	81.9
19	570	27	40	1.08	81.9
20	600	26.8	40	1.07	81.9

A.9: 0.5g Guar Concentration (20 ℃)

Sample:	20deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 3:08 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 9					
Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	231	40	9.26	21.1
2	60	228	40	9.13	21.3
3	90	228	40	9.1	21.1
4	120	229	40	9.17	21.1
5	150	230	40	9.2	21.2
6	180	230	40	9.2	21.2
7	210	231	40	9.25	21.1
8	240	231	40	9.25	21.2
9	270	232	40	9.26	21.2
10	300	230	40	9.18	21.1
11	330	231	40	9.25	21.2
12	360	232	40	9.29	21.1
13	390	229	40	9.17	21.1
14	420	226	40	9.05	21.1
15	450	228	40	9.11	21.1
16	480	229	40	9.15	21.1
17	510	228	40	9.11	21.2
18	540	228	40	9.1	21.2
19	570	227	40	9.09	21.2
20	600	226	40	9.03	21.2

A.10: 0.5g Guar Concentration (40 °C)

Sample Temperature:	40deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 3:30 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 10

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	167	40	6.67	41.8
2	60	168	40	6.72	41.9
3	90	171	40	6.82	41.8
4	120	170	40	6.82	41.8
5	150	171	40	6.83	41.8
6	180	171	40	6.84	41.7
7	210	172	40	6.87	41.8
8	240	173	40	6.93	41.9
9	270	172	40	6.88	41.9
10	300	172	40	6.9	41.9
11	330	174	40	6.96	41.8
12	360	175	40	7	41.7
13	390	174	40	6.97	41.7
14	420	173	40	6.92	41.6
15	450	173	40	6.94	41.7
16	480	177	40	7.07	41.7
17	510	178	40	7.12	41.8
18	540	176	40	7.05	41.8
19	570	175	40	6.99	41.7
20	600	174	40	6.97	41.8

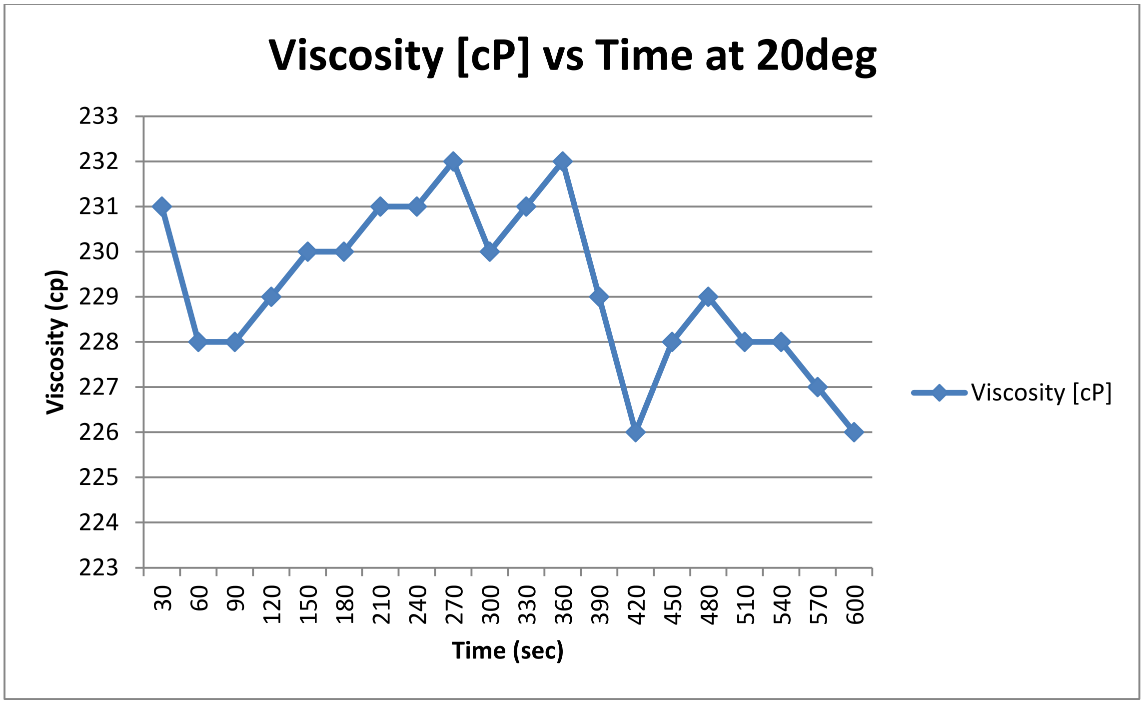

Chart 16: Viscosity profile for .5g Guar concentration at 20°C

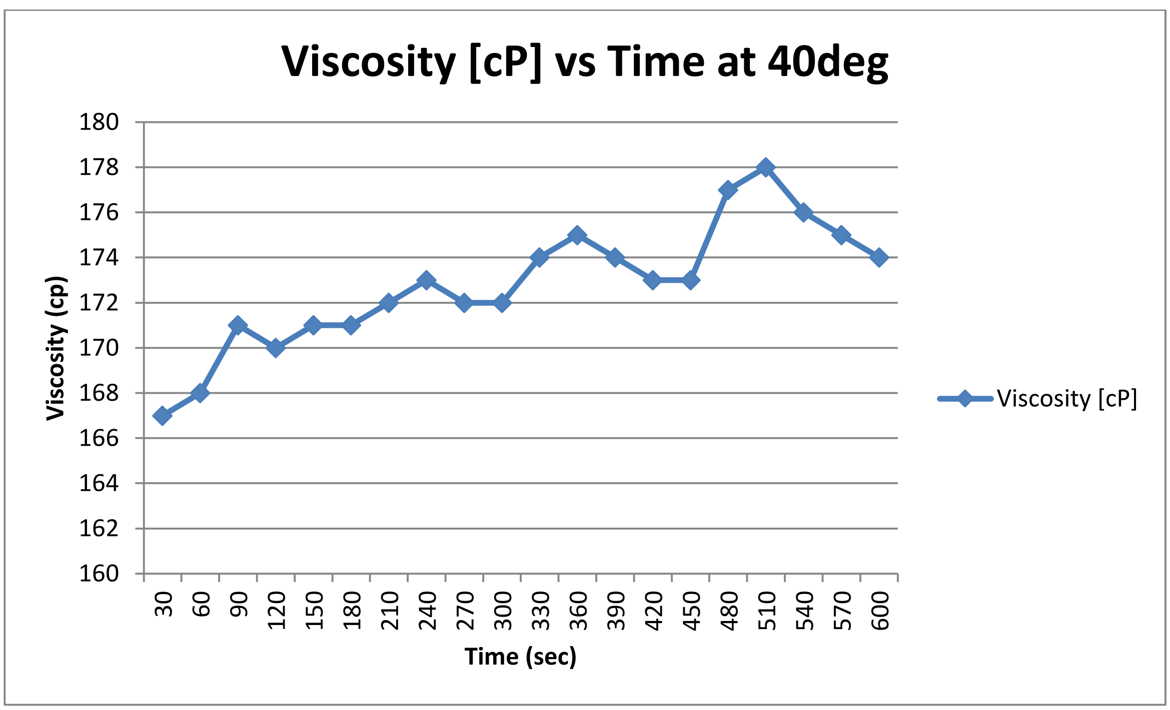

Chart 17: Viscosity profile for .5g Guar concentration at 40°C

A.11: 0.5g Guar Concentration (60 °C)

Sample Temperature:	60deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 3:56 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 11

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	129	40	5.16	61.7
2	60	130	40	5.19	61.7
3	90	129	40	5.16	61.8
4	120	126	40	5.04	61.7
5	150	131	40	5.24	61.6
6	180	128	40	5.13	61.7
7	210	130	40	5.21	61.7
8	240	131	40	5.24	61.6
9	270	130	40	5.2	61.8
10	300	130	40	5.19	61.8
11	330	130	40	5.2	61.7
12	360	130	40	5.2	61.7
13	390	129	40	5.16	61.7
14	420	130	40	5.19	61.8
15	450	133	40	5.32	61.8
16	480	134	40	5.36	61.8
17	510	132	40	5.29	61.7
18	540	130	40	5.2	61.8
19	570	133	40	5.31	61.8
20	600	133	40	5.33	61.8

A.12: 0.5g Guar Concentration (80 °C)

Sample Temperature:	80deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/20/2015; 4:15 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 12

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	84.1	40	3.37	82.1
2	60	81.4	40	3.25	82.1
3	90	83	40	3.32	82.1
4	120	82.8	40	3.31	82
5	150	82.4	40	3.3	82
6	180	84.1	40	3.37	81.9
7	210	82.2	40	3.29	81.8
8	240	83.6	40	3.34	82
9	270	84.9	40	3.4	81.9
10	300	84	40	3.36	81.8
11	330	77.9	40	3.12	81.8
12	360	75.9	40	3.04	81.9
13	390	76.1	40	3.05	81.8
14	420	79.2	40	3.17	81.8
15	450	77.7	40	3.11	81.9
16	480	70.8	40	2.83	82
17	510	66	40	2.64	81.9
18	540	71.1	40	2.84	81.8
19	570	72.6	40	2.9	81.7
20	600	69.4	40	2.78	81.9

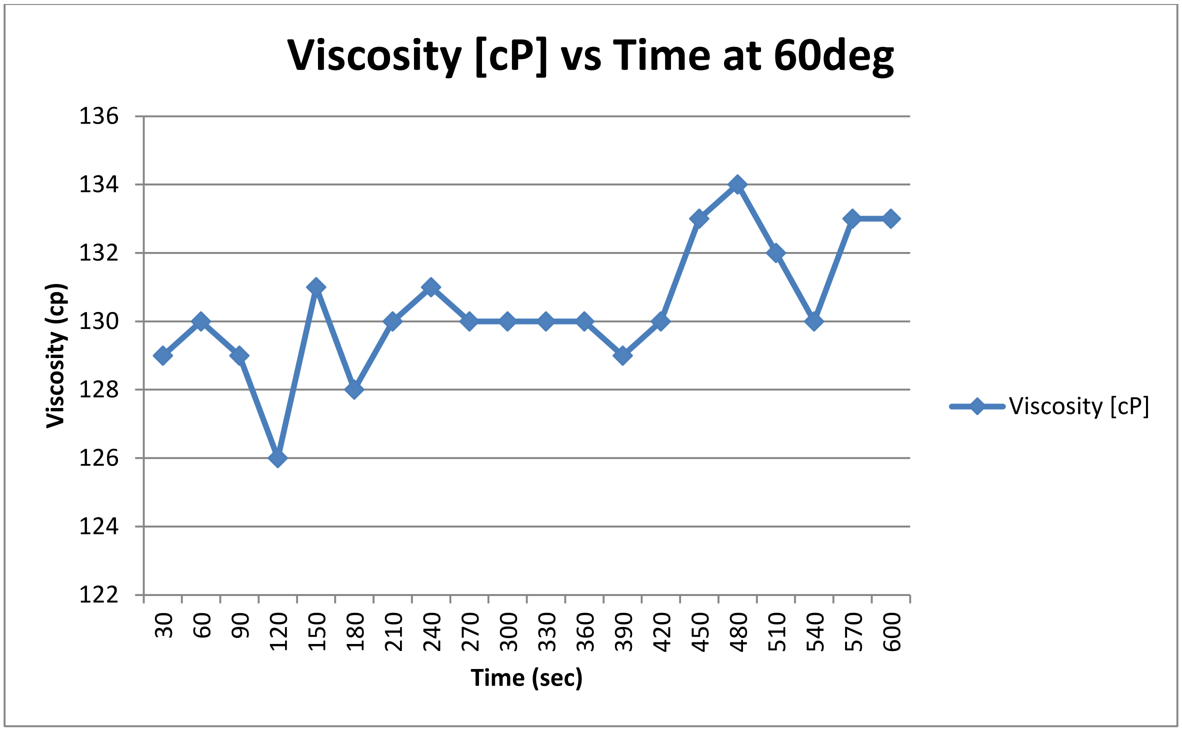

Chart 18: Viscosity profile for .5g Guar concentration at 60°C

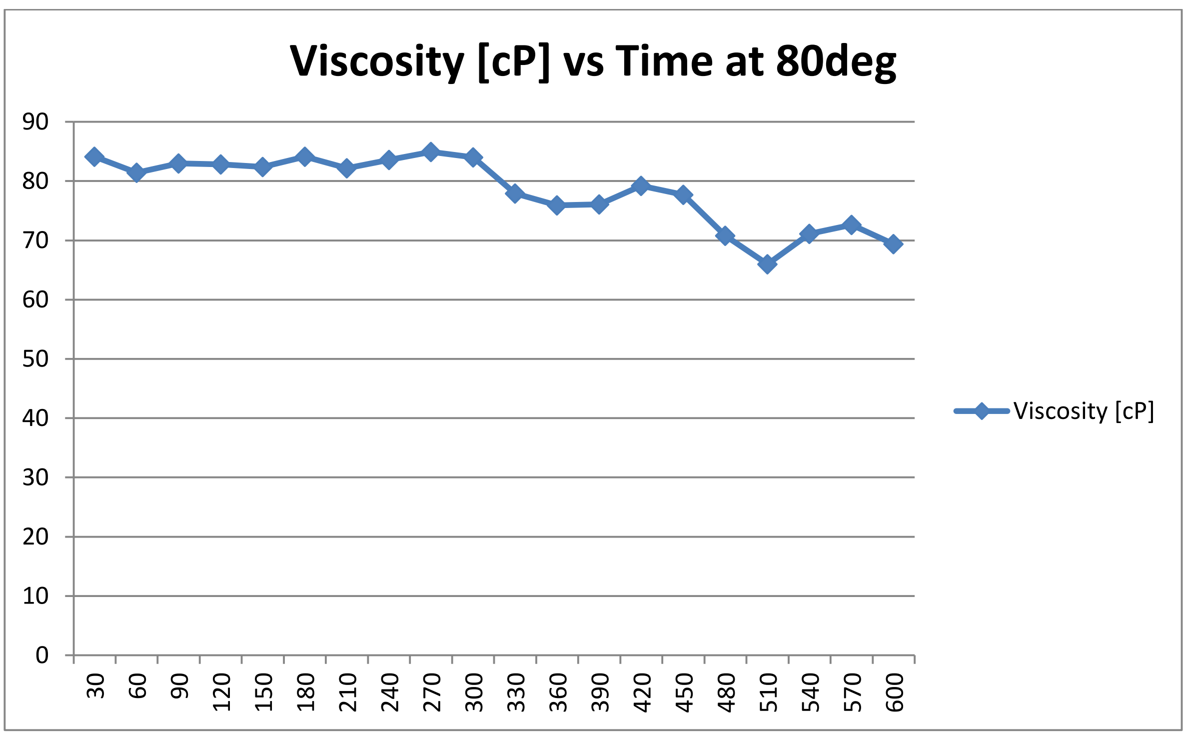

Chart 19: Viscosity profile for .5g Guar concentration at 80°C

A.13: 0.72g Guar Concentration (20 ℃)

Sample Temperature:	20deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 2:37 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 13

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	485	40	19.4	19.8
2	60	480	40	19.2	19.8
3	90	481	40	19.2	19.8
4	120	482	40	19.3	19.9
5	150	482	40	19.3	20
6	180	482	40	19.3	20
7	210	480	40	19.2	19.9
8	240	481	40	19.3	19.8
9	270	482	40	19.3	19.9
10	300	484	40	19.4	19.9
11	330	484	40	19.4	19.9
12	360	483	40	19.3	19.9
13	390	483	40	19.3	20
14	420	483	40	19.3	19.8
15	450	483	40	19.3	19.9
16	480	484	40	19.4	19.8
17	510	483	40	19.3	20
18	540	481	40	19.2	20
19	570	481	40	19.2	20.2
20	600	481	40	19.2	20

A.14: 0.72g Guar Concentration (40 ℃)

Sample Temperature:	40deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 3:23 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 14

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	387	40	15.5	41.5
2	60	386	40	15.4	41.5
3	90	388	40	15.5	41.6
4	120	389	40	15.6	41.6
5	150	390	40	15.6	41.5
6	180	390	40	15.6	41.5
7	210	391	40	15.6	41.5
8	240	391	40	15.6	41.4
9	270	387	40	15.5	41.4
10	300	387	40	15.5	41.5
11	330	388	40	15.5	41.6
12	360	387	40	15.5	41.5
13	390	386	40	15.5	41.4
14	420	389	40	15.6	41.5
15	450	391	40	15.6	41.5
16	480	390	40	15.6	41.4
17	510	388	40	15.5	41.4
18	540	389	40	15.5	41.5
19	570	388	40	15.5	41.5
20	600	389	40	15.5	41.5

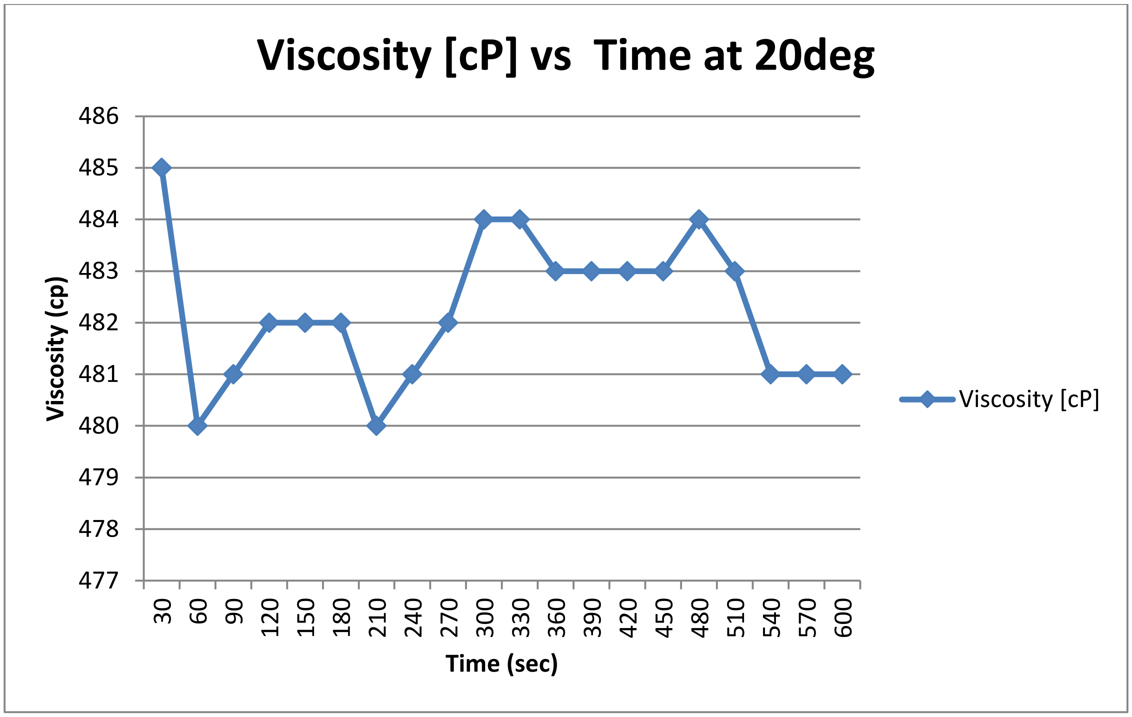

Chart 20: Viscosity profile for .72g Guar concentration at 20°C

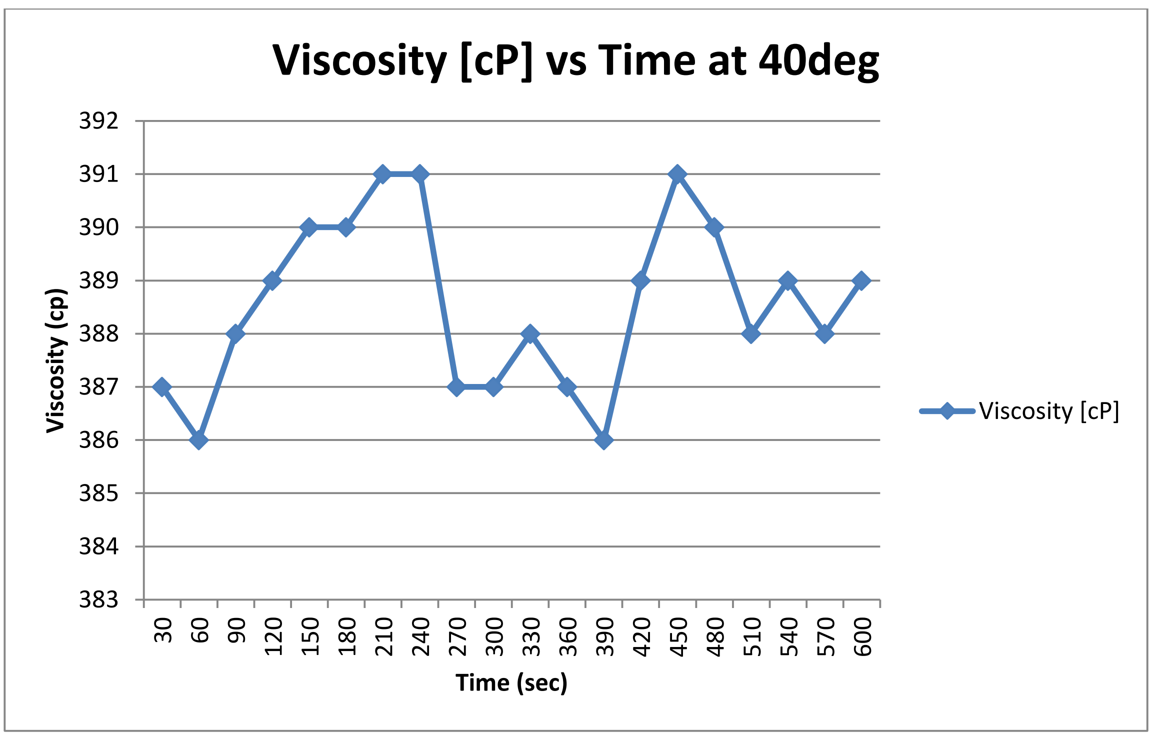

Chart 21: Viscosity profile for .72g Guar concentration at 40°C

A.15: 0.72g Guar Concentration (60 ℃)

SampleTemprature:	60deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 3:45 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 15

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	311	40	12.5	61.8
2	60	309	40	12.4	61.8
3	90	311	40	12.4	61.7
4	120	311	40	12.4	61.7
5	150	312	40	12.5	61.7
6	180	312	40	12.5	61.6
7	210	311	40	12.4	61.7
8	240	312	40	12.5	61.6
9	270	310	40	12.4	61.7
10	300	313	40	12.5	61.7
11	330	309	40	12.4	61.6
12	360	310	40	12.4	61.7
13	390	311	40	12.4	61.7
14	420	312	40	12.5	61.7
15	450	315	40	12.6	61.7
16	480	317	40	12.7	61.6
17	510	317	40	12.7	61.8
18	540	317	40	12.7	61.8
19	570	317	40	12.7	61.8
20	600	317	40	12.7	61.7

A.16: 0.72g Guar Concentration (80 °C)

Sample Temperature:	80deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	3/25/2015; 4:03 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 16

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	30	252	40	10.1	82.2
2	60	252	40	10.1	82.2
3	90	251	40	10	82.3
4	120	249	40	9.96	82.4
5	150	249	40	9.95	82.5
6	180	248	40	9.93	82.2
7	210	246	40	9.85	82.2
8	240	247	40	9.87	81.9
9	270	240	40	9.58	81.7
10	300	238	40	9.53	81.7
11	330	240	40	9.58	81.7
12	360	240	40	9.6	81.7
13	390	240	40	9.6	81.7
14	420	242	40	9.7	81.6
15	450	243	40	9.72	81.6
16	480	245	40	9.79	81.8
17	510	246	40	9.83	81.7
18	540	245	40	9.8	81.8
19	570	247	40	9.86	81.7
20	600	248	40	9.9	81.8

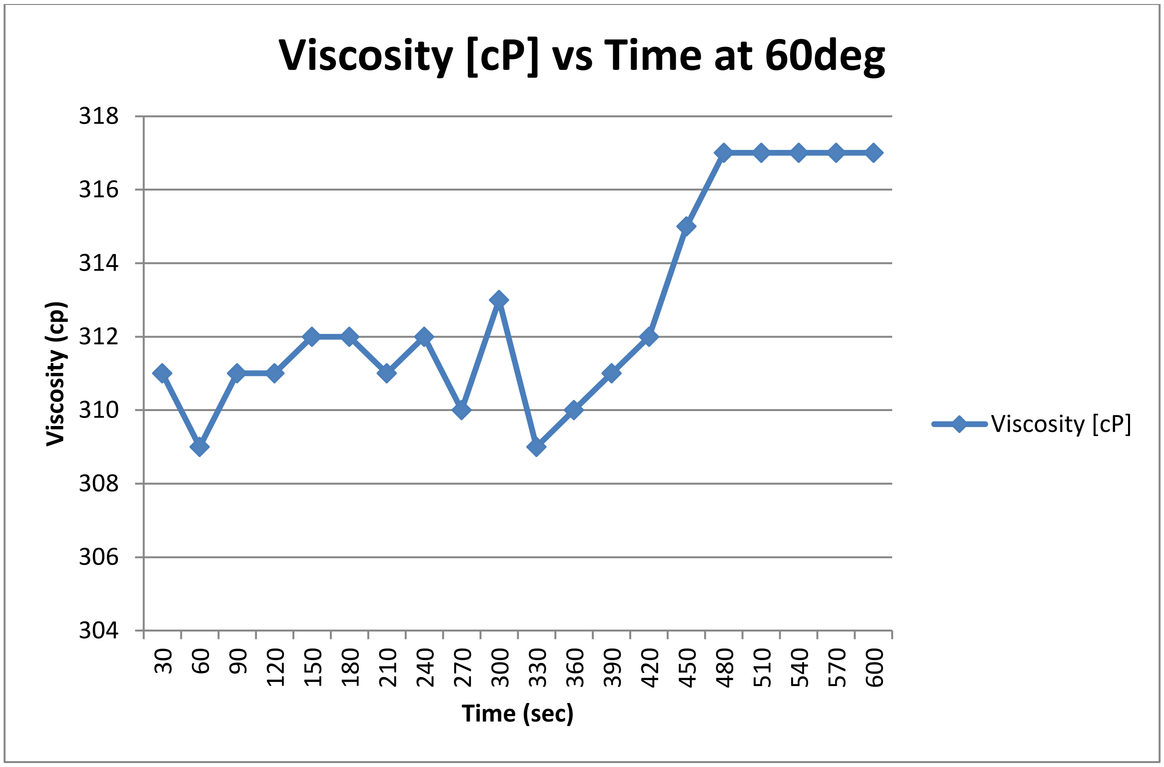

Chart 22: Viscosity profile for .72g Guar concentration at 60°C

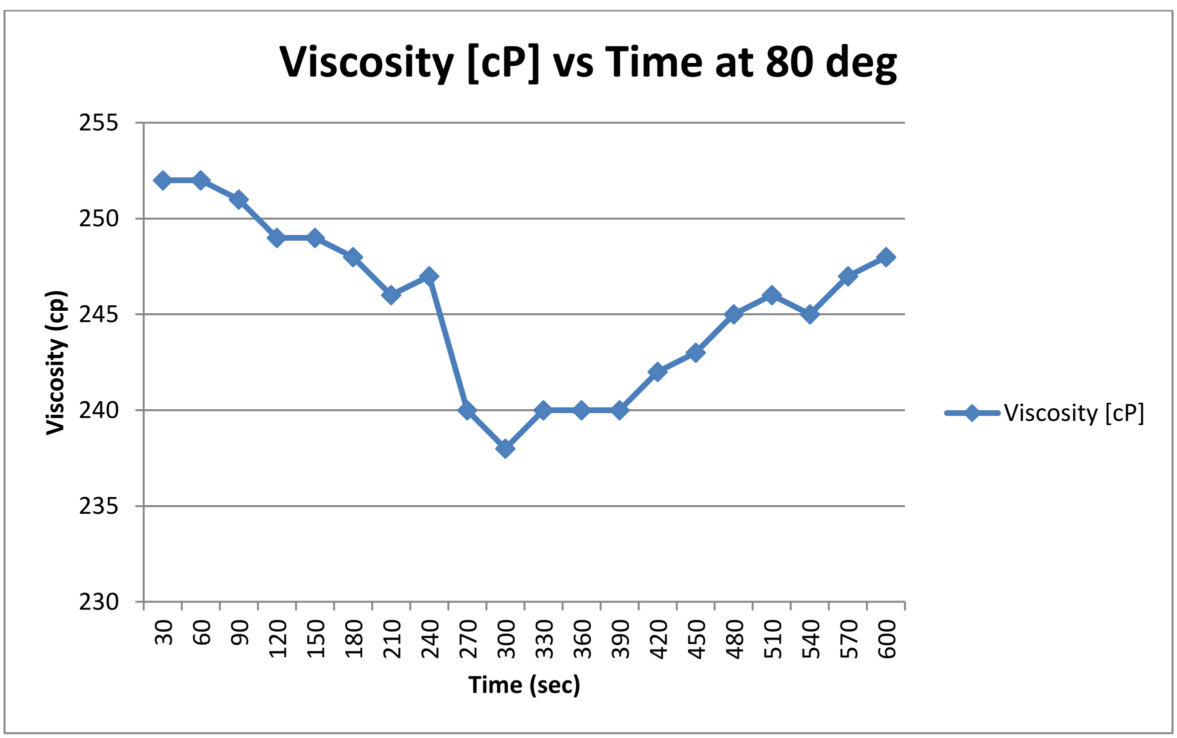

Chart 23: Viscosity profile for .72g Guar concentration at 80°C

A.17: 0.36g Guar and 5gpt Borax Concentration (20 °C)

Sample Temperature:	20DEG
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/9/2015; 11:28 AM
Measuring System:	CC17-SN32297; d=0 mm

Table 17

Meas. Pts.	Time	Viscosity at	Temperature	Shear Rate	Shear Stress
	[s]	20 °C	[°C]	[1/s]	[Pa]
1	30	654	21.6	40	26.1
2	60	644	21.6	40	25.8
3	90	675	21.5	40	27
4	120	704	21.6	40	28.2
5	150	735	21.6	40	29.4
6	180	749	21.6	40	30
7	210	763	21.6	40	30.5
8	240	780	21.6	40	31.2
9	270	793	21.7	40	31.7
10	300	799	21.7	40	32
11	330	813	21.6	40	32.5
12	360	827	21.7	40	33.1
13	390	838	21.7	40	33.5
14	420	857	21.7	40	34.3
15	450	868	21.7	40	34.7
16	480	884	21.7	40	35.4
17	510	900	21.7	40	36
18	540	913	21.6	40	36.5
19	570	921	21.7	40	36.8
20	600	930	21.6	40	37.2

A.18: 0.36g Guar and 5gpt Borax Concentration (40 °C)

Sample:	40DEG
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/9/2015; 11:47 AM
Measuring System:	CC17-SN32297; d=0 mm

Table 18

Meas. Pts.	Time	Viscosity	Temperature	Shear Rate	Shear Stress
	[s]	[cP]	[°C]	[1/s]	[Pa]
1	30	708	41.4	40	28.3
2	60	747	41.5	40	29.9
3	90	820	41.4	40	32.8
4	120	853	41.5	40	34.1
5	150	865	41.4	40	34.6
6	180	866	41.5	40	34.6
7	210	854	41.4	40	34.1
8	240	838	41.4	40	33.5
9	270	846	41.5	40	33.8
10	300	846	41.6	40	33.9
11	330	844	41.6	40	33.7
12	360	844	41.6	40	33.7
13	390	837	41.5	40	33.5
14	420	826	41.4	40	33.1
15	450	822	41.3	40	32.9
16	480	832	41.4	40	33.3
17	510	855	41.4	40	34.2
18	540	846	41.5	40	33.8
19	570	862	41.5	40	34.5
20	600	878	41.6	40	35.1

A.19: 0.36g Guar and 5gpt Borax Concentration (60 °C)

Sample Temperature:	60DEG
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/9/2015; 12:06 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 19

Meas. Pts.	Time	Viscosity	Temperature	Shear Rate	Shear Stress
	[s]	[cP]	[°C]	[1/s]	[Pa]
1	30	145	61.7	40	5.81
2	60	116	61.8	40	4.65
3	90	111	61.8	40	4.45
4	120	95.3	61.7	40	3.81
5	150	87.5	61.6	40	3.5
6	180	89.3	61.6	40	3.57
7	210	85.2	61.6	40	3.41
8	240	83.3	61.7	40	3.33
9	270	81.3	61.6	40	3.25
10	300	78.9	61.6	40	3.16
11	330	81.1	61.6	40	3.24
12	360	81.8	61.5	40	3.27
13	390	81.2	61.5	40	3.25
14	420	82.3	61.5	40	3.29
15	450	83.8	61.6	40	3.35
16	480	85.5	61.7	40	3.42
17	510	84.8	61.6	40	3.39
18	540	84.8	61.6	40	3.39
19	570	84.1	61.6	40	3.37
20	600	85.7	61.6	40	3.43

A.20: 0.36g Guar and 5gpt Borax Concentration (80 °C)

Sample Temeperature:	80DEG
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/9/2015; 12:26 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 20

Meas. Pts.	Time	Viscosity	Temperature	Shear Rate	Shear Stress
	[s]	[cP]	[°C]	[1/s]	[Pa]
1	30	34.7	82.1	40	1.39
2	60	32.7	82	40	1.31
3	90	30.9	82	40	1.23
4	120	30.1	82.2	40	1.2
5	150	29.6	82.1	40	1.18
6	180	29.5	82.2	40	1.18
7	210	29.2	82.2	40	1.17
8	240	28.8	82.1	40	1.15
9	270	28.9	82.1	40	1.16
10	300	28.8	82.1	40	1.15
11	330	28.8	82.1	40	1.15
12	360	28.6	82	40	1.14
13	390	28.3	81.9	40	1.13
14	420	28.4	81.7	40	1.14
15	450	28.6	81.8	40	1.14
16	480	28.4	81.7	40	1.14
17	510	28	81.7	40	1.12
18	540	27.5	81.7	40	1.1
19	570	27.6	81.8	40	1.1
20	600	27.7	81.7	40	1.11

A.21: Cross-linked Gel (0.36g guar & 5gpt borax) Breaking by APS (4ppt)

Sample Temperature:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 5:19 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 21

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	99.3	40	3.97	21.8
2	12	96.5	40	3.86	22
3	18	96	40	3.84	23.3
4	24	95.9	40	3.84	24.3
5	30	96	40	3.84	24.8
6	36	95.9	40	3.84	25.4
7	42	95.5	40	3.82	25.9
8	48	94.9	40	3.8	26.3
9	54	94.9	40	3.8	26.9
10	60	94.1	40	3.77	27.4
11	66	94.2	40	3.77	27.7
12	72	94.2	40	3.77	28.3
13	78	93.5	40	3.74	28.9
14	84	93.2	40	3.73	29.1
15	90	92.2	40	3.69	29.6
16	96	91.7	40	3.67	30.1
17	102	92.2	40	3.69	30.6
18	108	91.5	40	3.66	31.1
19	114	91	40	3.64	31.6
20	120	90.9	40	3.64	32.1
21	126	89.7	40	3.59	32.6
22	132	89	40	3.56	33.1
23	138	88.4	40	3.54	33.6
24	144	88	40	3.52	34.1
25	150	88.3	40	3.53	34.4
26	156	87.7	40	3.51	34.9
27	162	86.6	40	3.47	35.3
28	168	86.1	40	3.44	35.9
29	174	84.9	40	3.4	36.3

30	180	85.5	40	3.42	36.8
31	186	85.5	40	3.42	37.3
32	192	84	40	3.36	37.7
33	198	83.7	40	3.35	38.1
34	204	82.5	40	3.3	38.7
35	210	81.7	40	3.27	39.1
36	216	82	40	3.28	39.7
37	222	81.2	40	3.25	40.3
38	228	81.4	40	3.26	40.7
39	234	81.3	40	3.25	41
40	240	79.2	40	3.17	41.6
41	246	79	40	3.16	42.2
42	252	78	40	3.12	42.8
43	258	78.4	40	3.13	43.2
44	264	78.5	40	3.14	43.6
45	270	76.9	40	3.08	44.1
46	276	76.4	40	3.05	44.4
47	282	75.6	40	3.02	44.8
48	288	74.8	40	2.99	45.5
49	294	75.6	40	3.03	46.1
50	300	74.5	40	2.98	46.6
51	306	73.5	40	2.94	46.8
52	312	73.8	40	2.95	47.5
53	318	72.6	40	2.91	48
54	324	71.6	40	2.86	48.4
55	330	71.4	40	2.86	48.9
56	336	70.6	40	2.82	49.2
57	342	71.2	40	2.85	49.7
58	348	70.8	40	2.83	50.2
59	354	69.1	40	2.76	50.7
60	360	68.9	40	2.76	51.2
61	366	68	40	2.72	51.6
62	372	68.4	40	2.74	52
63	378	68.5	40	2.74	52.5
64	384	66.7	40	2.67	52.9
65	390	66.5	40	2.66	53.4
66	396	65.7	40	2.63	53.9
67	402	65.5	40	2.62	54.2
68	408	65.9	40	2.64	54.8
69	414	64.6	40	2.59	55.2
70	420	64.6	40	2.58	55.5

71	426	64.9	40	2.59	56
72	432	63.3	40	2.53	56.5
73	438	62.4	40	2.5	57.1
74	444	61.8	40	2.47	57.3
75	450	61.6	40	2.46	57.6
76	456	61.7	40	2.47	58.1
77	462	60.7	40	2.43	58.5
78	468	60.2	40	2.41	58.9
79	474	59.8	40	2.39	59.2
80	480	59.2	40	2.37	59.6
81	486	60.5	40	2.42	60.2
82	492	59.9	40	2.4	60.5
83	498	58	40	2.32	61
84	504	58.1	40	2.32	61.4
85	510	57.4	40	2.3	61.9
86	516	56.8	40	2.27	62.4
87	522	57.2	40	2.29	62.3
88	528	56.1	40	2.24	62
89	534	56.7	40	2.27	62.5
90	540	57.4	40	2.3	62.5
91	546	55.2	40	2.21	62.6
92	552	55	40	2.2	62.9
93	558	54.7	40	2.19	62.9
94	564	55.2	40	2.21	63
95	570	56	40	2.24	63.1
96	576	54.4	40	2.18	63
97	582	54.1	40	2.16	63.1
98	588	53.9	40	2.16	62.9
99	594	53.6	40	2.15	62.8
100	600	55	40	2.2	62.9

A.22: Cross-linked Gel (0.36g guar & 5gpt borax) Breaking by APS (6ppt)

Sample Temperature:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 4:34 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 22

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	88	40	3.52	22.3
2	12	90.4	40	3.62	23.7
3	18	90.6	40	3.62	24.4
4	24	90.8	40	3.63	25.1
5	30	89.9	40	3.6	25.6
6	36	89.8	40	3.59	26.1
7	42	89.5	40	3.58	26.5
8	48	89.2	40	3.57	26.8
9	54	88.7	40	3.55	27.3
10	60	88.4	40	3.54	28
11	66	88.1	40	3.52	28.5
12	72	89	40	3.56	28.9
13	78	87.2	40	3.49	29.4
14	84	87.2	40	3.49	29.8
15	90	86.6	40	3.46	30.3
16	96	86	40	3.44	30.8
17	102	86.1	40	3.44	31.2
18	108	85.1	40	3.4	31.9
19	114	85	40	3.4	32.1
20	120	85.2	40	3.41	32.8
21	126	83.8	40	3.35	33.2
22	132	82.9	40	3.32	33.6
23	138	82.6	40	3.3	34
24	144	81.8	40	3.27	34.6
25	150	82.7	40	3.31	35
26	156	81.8	40	3.27	35.6
27	162	80.8	40	3.23	36
28	168	80	40	3.2	36.4
29	174	78.9	40	3.16	36.9

30	180	79.7	40	3.19	37.5
31	186	79.4	40	3.18	38
32	192	77.9	40	3.12	38.5
33	198	77.5	40	3.1	38.8
34	204	76.8	40	3.07	39.2
35	210	76	40	3.04	39.7
36	216	76.1	40	3.04	40.3
37	222	75.1	40	3	40.9
38	228	75.1	40	3	41.1
39	234	75	40	3	41.7
40	240	73.6	40	2.94	42.4
41	246	73.1	40	2.93	42.7
42	252	72.6	40	2.9	43.4
43	258	72.2	40	2.89	43.8
44	264	72.6	40	2.9	44.1
45	270	71.2	40	2.85	44.6
46	276	70.7	40	2.83	45.2
47	282	69.9	40	2.8	45.6
48	288	69	40	2.76	46.1
49	294	69.8	40	2.79	46.4
50	300	68.9	40	2.76	47
51	306	67.9	40	2.72	47.7
52	312	68.1	40	2.72	48
53	318	67.1	40	2.69	48.5
54	324	66	40	2.64	48.9
55	330	65.7	40	2.63	49.4
56	336	65.3	40	2.61	49.8
57	342	65.6	40	2.62	50.2
58	348	65.4	40	2.61	50.7
59	354	63.8	40	2.55	51.2
60	360	63.3	40	2.53	51.6
61	366	62.8	40	2.51	52
62	372	63	40	2.52	52.3
63	378	63.3	40	2.53	52.8
64	384	61.7	40	2.47	53.3
65	390	61.3	40	2.45	53.4
66	396	60.5	40	2.42	54
67	402	60.2	40	2.41	54.4
68	408	60.6	40	2.42	55
69	414	59.6	40	2.38	55.5
70	420	59.2	40	2.37	55.9

71	426	59.6	40	2.38	56.4
72	432	58.5	40	2.34	56.7
73	438	57.5	40	2.3	57.2
74	444	57.2	40	2.29	57.7
75	450	56.7	40	2.27	58
76	456	57.5	40	2.3	58.5
77	462	56.7	40	2.27	58.8
78	468	55.5	40	2.22	59.2
79	474	55	40	2.2	59.6
80	480	54.5	40	2.18	60.1
81	486	55.1	40	2.2	60.5
82	492	55	40	2.2	60.8
83	498	53.5	40	2.14	61.2
84	504	53.3	40	2.13	61.6
85	510	52.9	40	2.12	61.7
86	516	52.3	40	2.09	62.3
87	522	52.6	40	2.11	62.3
88	528	51.8	40	2.07	62.4
89	534	52.2	40	2.09	62.4
90	540	52.6	40	2.11	62.8
91	546	51.2	40	2.05	62.6
92	552	50.8	40	2.03	62.5
93	558	50.5	40	2.02	62.7
94	564	50.3	40	2.01	62.8
95	570	51.4	40	2.06	62.8
96	576	51.8	40	2.07	62.8
97	582	50.7	40	2.03	62.9

A.23: Cross-linked Gel (0.36g guar & 5gpt borax) without APS

Sample:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 3:36 PM
Measuring System:	CC17-SN32297; d=0 mm

Table 23					
Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	2,330	40	93.3	22.4
2	12	2,160	40	86.4	23.8
3	18	2,220	40	88.7	24.6
4	24	1,960	40	78.2	25.1
5	30	1,900	40	75.9	25.7
6	36	1,770	40	71	26.2
7	42	1,600	40	64	26.6
8	48	1,480	40	59.4	27
9	54	1,410	40	56.3	27.7
10	60	1,350	40	53.9	28.1
11	66	1,310	40	52.4	28.7
12	72	1,210	40	48.5	29.1
13	78	1,180	40	47.2	29.7
14	84	1,160	40	46.6	30.2
15	90	1,130	40	45.3	30.7
16	96	1,090	40	43.4	31.2
17	102	1,040	40	41.7	31.7
18	108	1,100	40	44	32.3
19	114	1,060	40	42.6	32.7
20	120	1,070	40	43	33.2
21	126	1,080	40	43.4	33.6
22	132	1,050	40	42	34
23	138	1,040	40	41.6	34.7
24	144	1,080	40	43.1	35
25	150	981	40	39.2	35.6
26	156	1,010	40	40.3	36
27	162	991	40	39.6	36.6
28	168	952	40	38.1	37.2
29	174	903	40	36.1	37.8

30	180	899	40	36	38.3
31	186	885	40	35.4	38.8
32	192	846	40	33.8	39.4
33	198	833	40	33.3	39.7
34	204	806	40	32.2	40.4
35	210	780	40	31.2	40.5
36	216	762	40	30.5	41.1
37	222	743	40	29.7	41.6
38	228	688	40	27.5	42.4
39	234	652	40	26.1	42.9
40	240	621	40	24.9	43.5
41	246	561	40	22.4	43.8
42	252	517	40	20.7	44.3
43	258	459	40	18.3	44.7
44	264	404	40	16.2	45.2
45	270	369	40	14.8	45.7
46	276	325	40	13	46.1
47	282	290	40	11.6	46.6
48	288	264	40	10.6	47.2
49	294	221	40	8.83	47.7
50	300	198	40	7.91	48
51	306	177	40	7.06	48.4
52	312	155	40	6.21	48.7
53	318	151	40	6.06	49.2
54	324	140	40	5.6	49.5
55	330	131	40	5.23	50.3
56	336	126	40	5.02	50.8
57	342	109	40	4.37	51.3
58	348	109	40	4.35	51.6
59	354	108	40	4.33	52.2
60	360	105	40	4.21	52.6
61	366	107	40	4.28	53
62	372	96.7	40	3.87	53.5
63	378	92.8	40	3.71	53.7
64	384	91.9	40	3.68	54.2
65	390	86.3	40	3.45	54.6
66	396	95.9	40	3.83	54.9
67	402	90.3	40	3.61	55.5
68	408	83.2	40	3.33	55.9
69	414	81.8	40	3.27	56.3
70	420	74	40	2.96	57

71	426	82	40	3.28	57.3
72	432	92.4	40	3.69	57.9
73	438	78.7	40	3.15	58.3
74	444	81.8	40	3.27	58.6
75	450	73.2	40	2.93	59.3
76	456	70.3	40	2.81	59.6
77	462	76.2	40	3.05	60.3
78	468	77.5	40	3.1	60.5
79	474	76	40	3.04	61
80	480	78.3	40	3.13	61.2
81	486	65.9	40	2.64	61.8
82	492	68.1	40	2.73	62.2
83	498	71.2	40	2.85	62.5
84	504	71.5	40	2.86	63.1
85	510	77.1	40	3.08	63.5
86	516	66.3	40	2.65	63.9
87	522	62.6	40	2.5	64.3
88	528	63.2	40	2.53	64.7
89	534	62.2	40	2.49	65.3
90	540	74.1	40	2.97	65.6
91	546	68.2	40	2.73	66.1
92	552	60	40	2.4	66.5
93	558	63.5	40	2.54	66.9
94	564	60.1	40	2.4	67.1
95	570	64.4	40	2.57	67.5
96	576	68.9	40	2.76	67.9
97	582	57.4	40	2.3	68.5
98	588	62.8	40	2.51	68.5
99	594	63.9	40	2.56	69.1
100	600	61.1	40	2.44	69.5
101	606	60.3	40	2.41	70
102	612	54.5	40	2.18	70.3
103	618	56.3	40	2.25	70.8

A.24: Linear Gel (0.36g guar) Breaking by APS (3ppt)

Sample Temperature:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 1:54 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 24

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	68.2	40	2.73	21.9
2	12	68.9	40	2.75	22.4
3	18	69.1	40	2.76	23.6
4	24	69.1	40	2.77	24.4
5	30	69	40	2.76	25.1
6	36	68.9	40	2.75	25.5
7	42	68.8	40	2.75	25.9
8	48	68.6	40	2.74	26.4
9	54	68.4	40	2.73	26.7
10	60	68	40	2.72	27.3
11	66	67.8	40	2.71	27.9
12	72	67.4	40	2.69	28.2
13	78	67.1	40	2.68	28.9
14	84	66.7	40	2.67	29.4
15	90	66.3	40	2.65	29.8
16	96	66	40	2.64	30.2
17	102	65.6	40	2.62	30.8
18	108	65.2	40	2.61	31.2
19	114	64.7	40	2.59	31.8
20	120	64.3	40	2.57	32.4
21	126	63.9	40	2.56	32.8
22	132	63.5	40	2.54	33.3
23	138	62.9	40	2.52	33.6
24	144	62.4	40	2.5	34.1
25	150	62	40	2.48	34.7
26	156	61.6	40	2.46	35.3
27	162	61	40	2.44	35.7
28	168	60.7	40	2.43	36.2
29	174	60.1	40	2.41	36.6

30	180	59.7	40	2.39	37.2
31	186	59.2	40	2.37	37.6
32	192	58.8	40	2.35	38.1
33	198	58.4	40	2.33	38.5
34	204	57.9	40	2.32	39.2
35	210	57.5	40	2.3	39.6
36	216	57	40	2.28	39.9
37	222	56.7	40	2.27	40.4
38	228	56.1	40	2.25	40.9
39	234	55.8	40	2.23	41.4
40	240	55.4	40	2.22	41.9
41	246	55	40	2.2	42.4
42	252	54.3	40	2.17	42.8
43	258	54	40	2.16	43.2
44	264	53.5	40	2.14	43.6
45	270	53.1	40	2.12	44
46	276	52.8	40	2.11	44.5
47	282	52.4	40	2.1	45
48	288	52	40	2.08	45.3
49	294	51.6	40	2.06	45.8
50	300	51.1	40	2.04	46.4
51	306	50.6	40	2.03	47
52	312	50.3	40	2.01	47.6
53	318	49.8	40	1.99	48
54	324	49.4	40	1.98	48.5
55	330	49	40	1.96	49
56	336	48.6	40	1.94	49.3
57	342	48.1	40	1.93	49.9
58	348	47.8	40	1.91	50.5
59	354	47.5	40	1.9	50.8
60	360	47	40	1.88	51.3
61	366	46.6	40	1.87	51.8
62	372	46.1	40	1.85	52.3
63	378	45.9	40	1.83	52.7
64	384	45.4	40	1.81	53.2
65	390	45.2	40	1.81	53.6
66	396	44.8	40	1.79	54.2
67	402	44.3	40	1.77	54.8
68	408	43.9	40	1.76	55
69	414	43.5	40	1.74	55.6
70	420	43.1	40	1.72	56.1

71	426	42.8	40	1.71	56.5
72	432	42.3	40	1.69	56.7
73	438	42.7	40	1.71	57.4
74	444	42.1	40	1.68	57.7
75	450	41.6	40	1.66	58.4
76	456	41.4	40	1.66	58.7
77	462	40.6	40	1.62	59.1
78	468	40.4	40	1.62	59.4
79	474	40.4	40	1.62	59.9
80	480	39.6	40	1.58	60.4
81	486	39.5	40	1.58	60.7
82	492	39.1	40	1.56	61.3
83	498	38.5	40	1.54	61.7
84	504	38.5	40	1.54	62.1
85	510	38.3	40	1.53	62.4
86	516	37.9	40	1.52	62.8
87	522	37.8	40	1.51	63.3
88	528	37.3	40	1.49	63.7
89	534	36.9	40	1.48	64.2
90	540	36.7	40	1.47	64.8
91	546	36.3	40	1.45	65
92	552	36.1	40	1.45	65.4
93	558	35.7	40	1.43	65.8
94	564	35.4	40	1.42	66.4
95	570	35.1	40	1.41	66.8
96	576	34.8	40	1.39	67
97	582	34.6	40	1.38	67.4
98	588	34.4	40	1.37	68
99	594	34.2	40	1.37	68.6
100	600	35.3	40	1.41	68.8
101	606	33.5	40	1.34	69.2
102	612	33.5	40	1.34	69.6
103	618	33.3	40	1.33	70
104	624	33.4	40	1.34	70.4
105	630	32.7	40	1.31	70.8
106	636	32.1	40	1.29	71.1
107	642	31.9	40	1.27	71.5
108	648	32.3	40	1.29	71.8
109	654	31.9	40	1.28	72.2
110	660	32.6	40	1.3	72.7
111	666	32.5	40	1.3	72.9

112	672	31.2	40	1.25	73.4
113	678	31.8	40	1.27	73.7
114	684	30.4	40	1.22	74.2
115	690	30	40	1.2	74.7
116	696	30.9	40	1.23	74.9
117	702	30.3	40	1.21	75.3
118	708	30.4	40	1.22	75.8
119	714	29.7	40	1.19	76.1
120	720	29.1	40	1.16	76.4
121	726	29.1	40	1.16	76.8
122	732	28.2	40	1.13	77.1
123	738	28.5	40	1.14	77.6
124	744	28.7	40	1.15	77.7
125	750	27.9	40	1.12	78
126	756	27.6	40	1.1	78.5
127	762	26.9	40	1.08	78.9
128	768	26.3	40	1.05	79.2
129	774	26.7	40	1.07	79.5
130	780	26.6	40	1.07	79.9
131	786	25.8	40	1.03	80.3
132	792	26.6	40	1.06	80.6
133	798	24.8	40	0.993	80.6
134	804	24.6	40	0.984	80.8
135	810	24.8	40	0.994	81.2
136	816	24.5	40	0.98	81.2
137	822	25.3	40	1.01	81.5
138	828	24.7	40	0.988	81.4
139	834	23.4	40	0.937	81.6
140	840	23.2	40	0.929	81.8
141	846	22.9	40	0.915	82.1
142	852	23.8	40	0.951	82
143	858	24.2	40	0.967	82.1
144	864	22.6	40	0.906	82.2
145	870	22.5	40	0.902	82.3
146	876	22.2	40	0.889	82.5
147	882	21.7	40	0.868	82.5
148	888	22.4	40	0.896	82.4
149	894	22.4	40	0.897	82.4
150	900	21.9	40	0.876	82.4
151	906	22.2	40	0.887	82.5
152	912	20.9	40	0.835	82.5

153	918	20.9	40	0.835	82.4
154	924	21.4	40	0.855	82.5
155	930	20.8	40	0.834	82.5
156	936	21.3	40	0.851	82.4
157	942	20.5	40	0.82	82.3
158	948	20	40	0.802	82.2
159	954	20.5	40	0.822	82.2
160	960	19.5	40	0.782	82.1
161	966	20.3	40	0.813	82
162	972	20.6	40	0.822	82
163	978	19.5	40	0.78	82
164	984	19.6	40	0.785	81.9
165	990	19.1	40	0.763	82
166	996	18.9	40	0.756	82.1
167	1,000	19.6	40	0.784	81.9
168	1,010	19.1	40	0.764	81.9
169	1,010	18.9	40	0.758	81.9
170	1,020	19.2	40	0.766	82.1
171	1,030	18.2	40	0.729	81.9
172	1,030	18.1	40	0.726	81.8
173	1,040	18.2	40	0.73	81.9
174	1,040	18.2	40	0.727	81.8
175	1,050	18.8	40	0.753	81.9
176	1,060	17.6	40	0.705	81.9
177	1,060	17.3	40	0.692	81.9
178	1,070	17.6	40	0.704	81.9
179	1,070	16.9	40	0.675	81.9
180	1,080	17.8	40	0.71	81.9
181	1,090	18.2	40	0.728	81.9
182	1,090	16.7	40	0.67	81.9
183	1,100	17.2	40	0.689	82
184	1,100	16.4	40	0.654	82
185	1,110	16.4	40	0.657	82.1
186	1,120	17.1	40	0.683	82

A.25: Linear Gel (0.36g guar) Breaking by APS (2ppt)

Sample Temperature:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 12:51 PM
Measuring System:	CC39-SN33439; d=0 mm

Table 25

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	84.9	40	3.4	21.9
2	12	85.3	40	3.41	22.9
3	18	84.7	40	3.39	23.8
4	24	84.3	40	3.37	24.3
5	30	84.4	40	3.38	24.7
6	36	84.4	40	3.38	25.2
7	42	84.1	40	3.36	25.7
8	48	83.6	40	3.34	26
9	54	83.2	40	3.33	26.4
10	60	82.9	40	3.32	27.1
11	66	82.8	40	3.31	27.6
12	72	82.1	40	3.29	27.9
13	78	81.8	40	3.27	28.3
14	84	81.1	40	3.25	28.9
15	90	80.6	40	3.23	29.2
16	96	80.2	40	3.21	29.8
17	102	79.8	40	3.19	30.2
18	108	79.4	40	3.18	30.4
19	114	79.1	40	3.17	31
20	120	78.6	40	3.14	31.5
21	126	78.1	40	3.12	32
22	132	77.5	40	3.1	32.4
23	138	77.2	40	3.09	32.7
24	144	77.3	40	3.09	33.4
25	150	76.3	40	3.05	33.8
26	156	75.9	40	3.04	34.2
27	162	75.2	40	3.01	34.6
28	168	74.6	40	2.98	35.1
29	174	74.1	40	2.97	35.5

30	180	73.9	40	2.96	35.9
31	186	73.2	40	2.93	36.5
32	192	72.8	40	2.91	37
33	198	73	40	2.92	37.3
34	204	71.7	40	2.87	37.6
35	210	71.1	40	2.84	37.9
36	216	72.2	40	2.89	38.5
37	222	71.7	40	2.87	39
38	228	71.7	40	2.87	39.5
39	234	70.8	40	2.83	39.9
40	240	69.3	40	2.77	40.1
41	246	68.4	40	2.74	40.7
42	252	68	40	2.72	41.2
43	258	68.7	40	2.75	41.7
44	264	67.5	40	2.7	42
45	270	66.7	40	2.67	42.3
46	276	66.4	40	2.66	43
47	282	65.7	40	2.63	43.2
48	288	65.3	40	2.61	43.7
49	294	65.1	40	2.61	44.1
50	300	64.5	40	2.58	44.5
51	306	65	40	2.6	45.1
52	312	64	40	2.56	45.5
53	318	63	40	2.52	45.9
54	324	62.9	40	2.51	46.2
55	330	63	40	2.52	46.6
56	336	63.5	40	2.54	47
57	342	63.4	40	2.53	47.4
58	348	62	40	2.48	47.8
59	354	61.4	40	2.46	48.3
60	360	61	40	2.44	48.7
61	366	60.7	40	2.43	49.2
62	372	61	40	2.44	49.6
63	378	60	40	2.4	50
64	384	59.7	40	2.39	50.3
65	390	59.3	40	2.37	50.7
66	396	58.6	40	2.35	51.2
67	402	58.1	40	2.32	51.5
68	408	57.9	40	2.32	52.1
69	414	57.5	40	2.3	52.4
70	420	57.1	40	2.28	52.9

71	426	56.7	40	2.27	53.2
72	432	55.8	40	2.23	53.7
73	438	55.4	40	2.22	54.2
74	444	55.3	40	2.21	54.7
75	450	55.3	40	2.21	55.1
76	456	55	40	2.2	55.4
77	462	54.1	40	2.16	55.8
78	468	53.5	40	2.14	56.3
79	474	53.2	40	2.13	56.7
80	480	53	40	2.12	57.2
81	486	53.1	40	2.12	57.7
82	492	52.7	40	2.11	58
83	498	52.3	40	2.09	58.4
84	504	51.7	40	2.07	58.8
85	510	51	40	2.04	59.2
86	516	50.8	40	2.03	59.7
87	522	50.7	40	2.03	60.3
88	528	50.5	40	2.02	60.5
89	534	50.1	40	2	60.9
90	540	49.3	40	1.97	61.2
91	546	48.8	40	1.95	61.7
92	552	48.4	40	1.94	62
93	558	48.1	40	1.92	62.4
94	564	48.1	40	1.92	63.1
95	570	47.5	40	1.9	63.4
96	576	47.1	40	1.88	63.8
97	582	46.8	40	1.87	64.3
98	588	46.6	40	1.86	64.6
99	594	46.2	40	1.85	65
100	600	46.1	40	1.85	65.5
101	606	45.7	40	1.83	66
102	612	45.6	40	1.82	66.5
103	618	45.5	40	1.82	66.8
104	624	44.7	40	1.79	67
105	630	44.4	40	1.78	67.6
106	636	44.1	40	1.76	68.1
107	642	44.2	40	1.77	68.4
108	648	44.2	40	1.77	68.9
109	654	43.8	40	1.75	69.3
110	660	43	40	1.72	69.5
111	666	42.8	40	1.71	70.1

112	672	42.4	40	1.7	70.5
113	678	42.5	40	1.7	70.9
114	684	42.5	40	1.7	71.1
115	690	41.7	40	1.67	71.6
116	696	41.2	40	1.65	71.8
117	702	40.8	40	1.63	72.4
118	708	40.6	40	1.62	72.6
119	714	40.3	40	1.61	73.2
120	720	40.1	40	1.6	73.5
121	726	39.8	40	1.59	74
122	732	39.3	40	1.57	74.3
123	738	39	40	1.56	74.7
124	744	38.8	40	1.55	75.1
125	750	38	40	1.52	75.4
126	756	38	40	1.52	75.6
127	762	37.7	40	1.51	76.2
128	768	37.1	40	1.49	76.6
129	774	36.9	40	1.48	76.9
130	780	36.7	40	1.47	77.1
131	786	36.4	40	1.45	77.5
132	792	36.3	40	1.45	77.6
133	798	36	40	1.44	77.8
134	804	35.4	40	1.42	78.4
135	810	35	40	1.4	78.9
136	816	34.4	40	1.38	79.1
137	822	33.8	40	1.35	79.5
138	828	33.4	40	1.33	79.8
139	834	32.7	40	1.31	80
140	840	31.9	40	1.28	80.3
141	846	30.8	40	1.23	80.6
142	852	29.8	40	1.19	80.8
143	858	29.1	40	1.17	81.1
144	864	28	40	1.12	81.1
145	870	27	40	1.08	81.2
146	876	26.2	40	1.05	81.6
147	882	24.8	40	0.994	81.7
148	888	24	40	0.962	81.7
149	894	23.4	40	0.937	81.8
150	900	23.1	40	0.923	82
151	906	22.8	40	0.912	82.1
152	912	22.3	40	0.894	82.1

153	918	22.3	40	0.892	82.1
154	924	22.2	40	0.886	82.3
155	930	21.8	40	0.872	82.5
156	936	21.7	40	0.869	82.5
157	942	21.6	40	0.865	82.5
158	948	21.6	40	0.864	82.4
159	954	21.7	40	0.867	82.4
160	960	21.4	40	0.856	82.4
161	966	21.3	40	0.854	82.5
162	972	21.3	40	0.853	82.4
163	978	21.2	40	0.848	82.4
164	984	21.1	40	0.843	82.4
165	990	21.1	40	0.845	82.3
166	996	21	40	0.841	82.2

A.26: Linear Gel (0.36g guar) Breaking by APS (1ppt)

Sample Temperature:	20-80 deg
Application:	RHEOPLUS/32 V3.62 21007158-33024
Device:	RheolabQC SN81394432; FW1.26
Measuring Date/Time:	4/24/2015; 11:43 AM
Measuring System:	CC39-SN33439; d=0 mm

Table 26

Meas. Pts.	Time	Viscosity	Shear Rate	Shear Stress	Temperature
	[s]	[cP]	[1/s]	[Pa]	[°C]
1	6	91.3	40	3.65	21.9
2	12	87.7	40	3.51	23.2
3	18	86.2	40	3.45	24
4	24	85.5	40	3.42	24.4
5	30	85.8	40	3.43	25
6	36	85.9	40	3.44	25.5
7	42	85.6	40	3.42	26.2
8	48	85.2	40	3.41	26.5
9	54	84.6	40	3.39	27
10	60	84.4	40	3.38	27.3
11	66	84.2	40	3.37	27.8
12	72	84.5	40	3.38	28.6
13	78	83.9	40	3.36	29.1
14	84	83.2	40	3.33	29.7
15	90	82.4	40	3.3	30.2
16	96	81.9	40	3.28	30.6
17	102	82	40	3.28	30.9
18	108	81.3	40	3.25	31.5
19	114	80.6	40	3.23	31.9
20	120	80.6	40	3.23	32.5
21	126	79.8	40	3.19	33
22	132	78.9	40	3.16	33.5
23	138	78.4	40	3.14	34
24	144	77.9	40	3.12	34.5
25	150	77.8	40	3.11	34.8
26	156	77.6	40	3.11	35.4
27	162	76.7	40	3.07	35.9
28	168	76.1	40	3.05	36.4
29	174	75	40	3	36.9

30	180	75	40	3	37.3
31	186	75.3	40	3.01	37.9
32	192	74.6	40	2.99	38.2
33	198	73.8	40	2.95	38.7
34	204	72.8	40	2.91	39.1
35	210	71.9	40	2.88	39.6
36	216	72.3	40	2.89	40
37	222	72.5	40	2.9	40.5
38	228	71.8	40	2.87	40.9
39	234	71.4	40	2.85	41.5
40	240	70	40	2.8	41.9
41	246	69.2	40	2.77	42.5
42	252	68.9	40	2.76	42.9
43	258	68.9	40	2.75	43.6
44	264	69	40	2.76	43.9
45	270	67.6	40	2.71	44.4
46	276	66.8	40	2.67	45
47	282	65.8	40	2.63	45.2
48	288	65.1	40	2.6	45.8
49	294	65.5	40	2.62	46.1
50	300	64.9	40	2.6	46.6
51	306	63.6	40	2.54	47.2
52	312	64	40	2.56	47.7
53	318	63.1	40	2.52	48.1
54	324	61.9	40	2.48	48.6
55	330	62.2	40	2.49	49.2
56	336	61.7	40	2.47	49.7
57	342	61.6	40	2.46	50.1
58	348	62.3	40	2.49	50.5
59	354	60.3	40	2.41	50.9
60	360	59.2	40	2.37	51.2
61	366	58.7	40	2.35	51.6
62	372	59.3	40	2.37	52
63	378	60.1	40	2.4	52.6
64	384	58.8	40	2.35	52.9
65	390	57.7	40	2.31	53.6
66	396	56.7	40	2.27	54.1
67	402	56.1	40	2.24	54.4
68	408	56.8	40	2.27	54.6
69	414	56.3	40	2.25	55.3
70	420	56.1	40	2.24	55.5

71	426	56.3	40	2.25	56
72	432	54.7	40	2.19	56.5
73	438	53.8	40	2.15	57
74	444	53.8	40	2.15	57.5
75	450	54.2	40	2.17	57.8
76	456	55.6	40	2.22	58.1
77	462	53.8	40	2.15	58.5
78	468	52.5	40	2.1	59
79	474	51.8	40	2.07	59.5
80	480	51.5	40	2.06	60
81	486	52.7	40	2.11	59.9
82	492	52.7	40	2.11	60.7
83	498	51.4	40	2.06	61.2
84	504	50.7	40	2.03	61.6
85	510	50.3	40	2.01	62.1
86	516	50.1	40	2	62.2
87	522	50	40	2	62.6
88	528	49.6	40	1.99	63
89	534	49.1	40	1.96	63.5
90	540	49	40	1.96	64
91	546	48.4	40	1.94	64.3
92	552	48	40	1.92	64.7
93	558	47.9	40	1.91	65.2
94	564	47.6	40	1.91	65.6
95	570	47.3	40	1.89	65.9
96	576	46.8	40	1.87	66.3
97	582	46.4	40	1.86	66.8
98	588	46.1	40	1.84	67.3
99	594	45.9	40	1.84	67.6
100	600	45.7	40	1.83	68
101	606	45.4	40	1.82	68.5
102	612	44.9	40	1.8	68.8
103	618	44.5	40	1.78	69.1
104	624	44.1	40	1.76	69.6
105	630	43.9	40	1.75	70.1
106	636	43.9	40	1.75	70.4
107	642	43.6	40	1.74	70.8
108	648	43.4	40	1.73	71.3
109	654	43.2	40	1.73	71.5
110	660	42.7	40	1.71	71.8
111	666	42.4	40	1.7	72.5

112	672	42.3	40	1.69	72.7
113	678	42.2	40	1.69	73.2
114	684	41.9	40	1.67	73.6
115	690	41.6	40	1.66	74
116	696	41.1	40	1.65	74.5
117	702	41	40	1.64	74.8
118	708	40.8	40	1.63	75.1
119	714	40.4	40	1.62	75.5
120	720	40.3	40	1.61	75.8
121	726	40	40	1.6	76.2
122	732	39.6	40	1.59	76.6
123	738	39.4	40	1.57	77.1
124	744	39.1	40	1.56	77.3
125	750	39.3	40	1.57	77.7
126	756	38.9	40	1.56	77.9
127	762	38.5	40	1.54	78.3
128	768	38.5	40	1.54	78.6
129	774	38	40	1.52	78.7
130	780	38	40	1.52	79.1
131	786	37.8	40	1.51	79.3
132	792	37.6	40	1.5	79.4
133	798	37.6	40	1.5	79.6
134	804	37.2	40	1.49	79.9
135	810	37	40	1.48	79.9
136	816	36.9	40	1.47	80
137	822	36.6	40	1.46	80.1
138	828	36.8	40	1.47	80.3
139	834	36.6	40	1.47	80.4
140	840	36.5	40	1.46	80.4
141	846	36.2	40	1.45	80.6
142	852	35.4	40	1.41	80.6
143	858	35.3	40	1.41	80.8
144	864	35.2	40	1.41	80.9
145	870	35.4	40	1.42	81
146	876	35.3	40	1.41	81.2
147	882	35.1	40	1.4	81.3
148	888	35.1	40	1.4	81.4
149	894	34.7	40	1.39	81.4
150	900	34.4	40	1.38	81.5
151	906	34.8	40	1.39	81.7
152	912	35.1	40	1.4	81.7

153	918	34.5	40	1.38	81.9
154	924	34.2	40	1.37	81.8
155	930	33.9	40	1.36	81.9
156	936	33.6	40	1.34	82
157	942	34.3	40	1.37	82
158	948	34.3	40	1.37	82
159	954	34.2	40	1.37	82.1
160	960	34.1	40	1.36	82.2
161	966	33.5	40	1.34	82
162	972	32.7	40	1.31	82.2
163	978	32.5	40	1.3	82.1
164	984	32.7	40	1.31	82.1
165	990	33	40	1.32	82.2
166	996	32.9	40	1.32	82.1
167	1,000	32.2	40	1.29	82.1
168	1,010	31.7	40	1.27	82.1
169	1,010	31.6	40	1.26	82
170	1,020	31.7	40	1.27	81.9
171	1,030	31.8	40	1.27	81.9
172	1,030	32	40	1.28	81.8
173	1,040	31.5	40	1.26	81.9
174	1,040	31.1	40	1.24	81.8
175	1,050	30.7	40	1.23	81.8
176	1,060	30.8	40	1.23	81.8
177	1,060	31.6	40	1.26	81.7
178	1,070	31.7	40	1.27	81.7
179	1,070	31.7	40	1.27	81.8
180	1,080	31.1	40	1.24	81.7
181	1,090	30.3	40	1.21	81.7
182	1,090	30.6	40	1.22	81.7
183	1,100	30.9	40	1.24	81.7
184	1,100	31	40	1.24	81.7
185	1,110	31.2	40	1.25	81.7
186	1,120	30.4	40	1.22	81.8
187	1,120	29.9	40	1.2	81.7
188	1,130	29.6	40	1.18	81.8
189	1,130	29.1	40	1.17	81.8
190	1,140	29.4	40	1.18	82
191	1,150	29.2	40	1.17	82
192	1,150	29.4	40	1.18	82
193	1,160	28.8	40	1.15	82

194	1,160	28	40	1.12	82
195	1,170	27.9	40	1.12	82
196	1,180	28.3	40	1.13	82
197	1,180	29.5	40	1.18	82