Assessment of Nano-crystalline Cellulose as viscosifying agent and fluid loss modifier for drilling fluid

Prepared by

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Johannesburg, 20th October 2017

DECLARATION

I, Ramasela Queen Molekwa; hereby declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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20th October 2017

ABSTRACT

The success of a drilling operation is significantly dependent on the quality of the drilling fluid used, thus it is important to use drilling fluids that will operate optimally in a given exploration environment in order to maximise recovery. As current Oil and Gas fields are approaching their maturity, there is a need to explore further offshore in deeper waters. Drilling technologists are thus faced with a challenge of sourcing improved methods and technologies for exploration operations, often in very harsh environments. Drilling fluid constitutes about 15% of the drilling cost, and the common challenges experienced during drilling are fluid loss and rheological properties necessary to withstand extreme operating temperature and pressure conditions. This study evaluates the impact of different concentrations of Nano-crystalline cellulose (NCC) as additive for bentonite-water based drilling fluid, to improve the rheological properties and fluid circulation control.

TEMPO Oxidation synthesis of NCC yielded spherical NCC of sizes ranging between 40 and 90 nm, supported by strong hydrogen bonding within the NCC structure. Fluid loss measurements were carried out at varying temperatures of 30, 40, 50, 60, 70 °C and pressures of 100, 200, 300, 400 kPa. The increase in NCC concentration in drilling fluid samples from 0.2% to 1.2 wt% NCC resulted in fluid loss reduction ranging from 10.6 to 52.5%. More fluid loss was observed at higher temperatures due to reduced interaction between water absorbed and NCC. Viscosity measurements indicated that higher NCC concentrations improve the thermal stability of the fluid, as observed through increased viscosity of the fluid samples with increasing temperature ranging from 30 to 70˚C. Furthermore, the yield stress was improved at increased NCC concentrations (0.0 to 1.2 wt%) indicating the enhanced ability to suspend and facilitate the removal of drill cuttings and other solids to the surface. There was also better thixotropic behaviour and improved percentage regeneration with increasing NCC concentration from 0.0 – 1.2 w%, allowing NCC based fluid samples to have better flow properties. This confirms that NCC can be used as a potential additive for improvement of drilling fluid properties.

DEDICATION

To my pillars of strength and advocates; my wonderful Mother (Mmatshwene Rachel Molekwa and Grandmother (Ramaesela Lidah Molekwa)

and

to my entire wonderful family

for their continued support and encouragement in the pursuit of growth and excellence

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NOMENCLATURE

NCC	Nano-crystalline cellulose
WBM	Water based muds
OBM	Oil based muds
SBM	Synthetic based muds
EDM	Emulsion drilling muds
IEM	Invert emulsion muds
ADF	Air drilling fluids
TEMPO	2,2,6,6-Tetramethylpiperidin-1-oxyl
RPM	Revolutions per minute
SEM	Scanning electron microscope
MFC	Microfibrillated Cellulose
CMC	Carboxymethyl Cellulose
TEM	Transmission electron microscope
HTHP	High Temperature High Pressure
LTLP	Low Temperature Low Pressure
API	American Petroleum Institute
HCL	Hydrochloric Acid
NaBr	Sodium Bromide
NaCIO	Sodium hypochlorite
NaOH	Sodium Hydroxide
H3PO4	Phosphoric Acid
Mt	Montmorillonite
BT	Bentonite
3ITT	3 Interval Thixotropy Test
Na	Sodium
μ_a/μ_{app}	Apparent viscosity
γ	Shear rate
τ	Shear Stress

$\tau_{\circ}$	Yield Stress
Θ (lb/100ft^2)	Gel strength in pounds per square feet
ºF	Temperature unit: Degree Fahrenheit
℃	Temperature unit: Degree Celsius
μ_{Pl}	Plastic Viscosity
cp	Centipoise
t	Time
ρ	Density
g/cm^3	Density unit, grams per cubic meters
Pa.s	Pascal - second
ω (Rad/s)	Angular velocity in radian per second
φ (min^{-1})	Rotational speed in revolutions per minute
r	Distance between the inner and outer cylinders
s-1	Revolutions per second
σ_m	Measured torque
β_{cor}	Torque correction factor
θ_{600}	Viscometer dial readings at 600 rpm
θ_{300}	Viscometer dial readings at 300 rpm
k	Fluid consistency index
n	Flow behaviour index
kPa	Kilopascal
psi	Pounds per square inch

CHAPTER 1: BACKGROUND AND MOTIVATION

The global population is projected to increase by almost 20% and the global energy demand is estimated to increase by up to 60% in the next 30 years (International Energy Agency, 2015). More than a third of the global energy supply and over 95% of transport energy is attributed to oil and its products. Global oil production is currently estimated to be less than a few million barrels a year, with global consumption at around 30 billion barrels per year (Miller and Sorrell, 2013). Moreover, a growth rate of 1.5% for crude oil production has been reported from 1995 – 2005 and similar growth trends are projected (International Energy Agency, 2015).

Existing oil recovery methods allow for the extraction of about 40% of the oil reservoir and there is a constant need to employ enhanced techniques in order to increase the recovery factor (Muggeridge et al., 2014). As current oil fields are approaching maturity, there is a need to explore deeper waters. Drilling technologists are faced with a challenge to source improved methods and technologies for oil exploration operations. Thus, finding an accurate drilling fluid for drilling in specified and often harsh operating conditions has become a major research area. Although an estimated 10% of the drilling costs are attributed to the drilling fluid, an unsuitable drilling fluid can have detrimental cost implications (Hossain et al., 2015).

The current drilling fluid industrial application investigated is the substitution or enhancement of current conventional fluid additives with nanomaterials as additives; in order to optimise recovery, hence resulting in significant impact on the success of well completions (Abdo et al., 2013). There are several applications of nanomaterials in different industries such as pharmaceuticals, foods and chemicals, one such material is the cellulose derivative called Nano-crystalline cellulose (NCC) (Peng et al., 2011). It is considered to be environmentally safe as it is biodegradable and renewable. NCC is derived from naturally abundant wood biomass and is available as a gel, powder or liquid (Habibi et al., 2010).

The Canadian Forest Nanoproducts Network; Arboranano, has been actively involved in investigating NCC as a loss circulation material in drilling fluid since 2011 (Boluk, 2012). Current research includes methods for large scale production of Nano-crystalline cellulose and subsequent industrial trials by Arboranano. A NCC production capacity of one metric ton per day has been reported at the Canadian Province, Quebec (Boluk, 2012).

Addition of NCC to drilling fluid has the ability to minimise fluid loss by forming a film on the well to prevent mud from seeping into the environment (Li et al., 2015). The NCC-based drilling fluid has been developed and about 1000 kg NCC has been secured for the planned field trials in the near future by Arboranano (Boluk, 2012). This research project thus aims to study the rheological and fluid loss properties of NCC-enhanced drilling fluid to assess the potential of NCC as an additive to optimise drilling fluid properties.

1.1 Research Questions

The successful production of a well is significantly dependent on the performance of the drilling fluid. High energy demands have resulted in a projected rise in deeper offshore drilling occurring in high temperatures and pressures, whereby these harsh conditions affect the viscosity and suspension properties of the drilling fluid (amongst others). This has led to an increase in studies to improve the drilling fluid properties through searching for new additive materials for high temperature and pressure drilling applications. This research aims to answer the following questions:

- Can the addition of NCC enhance the viscosity and fluid loss properties of the drilling fluid?
- Can the addition of NCC improve the thermal stability of the water-based drilling fluid?

1.2 Research Objectives

- Prepare NCCs using TEMPO-mediated oxidation method
- Prepare a water-based drilling mud samples by mechanical mixing of bentonite with varying concentrations of NCC
- Investigate the effect of temperature and NCC concentration on the fluid loss and the viscosity of the drilling fluid samples
- Investigate the effect of aging temperature and time on the fluid loss and viscosity in order to improve the drilling process parameters based on NCC

1.3 Research Outline

This research report comprises of the following chapters:

Chapter 1: Background of the energy and drilling operations challenges and proposed use of Nano-crystalline cellulose to improve existing drilling fluids.

Chapter 2: Literature review to introduce key concepts of drilling fluids and detail of previous work that has been done in a similar research area where Nano-crystalline cellulose were investigated for drilling fluid applications.

Chapter 3: Detailed account of experimental methods, materials and analytical techniques employed for characterisation, fluid loss and rheology.

Chapter 4: Results obtained for the characterisation of Nano-crystalline cellulose, fluid loss and rheology tests of mud samples with varying Nano-crystalline cellulose concentrations followed by an interpretation of the observations and discussion.

Chapter 5: Conclusion suggesting the use of Nano-crystalline cellulose as viscosifying agents and fluid loss modifiers in drilling fluid applications in order to improve the drilling process and recommendations for possible focus area in future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Drilling fluids

Drilling fluids (also known as drilling muds) are available at relatively low costs but sourcing the proper fluid has significant impact on the success or failure of the drilling operations. Primarily used for lifting drill cuttings to the surface, drilling fluids also have an important role to contribute to the completion of a drilling well with optimal economical, safety and efficiency benefits (Bloys et al., 1994). Given the rise in deep water drilling, often in significantly hostile environments, there is a need for drilling fluids with advanced physical and chemical properties that will allow them to function in a wide variety of drilling conditions (Shah et al., 2010). This has resulted in recent studies of the composition of the drilling fluids targeting required behaviours. Since drilling fluids have become a significant expense in a drilling operation, fluids with varied compositions and properties with ease of control are more desirable to manage operational costs (Caenn et al., 2011; Rogers, 1978).

2.1.1 Functions of Drilling Fluids

Drilling fluids play an important role during the drilling operations, and perform the following functions (Bourgoyne et al., 1986):

- “Remove the rock fragments from the well to the surface during the drilling process,”
- “Control formation pressure,”
- “Keep the drill string submerged to reduce the effective weight of the drill string on the hook load,”
- “Exert hydrostatic pressure against subsurface formations to avoid fluids flowing back to the well, and”
- “Cool and lubricate the drill string and bit.”

Prior to being used, a drilling fluid should be tested in order to avoid corrosion of the drilling equipment and subsurface casing. The drilling fluid needs to consistently perform the above functions during the drilling operation irrespective of the formation type and operating conditions (Bourgoyne et al., 1986). Severe drilling problems; such as lost circulation and instability with varying conditions, can occur should any of the functions not be performed properly.

This could result in significant financial losses or even lead to drilling operations being abandoned. Amongst other key properties, a drilling fluid should have sufficient density to prevent formation of influx, viscosity and reduce fluid lost capacity (Abdo et al., 2013; Cole et al., 1976).

2.1.2 Drilling Fluid Types

There are different types of drilling fluids which are used in the petroleum industry, depending on the temperature and pressure of a drilling well (Caenn et al., 2011). The choice of drilling fluid is thus based on its performance and drilling conditions (Darley and Gray, 1988). The most common types of drilling fluids are water-based muds (WBM) and oil-based muds (OBM) (Abduo et al., 2016). Water-based drilling fluids are characterised by the suspended solid particles in water (or brine solution) and oil-based drilling fluids are characterised by the suspension of solids in oil. The solid component comprises of organic colloids and clays to contribute to the viscosity and filtration properties of the drilling fluid (Caenn et al., 2011). The following are different drilling fluid types (including the two mentioned above):

Water based muds (WBM)

The water-based drilling fluid is the most frequently used and it comprises of a continuous liquid phase (water), the colloidal fraction (reactive, about 0.005 – 1 micron) and inert fraction (weight material, about 1 – 50 microns) (Bergaya, 2006 and Bloys et al., 1994). The non-toxicity of the WBM disadvantages the use of other drilling fluid types. One of the most common materials used as a weighting agent is barite because it has a specific gravity of 4.1 and fewer solids are required to yield desired fluid density (Caenn et al., 2011). Addition of bentonite in the colloidal fraction enables mud control (Caenn et al., 2011). WBM consist of water or brine as the base fluid, which are environmentally friendly and can easily remove the drill cuttings. Additive materials with combined functions are preferred during the drilling operation, such as the use of surfactant with viscous and elastic characteristics. Viscoelastic surfactant based muds are expensive compared to conventional polymer in based muds; they require less conditioning thus saving amount of time lost in a drilling operation (Shah et al., 2010).

Oil based muds (OBM)

This type of mud has an expensive base fluid compared to the WBM. OBM presents several advantages such as excellent fluid loss control, no shale swelling, adequate lubrication to drill bits, and excellent ability to transport crushed materials (Shah et al., 2010).. Although given the above advantages, OBM show some drawback which include poor bonding between cement and formation due to oil wet surfaces, poor filter cake cleanup and environmental pollution. The use of refined palm oil in OBM; which is less toxic to marine and freshwater organisms, is advanced so as to reduce pollution caused by materials such as diesel (Dosunmu, 2010).

Synthetic based muds (SBM)

SBM can be used as alternatives where regulation prohibits the discharge of crushed materials from the use of OBM. SBM has comparable composition with OBM, but SBM contain low aromatic content, low toxicity and desirable environmentally friendly characteristics compared to OBM (Onwukwe, 2012). The currently revised SBM are made of linear paraffins or linear alpha olefins and have more advantages compared to the previous SBM which contained ether or esters. Advantages include low kinematic viscosity, improved environmental friendliness, cost effectiveness in production and application at lower operating pressures (Friedheim, 1997). In addition, the biodegradability of SBM makes this type of fluid more competitive for environmental performance (Shah et al., 2010).

Emulsion drilling muds (EDM)

These drilling muds consist of two phases, external phase (water or brine solution) and internal phase (Oil). There is a need to use surfactant to make the two phases miscible. These fluids are environmentally safe, have similar advantages to WBM and are less expensive compared to OBM (Shah et al., 2010).

Invert emulsion muds (IEM)

In IEM, oil becomes the continuous phase (external phase) and water (or brine) the dispersed phase (internal phase). Similar to the EDM, the fluid stability is achieved by addition of surfactants. IEM produces thin filter cake, thus increasing the hole stability and rate of penetration (Jha, 2014). Its non-biodegradability and instability at high temperatures and pressures make IEM less competitive in comparison to other fluids (Patel, 1999). To increase the biodegradability of IEM, researchers have proposed the use of materials such as synthetic esters (as external phase). As a result, IEM becomes resistant to contamination in the offshore operation, and highly stable under high temperature and pressure (Shah et al., 2010).

Air drilling fluids (ADF)

ADF are pneumatic drilling fluids, which use a compressed air or gas to remove cuttings from the wellbore. ADF require specialised equipment for effectiveness of operations (Lyons, 2009). These types of fluids are generally used in underbalanced drilling and present several advantages including high rate of penetration, no solid contamination, no formation damage and no lost circulation (Shah et al., 2010).

Foam fluids

These are pneumatic drilling fluids which are used in deepwater and ultra-deep water drilling; where the operating pressure is very narrow (Chen, 2005). These fluids require better control of mud density to avoid fractures (for slight increase in mud density) and fluid influx into the wellbore due to high pore pressure (for slight decrease in mud density). Foam fluids comprise of a liquid phase (minor component, water or brine solution) and gaseous phase (major component, inert gas). The fluid has a higher ability to transport cuttings compared to air drilling fluids (Shah et al., 2010).

2.1.3 Functions and additives materials for Water Based Drilling Fluids

Due to the simple formulation and advantages of WBM, this research study focused on the improvement of WBM properties using cheaper materials found in South Africa. An overview of the currently used additives materials and their functions is presented in this report in order to give a brief understanding of additive materials selection or their modification for required functions. Table 2.1 provides WBM additives materials and their functions (Van Dyke, 2000). Additives materials are added to enhance muds performance by modifying their properties in order to optimise the drilling operation (Skalle, 2010).

Table 2.1: Additive materials and their functions for water based fluid (Van Dyke, 2000; Skalle, 2010)

Functions	**Swelling inhibitors**	**Viscosity reducers**	**Dispersants**	**Temperature stability**
	Reduce swelling	Used to reduce viscosity	Modify the relationship between viscosity and solids volume reducing gel strength and increasing the pumping ability of a fluid. More specifically, they act as deflocculates to reduce attraction of clay particles that cause high viscosity and gelation	Increase rheological and filtration stability in fluids exposed to high temperatures.
Materials	Salt, lime, gypsum, encapsulating	Lignosulfonate, lignites, Tannates, phosphates	Tannins, lignite and lignosulphates, polyphosphates	Acrylic or sulphenated polymers, lignite, lignosulphate, tannin

Functions	**Bactericides**	**Calcium removers**	**Corrosion inhibitors**	**Alkalinity, pH control**
	Used to reduce bacteria count	To prevent and overcome contaminating effects of anhydrite, gypsum and calcium sulphates	Prevent corrosion, pH control, neutralize hazardous acid gases such as H_2S, prevents formation of scale in drilling fluid	To control acidity and alkalinity of fluid
Materials	Para formaldehyde, caustic soda, lime and starch preservatives.	Caustic soda, soda ash, bicarbonate of soda and certain polyphosphates	Hydrated lime, amine or phosphate based products.	Lime, caustic soda, soda ash, bicarbonate of soda

Functions	Defoamers	Emulsifiers	Filtrate loss	Lost circulation materials
	Reduce foaming action especially in brackish or saturated saltwater muds	To create a heterogeneous mixture of two insoluble liquids	Reduce water loss from the drilling mud into the formation.	To plug the zone of loss in the formation.
Materials		Oil based muds – fatty acids, amine-based chemicals. Water based muds – detergents, soaps, organic acids	Bentonite clay, CMC, lignite, polyacrylate, pregelatinised starch	

Functions	Flocculants	Foaming agents	Lubricants	Shale inhibitors
	Increase viscosity, improve hole cleaning, de-water or clarify low-solids fluids. Particles in suspension will aggregate into flocs causing solids to settle out	Permit air or gas drilling through water-bearing formations.	Increase horsepower transmitted to the bit by reducing the coefficient of friction; also reduces torque and drag.	Reduce shale hydration when drilling water sensitive shales, thereby preventing excessive wellbore enlargement and caving of shale
Materials	Salt, hydrated lime, gypsum, soda ash, bicarbonate of soda, polymers.	Surfactants (foamers)	Oils, graphite, synthetic liquids, glycol or surfactants	Gypsum, sodium silicate and calcium lignosulfonates, lime and salt

2.2 Drilling fluid Rheology

2.2.1 Rheology measurements equipment

There are different equipments used to measure the rheological properties of drilling fluids. The drilling fluid rheology is affected by the operating pressure, temperature and fluid composition (Lavrov, 2016). Currently used equipments are limited and can only measure low range of viscosity, pressure and temperature. There is a need to design equipment, which could analyse the fluid behaviour onsite to withstand severe conditions of pressure and temperature.

Fann 35 viscometer

The viscosity of the drilling mud is usually measured onsite using the Fann 35 viscometer. This equipment works at atmospheric pressure for temperatures ranging from 25^0C to 93.33^0C. There are only six different settings of shear rate, which is a limitation for better evaluation of fluid behaviour. Therefore, extrapolation is required for measurement of rheological behaviour based on the Bingham model (Almahdawi et al., 2014; Cole et al., 1976; Rogers et al., 1978; Skalle, 2012).

$$\text{Plastic viscosity } (\mu_{Pl}) = \frac{\tau_x - \tau_y}{\gamma_x - \gamma_y} \tag{2.1}$$

Where $\tau_{x\ or\ y}$ and $\gamma_{x\ or\ y}$ are yield stress and shear rate, respectively

Funnel viscometer

This type of viscosity measurement is routinely used in the drilling industry (Azar, 2007). The Marsh Funnel is simple yet effective in measuring relative mud viscosities. It measures the time (in seconds) required for a set volume of fluid to flow through the tube at the bottom of the funnel (Cole et al., 1976; Rogers et al., 1978).

$$\mu_{app} = \rho\,(t - 25) \tag{2.2}$$

Where μ_{app} = apparent viscosity (in centipoise), ρ = density (in g/cm^3) and t = time for a quart funnel to flow (in seconds)

Rheometer

Rheometers are advanced instruments, which can take measurements in rotation and oscillation modes (Malouf, 2008). Several variations of rheometers are used depending on the viscosity range required. Calculations of the viscosity for a rotational rheometer with concentric cylinder is shown in Figure 2.1

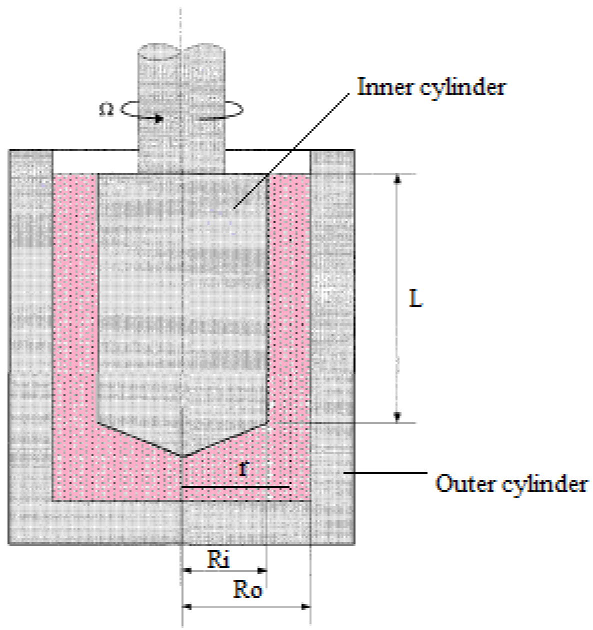

Figure 2.1: Schematic diagram of rheometer bob cylinder and outer cylinder (Malouf, 2008)

The viscosity μ (Pa.s) is given as the ratio of shear stress (τ_i) and shear rate (γ_i)

$$\mu \text{ (Pa.s)} = \frac{\tau_i}{\gamma_i} \tag{2.3}$$

Shear rate calculation is based on the geometry of the inner (R_i) and outer (R_0) cylinders, angular velocity ω (Rad/s), and rotational speed φ (min^{-1}). At the inner cylinder, the shear rate (γ_i) is given by:

$$\gamma_{i.} = 2\ \omega\ \frac{R_0^2}{R_0^2 - R_i^2} \tag{2.4}$$

With angular velocity given by:

$$\omega \text{ (Rad/s)} = \frac{\pi\ \varphi}{30} \tag{2.5}$$

Within the annulus, the shear rate (γ_r) is given by:

$$\gamma_{r.} = \frac{2\ \omega}{r}\ \frac{R_0^2}{R_0^2 - R_i^2} \tag{2.6}$$

Where r is the distance between the inner and outer cylinders

At the inner cylinder, the shear stress (τ_i) is given by:

$$\tau_{i.} = \frac{\sigma_m}{2\ \pi\ L\ R_i^2\ \beta_{cor}} \tag{2.7}$$

Where σ_m and β_{cor} are measured torque and torque correction factor

At the outer cylinder, the shear stress (τ_0) is given by:

$$\tau_{0.} = \frac{\sigma_m}{2\ \pi\ L\ R_0^2\ \beta_{cor}} \tag{2.8}$$

Between the inner and the outer cylinders, the shear stress (τ_i) is given by:

$$\tau_{r.} = \frac{\sigma_m}{2\,\pi\,L\,r\,\beta_{cor}} \quad (2.9)$$

2.2.2 Drilling mud properties

The measurement of drilling fluid properties such as density, gel strength, viscosity and yield point gives a better profile for its application at different drilling conditions.

Rheological properties

The rheological properties describe the flow behaviour of a drilling fluid at different operating conditions (Makinde, 2011). The nature of the flow is determined once the shear stress initiates the movement of the fluid. The main rheological properties are discussed below:

Gel strength

Gel strength measures the shear stress required to initiate flow of a drilling fluid that has been dormant for a period of time (Awele, 2014). This can also be determined by the ability of a drilling fluid to suspend drill cuttings (and other solids) when the drilling mud circulation stops during the removal of the drill string from the wellbore (tripping). Flocculation favours an increase in gel strength but this should be controlled to avoid pipe breakdown during tripping. The gel strength indication helps in reformulating the drilling fluid in case of degradation, often occurring in ultra-deep operations. The reformulated fluid renews its ability to transport cuttings (Awele, 2014; Olatunde, 2012). A drilling fluid with higher viscosity will not necessarily have high gel strength therefore; the two properties should not be interchanged (Awele, 2014). The viscosity and gel strengths tend to increase during the drilling operation through the addition of drill cuttings. This can be modified by operating conditions or by addition of more fluids

Plastic viscosity

Plastic viscosity gives a measure of the internal resistance to flow due to the amount, type and size of solids present in the drilling mud (Riyapan, 2012). The resistance to flow is caused by mechanical friction between the solids with one another in the drilling mud, the solids and the liquid surrounding them, and the shearing of the liquid itself. As a result, the plastic viscosity depends on the concentration of solids in the drilling mud (Awele, 2014; Riyapan, 2012). An increase in plastic viscosity would delay the rate of flow and will increase the pressure drop down the drill string (Awele, 2014). Therefore, it is necessary to keep a low plastic viscosity for safe operating process, by controlling factors such as time, temperature, agitation and the amount of drilled solids in the drilling mud (Awele, 2014; Annis, 1996).

Yield point

Yield point is a measurement of the electro-chemical or attractive forces between the particles in a drilling fluid underflow conditions (Riyapan, 2012). This is a result of opposite charges located on or near the particle surfaces causing initial resistance to flow. These forces depend on the type of solids present and their surface charges, the concentrations of these solids, and the type and concentration of other ions in the fluid environment (Abdou et al., 2011 and Riyapan, 2012). Regulation of yield point helps in maintaining a desired viscosity. Chemical treatment is necessary for controlling the electrical interaction of the solids while the mechanical interaction is controlled by the regulation of the quantity and nature of solids in a drilling fluid (Abdou et al., 2011).

Thixotropy

Thixotropy is a property of a fluid described by the decrease in viscosity with application of constant shear stress and shear rate. This behaviour is time-dependent and reversible (Seyssiecq, 2003). When a fluid is allowed to rest over a period of time, its ability to have reformation of the gel structure defines its thixotropic behaviour (Schramm, 2000). The structure of non-thixotropic fluids can be broken by shear and fail to reform once destroyed. A three-dimensional network structure is created through bonds in thixotropic dispersions, known as a gel and these forces are relatively weak compared to forces within particles such that they break easily when the dispersion is exposed to shear over a period of time (Figure 2.2) (Schramm, 2000).

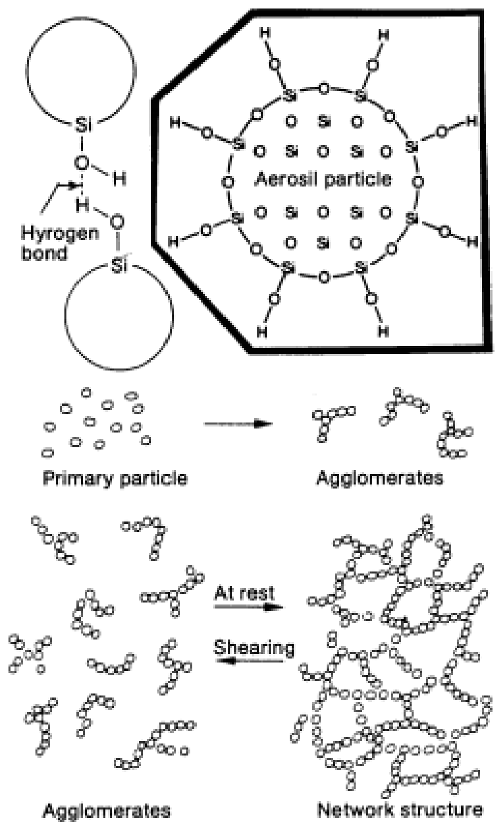

Figure 2.2 Interaction of particles in thixotropic dispersions (Schramm, 2000)

Filtration Control and Lost Circulation

Filtration control is particularly important when the hydrostatic pressure is greater than that of the formation. Drilling fluids must thus minimise fluid loss by a quick formation of a filter cake which is thin enough for the product to flow into the wellbore (Kabir 2011). Encapsulated lime, shredded cellophane and hydrolysed poly(acrylonitrile) have been widely used as lost circulation additives amongst others (Caenn et al., 2011). Drilling operators require that filtrations tests be performed under temperature and pressure conditions simulating those of a drilling well. The High Pressure High Temperature Filtration (HPHT) instrument can simulate drilling pressures of at least 1000 psi (68.95 bar) and maximum operating temperatures of 350°F (176.67°C). The Low Pressure Low Temperature (LPLT) and HPHT filtration Instruments are used for filtration measurements of drilling fluids as recommended by the American Petroleum Institute (Caenn et al., 2011; Rogers, 1978). Lost circulation occurs due to natural fissures and fractures in the formation caused by tectonic forces and mud pressures exceeding the formation fracture pressure (Zhang, 2002). Materials such as fibers are added through the fissures and fractures to reduce lost circulation (Rabia, 2002).

Effect of temperature on the rheological properties and fluid lost control

The drilling well temperatures increase with depth and higher temperatures have significant effect on the components of the drilling fluids (Amani, 2012). The drilling fluid components tend to lose effectiveness and stability thus they often degrade with increasing temperatures. The common rise in temperature with depth is 1°F per 60 to 100 feet. Critical temperature for starch is about 225°F (107°C) and for cellulose polymers it is around 275°F (135°C) (Caenn et al., 2011). Drilling fluids have different temperature endurances, for example, asphaltic oil based drilling muds have been used at operating temperatures of up to 550°F (287°C). There is an increasing need to develop alternative components that will contribute to temperature endurance without compromising the functional properties of drilling fluids (Caenn et al., 2011; Cole et al., 1976).

2.2.3 Rheology models for drilling fluids

In the drilling sector, the rheological models help in controlling the rheological behaviour of drilling fluid. Models describe the relationship between shear rate and the shear stress. Two types of models were developed, namely; Newtonian (direct proportionality between shear rate and shear stress) or Non-Newtonian (indirect proportionality between shear rate and shear stress) (Skalle, 2010). The use of a rotational viscometer aids in determination of the rheological model constant by plotting the shear stress against shear rate from the rotational viscometer data.

Newtonian Model

A Newtonian drilling fluid has a linear relationship between the shear stress (τ) and the shear rate (γ). The fluid viscosity (μ) can be determined from the slope of graph. Figure 2.3 illustrates the relationship between the two parameters.

Figure 2.3: Flow curve for Newtonian model (Awele, 2014)

The Newtonian model is given by equation (2.10)

$$\tau = \mu \gamma \qquad (2.10)$$

Bingham Plastic Model

The Bingham Plastic Model describes the fluid movement by modifying the Newtonian model, overlooking the minimum force applied before the movement takes place (Awele, 2014). The minimum stress at which movement has been initiated is called yield point (τ_y) or yield strength. However, this model cannot accurately predict the fluid behaviour at very high shear rates or at low shear rates (Awele, 2014; Riyapan, 2012). The Bingham plastic model profile is given in Figure 2.4 below.

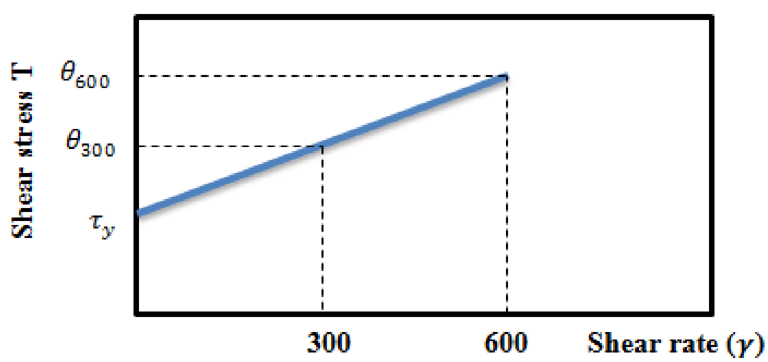

Figure 2.4: Flow curve for Bingham plastic model (Awele, 2014)

The Bingham plastic model is given mathematically by equation (2.11)

$$\tau = \tau_y + \mu \gamma \qquad (2.12)$$

The plastic viscosity (μ_{Pl}) and yield point (τ_y) can be determined experimentally at different shear rates. Two approaches are used to determine the plastic viscosity and yield point, namely; the (a) oil field approach and the (b) standard approach (Awele, 2014).

(a) Oil field approach

The plastic viscosity and yield point between the 600 and 300 rpm dial readings using Bingham plastic model are given by equations (2.13) and (2.14), respectively.

$$\mu_{Pl} = \theta_{600} - \theta_{300} \tag{2.13}$$

$$\tau_y = \theta_{300} - \mu_{Pl} \tag{2.14}$$

Where θ_{600} and θ_{300} are viscometer dial readings at 600 and 300 rpm, respectively.

(b) Standard approach

The plastic viscosity and the yield points are given by equations (2.15) and (2.16), respectively.

$$\mu_{Pl} = \frac{\tau_{600} - \tau_{300}}{\gamma_{600} - \gamma_{300}} \tag{2.15}$$

$$\tau_y = \tau_{000} - \mu_{Pl} * \gamma_{600} \tag{2.16}$$

Power Law Model

The Power Law model is a nonlinear relationship, which accurately predicts the fluid behaviour at high shear rates (Nguyen, 2012). This model is given by equation (2.17):

$$\tau = k\,\gamma^n \tag{2.17}$$

Where k and n are the fluid consistency index and flow behaviour index, respectively

The viscosity of the fluid is determined by the value of k, the more viscous the fluid is, the higher the k value. The power *n* measures the degree of non-Newtonian behaviour of the fluid (If n = 1, the fluid behaves as a Newtonian fluid) (Awele, 2014; Riyapan, 2012). The Power Law model profile is given in Figure 2.5.

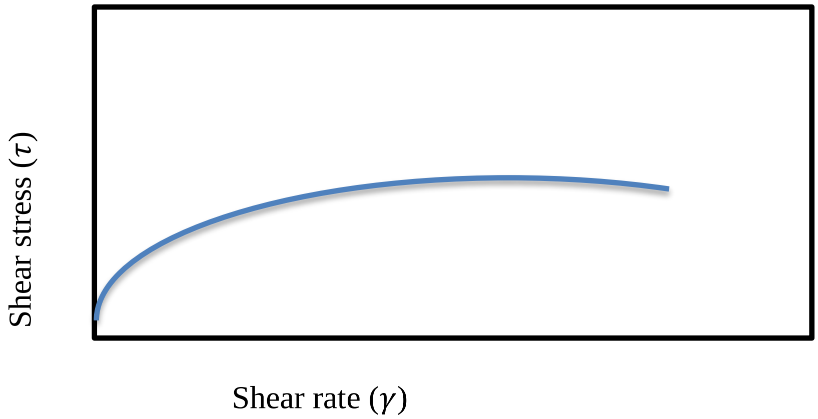

Figure 2.5: Flow curve for Power Law model (Awele, 2014)

Herschel-Buckley Model

The Herschel-Buckley model (Figure 2.6) is a modified Power Law model, which requires a yield stress to initiate flow (Awele, 2014). This model describes the flow behaviour of most drilling fluids; at n = 1, the model becomes a Bingham plastic model and when the yield point vanishes, the model fits the Power Law model. The Herschel-Buckley model equation is given by equation (2.18)

$$\tau = \tau_y + k\,\gamma^n \qquad (2.18)$$

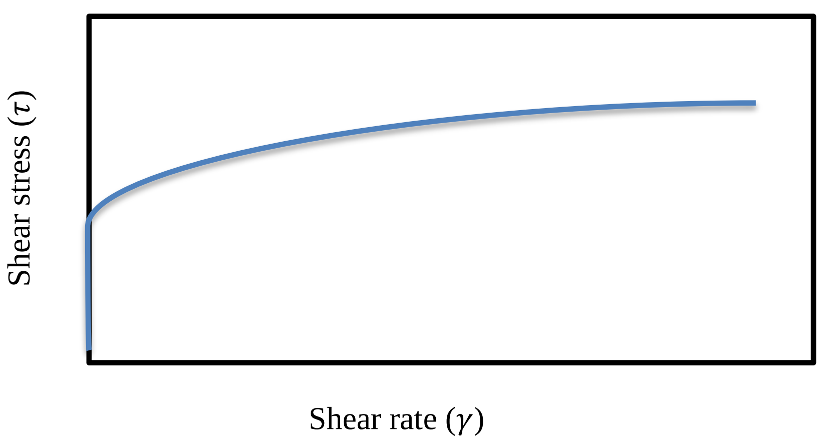

Figure 2.6: Flow curve for Herschel-Buckley model (Awele, 2014)

Casson Model

The Casson model (equation 2.19) was initially used to determine rheological properties of paints and inks (Khalil and Mohamed, 2012). This two parameter model has been successfully used to describe viscoelastic fluid properties, especially in drilling fluids with high bentonite concentrations. The model has been found to be more accurate at shear rates that are very low and very high (Becker, 2003).

$$\sqrt{\tau} \;=\; \sqrt{\tau_0} + \sqrt{\mu_p \gamma}\,, \quad \tau > \tau_0 \tag{2.19}$$

Where τ is shear stress, τ_0 is the yield stress, μ_p is the plastic viscosity and γ is the shear rate.

2.3 Bentonite

The size variation of the bentonite clay has an effect on the surface area of the particles which subsequently affect the rheological properties of bentonite muds. Abdou et al. (2013) compared the rheological properties of the local-bentonite and nano-bentonite in drilling fluids. From this study, it was observed that the apparent viscosity for local-bentonite increased from 3 to 35 cp after treatment, which is higher than the American Petroleum Institute (API) requirements (15 cp). For nano-bentonite, the apparent viscosity was lower than the API standard as it only increased from 2.5 to 6 cp. The same results were observed for the plastic viscosity. After treatment, the local bentonite had higher gel strength (2 to 20 lb/ 100ft^2) as compared to the nano-bentonite which had gel strength lower than the API standard. Treated local bentonite showed improved fluid loss from 22 to 13 ml whereas nano-bentonite had much higher fluid loss (240 to 54 ml) than the maximum acceptable API bentonite fluid loss (Abdou et al., 2013). Water based muds with less bentonite content show better thixotropic properties than more structured mud formulations with high bentonite content (Dolz et al., 2007)

2.4 Cellulose as drilling fluid additive

Cellulose is a biopolymer that is most abundant in nature. It is a renewable material which has low toxicity and is biodegradable (Vroman, 2009). Application of cellulose and its derivatives has advanced in recent years, because of its desirable properties such as biodegradability, hydrophilicity and chirality (Peng et al., 2011). One such derivative is Nano-crystalline cellulose (NCC), which is being studied as a nanomaterial of choice for various applications such as foods (e.g packaging), chemicals (e.g adhesives, coatings), pharmaceuticals (e.g drug delivery) and drilling fluid technology amongst others (Habibi, 2010; Peng et al., 2011). NCCs are mainly synthesised through acid hydrolysis of cellulose fibres and they have high surface area, nanoscale dimension, high modulus and specific strength relative to cellulose fibres (Lu and Hsieh, 2010; Wang et al., 2007). At a few hundred nanometers in length with diameters of around 10-20 nanometers, NCCs have different morphologies depending on origin and method of preparation (Peng et al., 2011; Habibi et al., 2010). NCC prepared by Sulphuric Acid Hydrolysis of Microfibrillated Cellulose (MFC) have shown morphology of rod (Figure 2.7) (Peng et al., 2011) and spherical necklace NCC have been prepared through mixed acid (sulphuric acid and hydrochloric acid) hydrolysis of microcrystalline cellulose (MCC) (Figure 2.8) (Wang et al., 2007). Addition of NCC to Bentonite water based fluids resulted in significant enhanced viscosity, stability, yield point and fluid loss control properties as compared to the addition of Microfibrillated Cellulose (MFC) to Bentonite water based fluids (Li et al., 2015).

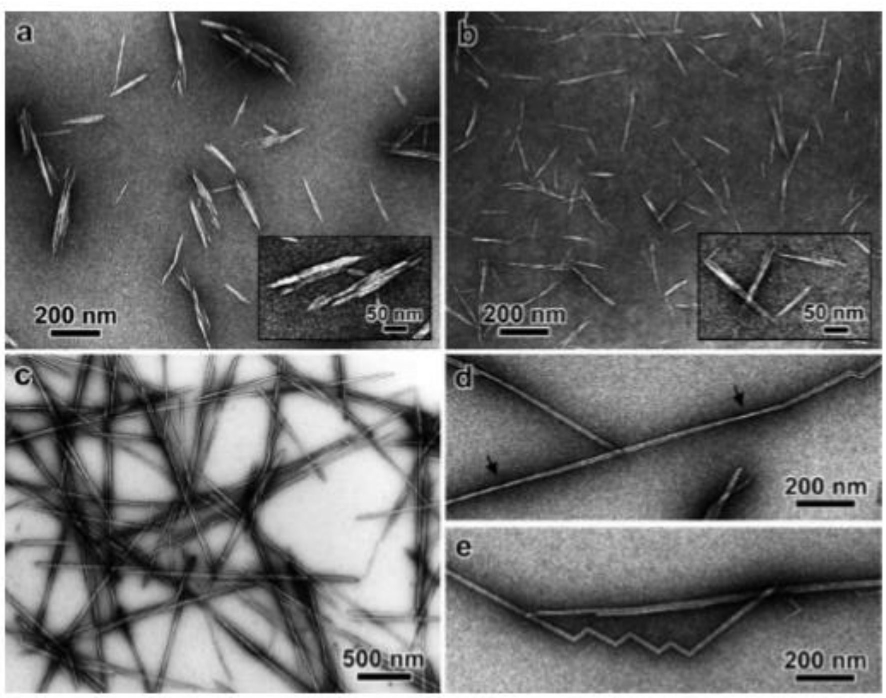

Figure 2.7: TEM images of nanocrystals produced through acid hydrolysis of cotton (a), avicel (b) and tunicate cellulose (c-e) (Peng et al., 2011)

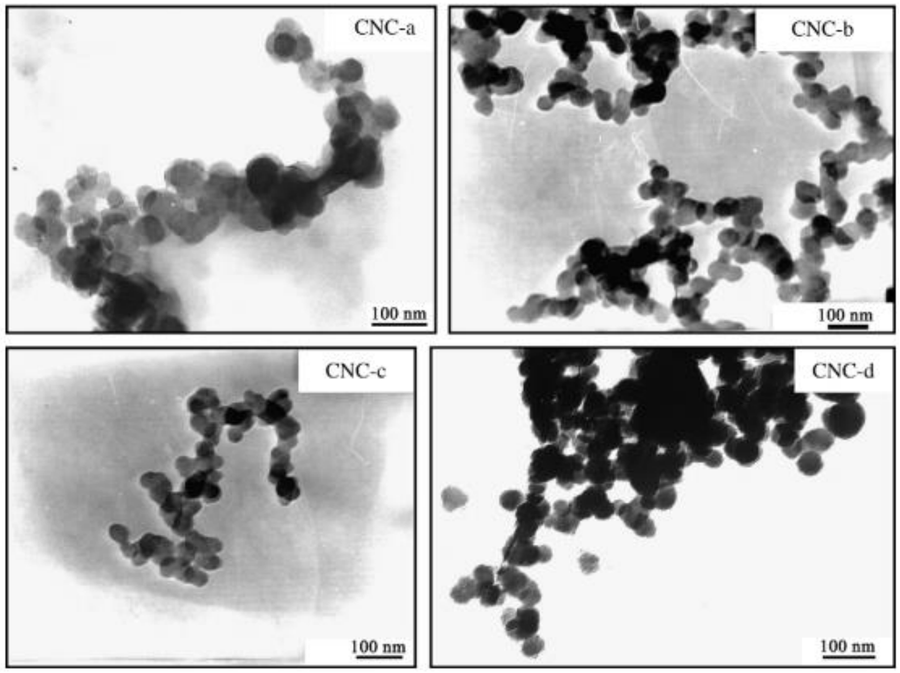

Figure 2.8: TEM images of spherical Nanocrysalline cellulose (NCC) prepared through mixed acid hydrolysis (Wang et al., 2007)

2.4.1 Rheological Properties of Nano Crystalline Cellulose Suspensions

Urena-Benavides et al. (2011) investigated the effect of temperature on the viscosity and also the viscosity profile against the NCC concentrations. The authors prepared aqueous suspensions with NCC concentrations ranging from 3.07 to 17.3 vol %. The effect of temperature was studied for the above NCC concentrations between 20 and 45^{o}C. There was an observed decrease in viscosity with an increase of temperature for lower NCC concentrations (between 3.07 to 6.99 vol%), whereas no effect was observed up to 35^{o}C for higher concentration, except for an increase of viscosity with temperature between 35 to 40^{o}C. There was an observed increase in viscosity for NCC concentration from 3.07 to 12.1; but for higher concentrations, the increase was not significant. This study showed little effect of shear rate on the viscosity at low NCC concentrations and a significant decrease of shear rate at higher NCC concentrations (Urena-Benavides et al., 2011).

Li et al. (2015) studied the effect of cellulose nanoparticles on fluid loss and rheological properties of bentonite water-based drilling fluids. The authors prepared the NCC/Bentonite and microfibrillated cellulose (MFC)/BT water-based drilling fluids with NCC and MFC concentrations of 0.1, 0.25, 0.5, and 1.0 wt % for a comparative study. The steady-flow shear viscosity was measured in the shear range of 0.1 to 1200 s^{-1} at 25 °C. At 0 w% NCC, there was no significant change in viscosity observed with increasing shear rate in bentonite water-based drilling fluids. At higher concentrations between 0.5 and 1.0 wt%, both NCC/BT and MFC/BT suspensions showed resultant lower viscosities at higher shear rates, and vice versa. MFC suspensions showed higher viscosities than NCC suspensions, however, the inverse was observed when bentonite was introduced, thus; NCC/BT suspensions had higher viscosities as compared to MFC/BT suspensions at the same concentration, i.e. 1.0 w% NCC. MFC resulted in the increase of viscosity to 4.849Pa·s and 1.448Pa.s, respectively citing improved surface interaction between NCCs and bentonite layers. Higher shear stress was also observed in NCC/BT suspensions as compared to MFC/BT suspensions at the same concentration. At 1.0 w% NCC and MFC, the MFC/BT suspension had a yield point of 0.88Pa whereas the NCC/BT suspension had an even higher yield point of 3.12 Pa (Li et al., 2015).

Filtration properties were measured at room temperature and a pressure of 100 psi. The volumes of filtrate through the filter paper were determined at 1.0, 7.5, 15, 20, and 30 min after each measurement. There was no significant impact on fluid loss observed in the case of MFC/BT suspensions but there was a decrease in fluid loss with an increase in NCC concentration from 0.1 to 1.0 w%; where the fluid loss volume decreased from 31.0 to 19.3 mL. The study showed that NCCs provide better rheological properties as compared to MFCs and only an addition of small amounts of NCCs was required for the improved properties; implying that the amount of Bentonite needed for the water based drilling fluid can be reduced. At temperatures between 20 and 80°C, the NCC/BT suspension showed better thermal stability as the viscosities were well maintained across the different concentrations whereas the viscosity of the MFC/BT suspension dropped from 60°C (Li et al., 2015).

CHAPTER 3: EXPERIMENTAL AND ANALYSIS

3.1 Materials

Microfibrillated cellulose suspension (3.2%), Na-Bentonite from (Sigma-Aldrich, S.A.), TEMPO (2,2,6,6-tetramethylpipiridine-1-oxyl), 13% sodium hypochlorite(NaClO) from (Rochelle Chemicals and Lab Equipment C.C., S.A.), sodium bromide (NaBr), sodium hydroxide (NaOH) pellets, and deionised water to prepare aqueous solution for different NCC concentrations and bentonite slurry.

3.2. Experimental Procedure

3.2.1 Preparation of Nano-crystalline cellulose

Nano-crystalline cellulose preparation was adapted from Makonjwa (2015). Microfibrillated cellulose (MFC) was dispersed in deionised water overnight followed by the addition of 0.369g 2,2,6,6-Tetramethylpiperidine (TEMPO) and 3.69g sodium bromide (NaBr). The oxidation reaction was then started by adding 1.12g Sodium hypochlorite (NaClO) per gram of cellulose. The pH of the reaction was maintained at 10 through continuous addition of 0.5M NaOH solution droplets as the pH meter showed a decrease in pH for 6 hours or continued until the reaction pH did not decrease indicating that the reaction was complete. The oxidised cellulose was then washed using deionised water and filtered with filter paper. Post washing, the oxidised cellulose/water slurry was sonicated for 45 min using a sonicator at an output power of at least 300W in an ice bath. The dispersion was then stored at 9ºC before use.

3.2.2 Mud preparation

Mud batches of 6 wt% bentonite were prepared by adding bentonite to deionised water while stirring simultaneously with a magnetic stirrer for 45min to achieve homogeneity. Water-bentonite dispersions were then mixed with NCC to form 0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 wt% NCC batches and allowed to rest for 16 hours.

3.3 Analysis

3.3.1 Characterisation of Nano-crystalline cellulose

Transmission electron microscopy (TEM) analysis was conducted using an FEI Tecnai T12 instrument to investigate the morphology and nano crystal size of the NCC by placing drops of dilute NCC suspension on a carbon-coated copper grid. Once dried, the sample was subjected to varying magnifications under a microscope.

3.3.2 Fluid Loss

Fluid loss tests were conducted using the laboratory filter press equipment (Figure 3.1). Li et al (2015) studied the fluid loss properties of NCC-Bentonite based mud samples (at 689.5 kPa and room temperature) for NCC w% of 0.1, 0.25, 0.5, 1.0% and reported a steady decrease in fluid loss with increasing NCC concentration with a notable 44% decrease in fluid loss for the NCC 1.0 w% sample. A mud sample of 1.0 w% NCC was the reported optimum fluid loss modifying concentration by Li et al (2015). 100 ml of the prepared mud sample of 1.0 w% NCC was first heated to 30, 40, 50, 60 and 70 °C using a controlled hot plate before being transferred into the filter press measuring cell. The mud samples, heated at different temperatures, were pressurised at 100, 200, 300 and 400 kPa using air; and the filtrates were recorded after 30 minutes. 100 ml of prepared mud samples (0.0, 0.2, 0.4, 0.6, 0.8 and 1.2 w% NCC) were used for filtration test.

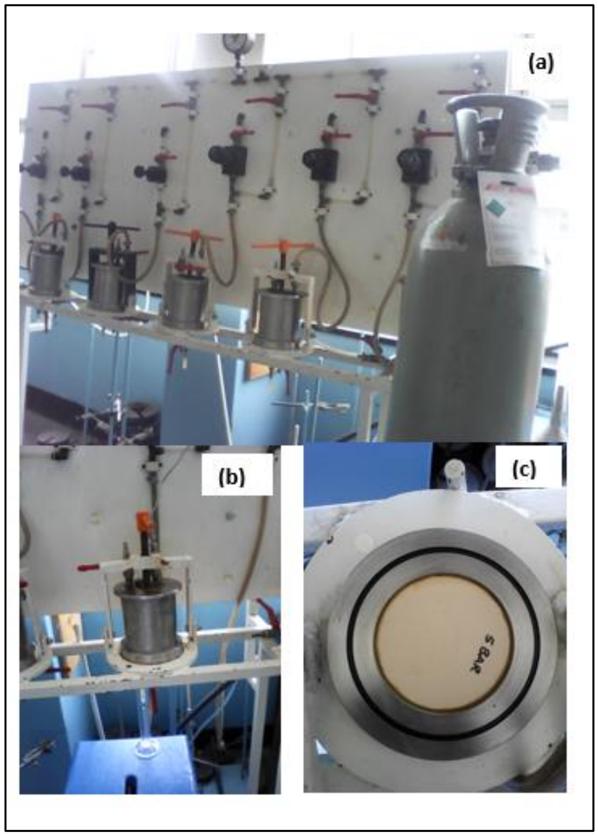

Figure 3.1: Fluid loss equipment with air cylinder (a), graduated cylinder (b) used for filtrate collection and the 5 bar ceramic disc (c) for the cell used (Civil Engineering Soil laboratory, University of the Witwatersrand, South Africa)

3.3.3 Rheology

RheolabQC (Anton Paar) rotational rheometer (Figure 3.2) was used for rheological analyses using the CC39 measuring component system. About 45 ml of each prepared mud sample was transferred into the measuring cup before being mounted onto the rheometer. Shear thinning; viscosity at varying shear rates, viscosity over time, viscosity over a varying temperature range and the reversible drop in viscosity (thixotropy) were measured.

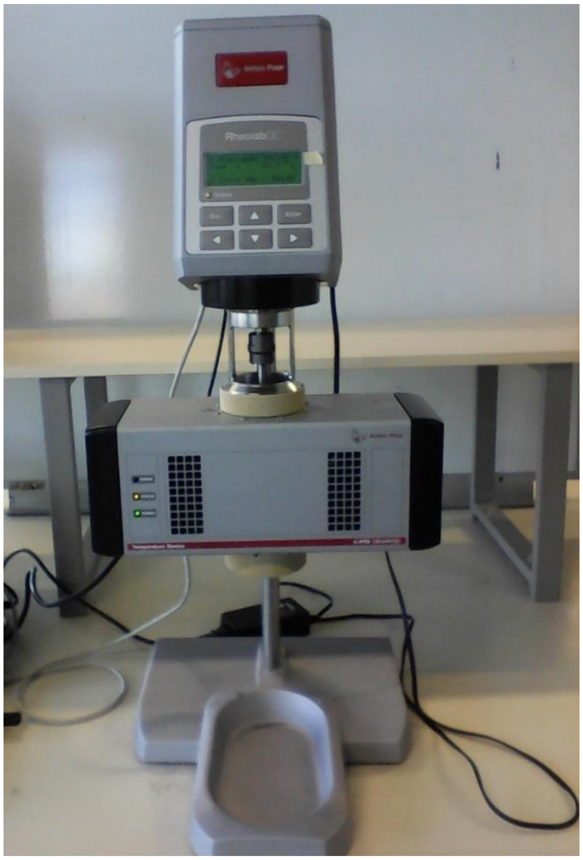

Figure 3.2: RheolabQC rotational rheometer (from Anton Paar, South Africa)

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Characterisation of NCCs

The resultant morphology of the Nano-crystalline cellulose (NCC) is dependent on the source of cellulose and the process of production or synthesis used (George et al., 2015). The acid hydrolysis processes for the synthesis of NCC has been reported to yield rod/needle like nanocrystal structures when observed under TEM (Peng et al., 2011; Lu and Hsieh, 2010; Montanari et al., 2005). The TEMPO mediated oxidation of Microfibrillated cellulose (MFC) resulted in the production of spherical NCC as observed in Figure 4.1 at 200 nm (a) and 500 nm (b). Similar spherical NCC structures prepared using the same method have been previously reported (Lu and Hsieh, 2010; Wang et al., 2007; Wang et al., 2008). The observed nanosized particles aggregation can be accounted for by the evaporation of absorbed water. The sizes of dried synthesised NCC ranged between 40 and 90 nm, due to the strong hydrogen bonding within the NCC structure. This intermolecular force overcomes the repulsive force surface charge, promoting the self-association of the network structure (Wang et al., 2007; Habibi et al., 2010).

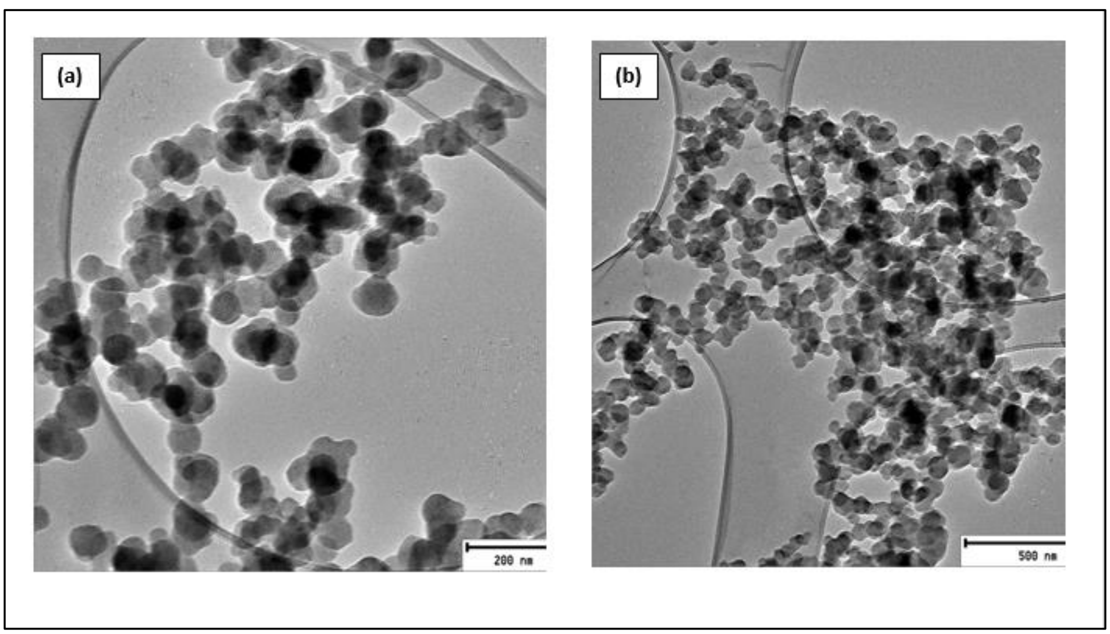

Figure 4.1: NCC TEM images at 200 nm (a) and 500 nm (b) (FEI T12 TEM, Microscopy and Microanalysis Unit, University of the Witwatersrand, South Africa)

4.2 Fluid loss

The temperature variation was achieved by manually heating the sample on a controlled hotplate before transferring into the measuring cell. A general increase in fluid loss with increasing temperature from 30-70 °C was observed when the 1.0 w% NCC mud sample was pressurised at 100, 200 and 300 kPa, with a slight variation at 400 kPa where the fluid loss fluctuates with increasing temperatures (Figure 4.2). Figures 4.2 and 4.3 were plotted from the data in Appendix A, Table A1. As seen in Figures 4.2 and 4.3, temperature and pressure affect the amount of fluid loss during the filtration test. The increase in temperature reduced the interaction between water absorbed and NCC, resulting in more fluid loss. Hydrogen bond strength depends linearly on bond length, which decreases with temperature. This confirmed the findings of Dougherty (1998) that the apparent hydrogen bond strength depends linearly on temperature. At constant temperature, Figure 4.3 demonstrates nonlinear behavior of hydrogen bond length with pressure. At higher pressure, the effect of observed temperature on the fluid loss is reduced. This could be explained by the compensation between the bond's attractive energy (ΔH) and the energy required for orderliness apparent in NCC structure (ΔS).

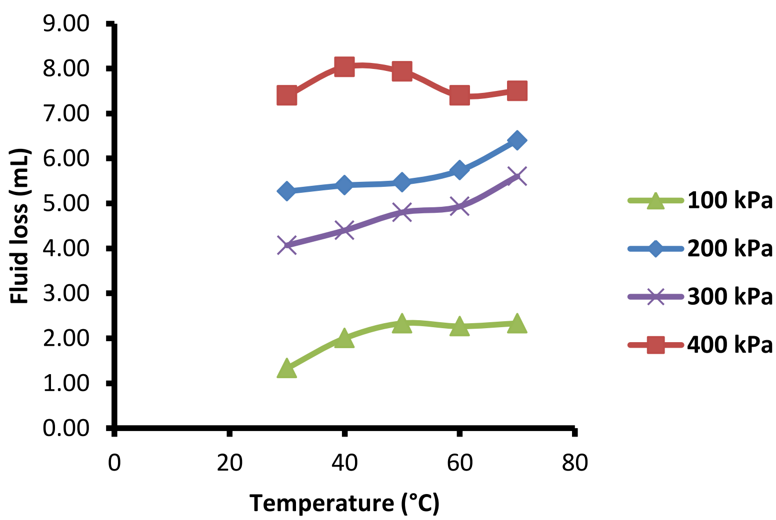

Figure 4.2: Fluid loss over various temperatures and pressures for 1.0% NCC mud sample

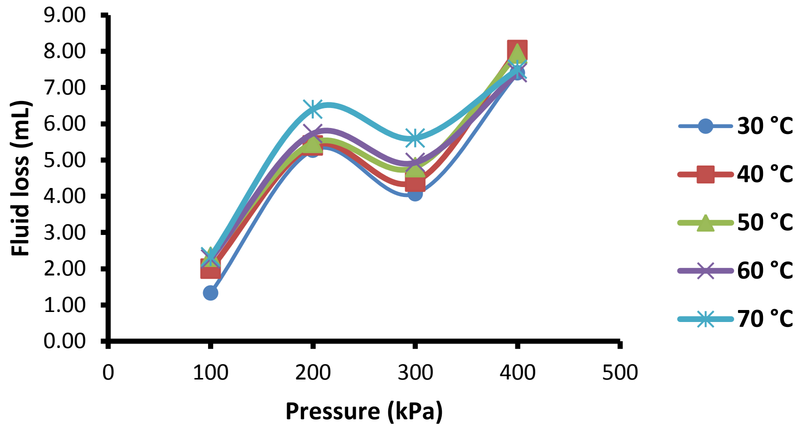

Figure 4.3: Optimum temperature and pressure for 1.0% NCC mud sample fluid loss

The effect of variation in NCC concentrations was investigated at higher observed fluid loss (400 kPa and 40 ^{0}C). Figure 4.4 was plotted from the data in Appendix A, Table A2. Figure 4.4 showed a steady decrease in fluid loss with an increase in NCC concentration in the mud samples from 0.0 to 1.2 w%. This resulted in reduction in filtrate volume of 10.6, 17.9, 31.7, 47.2, 44.8% and 52.5% for the 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 w% NCC mud samples, respectively compared to the 0.0 w% NCC mud sample. With a projected increase in deeper offshore drilling where operating conditions are significantly harsh, there is a compelling need for drilling fluid with desirable filtration properties and thermal stability. NCC addition demonstrates the ability to dramatically improve the filtration properties of the drilling mud and this can be attributed to the fact that NCC has a higher affinity to water as seen in the fluid loss results

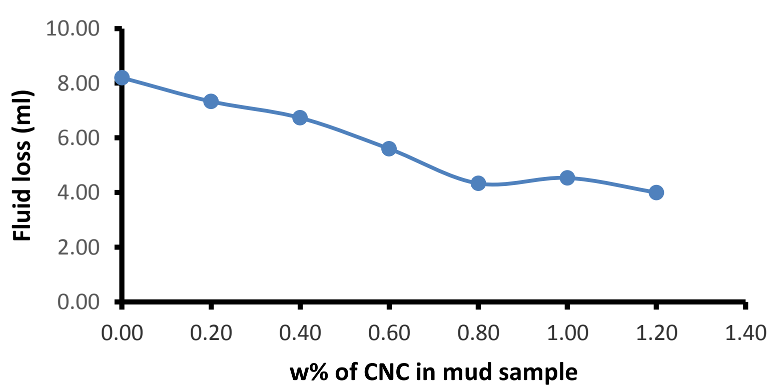

Figure 4.4: Fluid loss at 400 kPa and 40 °C for varying w% of NCC in mud sample

4.3 Rheology

4.3.1 Viscosity vs time

Viscosity measurements were conducted at a constant shear rate of $50s^{-1}$ over a period of 180 s, at temperatures of 30, 40, 50, 60 and 70°C. Figures 4.5 (a-g) and 4.6 (a-e) were plotted from the data in Appendix B. The results showed that the 0.0 w% NCC mud sample suffered an immediate loss in thermal stability at temperatures as low as 40˚C (Figure 4.5 (a)), whereas higher viscosities were observed at comparative temperatures with increasing w% addition of NCC to the mud sample (Figure 4.5 (b-g)). The profile for mud samples with 0.2 – 1.2 w% NCC shows a gradual drop in viscosity (Figure 4.5 (b-g)) compared to 0.0% NCC mud sample, suggesting better stability at higher temperatures. The notable drop in thermal stability is observed for the 0.0 w% NCC mud sample in comparison to the 1.2 w% NCC mud sample as plotted at 30, 40, 50, 60 and 70°C (Figure 4.6). The NCC content increased the viscosity of the mud sample, and with increasing temperature. Mud sample with 1.0 w% NCC shows comparable viscosity behaviour to that of pure bentonite (0.0 w% NCC). The effect of temperature is well seen at low NCC content up to 1.0 w%. Insignificant differences in viscosity were seen at 1.2% NCC. 67, 33.8, 30, and 22 mPa.s differences were observed between 60 and 70 ˚C at 1.0, 0.8, 0.6 and 0.4 w% NCC respectively. With the resultant reduction in fluid loss, 1.0 w% NCC show a better rheological behaviour and could improve the drilling operation, therefore investigation on 1.0% NCC should be carried out in order to come up with better conclusions.

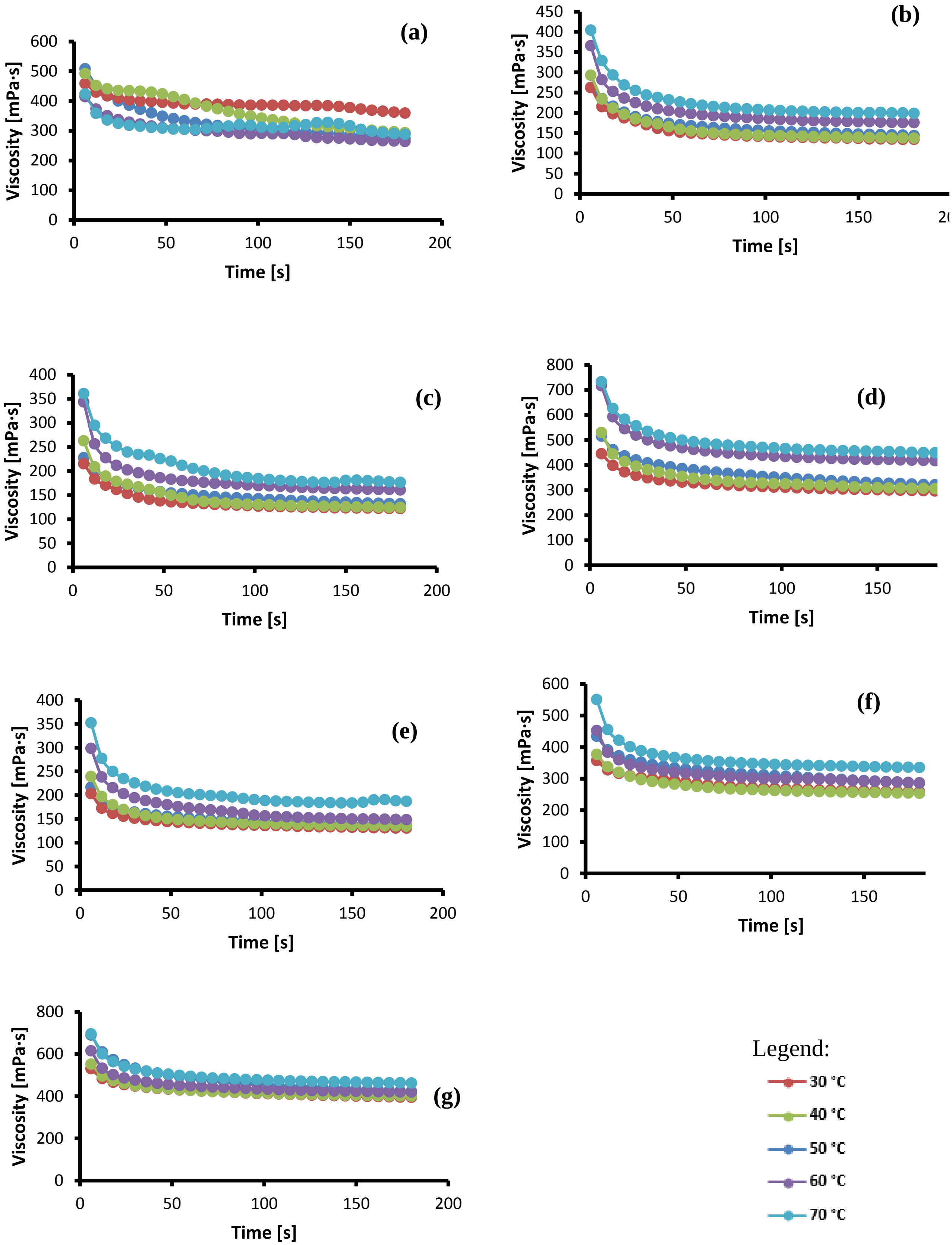

Figure 4.5: Viscosity over time at varying temperatures for 0.0% (a), 0.2% (b), 0.4 % (c), 0.6% (d), 0.8% (e), 1.0% (f) and 1.2 % (g) of CNC in mud sample

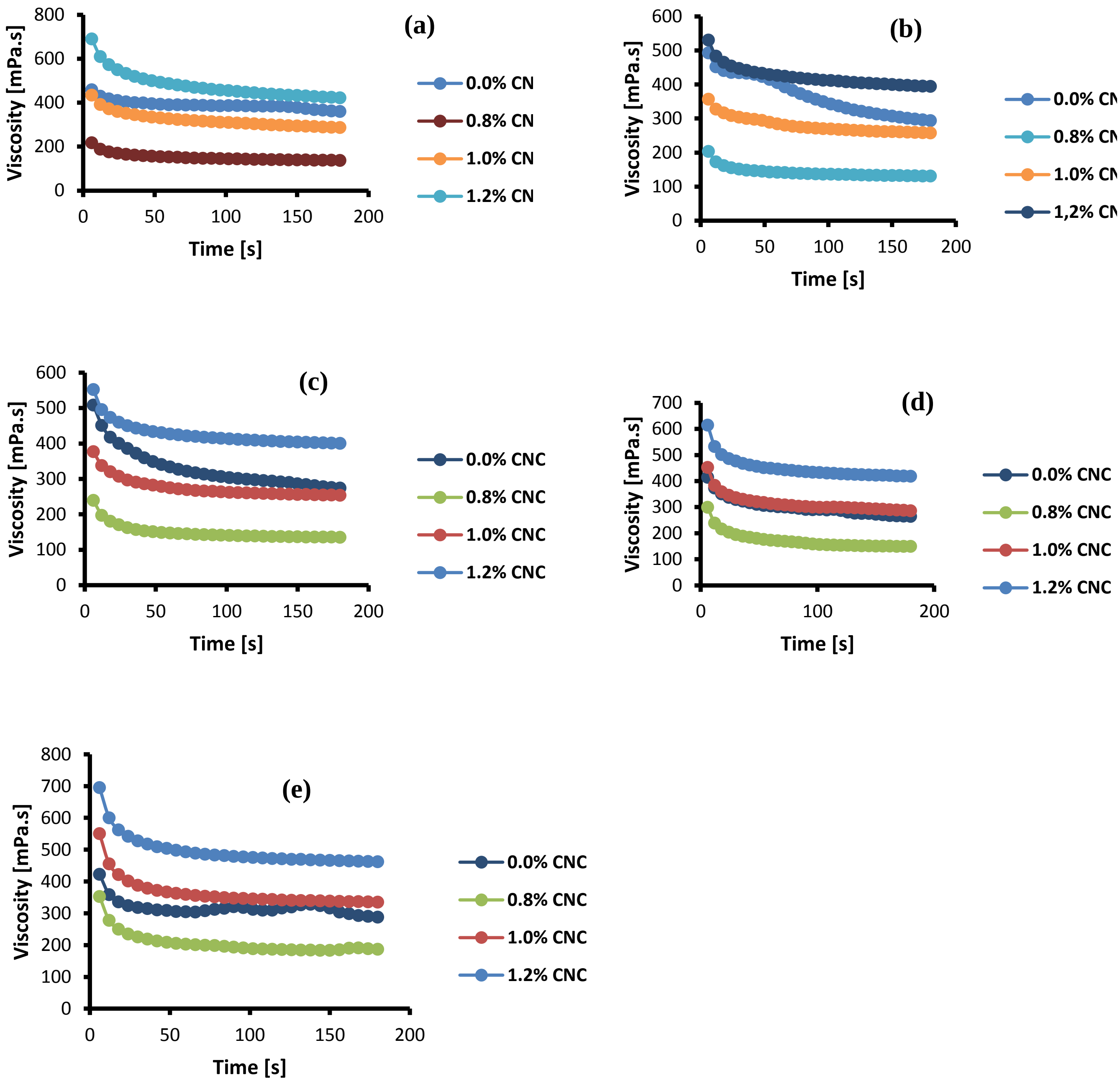

Figure 4.6: Viscosity of varying w% of NCC in mud sample over time at (a) 30°C, (b) 40°C, (c) 50°C, (d) 60°C and (e) 70°C

4.3.2 Temperature ramp

When the mud samples were subjected to a temperature ramp from 30 - 70°C for 40 minutes, the mud sample with 0.0% w% NCC showed a 36% decrease in viscosity, whereas a 22% and 25% loss was observed in the 1.0 w% and 1.2 w% NCC respectively (Figure 4.7). Figure 4.7 was plotted from the data in Appendix C. It can be seen that addition of NCC content in the mud sample improved the thermal stability of the mud, more evident in higher NCC concentrations of 1.0 and 1.2 w% which have higher viscosities than muds with less NCC. This indicates that addition of NCC can help improve viscosity properties of the mud because lower mud viscosity can result in drill cuttings settling at the bottom of the well instead of being suspended and carried to the surface by the mud.

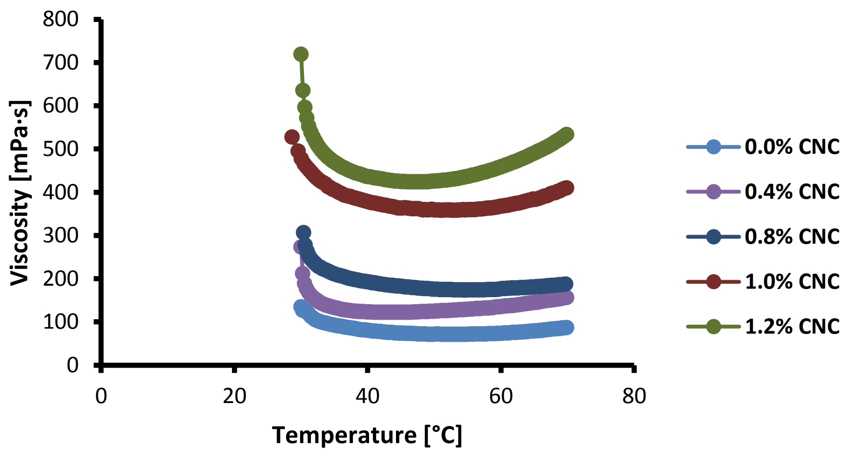

Figure 4.7: Viscosity of varying w% of NCC in mud sample over a temperature range of 30°C - 70°C

4.3.3 Flow curves

Yield stress measurements were conducted by plotting the flow curves at different shear rates up to 300 (1/s) at a temperature of 25°C. Using the Casson model built into the RheolabQC rotational rheometer's analysis functionality, the yield stress was determined to be 9.35 Pa for the 0.0 w% NCC and 20.017 and 33.305 Pa for the 1.0 and 1.2 w% NCC, respectively indicating an enhanced ability of the NCC muds to carry drill cuttings to the surface (shown in Figure 4.8).

Figures 4.8 and 4.9 are plotted from the data in Appendix D. The flow curves shown below in Figures 4.8 and 4.9 describe the NCC–bentonite mud sample as a Herschel-Buckley fluid ($\tau = \tau_y + k\,\gamma^n$) with n = 3 in this investigation. R-square value (R^2 = 0.97858) for the curve graph given by y = 25.5 + 0.16 x + 8.4e-07 x^3 - 0.0005 x^2 is greater than the R-square value (R^2 = 0.730) for linear graph given by y = 0.0964x + 28.009. From Figure 4.8, it can be seen that as the concentration of NCC decreases, the behaviour of the fluid changes to fit the Bingham plastic model (linear graph). These illustrate that the NCC is a fluid loss reducing material which modified bentonite-based fluid behaviour.

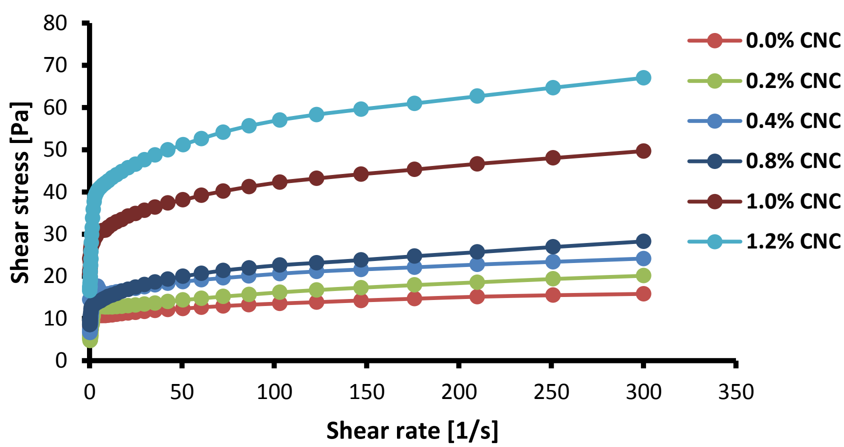

Figure 4.8: Flow curves for different w% NCC mud samples at 25 °C

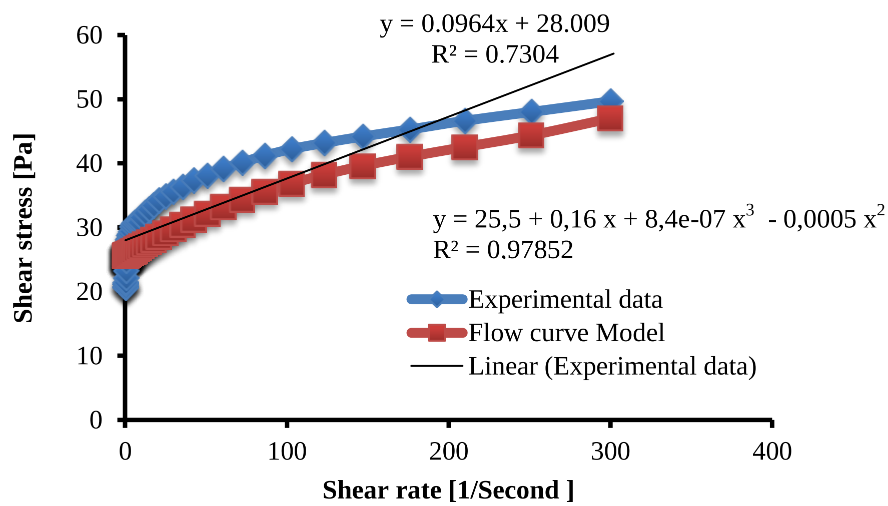

Figure 4.9: Flow curves for 1.2% NCC mud sample at 25 °C

4.3.4 Thixotropy

Thixotropy is a measure of the reversible drop in viscosity when the drilling fluid is subjected to flow over a period of time and a better thixotropy indicates the improved resistance in structural re-arrangement during flow (Maxey, 2007). The 3 Interval Thixotropy Test (3ITT) was carried out in rotation first at a very low constant shear load of 0.25 1/s (rest interval) followed by a constant high shear load of 1000 1/s (load interval) and regeneration interval of 0.25 1/s at a temperature of 25°C over a period of 600 s (as shown in Figure 4.10). Figure 4.10 was plotted from the data in Appendix E.

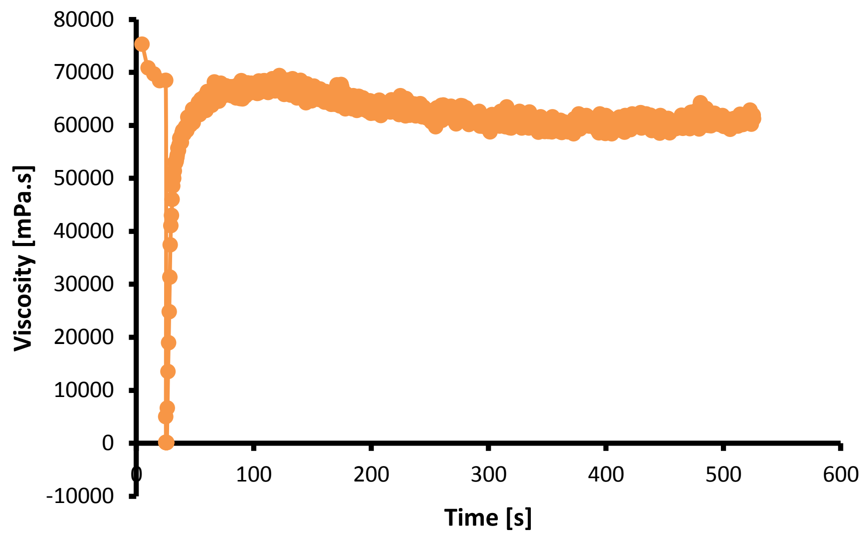

Figure 4.10: Shear thinning over time for 1.0 w% NCC mud sample over time at 25°C

It is evident that the time dependent shear thinning of 1.0 and 1.2 w% NCC mud samples have far better properties than those of the 0.0 w% NCC mud sample (Figure 4.11). Figure 4.11 was plotted from the data in Appendix E. The 3 Interval Thixotropy Test for structural regeneration showed that 4.3044 s was required for 50% regeneration to be reached for the 0.0 w% NCC mud sample, which was higher than the 2.75 and 1.6879 s required for 50% regeneration of the 1.0 and 1.2 w% NCC mud samples, respectively. Furthermore, the percentage regeneration after 500 s increased from 69.8% for the 0.0 w% NCC mud sample to 89.5 and 89.3% for the 1.0 and 1.2 w% NCC mud samples, respectively. Therefore, NCC content reduces time required for fluid regeneration and achieves better fluid recovery after shearing. Low bentonite content in water based drilling fluids show better thixotropic behaviour than in fluids with high bentonite content (Dolz et al., 2007).

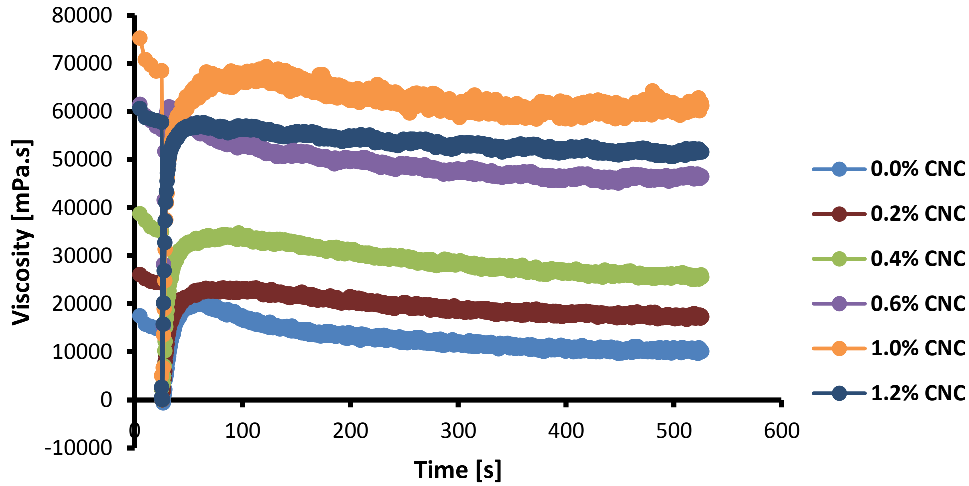

Figure 4.11: Thixotropic properties of varying w% NCC mud samples over time at 25°C

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Although the cost of drilling fluids does not constitute a considerable portion of the drilling process, it can however pose detrimental impact on the operation following a malfunction; hence it is imperative to source a drilling fluid with optimal characteristics and functional properties for a specific drilling environment. . The sizes of dried synthesised NCC ranged 40 and 90 nm, due to the strong hydrogen bonding within the NCC structure. The increase in the addition of NCC concentration to the mud samples from 0.0 – 1.2 w% showed an improvement in fluid loss, making NCC a desirable additive for optimisation of the performance of bentonite-water based muds. Higher fluid loss was observed with increasing temperature due to reduced interaction between water absorbed and NCC.

Higher concentrations of NCC of up to 1.2 w% in the mud sample, resulted in improved thermal stability when viscosity was measured over a period of time within a set temperature range from 30 - 70°C. NCC content increased viscosity of mud samples, with increasing temperature and the effect of temperature was observed up to NCC concentration of 1.0 w%, with insignificant difference at NCC concentration of 1.2 w%. Thus 1.0 w% NCC can be further investigated as the optimum concentration in future. This observation makes NCC a candidate for application in a wide array of drilling environments at specified concentrations for the desired performance characteristics. Furthermore, an increase in the NCC concentration from 0.0 – 1.2 w% in the mud samples improved the yield stress indicating the enhanced ability to suspend and carry drill cuttings to the surface as compared to mud samples with little or no NCC additive.

There was also better thixotropic profiles and improved percentage regeneration as the NCC concentration increased from 0.0 – 1.2 w% in the mud samples, allowing the NCC based mud samples to have better flow properties and functional properties. Thus it can be concluded that NCC should be considered for the drilling fluid application as it has displayed notable optimisation of the viscosity and fluid loss parameters to achieve better flow and suspension properties during the drilling process.

5.2 Recommendations

- For future fluid loss studies, it is recommended that:
    - A dynamic experimental setup be constructed, with an attached or built in temperature device in order to accurately control the temperature when fluid loss measurements are conducted at varying temperature and pressure conditions to avoid excessive loss of thermal stability during the study.
    - Measurements of fluid loss should be taken at a wider temperature and pressure range (at least temperatures of up to 100˚C and pressures up to 1000 kPa), as this study only had measuring cells that could accommodate pressures of up to 400 kPa. This will allow a comprehensive study of the mud properties at extreme conditions, as the optimum NCC concentration will be dependent on the application conditions.

It is further recommended that a comparative study be conducted for the fluid loss and rheological properties of the muds incorporating TEMPO oxidation prepared NCCs and acid hydrolysis prepared NCCs, to deduce which composition yields optimum drilling fluid properties.

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APPENDICES

Appendix A: Fluid Loss Analysis

Table A1: Fluid loss data for NCC-Bentonite sample with 1.0% NCC concentration at different temperatures and pressures

100 kPa					
Temperature (°C)	Fluid loss #1 (ml)	Fluid loss #2 (ml)	Fluid loss #3 (ml)	Average (ml)	STD Dev
30	1,20	1,60	1,20	1,33	0,23
40	2,20	1,80	2,00	2,00	0,20
50	2,40	2,40	2,20	2,33	0,12
60	2,40	2,20	2,20	2,27	0,12
70	2,20	2,40	2,40	2,33	0,12
200 kPa					
Temperature (°C)	Fluid loss #1 (ml)	Fluid loss #2 (ml)	Fluid loss #3 (ml)	Average (ml)	STD Dev
30	5,80	5,00	5,00	5,27	0,46
40	6,20	5,40	4,60	5,40	0,80
50	5,20	6,40	4,80	5,47	0,83
60	6,40	5,80	5,00	5,73	0,70
70	8,60	5,80	4,80	6,40	1,97
300 kPa					
Temperature (°C)	Fluid loss #1 (ml)	Fluid loss #2 (ml)	Fluid loss #3 (ml)	Average (ml)	STD Dev
30	4,20	4,20	3,80	4,07	0,23
40	4,80	4,20	4,20	4,40	0,35
50	4,80	5,00	4,60	4,80	0,20
60	5,20	4,80	4,80	4,93	0,23
70	6,00	5,80	5,00	5,60	0,53
400 kPa					
Temperature (°C)	Fluid loss #1 (ml)	Fluid loss #2 (ml)	Fluid loss #3 (ml)	Average (ml)	STD Dev
30	7,80	8,40	6,00	7,40	1,25
40	8,00	9,60	6,50	8,03	1,55
50	8,20	8,40	7,20	7,93	0,64

60	6,00	8,20	8,00	7,40	1,22
70	6.40	8.30	7,80	7.50	0,98

Table A2: Fluid loss data for NCC-Bentonite samples with varying w% NCC at 400 kPa and 40°C

400 kPa and 40 degrees					
% NCC Concentration	Fluid loss #1 (ml)	Fluid loss #2 (ml)	Fluid loss #3 (ml)	Average (ml)	STD Dev
0,00	9,00	7,20	8,40	8,20	0,92
0,20	8,00	7,00	7,00	7,33	0,58
0,40	7,80	6,40	6,00	6,73	0,95
0,60	5,60	5,40	5,80	5,60	0,20
0,80	5,00	4,00	4,00	4,33	0,58
1,00	4,80	4,80	4,00	4,53	0,46
1,20	4,20	4,00	3,80	4,00	0,20

Appendix B: Rheological analysis: Viscosity vs Time

Table B1: Viscosity vs time for NCC-Bentonite sample with 0.0% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	458,15	492,33	508,23	414,19	422,65
12	429,43	451,63	450,9	372,31	358,14
18	416,74	440,47	417,14	350,34	335,56
24	409,38	435,43	400,16	337,02	324,11
30	403,25	434,08	385,61	328,42	318,29
36	399,77	432,52	371,99	321,99	314,63
42	398	429,43	359,34	315,84	310,8
48	395,11	423,66	348,45	309,87	308,37
54	392,48	414,29	340,33	306,52	305,18
60	390,28	404,88	333,4	304,2	304,57
66	389,66	392,49	326,55	301,32	303,47
72	389,01	382,31	321,2	299,54	307,75

78	388,55	373,31	317,17	297,71	311,9
84	387,45	364,44	313,02	295,04	315,51
90	386,24	356,37	309,67	291,11	320,28
96	385,59	349,12	306,23	289,31	317,9
102	386,08	342,28	303,6	290,61	312,01
108	385,67	336,43	300,75	288,88	309,2
114	384,97	330,55	299,11	290,36	309,95
120	384,04	325,4	297,49	286,44	316,11
126	383,67	320,82	295,42	280,61	319,79
132	384,19	316,82	293,49	276,46	326,61
138	383,65	313,23	291,55	275,08	327,7
144	381,47	310,21	289,4	275,02	323,63
150	377,34	306,91	286,35	272,09	316,67
156	372,62	303,55	283,5	269,97	304,1
162	368,19	301	280,5	267,57	298,27
168	364,96	298,29	277,59	265,83	293,1
174	362,17	296,04	275,66	265,5	290,27
180	359,17	293,59	273,59	263,91	287,8

Table B2: Viscosity vs time for NCC-Bentonite sample with 0.2% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	262,6	262,49	293,13	365,79	403,88
12	235,34	215,37	234,23	281,8	328,65
18	216,44	197,25	211,8	252,91	293,33
24	201,81	187,41	196,23	236,37	268,91
30	190,45	179,91	184,92	224,97	255,15
36	182,95	170,58	177,53	216,51	244,18
42	177,79	161,62	172,78	209,97	238,08
48	173,72	155,57	165,58	205,37	232,12
54	170,6	152,27	159,18	201,37	227,18
60	167,88	150	155,07	198,15	222,31
66	165,7	147,99	152,11	195,28	218,63
72	163,24	146,66	149,7	192,88	215,58
78	161,62	145,4	148,26	191,14	213,17
84	159,82	143,95	146,69	189,35	211,24
90	158,1	142,97	145,58	187,96	209,64

96	156,66	142,09	144,7	186,41	208,15
102	155,03	141,13	144,12	185,14	206,85
108	154,32	140,35	143,44	183,59	205,98
114	153,33	140,01	142,68	182,54	204,82
120	152,42	139,08	141,94	181,3	204,17
126	151,75	138,55	141,21	180,5	203,02
132	150,24	138,27	140,99	179,66	202,39
138	149,01	137,8	140,31	179,11	201,45
144	148,43	137,34	139,95	178,75	200,93
150	147,65	136,62	139,63	178,06	200,44
156	146,9	135,97	139,29	177,81	200,27
162	146,17	135,81	138,85	176,82	200,95
168	145,62	135,4	138,28	176,26	199,99
174	144,86	134,7	138,02	175,83	199,76
180	143,93	134,36	137,57	175,48	198,91

Table B3: Viscosity vs time for NCC-Bentonite sample with 0.4% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	227,4	214,95	262,41	343,35	360,41
12	201,75	183,12	208,46	256,23	294,49
18	187,96	170,31	189,34	227,3	267,68
24	177,19	161,3	178,3	211,58	251,78
30	169,44	153,16	172,35	202,24	239,27
36	164,05	145,46	167,02	196,32	234,08
42	160,17	141,03	161,54	190,45	232,82
48	156,99	137,87	156,12	185,88	225,38
54	154,14	135,56	149,55	182,52	220,34
60	152,33	134,02	144,35	179,96	211,65
66	150,07	132,77	139,86	178,07	205,01
72	148,48	131,54	136,86	176,2	199,88
78	146,79	130,3	134,54	174,37	195,7
84	145,25	129,3	133,17	174,1	191,25
90	144	128,53	131,88	172,7	188,36
96	142,84	127,88	130,92	170,73	186,35
102	142,02	126,84	130,24	169,52	184,05
108	140,75	126,46	129,54	168,8	182,08
114	139,9	125,89	128,6	167,7	180,3
120	138,77	125,41	127,79	166,35	179,23

126	137,79	124,74	127,4	165,49	177,78
132	136,92	124,55	127,03	164,7	176,66
138	136,22	123,84	126,62	164,02	176,29
144	135,61	123,5	126,31	163,46	176,35
150	134,95	123,46	125,95	162,91	180,41
156	134,26	122,94	125,47	162,45	180,93
162	133,36	122,66	125,08	161,9	179,53
168	132,78	122,3	124,83	161,54	178,53
174	132,02	121,77	124,34	161,38	177,29
180	131,53	121,59	124,16	160,65	176,11

Table B4: Viscosity vs time for NCC-Bentonite sample with 0.6% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	514,94	444,48	529,61	716,67	732,87
12	461,47	397,92	444,13	592,14	626,23
18	436,42	372,9	413,79	545,37	583,44
24	420,13	358,2	395,67	518,74	555,96
30	408,46	348,83	381,49	500,09	534,5
36	400,15	341,36	371,29	486,87	519,16
42	392,72	336,17	363,36	476,63	508,25
48	386,21	331,82	354,18	468,54	499,25
54	380,71	328,57	347,08	462,17	492,96
60	375,55	325,2	342	456,7	487,12
66	371,17	322,65	337,99	451,84	482,89
72	367,02	319,84	334,75	448,01	479,31
78	362,82	317,5	331,28	444,45	476,68
84	358,8	315,25	329,27	441,33	473,6
90	354,83	313,44	327,59	438,52	471
96	351,29	311,8	326,04	435,45	468,34
102	348,36	310,17	324,73	433,23	466,33
108	345,22	308,52	323,02	431,01	463,07
114	342,54	307,41	321,66	429,28	461,14
120	339,72	306,26	319,64	427,66	460,46
126	337,24	305,17	318,06	426,15	458,6
132	334,96	303,79	315,25	424,82	457,66
138	333,05	302,63	312,54	423,36	456,21

144	330,82	301,66	310,76	422,24	455,19
150	329,16	300,73	309,52	421,38	454,17
156	327,28	300,25	308,74	421,65	453,35
162	325,66	299,14	307,54	420,24	452,86
168	323,77	298,43	306,98	419,25	450,54
174	322,44	297,48	306,5	418,43	450
180	320,86	296,57	305,99	417,14	448,77

Table B5: Viscosity vs time for NCC-Bentonite sample with 0.8% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	216,62	203,31	239,26	298,9	352,61
12	187,55	172,46	197,21	238,17	277,32
18	175,85	161,44	180,35	215,91	249,91
24	169,15	155,34	170,19	203,01	235,1
30	164,42	151,42	162,37	194,61	225,69
36	161,09	148,51	157,18	188,45	218,63
42	158,2	146,53	153,36	184,36	212,79
48	155,71	144,72	150,55	180,22	208,6
54	153,94	142,96	148,66	176,15	205,28
60	152,5	141,77	146,82	173,14	202,81
66	150,71	140,84	145,5	170,96	201,01
72	149,28	139,81	144,44	168,94	199,23
78	148,01	138,82	143,36	166,62	198,45
84	146,98	137,89	142,22	164,42	196,07
90	146,12	137,28	141,52	161,39	193,27
96	145,1	136,73	140,63	158,28	190,71
102	144,27	136,18	140,09	156,46	188,7
108	143,39	135,77	139,55	155,08	187,86
114	142,71	135,25	138,96	154,32	186,76
120	142,03	134,43	138,41	153,5	186,04
126	141,29	133,91	137,83	152,75	185,02
132	140,86	133,6	137,24	151,98	184,6
138	140,16	133,34	137,19	151,48	184,01
144	139,52	132,81	136,78	150,97	183,47
150	139,09	132,43	136,34	150,27	183,48
156	138,57	132,21	135,98	150,18	185,14
162	138,08	131,62	135,77	149,83	190
168	137,68	131,33	135,42	149,3	190,66

174	137,41	131	135,34	149,05	188,24
180	136,75	131,04	134,98	148,59	187,16

Table B6: Viscosity vs time for NCC-Bentonite sample with 1.0% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	433,8	356,62	376,24	452,1	549,98
12	390,8	327,43	337,17	383,19	454,95
18	371,95	315,99	319,71	358,88	421,12
24	359,58	308,86	306,92	345,26	401,1
30	351,38	303,64	296,65	336,12	387,91
36	344,37	300,21	290,3	329,24	379
42	338,56	297,11	285,86	324,75	371,79
48	333,81	294,01	281,99	320,27	366,52
54	329,75	289,18	278,54	316,94	362,4
60	326,45	283,91	274,97	313,49	358,98
66	323,12	280,02	271,67	310,64	355,85
72	320,68	277,04	269,45	308,55	353,28
78	317,93	274,84	267,35	305,96	351,31
84	315,8	273,18	265,92	303,21	349,52
90	313,39	271,67	264,52	301,99	347,8
96	311,3	270,05	263,4	300,19	346,41
102	309,4	268,85	261,9	299,06	344,82
108	307,49	267,45	260,93	299,2	343,73
114	305,41	266,68	260,18	299,48	342,86
120	303,45	265,35	259,56	298,63	341,72
126	301,1	264,16	258,73	297,7	341,13
132	299,01	263,21	257,82	297,14	340,3
138	297,17	262,44	257,21	295,32	339,67
144	295,09	261,63	256,52	293,8	338,83
150	293,57	260,97	255,89	292,22	338,04
156	291,92	260,24	255,52	291,37	337,41
162	290,66	259,39	255,04	289,96	336,58
168	289,09	258,68	254,26	288,89	336,17
174	287,63	258,08	253,91	287,13	335,53

180	286,45	257,71	253,37	285,75	335,27

Table B7: Viscosity vs time for NCC-Bentonite sample with 1.2% NCC at varying temperatures and a shear rate of 50 s^{-1}

Time [s]	Viscosity [mPa.s]				
	30 °C	40 °C	50 °C	60 °C	70 °C
6	689,13	529,8	551,56	614,18	695,06
12	609,12	482,97	495,14	532,26	600,2
18	572,88	464,74	473,22	501,27	562,12
24	549,2	454,16	459,31	485,23	541,53
30	532,24	446,84	449,88	476	527,21
36	518,98	440,99	443,23	467,51	517,17
42	508,51	436,05	437,92	460,54	509,43
48	499,79	432,46	433,55	455,54	503,76
54	492,1	428,9	429,95	451,04	498,07
60	485,88	426,31	426,72	448,56	493,38
66	479,66	423,67	423,91	445,41	489,23
72	474,54	420,92	421,26	442,46	485,63
78	469,39	418,69	419,3	440,08	483,21
84	465,15	416,47	417,5	437,68	480,85
90	461,03	414,76	415,77	435,74	478,96
96	457,32	412,61	414,16	433,5	477,32
102	454,02	411,25	412,67	431,95	475,44
108	450,74	409,52	411,23	430,55	474
114	447,62	407,94	409,81	428,94	472,25
120	444,32	406,27	408,87	427,42	471,21
126	441,4	404,71	407,62	426,13	469,82
132	438,91	403,49	406,82	424,86	469,21
138	436,44	402,22	405,39	423,83	467,75
144	434,32	401,13	404,73	423,04	467,22
150	431,99	400,04	403,65	422,39	466,1
156	429,56	398,48	402,75	421,61	465
162	427,59	397,27	402,13	420,52	464,37
168	425,56	396,13	401,35	419,47	463,52
174	423,89	394,91	400,44	418,72	462,77
180	422,05	394,02	399,68	418,44	462,09

Appendix C: Rheological analysis: Viscosity vs Temperature

Table C1: Viscosity of 0.0% NCC mud sample over a temperature range of 30 - 70°C for 40 minutes

0.0% NCC					
Point No.	Time	Temperature	Shear Stress	Viscosity	Torque
	[min]	[°C]	[Pa]	[mPa·s]	[mN·m]
1	0,333	30,02	6,7436	134,87	1,1325
2	0,667	30,28	6,3354	126,71	1,064
3	1	30,57	6,3315	126,63	1,0633
4	1,333	30,88	6,1656	123,31	1,0355
5	1,667	31,18	5,9128	118,26	0,99301
6	2	31,5	5,6404	112,81	0,94726
7	2,333	31,83	5,4261	108,52	0,91127
8	2,667	32,14	5,2568	105,14	0,88284
9	3	32,47	5,1468	102,94	0,86437
10	3,333	32,81	5,0514	101,03	0,84835
11	3,667	33,13	4,9798	99,596	0,83632
12	4	33,46	4,8982	97,965	0,82262
13	4,333	33,79	4,8353	96,705	0,81205
14	4,667	34,12	4,7831	95,661	0,80328
15	5	34,46	4,7156	94,313	0,79196
16	5,333	34,79	4,6629	93,258	0,7831
17	5,667	35,12	4,6048	92,097	0,77335
18	6	35,46	4,5617	91,233	0,7661
19	6,333	35,79	4,5097	90,194	0,75737
20	6,667	36,13	4,475	89,5	0,75155
21	7	36,46	4,4191	88,383	0,74216
22	7,333	36,8	4,3795	87,59	0,73551
23	7,667	37,13	4,326	86,52	0,72652
24	8	37,47	4,2987	85,974	0,72194
25	8,333	37,81	4,2541	85,083	0,71445
26	8,667	38,15	4,2094	84,187	0,70693
27	9	38,49	4,1595	83,191	0,69857
28	9,333	38,82	4,1286	82,572	0,69337

29	9,667	39,16	4,0872	81,743	0,68641
30	10	39,51	4,0665	81,33	0,68294
31	10,333	39,83	4,0232	80,465	0,67567
32	10,667	40,18	3,9975	79,95	0,67135
33	11	40,52	3,9633	79,265	0,6656
34	11,333	40,86	3,9402	78,803	0,66172
35	11,667	41,2	3,9167	78,334	0,65778
36	12	41,54	3,8981	77,963	0,65466
37	12,333	41,87	3,8724	77,447	0,65034
38	12,667	42,21	3,8417	76,834	0,64518
39	13	42,54	3,8277	76,554	0,64284
40	13,333	42,89	3,7944	75,888	0,63724
41	13,667	43,23	3,7842	75,684	0,63553
42	14	43,57	3,7659	75,318	0,63245
43	14,333	43,9	3,7451	74,903	0,62897
44	14,667	44,23	3,7167	74,334	0,62419
45	15	44,58	3,7025	74,049	0,6218
46	15,333	44,91	3,6802	73,605	0,61807
47	15,667	45,25	3,6899	73,799	0,6197
48	16	45,6	3,6655	73,309	0,61559
49	16,333	45,93	3,6609	73,217	0,61481
50	16,667	46,26	3,6621	73,242	0,61502
51	17	46,61	3,6502	73,004	0,61302
52	17,333	46,94	3,6278	72,555	0,60926
53	17,667	47,28	3,6242	72,483	0,60865
54	18	47,63	3,6062	72,124	0,60563
55	18,333	47,96	3,6091	72,183	0,60613
56	18,667	48,3	3,5829	71,658	0,60172
57	19	48,64	3,5824	71,648	0,60164
58	19,333	48,98	3,5668	71,336	0,59902
59	19,667	49,32	3,5705	71,41	0,59964
60	20	49,65	3,5634	71,267	0,59844
61	20,333	50	3,5617	71,233	0,59816
62	20,667	50,33	3,5774	71,548	0,6008
63	21	50,67	3,5985	71,969	0,60433
64	21,333	51,01	3,571	71,42	0,59973
65	21,667	51,34	3,5667	71,333	0,599
66	22	51,69	3,5504	71,008	0,59627
67	22,333	52,01	3,5573	71,146	0,59742
68	22,667	52,35	3,5419	70,838	0,59484
69	23	52,71	3,5523	71,046	0,59658
70	23,333	53,02	3,5596	71,192	0,59781
71	23,667	53,37	3,5695	71,391	0,59948

72	24	53,71	3,5648	71,297	0,59869
73	24,333	54,05	3,5631	71,261	0,59839
74	24,667	54,38	3,5483	70,966	0,59591
75	25	54,72	3,5603	71,206	0,59793
76	25,333	55,06	3,5555	71,109	0,59712
77	25,667	55,4	3,5787	71,574	0,60102
78	26	55,74	3,5655	71,311	0,59881
79	26,333	56,07	3,5871	71,743	0,60243
80	26,667	56,41	3,5782	71,564	0,60094
81	27	56,74	3,5964	71,928	0,60399
82	27,333	57,09	3,5824	71,648	0,60164
83	27,667	57,43	3,607	72,14	0,60577
84	28	57,75	3,6025	72,05	0,60502
85	28,333	58,1	3,6224	72,449	0,60836
86	28,667	58,42	3,6275	72,551	0,60922
87	29	58,77	3,6386	72,771	0,61107
88	29,333	59,1	3,6415	72,831	0,61157
89	29,667	59,44	3,6592	73,183	0,61453
90	30	59,79	3,6723	73,446	0,61673
91	30,333	60,12	3,6823	73,645	0,61841
92	30,667	60,45	3,6972	73,945	0,62092
93	31	60,79	3,706	74,119	0,62239
94	31,333	61,13	3,7216	74,433	0,62502
95	31,667	61,47	3,7483	74,967	0,62951
96	32	61,81	3,7697	75,393	0,63309
97	32,333	62,14	3,7651	75,302	0,63232
98	32,667	62,48	3,7864	75,728	0,6359
99	33	62,82	3,8016	76,032	0,63845
100	33,333	63,15	3,8193	76,385	0,64142
101	33,667	63,49	3,835	76,7	0,64406
102	34	63,83	3,8667	77,333	0,64938
103	34,333	64,16	3,8878	77,756	0,65293
104	34,667	64,51	3,9115	78,23	0,65691
105	35	64,84	3,9245	78,49	0,65909
106	35,333	65,18	3,9579	79,158	0,6647
107	35,667	65,53	3,9777	79,554	0,66803
108	36	65,85	4,0089	80,178	0,67326
109	36,333	66,19	4,017	80,34	0,67462
110	36,667	66,53	4,0612	81,225	0,68206
111	37	66,87	4,0766	81,532	0,68463
112	37,333	67,19	4,115	82,3	0,69109
113	37,667	67,54	4,1394	82,787	0,69518
114	38	67,87	4,1685	83,37	0,70007

115	38,333	68,2	4,1907	83,815	0,7038
116	38,667	68,55	4,2231	84,463	0,70925
117	39	68,88	4,2403	84,805	0,71212
118	39,333	69,21	4,2866	85,731	0,7199
119	39,667	69,56	4,2989	85,979	0,72198
120	40	69,9	4,3254	86,508	0,72642

Table C2: Viscosity of 0.4% NCC mud sample over a temperature range of 30 - 70°C for 40 minutes

0.4% NCC					
Point No.	Time	Temperature	Shear Stress	Viscosity	Torque
	[min]	[°C]	[Pa]	[mPa·s]	[mN·m]
1	0,333	30,01	13,634	272,65	2,2897
2	0,667	30,27	10,578	211,55	1,7765
3	1	30,55	9,4482	188,96	1,5868
4	1,333	30,86	8,8491	176,98	1,4861
5	1,667	31,16	8,383	167,66	1,4079
6	2	31,48	8,1064	162,13	1,3614
7	2,333	31,8	7,8533	157,07	1,3189
8	2,667	32,11	7,6779	153,56	1,2894
9	3	32,45	7,4704	149,41	1,2546
10	3,333	32,78	7,2909	145,82	1,2244
11	3,667	33,1	7,1422	142,84	1,1995
12	4	33,43	7,0225	140,45	1,1794
13	4,333	33,76	6,9213	138,43	1,1624
14	4,667	34,1	6,8553	137,11	1,1513
15	5	34,43	6,7606	135,21	1,1354
16	5,333	34,75	6,6944	133,89	1,1243
17	5,667	35,09	6,6299	132,6	1,1134
18	6	35,42	6,5785	131,57	1,1048
19	6,333	35,76	6,5049	130,1	1,0924
20	6,667	36,1	6,448	128,96	1,0829
21	7	36,43	6,3945	127,89	1,0739
22	7,333	36,76	6,3571	127,14	1,0676
23	7,667	37,1	6,3124	126,25	1,0601
24	8	37,45	6,2838	125,68	1,0553
25	8,333	37,79	6,2509	125,02	1,0498
26	8,667	38,12	6,2317	124,63	1,0466
27	9	38,46	6,2105	124,21	1,043
28	9,333	38,79	6,1965	123,93	1,0407

29	9,667	39,13	6,1866	123,73	1,039
30	10	39,47	6,1681	123,36	1,0359
31	10,333	39,8	6,1532	123,06	1,0334
32	10,667	40,15	6,1447	122,89	1,032
33	11	40,49	6,1344	122,69	1,0302
34	11,333	40,83	6,1204	122,41	1,0279
35	11,667	41,17	6,1238	122,48	1,0284
36	12	41,51	6,1035	122,07	1,025
37	12,333	41,85	6,1063	122,13	1,0255
38	12,667	42,18	6,1082	122,16	1,0258
39	13	42,52	6,1031	122,06	1,025
40	13,333	42,87	6,1115	122,23	1,0264
41	13,667	43,21	6,0933	121,87	1,0233
42	14	43,54	6,0994	121,99	1,0243
43	14,333	43,88	6,1072	122,14	1,0257
44	14,667	44,2	6,0962	121,92	1,0238
45	15	44,56	6,1038	122,08	1,0251
46	15,333	44,9	6,1164	122,33	1,0272
47	15,667	45,23	6,1043	122,09	1,0252
48	16	45,58	6,1115	122,23	1,0264
49	16,333	45,91	6,1204	122,41	1,0279
50	16,667	46,25	6,123	122,46	1,0283
51	17	46,6	6,1245	122,49	1,0286
52	17,333	46,93	6,1345	122,69	1,0302
53	17,667	47,27	6,1453	122,91	1,0321
54	18	47,61	6,1508	123,02	1,033
55	18,333	47,93	6,1771	123,54	1,0374
56	18,667	48,28	6,1712	123,42	1,0364
57	19	48,61	6,1782	123,56	1,0376
58	19,333	48,96	6,1958	123,92	1,0405
59	19,667	49,29	6,2099	124,2	1,0429
60	20	49,64	6,2134	124,27	1,0435
61	20,333	49,98	6,2274	124,55	1,0459
62	20,667	50,31	6,2416	124,83	1,0482
63	21	50,65	6,2587	125,17	1,0511
64	21,333	50,99	6,2807	125,61	1,0548
65	21,667	51,33	6,2828	125,66	1,0551
66	22	51,67	6,2943	125,89	1,0571
67	22,333	52,01	6,3066	126,13	1,0591
68	22,667	52,34	6,3382	126,76	1,0644
69	23	52,7	6,3358	126,72	1,064
70	23,333	53,02	6,3547	127,09	1,0672
71	23,667	53,36	6,3591	127,18	1,068

72	24	53,7	6,3861	127,72	1,0725
73	24,333	54,04	6,3948	127,9	1,074
74	24,667	54,38	6,4076	128,15	1,0761
75	25	54,71	6,4382	128,76	1,0812
76	25,333	55,05	6,4444	128,89	1,0823
77	25,667	55,39	6,4608	129,22	1,0851
78	26	55,73	6,476	129,52	1,0876
79	26,333	56,06	6,5004	130,01	1,0917
80	26,667	56,4	6,5344	130,69	1,0974
81	27	56,74	6,5238	130,48	1,0956
82	27,333	57,08	6,555	131,1	1,1009
83	27,667	57,41	6,5798	131,6	1,105
84	28	57,75	6,5945	131,89	1,1075
85	28,333	58,09	6,5961	131,92	1,1078
86	28,667	58,41	6,6215	132,43	1,112
87	29	58,76	6,6391	132,78	1,115
88	29,333	59,1	6,6974	133,95	1,1248
89	29,667	59,44	6,7192	134,38	1,1284
90	30	59,78	6,7477	134,95	1,1332
91	30,333	60,11	6,7908	135,82	1,1405
92	30,667	60,46	6,8002	136	1,142
93	31	60,79	6,8332	136,66	1,1476
94	31,333	61,13	6,8518	137,04	1,1507
95	31,667	61,46	6,8901	137,8	1,1571
96	32	61,81	6,9002	138	1,1588
97	32,333	62,14	6,9359	138,72	1,1648
98	32,667	62,49	6,9732	139,46	1,1711
99	33	62,81	7,0008	140,02	1,1757
100	33,333	63,14	7,0436	140,87	1,1829
101	33,667	63,49	7,0743	141,49	1,1881
102	34	63,83	7,1079	142,16	1,1937
103	34,333	64,16	7,1467	142,93	1,2002
104	34,667	64,5	7,1832	143,66	1,2064
105	35	64,83	7,208	144,16	1,2105
106	35,333	65,18	7,2413	144,83	1,2161
107	35,667	65,51	7,2719	145,44	1,2213
108	36	65,85	7,313	146,26	1,2282
109	36,333	66,18	7,3557	147,11	1,2353
110	36,667	66,52	7,4053	148,11	1,2437
111	37	66,86	7,4582	149,16	1,2525
112	37,333	67,19	7,4874	149,75	1,2575
113	37,667	67,54	7,5256	150,51	1,2639
114	38	67,88	7,5475	150,95	1,2676

115	38,333	68,2	7,5865	151,73	1,2741
116	38,667	68,55	7,6356	152,71	1,2823
117	39	68,88	7,6661	153,32	1,2875
118	39,333	69,21	7,7217	154,43	1,2968
119	39,667	69,54	7,7644	155,29	1,304
120	40	69,89	7,809	156,18	1,3115

Table C3: Viscosity of 0.8% NCC mud sample over a temperature range of 30 - 70°C for 40 minutes

0.8% NCC					
Point No.	Time	Temperature	Shear Stress	Viscosity	Torque
	[min]	[°C]	[Pa]	[mPa·s]	[mN·m]
1	0,168	30,4	15,327	306,52	2,574
2	0,336	30,66	13,879	277,58	2,3309
3	0,504	30,91	13,155	263,1	2,2093
4	0,672	31,16	12,671	253,42	2,128
5	0,84	31,48	12,325	246,5	2,0699
6	1,008	31,76	12,055	241,09	2,0245
7	1,177	32,09	11,804	236,08	1,9824
8	1,345	32,38	11,594	231,89	1,9472
9	1,513	32,68	11,41	228,21	1,9163
10	1,681	33,02	11,276	225,52	1,8938
11	1,849	33,26	11,142	222,83	1,8712
12	2,017	33,6	11,011	220,21	1,8492
13	2,185	33,96	10,895	217,91	1,8298
14	2,353	34,24	10,789	215,78	1,8119
15	2,521	34,53	10,69	213,81	1,7954
16	2,689	34,89	10,592	211,84	1,7789
17	2,857	35,18	10,5	210	1,7634
18	3,025	35,53	10,414	208,28	1,749
19	3,193	35,82	10,347	206,93	1,7376
20	3,361	36,16	10,267	205,34	1,7243
21	3,529	36,51	10,197	203,94	1,7126
22	3,698	36,8	10,133	202,66	1,7017
23	3,866	37,09	10,059	201,19	1,6894
24	4,034	37,46	10,001	200,02	1,6796
25	4,202	37,81	9,9405	198,81	1,6694
26	4,37	38,1	9,8938	197,88	1,6616
27	4,538	38,47	9,8354	196,71	1,6518
28	4,706	38,79	9,7844	195,69	1,6432

29	4,874	39,1	9,7263	194,53	1,6335
30	5,042	39,45	9,684	193,68	1,6264
31	5,21	39,75	9,6435	192,87	1,6196
32	5,378	40,12	9,6044	192,09	1,613
33	5,546	40,46	9,568	191,36	1,6069
34	5,714	40,67	9,5262	190,53	1,5999
35	5,882	41,13	9,4923	189,85	1,5942
36	6,05	41,44	9,4428	188,85	1,5858
37	6,219	41,77	9,4092	188,18	1,5802
38	6,387	42,03	9,3748	187,5	1,5744
39	6,555	42,39	9,3353	186,71	1,5678
40	6,723	42,77	9,2916	185,83	1,5605
41	6,891	43,08	9,2575	185,15	1,5547
42	7,059	43,45	9,2256	184,51	1,5494
43	7,227	43,76	9,1974	183,95	1,5446
44	7,395	44,02	9,1684	183,37	1,5398
45	7,563	44,37	9,1475	182,95	1,5363
46	7,731	44,74	9,121	182,42	1,5318
47	7,899	45,13	9,0871	181,74	1,5261
48	8,067	45,46	9,0603	181,21	1,5216
49	8,235	45,75	9,0382	180,76	1,5179
50	8,403	46,11	9,0105	180,21	1,5132
51	8,571	46,49	8,9856	179,71	1,5091
52	8,739	46,8	8,962	179,24	1,5051
53	8,908	47,15	8,9425	178,85	1,5018
54	9,076	47,46	8,918	178,36	1,4977
55	9,244	47,78	8,8972	177,94	1,4942
56	9,412	48,16	8,8716	177,43	1,4899
57	9,58	48,48	8,8542	177,08	1,487
58	9,748	48,74	8,8439	176,88	1,4853
59	9,916	49,13	8,8257	176,51	1,4822
60	10,084	49,5	8,8053	176,11	1,4788
61	10,252	49,83	8,7848	175,7	1,4753
62	10,42	50,14	8,7746	175,49	1,4736
63	10,588	50,51	8,7533	175,07	1,4701
64	10,756	50,83	8,7506	175,01	1,4696
65	10,924	51,21	8,7442	174,88	1,4685
66	11,092	51,52	8,7319	174,64	1,4665
67	11,261	51,84	8,7315	174,63	1,4664
68	11,429	52,16	8,7236	174,47	1,4651
69	11,597	52,54	8,7243	174,48	1,4652
70	11,765	52,83	8,706	174,12	1,4621
71	11,933	53,19	8,6932	173,86	1,46

72	12,101	53,55	8,683	173,66	1,4583
73	12,269	53,87	8,6899	173,8	1,4594
74	12,437	54,24	8,6824	173,65	1,4581
75	12,605	54,54	8,6646	173,29	1,4552
76	12,773	54,91	8,6799	173,6	1,4577
77	12,941	55,18	8,6804	173,61	1,4578
78	13,109	55,58	8,6846	173,69	1,4585
79	13,277	55,84	8,6837	173,68	1,4584
80	13,445	56,24	8,6913	173,83	1,4596
81	13,613	56,59	8,6966	173,93	1,4605
82	13,782	56,89	8,7022	174,05	1,4615
83	13,95	57,27	8,71	174,2	1,4628
84	14,118	57,56	8,7072	174,14	1,4623
85	14,286	57,96	8,7182	174,36	1,4642
86	14,454	58,23	8,7252	174,5	1,4653
87	14,622	58,52	8,7279	174,56	1,4658
88	14,79	58,93	8,7309	174,62	1,4663
89	14,958	59,28	8,7468	174,93	1,469
90	15,126	59,65	8,7668	175,34	1,4723
91	15,294	59,96	8,7986	175,97	1,4777
92	15,462	60,24	8,829	176,58	1,4828
93	15,63	60,63	8,8524	177,05	1,4867
94	15,798	60,98	8,8783	177,57	1,491
95	15,966	61,37	8,8896	177,79	1,4929
96	16,134	61,67	8,9055	178,11	1,4956
97	16,303	61,96	8,9093	178,19	1,4963
98	16,471	62,34	8,9186	178,37	1,4978
99	16,639	62,63	8,9323	178,65	1,5001
100	16,807	62,92	8,9364	178,73	1,5008
101	16,975	63,33	8,9545	179,09	1,5038
102	17,143	63,67	8,9693	179,39	1,5063
103	17,311	64,08	8,995	179,9	1,5106
104	17,479	64,34	9,0039	180,08	1,5121
105	17,647	64,62	9,0205	180,41	1,5149
106	17,815	65,03	9,0373	180,75	1,5177
107	17,983	65,31	9,0543	181,09	1,5206
108	18,151	65,7	9,0742	181,48	1,5239
109	18,319	66,05	9,0982	181,96	1,528
110	18,487	66,34	9,1139	182,28	1,5306
111	18,656	66,72	9,1276	182,55	1,5329
112	18,824	67,02	9,1588	183,18	1,5382
113	18,992	67,41	9,1748	183,49	1,5408
114	19,16	67,7	9,1971	183,94	1,5446

115	19,328	68,05	9,2232	184,46	1,549
116	19,496	68,43	9,2466	184,93	1,5529
117	19,664	68,73	9,2737	185,47	1,5575
118	19,832	69,12	9,2992	185,98	1,5617
119	20	69,43	9,3207	186,41	1,5653
120	20,168	69,74	9,3489	186,98	1,5701

Table C4: Viscosity of 1.0% NCC mud sample over a temperature range of 30 - 70°C for 40 minutes

1.0% NCC					
Point No.	Time	Temperature	Shear Stress	Viscosity	Torque
	[min]	[°C]	[Pa]	[mPa·s]	[mN·m]
1	0,333	28,66	26,381	527,61	1,4007
2	0,667	29,6	24,722	494,43	1,3126
3	1	30,08	23,851	477,01	1,2663
4	1,333	30,49	23,25	464,99	1,2344
5	1,667	30,88	22,901	458,01	1,2159
6	2	31,26	22,54	450,8	1,1967
7	2,333	31,62	22,25	445,01	1,1814
8	2,667	31,97	21,941	438,82	1,165
9	3	32,33	21,671	433,42	1,1506
10	3,333	32,69	21,395	427,9	1,136
11	3,667	33,03	21,218	424,37	1,1266
12	4	33,39	21,08	421,59	1,1192
13	4,333	33,72	20,916	418,32	1,1105
14	4,667	34,07	20,648	412,96	1,0963
15	5	34,41	20,512	410,24	1,0891
16	5,333	34,75	20,322	406,44	1,079
17	5,667	35,1	20,213	404,25	1,0732
18	6	35,44	20,081	401,61	1,0662
19	6,333	35,77	19,923	398,45	1,0578
20	6,667	36,12	19,805	396,09	1,0515
21	7	36,46	19,689	393,78	1,0454
22	7,333	36,8	19,61	392,19	1,0412
23	7,667	37,13	19,538	390,76	1,0374
24	8	37,47	19,478	389,57	1,0342
25	8,333	37,82	19,387	387,74	1,0293
26	8,667	38,16	19,306	386,12	1,025
27	9	38,5	19,218	384,35	1,0204
28	9,333	38,84	19,155	383,09	1,017

29	9,667	39,18	19,067	381,33	1,0123
30	10	39,52	18,992	379,84	1,0084
31	10,333	39,85	18,943	378,85	1,0058
32	10,667	40,19	18,878	377,55	1,0023
33	11	40,53	18,796	375,91	0,99795
34	11,333	40,87	18,743	374,86	0,99516
35	11,667	41,21	18,705	374,09	0,99312
36	12	41,55	18,654	373,07	0,99041
37	12,333	41,89	18,61	372,21	0,98811
38	12,667	42,24	18,547	370,94	0,98475
39	13	42,57	18,502	370,04	0,98235
40	13,333	42,9	18,467	369,34	0,98049
41	13,667	43,24	18,396	367,93	0,97674
42	14	43,58	18,35	366,99	0,97427
43	14,333	43,92	18,292	365,83	0,97119
44	14,667	44,25	18,214	364,29	0,96708
45	15	44,59	18,168	363,36	0,96463
46	15,333	44,94	18,142	362,85	0,96326
47	15,667	45,27	18,143	362,86	0,96329
48	16	45,61	18,192	363,85	0,96592
49	16,333	45,95	18,172	363,45	0,96485
50	16,667	46,29	18,117	362,33	0,9619
51	17	46,63	18,097	361,93	0,96083
52	17,333	46,96	18,074	361,48	0,95963
53	17,667	47,3	18,09	361,79	0,96046
54	18	47,64	18,075	361,5	0,95967
55	18,333	47,98	17,998	359,97	0,95561
56	18,667	48,32	17,954	359,08	0,95325
57	19	48,66	17,956	359,12	0,95336
58	19,333	48,99	17,951	359,02	0,95309
59	19,667	49,34	17,958	359,17	0,95349
60	20	49,66	18,001	360,02	0,95575
61	20,333	50	17,953	359,06	0,95321
62	20,667	50,34	17,919	358,39	0,95142
63	21	50,68	17,926	358,52	0,95176
64	21,333	51,02	17,908	358,16	0,95082
65	21,667	51,37	17,915	358,29	0,95118
66	22	51,7	17,925	358,49	0,9517
67	22,333	52,03	17,923	358,45	0,95159
68	22,667	52,37	17,922	358,44	0,95158
69	23	52,7	17,916	358,31	0,95123
70	23,333	53,04	17,906	358,11	0,95069
71	23,667	53,37	17,908	358,16	0,95081

72	24	53,72	17,94	358,81	0,95253
73	24,333	54,05	17,939	358,78	0,95247
74	24,667	54,39	17,968	359,36	0,95399
75	25	54,73	17,946	358,91	0,95282
76	25,333	55,05	17,961	359,23	0,95365
77	25,667	55,4	17,976	359,51	0,9544
78	26	55,74	17,976	359,51	0,95441
79	26,333	56,08	17,989	359,78	0,95512
80	26,667	56,41	18,002	360,04	0,95581
81	27	56,75	18,03	360,61	0,95731
82	27,333	57,09	18,053	361,06	0,95852
83	27,667	57,43	18,081	361,62	0,96002
84	28	57,76	18,109	362,19	0,96151
85	28,333	58,11	18,142	362,84	0,96325
86	28,667	58,44	18,177	363,54	0,9651
87	29	58,77	18,195	363,9	0,96605
88	29,333	59,11	18,237	364,75	0,96831
89	29,667	59,44	18,279	365,57	0,97049
90	30	59,79	18,349	366,99	0,97425
91	30,333	60,12	18,389	367,79	0,97637
92	30,667	60,47	18,419	368,38	0,97794
93	31	60,8	18,462	369,25	0,98025
94	31,333	61,13	18,509	370,17	0,98271
95	31,667	61,47	18,576	371,52	0,98627
96	32	61,81	18,595	371,9	0,98728
97	32,333	62,15	18,663	373,26	0,99091
98	32,667	62,49	18,701	374,02	0,99292
99	33	62,82	18,756	375,11	0,99583
100	33,333	63,16	18,837	376,75	1,0002
101	33,667	63,5	18,896	377,92	1,0033
102	34	63,83	18,959	379,18	1,0066
103	34,333	64,17	19,038	380,75	1,0108
104	34,667	64,51	19,1	382,01	1,0141
105	35	64,85	19,188	383,77	1,0188
106	35,333	65,18	19,166	383,32	1,0176
107	35,667	65,52	19,234	384,68	1,0212
108	36	65,85	19,309	386,19	1,0252
109	36,333	66,18	19,43	388,6	1,0316
110	36,667	66,54	19,511	390,22	1,0359
111	37	66,86	19,58	391,61	1,0396
112	37,333	67,21	19,682	393,64	1,045
113	37,667	67,54	19,806	396,13	1,0516
114	38	67,87	19,911	398,21	1,0572

115	38,333	68,21	19,941	398,83	1,0588
116	38,667	68,55	20,068	401,36	1,0655
117	39	68,89	20,173	403,46	1,0711
118	39,333	69,21	20,312	406,24	1,0784
119	39,667	69,55	20,401	408,01	1,0832
120	40	69,9	20,497	409,93	1,0883

Table C5: Viscosity of 1.2% NCC mud sample over a temperature range of 30 - 70°C for 40 minutes

1.2% NCC					
Point No.	Time	Temperature	Shear Stress	Viscosity	Torque
	[min]	[°C]	[Pa]	[mPa·s]	[mN·m]
1	0,333	30,02	35,95	718,93	6,0375
2	0,667	30,29	31,759	635,17	5,3337
3	1	30,58	29,82	596,39	5,0081
4	1,333	30,87	28,568	571,35	4,7978
5	1,667	31,19	27,637	552,75	4,6415
6	2	31,51	26,928	538,57	4,5224
7	2,333	31,83	26,364	527,27	4,4276
8	2,667	32,17	25,881	517,61	4,3465
9	3	32,48	25,468	509,37	4,2772
10	3,333	32,8	25,117	502,35	4,2183
11	3,667	33,13	24,794	495,88	4,164
12	4	33,47	24,497	489,94	4,1141
13	4,333	33,8	24,221	484,41	4,0677
14	4,667	34,12	23,989	479,78	4,0288
15	5	34,47	23,784	475,67	3,9943
16	5,333	34,79	23,589	471,79	3,9617
17	5,667	35,14	23,411	468,22	3,9317
18	6	35,47	23,263	465,27	3,9069
19	6,333	35,81	23,089	461,78	3,8777
20	6,667	36,14	22,94	458,79	3,8525
21	7	36,47	22,806	456,12	3,8301
22	7,333	36,82	22,674	453,48	3,808
23	7,667	37,14	22,55	450,99	3,787
24	8	37,48	22,434	448,69	3,7677
25	8,333	37,83	22,334	446,68	3,7509
26	8,667	38,16	22,241	444,83	3,7353
27	9	38,51	22,155	443,11	3,7208
28	9,333	38,84	22,069	441,39	3,7064

29	9,667	39,17	21,99	439,8	3,6931
30	10	39,52	21,908	438,15	3,6792
31	10,333	39,84	21,835	436,71	3,6671
32	10,667	40,19	21,775	435,49	3,6569
33	11	40,54	21,727	434,53	3,6488
34	11,333	40,87	21,687	433,74	3,6422
35	11,667	41,21	21,644	432,88	3,6349
36	12	41,53	21,594	431,89	3,6266
37	12,333	41,89	21,549	430,98	3,619
38	12,667	42,23	21,512	430,24	3,6128
39	13	42,56	21,454	429,09	3,6031
40	13,333	42,9	21,407	428,14	3,5951
41	13,667	43,24	21,371	427,42	3,5891
42	14	43,56	21,338	426,75	3,5835
43	14,333	43,9	21,302	426,04	3,5775
44	14,667	44,25	21,272	425,45	3,5726
45	15	44,59	21,256	425,12	3,5698
46	15,333	44,94	21,239	424,78	3,5669
47	15,667	45,26	21,232	424,63	3,5657
48	16	45,6	21,219	424,39	3,5636
49	16,333	45,94	21,204	424,09	3,5611
50	16,667	46,28	21,191	423,83	3,559
51	17	46,62	21,179	423,58	3,5569
52	17,333	46,95	21,179	423,58	3,5569
53	17,667	47,29	21,176	423,52	3,5564
54	18	47,63	21,183	423,66	3,5576
55	18,333	47,97	21,188	423,77	3,5584
56	18,667	48,31	21,192	423,84	3,5591
57	19	48,65	21,197	423,93	3,5598
58	19,333	48,98	21,207	424,14	3,5616
59	19,667	49,33	21,23	424,59	3,5653
60	20	49,66	21,251	425,03	3,569
61	20,333	50,01	21,28	425,59	3,5738
62	20,667	50,33	21,293	425,87	3,5761
63	21	50,67	21,311	426,22	3,579
64	21,333	51,02	21,335	426,7	3,5831
65	21,667	51,35	21,364	427,28	3,5879
66	22	51,69	21,384	427,68	3,5913
67	22,333	52,02	21,425	428,49	3,5981
68	22,667	52,37	21,455	429,1	3,6032
69	23	52,71	21,489	429,78	3,6089
70	23,333	53,04	21,537	430,74	3,617
71	23,667	53,38	21,572	431,44	3,6229

72	24	53,72	21,613	432,27	3,6298
73	24,333	54,05	21,666	433,32	3,6386
74	24,667	54,39	21,716	434,32	3,6471
75	25	54,73	21,767	435,34	3,6556
76	25,333	55,07	21,826	436,52	3,6655
77	25,667	55,42	21,881	437,61	3,6747
78	26	55,74	21,95	438,99	3,6863
79	26,333	56,08	22,01	440,2	3,6964
80	26,667	56,42	22,077	441,54	3,7077
81	27	56,75	22,148	442,96	3,7196
82	27,333	57,1	22,214	444,29	3,7307
83	27,667	57,42	22,287	445,74	3,7429
84	28	57,78	22,352	447,04	3,7538
85	28,333	58,12	22,432	448,64	3,7673
86	28,667	58,45	22,512	450,24	3,7808
87	29	58,78	22,604	452,08	3,7962
88	29,333	59,11	22,684	453,68	3,8096
89	29,667	59,44	22,766	455,31	3,8233
90	30	59,8	22,852	457,04	3,8378
91	30,333	60,13	22,954	459,09	3,855
92	30,667	60,46	23,041	460,83	3,8697
93	31	60,8	23,135	462,7	3,8853
94	31,333	61,14	23,236	464,71	3,9023
95	31,667	61,48	23,342	466,84	3,9201
96	32	61,81	23,432	468,64	3,9353
97	32,333	62,14	23,525	470,5	3,9508
98	32,667	62,49	23,635	472,7	3,9693
99	33	62,83	23,746	474,92	3,988
100	33,333	63,17	23,856	477,13	4,0065
101	33,667	63,5	23,962	479,25	4,0243
102	34	63,83	24,07	481,41	4,0424
103	34,333	64,17	24,191	483,82	4,0627
104	34,667	64,52	24,32	486,4	4,0844
105	35	64,85	24,442	488,85	4,1049
106	35,333	65,18	24,561	491,23	4,1249
107	35,667	65,52	24,683	493,67	4,1454
108	36	65,86	24,801	496,02	4,1652
109	36,333	66,19	24,924	498,49	4,1859
110	36,667	66,54	25,056	501,13	4,208
111	37	66,86	25,2	503,99	4,2321
112	37,333	67,2	25,347	506,94	4,2569
113	37,667	67,55	25,484	509,69	4,2799
114	38	67,88	25,64	512,8	4,3061

115	38,333	68,22	25,8	515,99	4,3329
116	38,667	68,56	25,96	519,2	4,3598
117	39	68,89	26,115	522,31	4,3859
118	39,333	69,23	26,287	525,74	4,4147
119	39,667	69,56	26,469	529,37	4,4452
120	40	69,9	26,648	532,95	4,4753

Appendix D: Rheological analysis: Shear Stress vs Shear Rate

Table D1: Shear stress vs shear rate for NCC-Bentonite sample with 0.0% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
0,0976	9,2469	94,747
0,121	9,1663	75,975
0,143	8,3364	58,322
0,171	8,1022	47,438
0,204	7,8226	38,407
0,243	7,7579	31,881
0,291	7,7378	26,585
0,348	7,9044	22,705
0,415	8,1638	19,656
0,496	8,3237	16,772
0,593	8,2328	13,881
0,708	8,4363	11,924
0,845	8,7868	10,398
1,01	9,2983	9,1956
1,21	9,8026	8,1172
1,44	10,256	7,1075
1,72	10,537	6,1123
2,06	10,743	5,2187
2,46	10,874	4,4186
2,94	10,796	3,6709
3,51	10,928	3,1112
4,2	10,799	2,5742
5,01	10,701	2,1344
5,99	10,66	1,7797
7,16	10,644	1,4874
8,55	10,674	1,2488

10,2	10,74	1,0517
12,2	10,822	0,88709
14,6	10,935	0,75029
17,4	11,132	0,63925
20,8	11,265	0,54149
24,9	11,431	0,45994
29,7	11,635	0,39185
35,5	11,868	0,33454
42,4	12,096	0,2854
50,6	12,341	0,24372
60,5	12,641	0,20897
72,3	12,937	0,17899
86,3	13,247	0,15341
103	13,55	0,13135
123	13,87	0,11254
147	14,263	0,096865
176	14,68	0,083456
210	15,154	0,072093
251	15,509	0,061761
300	15,828	0,052759

Table D2: Shear stress vs shear rate for NCC-Bentonite sample with 0.2% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
0,1	8,6529	86,452
0,12	7,0851	59,256
0,143	5,9359	41,57
0,171	5,3477	31,347
0,204	5,0832	24,953
0,244	4,8403	19,869
0,291	4,7698	16,397
0,348	4,8804	14,041
0,415	5,0041	12,053
0,495	5,2287	10,553
0,593	5,5288	9,3292
0,708	5,9421	8,3956
0,845	6,5375	7,7358
1,01	7,3774	7,3038
1,21	8,3993	6,9628
1,44	8,6187	5,9701

1,72	9,3445	5,424
2,06	10,511	5,111
2,46	11,745	4,7765
2,94	12,96	4,4122
3,51	13,574	3,8669
4,2	13,697	3,2632
5,02	13,295	2,6507
5,99	12,991	2,1683
7,16	12,784	1,7864
8,55	12,686	1,4842
10,2	12,737	1,2473
12,2	12,704	1,0412
14,6	12,79	0,87743
17,4	12,889	0,74016
20,8	13,026	0,62617
24,9	13,203	0,53118
29,7	13,423	0,45205
35,5	13,653	0,38488
42,4	14,002	0,33035
50,6	14,36	0,28359
60,5	14,749	0,2438
72,3	15,196	0,21024
86,4	15,647	0,1812
103	16,191	0,15693
123	16,727	0,13571
147	17,292	0,11742
176	17,915	0,10187
210	18,569	0,088352
251	19,358	0,0771
300	20,119	0,067064

Table D3: Shear stress vs shear rate for NCC-Bentonite sample with 0.4% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
	14,448	145,09
0,12	7,3855	61,604
0,143	6,7623	47,284
0,171	6,7076	39,3
0,204	6,6598	32,661
0,244	6,8199	28,004

0,291	7,0182	24,131
0,347	7,2356	20,832
0,415	7,6123	18,343
0,496	8,0341	16,187
0,592	8,4075	14,195
0,708	8,9838	12,694
0,846	9,6745	11,434
1,01	10,407	10,301
1,21	11,394	9,4413
1,44	12,547	8,7064
1,72	14,1	8,192
2,06	15,691	7,6195
2,46	16,147	6,5594
2,94	16,908	5,7523
3,51	17,485	4,9771
4,2	17,647	4,2011
5,02	17	3,3882
5,99	16,175	2,6995
7,16	15,81	2,2096
8,55	15,756	1,8427
10,2	15,817	1,5489
12,2	16,052	1,3156
14,6	16,254	1,1151
17,4	16,498	0,94752
20,8	16,85	0,81
24,9	17,136	0,68943
29,7	17,497	0,58919
35,5	17,934	0,50554
42,4	18,295	0,43164
50,6	18,73	0,36989
60,5	19,149	0,31653
72,3	19,583	0,27096
86,3	20,059	0,2323
103	20,618	0,19986
123	21,143	0,17154
147	21,611	0,14676
176	22,129	0,12578
210	22,773	0,10836
251	23,431	0,093309
300	24,199	0,080666

Table D4: Shear stress vs shear rate for NCC-Bentonite sample with 0.8% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
0,1	9,5881	95,547
0,119	8,7567	73,279
0,143	8,5437	59,836
0,171	8,5132	49,905
0,204	8,5526	41,964
0,243	8,7677	36,013
0,291	9,0354	31,065
0,347	9,4997	27,35
0,415	10,072	24,258
0,496	10,672	21,519
0,593	11,196	18,892
0,708	11,706	16,539
0,846	12,28	14,516
1,01	12,627	12,486
1,21	12,712	10,524
1,44	13,051	9,0464
1,72	13,065	7,577
2,06	13,292	6,4534
2,46	13,267	5,3907
2,94	13,541	4,6052
3,51	13,663	3,8908
4,2	13,782	3,2845
5,01	13,967	2,7859
5,99	14,188	2,3682
7,15	14,493	2,0257
8,55	14,825	1,7344
10,2	15,225	1,4908
12,2	15,503	1,2706
14,6	15,927	1,0926
17,4	16,4	0,9417
20,8	16,903	0,81244

24,9	17,423	0,7009
29,7	18,028	0,60712
35,5	18,62	0,52489
42,4	19,295	0,45519
50,6	19,981	0,39458
60,5	20,638	0,34111
72,3	21,365	0,29557
86,4	21,985	0,25457
103	22,627	0,21931
123	23,183	0,18807
147	23,845	0,16191
176	24,753	0,14076
210	25,721	0,12232
251	26,933	0,10722
300	28,266	0,094223

Table D5: Shear stress vs shear rate for NCC-Bentonite sample with 1.0% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
0,1	24,18	241,25
0,119	21,194	177,38
0,143	20,814	145,75
0,171	20,615	120,87
0,204	20,783	102,01
0,243	21,218	87,157
0,291	21,435	73,708
0,347	22,17	63,829
0,415	23,28	56,078
0,496	24,818	50,065
0,593	26,064	43,988
0,708	26,526	37,459
0,846	26,894	31,79
1,01	27,431	27,142
1,21	27,548	22,808
1,44	27,586	19,125
1,72	28,159	16,338
2,06	28,047	13,622
2,46	28,815	11,71
2,94	29,037	9,8833
3,51	29,443	8,3851

4,2	30,124	7,1783
5,01	30,482	6,0818
5,99	30,71	5,1279
7,16	30,814	4,3065
8,55	30,892	3,6137
10,2	31,627	3,0978
12,2	32,307	2,648
14,6	32,879	2,2559
17,4	33,453	1,9213
20,8	34,254	1,6465
24,9	34,887	1,4037
29,7	35,608	1,1991
35,5	36,38	1,0254
42,4	37,343	0,88113
50,6	38,083	0,75205
60,5	39,143	0,64705
72,3	40,149	0,55548
86,4	41,216	0,47731
103	42,256	0,4096
123	43,181	0,35034
147	44,195	0,30012
176	45,293	0,25744
210	46,645	0,2219
251	48,015	0,19127
300	49,674	0,16556

Table D6: Shear stress vs shear rate for NCC-Bentonite sample with 1.2% NCC at 25 °C

Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [Pa·s]
0,1	17,405	173,99
0,12	16,777	140,38
0,143	16,585	116,17
0,171	16,975	99,533
0,204	17,302	84,913
0,243	17,713	72,768
0,291	18,332	63,046
0,347	19,027	54,756
0,415	19,857	47,835
0,496	21,13	42,604
0,593	22,594	38,126

0,708	24,119	34,071
0,846	25,798	30,507
1,01	27,961	27,677
1,21	29,816	24,695
1,44	31,521	21,855
1,72	33,762	19,592
2,06	35,824	17,397
2,46	37,672	15,309
2,94	38,767	13,185
3,51	39,528	11,249
4,2	40,153	9,5655
5,01	40,592	8,0941
5,99	41,075	6,8556
7,16	41,577	5,8083
8,55	42,035	4,9149
10,2	42,628	4,1727
12,2	43,322	3,5489
14,6	44,03	3,0198
17,4	44,825	2,5731
20,8	45,682	2,1947
24,9	46,567	1,8729
29,7	47,622	1,603
35,5	48,712	1,3725
42,4	49,947	1,1781
50,7	51,191	1,0106
60,5	52,613	0,86945
72,3	54,154	0,74902
86,4	55,64	0,64419
103	57,025	0,55261
123	58,32	0,47303
147	59,57	0,40442
176	60,965	0,34646
210	62,657	0,29811
251	64,69	0,25754
300	67,014	0,22329

Appendix E: Rheological analysis: Thixotropy

Table E1: Thixotropic analysis for NCC-Bentonite sample with 0.0% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	4,3654	17437
10	3,9354	15735
15	3,8229	15280
20	3,7145	14865
25	3,5902	14366
25,12	444,37	2199,9
25,22	196,8	198,44
25,32	20,173	20,141
25,42	34,09	34,114
25,52	31,739	31,742
25,62	30,235	30,225
25,72	29,268	29,275
25,82	30,276	30,279
25,92	28,44	28,426
26,02	27,526	27,512
26,53	-0,16022	-657,29
27,03	0,11404	462,33
27,53	0,26095	1065,2
28,03	0,51805	2125,4
28,53	0,98283	4118,3
29,03	1,1892	4757
29,53	1,33	5367,7
30,03	1,5901	6502,3
30,53	1,8971	7666,2
31,03	2,0632	8299,7
31,53	2,2261	8982,1
32,03	2,4326	9819,6
32,53	2,5988	10475
33,03	2,8044	11215
33,53	2,9173	11774
34,03	3,0729	12341
34,53	3,2776	13242
35,03	3,3498	13357
35,53	3,3714	13475

36,03	3,4476	13809
36,53	3,6699	14750
37,03	3,6928	14768
37,53	3,8858	15594
38,03	3,9249	15673
38,53	4,0819	16392
39,03	4,1089	16473
39,53	4,1004	16442
40,03	4,1902	16842
40,53	4,3704	17509
41,03	4,4139	17657
41,53	4,356	17351
42,03	4,3035	17313
42,53	4,5632	18356
43,03	4,6269	18511
43,53	4,6371	18570
44,03	4,6093	18436
44,53	4,5781	18321
45,03	4,7058	18825
45,53	4,7612	18988
46,03	4,7357	18990
46,53	4,7807	19106
47,03	4,8764	19548
47,53	4,9333	19745
48,03	4,8382	19362
48,53	4,7866	19113
49,03	4,8228	19386
49,53	4,9153	19625
50,03	4,7896	19151
50,53	4,8414	19433
51,03	4,9351	19812
51,53	4,9438	19774
52,03	4,9973	20027
52,53	4,887	19497
53,03	4,9925	19930
53,53	4,9132	19617
54,03	4,8592	19448
54,53	5,031	20250
55,03	4,9952	19886
55,53	4,9823	19981
56,03	5,0379	20178

56,53	5,0589	20245
57,03	5,0319	20032
57,53	5,0031	20020
58,03	5,0042	20000
58,53	5,0162	20098
59,03	4,9839	19911
59,53	4,9712	19912
60,03	4,9805	19913
60,53	5,0135	20015
61,03	5,015	20071
61,53	5,0697	20278
62,03	5,0003	19985
62,53	5,0762	20294
63,04	5,0151	20021
63,53	5,0382	20157
64,03	4,9618	19864
64,53	4,9988	20037
65,03	5,0389	20101
65,53	5,0053	19971
66,04	4,9345	19729
66,53	4,9156	19638
67,03	4,8879	19537
67,55	4,8533	19370
68,03	4,8522	19349
68,53	4,9218	19654
69,05	4,9445	19670
69,53	4,7628	19037
70,03	4,8248	19301
70,56	4,789	19163
71,03	4,9019	19599
71,53	4,8218	19344
72,03	4,8013	19226
72,53	4,9036	19623
73,03	4,7472	18846
73,53	4,6949	18798
74,03	4,7556	19040
74,53	4,8542	19454
75,03	4,8217	19232
75,53	4,6633	18668
76,03	4,8242	19309
76,53	4,7024	18798

77,03	4,6666	18680
77,53	4,6421	18562
78,03	4,6928	18761
78,53	4,6693	18660
79,03	4,7039	18779
79,53	4,6178	18461
80,03	4,7008	18841
80,53	4,6277	18484
81,03	4,6015	18395
81,53	4,6418	18621
82,03	4,6197	18462
82,53	4,5303	18064
83,03	4,4882	17935
83,53	4,589	18389
84,03	4,5079	17948
84,53	4,5238	18105
85,03	4,4814	17951
85,53	4,4194	17683
86,03	4,5253	18137
86,53	4,669	18729
87,03	4,5985	18371
87,53	4,4428	17748
88,03	4,4839	18007
88,53	4,4883	17818
89,03	4,4116	17694
89,53	4,5431	18199
90,03	4,458	17774
90,53	4,4353	17802
91,03	4,5324	18142
91,53	4,4797	17907
92,03	4,3894	17570
92,53	4,589	18339
93,03	4,3961	17517
93,53	4,348	17407
94,03	4,3965	17542
94,53	4,3474	17420
95,03	4,4324	17732
95,53	4,3487	17362
96,03	4,3248	17291
96,53	4,3965	17565
97,03	4,3908	17562

97,53	4,3104	17272
98,03	4,3194	17300
98,53	4,2107	16818
99,03	4,2885	17254
99,53	4,3768	17481
100,03	4,268	16996
100,53	4,1919	16753
101,03	4,2722	17136
101,53	4,199	16683
102,03	4,1213	16450
102,53	4,1394	16633
103,03	4,2126	16869
103,53	4,1773	16768
104,03	4,2433	16968
104,53	4,1851	16688
105,03	4,141	16573
105,53	4,1082	16411
106,03	4,1415	16628
106,53	4,2207	16911
107,03	4,0468	16113
107,53	4,0576	16238
108,03	4,1626	16655
108,53	4,1815	16736
109,03	4,0239	15969
109,53	4,0175	16139
110,03	4,142	16586
110,53	4,0591	16243
111,03	4,0406	16169
111,53	4,0385	16070
112,03	4,026	16108
112,53	3,9398	15722
113,03	3,9581	15879
113,53	4,117	16560
114,03	4,0329	16054
114,53	4,0675	16249
115,03	4,0209	16055
115,53	4,005	15929
116,03	3,9269	15708
116,53	3,903	15625
117,03	4,0142	16071
117,53	4,0199	16096

118,03	3,9462	15730
118,53	3,9408	15889
119,03	3,9383	15669
119,53	3,8905	15538
120,03	3,8615	15397
120,53	3,8456	15388
121,03	3,8838	15602
121,53	3,8792	15475
122,03	3,9092	15678
122,53	3,8466	15332
123,03	3,8095	15310
123,53	3,9941	15951
124,03	3,8916	15551
124,53	3,7949	15117
125,03	3,7509	15035
125,53	4,0023	16142
126,03	3,8107	15149
126,53	3,7541	15054
127,03	3,9041	15713
127,53	3,919	15618
128,03	3,827	15241
128,53	3,748	15010
129,03	3,8013	15264
129,53	3,7804	15088
130,03	3,8414	15436
130,53	3,8341	15363
131,03	3,8529	15367
131,53	3,7547	14999
132,03	3,8509	15399
132,53	3,7573	15012
133,03	3,7451	14958
133,53	3,7502	15090
134,03	3,7932	15176
134,53	3,7398	14913
135,03	3,692	14757
135,53	3,7558	14960
136,03	3,7312	14978
136,53	3,7486	14964
137,03	3,727	14896
137,53	3,7606	15068
138,03	3,78	15151

138,53	3,7474	14970
139,03	3,7811	15086
139,53	3,7413	14923
140,03	3,707	14867
140,53	3,6763	14737
141,03	3,8018	15230
141,53	3,7284	14907
142,03	3,7272	14909
142,53	3,7197	14899
143,03	3,6597	14645
143,53	3,6987	14836
144,03	3,6952	14810
144,53	3,6134	14421
145,03	3,6107	14455
145,53	3,5806	14359
146,03	3,8042	15314
146,53	3,7021	14717
147,03	3,6666	14664
147,53	3,7095	14853
148,03	3,6324	14505
148,53	3,5953	14348
149,03	3,641	14528
149,53	3,6585	14671
150,03	3,6534	14594
150,53	3,6395	14452
151,03	3,6389	14636
151,53	3,5708	14220
152,03	3,5579	14187
152,53	3,6155	14510
153,03	3,6164	14464
153,53	3,5957	14437
154,03	3,6216	14480
154,53	3,5321	14082
155,03	3,4857	13950
155,53	3,5368	14215
156,03	3,6496	14620
156,53	3,5332	14119
157,03	3,5719	14306
157,53	3,583	14322
158,03	3,5131	14028
158,53	3,4745	13870

159,03	3,4488	13789
159,53	3,5399	14260
160,03	3,5632	14197
160,53	3,6169	14582
161,03	3,6659	14585
161,53	3,5017	14049
162,03	3,6038	14421
162,53	3,4171	13598
163,03	3,432	13789
163,53	3,587	14343
164,03	3,5512	14195
164,53	3,5188	14045
165,03	3,5503	14249
165,53	3,5078	14056
166,04	3,464	13796
166,53	3,5059	14012
167,03	3,4796	13985
167,55	3,403	13550
168,03	3,4132	13732
168,53	3,4717	13846
169,06	3,4615	13833
169,53	3,416	13647
170,03	3,3676	13479
170,53	3,4179	13701
171,03	3,5048	14050
171,53	3,4844	13944
172,03	3,5044	14001
172,53	3,3312	13278
173,03	3,4564	13925
173,53	3,4882	13896
174,03	3,3918	13494
174,53	3,4294	13758
175,03	3,4856	13974
175,53	3,3833	13472
176,03	3,4245	13770
176,53	3,4957	13927
177,03	3,4302	13762
177,53	3,5369	14191
178,03	3,5224	14035
178,53	3,3807	13432
179,03	3,3502	13428

179,53	3,4534	13915
180,03	3,4959	13929
180,53	3,3861	13557
181,03	3,5345	14212
181,53	3,4362	13700
182,03	3,4739	13829
182,53	3,3784	13422
183,03	3,4638	13902
183,53	3,4219	13693
184,03	3,4962	13985
184,53	3,3747	13501
185,03	3,4235	13684
185,53	3,4268	13658
186,03	3,4204	13670
186,53	3,3116	13189
187,03	3,3409	13404
187,53	3,4337	13751
188,03	3,3884	13499
188,53	3,369	13514
189,03	3,4004	13630
189,53	3,3426	13324
190,03	3,3459	13364
190,53	3,3965	13522
191,03	3,3388	13433
191,53	3,4273	13646
192,03	3,3585	13473
192,53	3,39	13549
193,03	3,4495	13833
193,53	3,3948	13483
194,03	3,2842	13122
194,53	3,3453	13491
195,03	3,4222	13636
195,53	3,2383	12875
196,03	3,2737	13108
196,53	3,3841	13581
197,03	3,3352	13301
197,53	3,2159	12785
198,03	3,2667	13091
198,53	3,4659	13933
199,03	3,3532	13373
199,53	3,3053	13268

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200,53	3,3734	13432
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201,53	3,3224	13257
202,03	3,3116	13303
202,53	3,397	13558
203,03	3,28	13136
203,53	3,3562	13471
204,03	3,2549	13001
204,53	3,3943	13551
205,03	3,2207	12862
205,53	3,2115	12887
206,03	3,3216	13231
206,53	3,2683	13035
207,03	3,2931	13224
207,53	3,3657	13456
208,03	3,2986	13213
208,53	3,3535	13434
209,03	3,2855	13069
209,53	3,1208	12426
210,03	3,3455	13548
210,53	3,4389	13671
211,03	3,2675	13067
211,53	3,2941	13221
212,03	3,3579	13465
212,53	3,3078	13232
213,03	3,2465	12959
213,53	3,187	12706
214,03	3,2057	12873
214,53	3,3468	13484
215,03	3,3325	13263
215,53	3,2538	13034
216,03	3,2587	12992
216,53	3,2494	12995
217,03	3,274	13071
217,53	3,1972	12746
218,03	3,1963	12831
218,53	3,2055	12785
219,03	3,2069	12853
219,53	3,2101	12804
220,03	3,1886	12779

220,53	3,1839	12728
221,03	3,2142	12857
221,53	3,2551	12991
222,03	3,2626	13021
222,53	3,2808	13197
223,03	3,1351	12479
223,53	3,176	12731
224,03	3,2729	13177
224,53	3,1448	12508
225,03	3,1688	12740
225,53	3,3107	13300
226,03	3,277	13090
226,53	3,2723	13107
227,03	3,1828	12713
227,53	3,2274	12976
228,03	3,1843	12715
228,53	3,1731	12707
229,03	3,1442	12562
229,53	3,2398	12939
230,03	3,152	12576
230,53	3,1256	12540
231,03	3,3356	13373
231,53	3,158	12555
232,03	3,2287	13047
232,53	3,3335	13341
233,03	3,1934	12693
233,53	3,0855	12335
234,03	3,1395	12586
234,53	3,2794	13151
235,03	3,2073	12810
235,53	3,227	12864
236,03	3,2092	12898
236,53	3,2194	12879
237,03	3,1639	12631
237,53	3,1339	12527
238,03	3,1812	12748
238,53	3,231	12983
239,03	3,1345	12537
239,53	3,1395	12508
240,03	3,0989	12468
240,53	3,1825	12687

241,03	3,1331	12570
241,53	3,1676	12613
242,03	3,2028	12851
242,53	3,1494	12572
243,03	3,0777	12283
243,53	3,0853	12356
244,03	3,0965	12465
244,53	3,1901	12749
245,03	3,0712	12238
245,53	3,2568	13047
246,03	3,1036	12341
246,53	3,1851	12850
247,03	3,1997	12691
247,53	2,9744	11922
248,03	3,1591	12708
248,53	3,1151	12396
249,03	3,1027	12411
249,53	3,1844	12808
250,03	3,0978	12314
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251,03	3,1694	12687
251,53	3,1672	12680
252,03	3,1781	12738
252,53	3,1315	12493
253,03	2,9798	11895
253,53	3,0646	12321
254,03	3,1259	12493
254,53	3,082	12279
255,03	3,0453	12154
255,53	3,0935	12419
256,03	3,13	12549
256,53	3,1872	12752
257,03	3,1229	12419
257,53	3,0559	12237
258,03	3,0695	12267
258,53	3,0628	12310
259,03	3,1602	12633
259,53	3,148	12595
260,03	2,9972	11955
260,53	3,0454	12207
261,03	3,2172	12917

261,53	3,0582	12153
262,03	3,1331	12685
262,53	3,0563	12122
263,03	3,0006	12053
263,53	3,0223	12100
264,04	3,0033	12033
264,53	3,2214	12939
265,03	3,0481	12051
265,54	3,0547	12273
266,03	3,0118	12028
266,53	3,0326	12083
267,05	3,1345	12598
267,53	3,0062	12009
268,03	2,9661	11837
268,56	2,9538	11863
269,03	3,0984	12401
269,53	3,0436	12117
270,03	3,0551	12285
270,53	3,0559	12239
271,03	2,9647	11810
271,53	2,955	11845
272,03	3,0182	12115
272,53	3,0508	12202
273,03	3,0547	12197
273,53	2,9372	11792
274,03	3,0988	12331
274,53	2,9268	11768
275,03	3,0818	12323
275,53	3,0454	12166
276,03	2,9927	11961
276,53	3,0062	11991
277,03	2,9408	11752
277,53	2,9586	11848
278,03	3,0586	12320
278,53	3,1243	12404
279,03	2,9217	11676
279,53	3,1114	12525
280,03	2,9374	11656
280,53	2,9812	12004
281,03	3,0409	12167
281,53	3,067	12299

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282,53	2,8624	11485
283,03	3,0268	12278
283,53	3,1452	12567
284,03	2,9891	11978
284,53	3,0446	12241
285,03	3,0786	12332
285,53	2,9824	11905
286,03	2,855	11362
286,53	2,9216	11734
287,03	3,0327	12203
287,54	3,0871	12261
288,04	2,8448	11378
288,54	3,0204	12071
289,04	2,999	11966
289,54	2,9925	11956
290,04	2,9884	11949
290,54	2,9373	11755
291,04	2,9193	11703
291,54	2,9442	11819
292,04	3,0016	11973
292,54	2,9975	11946
293,03	2,9771	11883
293,53	2,9935	11965
294,03	2,9027	11582
294,53	2,8943	11647
295,03	3,1047	12462
295,53	2,94	11668
296,03	2,8545	11428
296,53	2,997	11987
297,03	3,0058	12047
297,53	3,0154	12004
298,03	2,9449	11780
298,53	2,8687	11478
299,03	2,9469	11860
299,53	2,9981	12023
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301,03	2,9409	11780
301,53	2,9443	11861
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303,03	2,9084	11668
303,53	2,9434	11765
304,03	2,8447	11363
304,53	2,9387	11817
305,03	2,977	11894
305,53	2,8975	11627
306,03	2,9441	11765
306,53	2,941	11794
307,03	2,9301	11737
307,53	2,94	11823
308,03	2,8692	11581
308,53	2,8862	11572
309,03	2,945	11764
309,53	2,8581	11416
310,03	2,8104	11184
310,53	3,0529	12243
311,03	2,9518	11725
311,53	2,8199	11260
312,03	2,8897	11564
312,53	2,8219	11231
313,03	2,9092	11713
313,53	2,9746	11876
314,03	2,8393	11293
314,53	2,7548	11072
315,03	2,767	11075
315,53	2,9659	11961
316,03	2,9602	11757
316,53	2,8761	11532
317,03	3,0123	12039
317,53	2,8647	11419
318,03	2,7806	11103
318,53	2,8541	11484
319,03	2,8864	11580
319,53	2,9779	11922
320,03	3,0136	12012
320,53	2,8533	11416
321,03	2,9672	11878
321,53	2,9248	11625
322,03	2,8407	11363
322,53	2,7986	11245

323,03	2,8957	11636
323,53	2,9551	11773
324,03	2,9578	11815
324,53	2,8093	11140
325,03	2,8008	11243
325,53	2,8619	11443
326,03	2,8473	11445
326,53	2,962	11829
327,03	2,8846	11510
327,53	2,7911	11161
328,03	2,7652	11045
328,53	2,7895	11120
329,03	2,7717	11112
329,53	2,8389	11276
330,03	2,8041	11254
330,53	2,9859	11951
331,03	2,7688	11114
331,53	2,8224	11325
332,03	2,7968	11184
332,53	2,8124	11287
333,03	2,9068	11602
333,53	2,802	11139
334,03	2,8561	11471
334,53	2,8725	11460
335,03	2,8158	11293
335,53	2,7897	11085
336,03	2,8038	11275
336,53	2,8481	11355
337,03	2,7913	11113
337,53	2,6352	10570
338,03	2,8655	11497
338,53	2,7476	10997
339,03	2,9211	11715
339,53	2,7986	11114
340,03	2,7776	11165
340,53	2,8523	11386
341,03	2,8509	11444
341,53	2,8934	11508
342,03	2,7498	11102
342,53	2,8289	11256
343,03	2,7609	11081

343,53	2,8385	11221
344,03	2,8218	11384
344,53	2,873	11390
345,03	2,7934	11139
345,53	2,8714	11534
346,03	2,9364	11737
346,53	2,7862	11177
347,03	2,8702	11535
347,53	2,8164	11214
348,03	2,7115	10811
348,53	2,8169	11329
349,03	2,7918	11136
349,53	2,868	11501
350,03	2,829	11265
350,53	2,8178	11306
351,03	2,8662	11456
351,53	2,8475	11389
352,03	2,8016	11200
352,53	2,8497	11481
353,03	2,7042	10664
353,53	2,759	11228
354,03	2,8218	11195
354,53	2,7918	11167
355,03	2,8024	11197
355,53	2,7366	10952
356,03	2,7494	10953
356,53	2,7535	11020
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357,53	2,8321	11338
358,03	2,7013	10763
358,53	2,769	11166
359,03	2,7555	10927
359,53	2,6958	10807
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360,53	2,7745	11081
361,03	2,7733	11068
361,53	2,758	11071
362,03	2,7306	10905
362,53	2,7227	10924
363,03	2,8142	11266
363,53	2,7568	10963

364,03	2,6893	10713
364,53	2,8407	11385
365,03	2,6873	10700
365,53	2,6632	10639
366,03	2,6986	10820
366,53	2,794	11234
367,03	2,6416	10478
367,53	2,6459	10623
368,03	2,8276	11301
368,53	2,8444	11415
369,03	2,6639	10614
369,53	2,757	11062
370,03	2,808	11238
370,53	2,6703	10629
371,03	2,6827	10731
371,53	2,6704	10712
372,03	2,7578	11040
372,53	2,6561	10561
373,03	2,6893	10744
373,53	2,6684	10651
374,03	2,7197	10948
374,53	2,7524	10975
375,03	2,615	10352
375,53	2,6211	10508
376,03	2,685	10788
376,53	2,7203	10896
377,03	2,7645	11084
377,53	2,6276	10496
378,03	2,7228	10971
378,53	2,7603	11032
379,03	2,5852	10279
379,53	2,4978	10037
380,03	2,735	11011
380,53	2,6913	10735
381,03	2,5434	10198
381,53	2,7333	11068
382,03	2,7659	11067
382,53	2,6381	10476
383,03	2,6	10421
383,53	2,6253	10466
384,03	2,6448	10646

384,53	2,8263	11304
385,03	2,7328	10868
385,53	2,6875	10712
386,03	2,6267	10527
386,53	2,594	10392
387,03	2,7668	11105
387,53	2,6464	10616
388,03	2,7471	10992
388,53	2,6908	10783
389,03	2,6362	10443
389,53	2,5955	10430
390,03	2,7023	10802
390,53	2,6685	10695
391,03	2,6903	10756
391,53	2,7435	10915
392,03	2,6527	10597
392,53	2,6792	10660
393,03	2,6166	10527
393,53	2,7318	10988
394,03	2,7481	10996
394,53	2,6853	10685
395,03	2,6547	10663
395,53	2,8116	11306
396,03	2,6766	10652
396,53	2,6893	10760
397,03	2,6903	10786
397,53	2,715	10803
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399,03	2,7293	10802
399,53	2,547	10135
400,03	2,5196	10142
400,53	2,7196	10962
401,03	2,6931	10766
401,53	2,7536	11045
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402,53	2,6315	10489
403,03	2,5842	10337
403,53	2,647	10613
404,03	2,6699	10668
404,53	2,6524	10659

405,03	2,6797	10724
405,53	2,6513	10670
406,03	2,6726	10715
406,53	2,6416	10409
407,03	2,5035	10008
407,53	2,6518	10691
408,03	2,7404	10950
408,53	2,6606	10550
409,03	2,5425	10196
409,53	2,652	10671
410,03	2,5459	10125
410,53	2,6079	10520
411,03	2,7422	10953
411,53	2,6419	10587
412,03	2,6128	10453
412,53	2,6125	10416
413,03	2,564	10269
413,53	2,5222	10104
414,03	2,6497	10582
414,53	2,5762	10257
415,03	2,7851	11231
415,53	2,7052	10730
416,03	2,6451	10559
416,53	2,6571	10573
417,04	2,5547	10212
417,53	2,6586	10749
418,03	2,6948	10759
418,54	2,7092	10801
419,03	2,6472	10569
419,53	2,6736	10666
420,05	2,6772	10721
420,53	2,5811	10297
421,03	2,6036	10486
421,56	2,6824	10802
422,03	2,7322	10857
422,53	2,5118	10097
423,06	2,6046	10425
423,53	2,6039	10439
424,03	2,6244	10495
424,53	2,6456	10575
425,03	2,5118	10061

425,53	2,6532	10628
426,03	2,6573	10595
426,53	2,6421	10532
427,03	2,5467	10166
427,53	2,5256	10138
428,03	2,4988	9996,4
428,53	2,5656	10252
429,03	2,6551	10594
429,53	2,5552	10197
430,03	2,5839	10388
430,53	2,5722	10219
431,03	2,6254	10470
431,53	2,5038	10005
432,03	2,7261	10941
432,53	2,5834	10254
433,03	2,5738	10335
433,53	2,6216	10494
434,03	2,5679	10269
434,53	2,5888	10345
435,03	2,6382	10587
435,53	2,6571	10599
436,03	2,6425	10667
436,53	2,6991	10794
437,03	2,5612	10234
437,53	2,5969	10366
438,03	2,5329	10111
438,53	2,7098	10827
439,03	2,6105	10462
439,53	2,6509	10572
440,03	2,6348	10619
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441,03	2,5082	10029
441,53	2,5956	10414
442,03	2,7173	10899
442,53	2,647	10510
443,03	2,5649	10236
443,53	2,5422	10167
444,03	2,5447	10144
444,53	2,5883	10371
445,03	2,6252	10571
445,53	2,6467	10574

446,03	2,6368	10449
446,53	2,4689	9868
447,03	2,5435	10260
447,53	2,668	10715
448,03	2,6943	10671
448,53	2,4168	9673,3
449,03	2,5322	10215
449,53	2,5937	10397
450,03	2,6066	10425
450,53	2,6207	10525
451,03	2,5241	10061
451,53	2,586	10368
452,03	2,44	9699,9
452,53	2,5368	10201
453,03	2,5922	10430
453,53	2,5841	10344
454,03	2,6227	10464
454,53	2,6084	10442
455,03	2,4796	9832,4
455,53	2,514	10045
456,03	2,5405	10204
456,53	2,5773	10333
457,03	2,6307	10566
457,53	2,5735	10261
458,03	2,4979	10036
458,53	2,6115	10505
459,03	2,5549	10198
459,53	2,5092	10038
460,03	2,5532	10240
460,53	2,5717	10233
461,03	2,458	9861,6
461,53	2,637	10600
462,03	2,6076	10371
462,53	2,5908	10396
463,03	2,7665	11066
463,53	2,5207	10030
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464,53	2,5884	10370
465,03	2,6598	10650
465,53	2,5965	10317
466,03	2,5828	10329

466,53	2,7711	11086
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467,53	2,5237	10128
468,03	2,5615	10211
468,53	2,6045	10482
469,03	2,5931	10375
469,53	2,5764	10304
470,03	2,6224	10505
470,53	2,5982	10362
471,03	2,5265	10139
471,53	2,5536	10230
472,03	2,6018	10474
472,53	2,5431	10156
473,03	2,5713	10249
473,53	2,5178	10105
474,03	2,5477	10144
474,53	2,5301	10127
475,03	2,612	10501
475,53	2,5334	10064
476,03	2,5019	10022
476,53	2,5191	10057
477,03	2,5406	10214
477,53	2,5701	10245
478,03	2,578	10296
478,53	2,5761	10254
479,03	2,5094	10043
479,53	2,5206	10022
480,03	2,6353	10638
480,53	2,6755	10676
481,03	2,5044	10010
481,53	2,5164	10045
482,03	2,5183	10113
482,53	2,5806	10301
483,03	2,5562	10207
483,53	2,5821	10264
484,03	2,5268	10174
484,53	2,6648	10599
485,03	2,4699	9955,2
485,53	2,6963	10715
486,03	2,4984	9890,3
486,53	2,5618	10323

487,03	2,6732	10759
487,53	2,7329	10820
488,03	2,5937	10357
488,53	2,6337	10584
489,03	2,6588	10643
489,53	2,6243	10455
490,03	2,6365	10578
490,53	2,6542	10643
491,03	2,6099	10400
491,53	2,4667	9890,5
492,03	2,6128	10488
492,53	2,5636	10299
493,03	2,7079	10791
493,53	2,5249	10084
494,03	2,5756	10247
494,53	2,5028	9987,5
495,03	2,5412	10255
495,53	2,6461	10583
496,03	2,6016	10387
496,53	2,5643	10320
497,03	2,6655	10613
497,53	2,4874	9822,7
498,03	2,4322	9739,9
498,53	2,481	9973,7
499,03	2,533	10150
499,53	2,5184	10090
500,03	2,692	10799
500,53	2,5876	10302
501,03	2,601	10457
501,53	2,5478	10133
502,03	2,5214	10119
502,53	2,5401	10092
503,03	2,5793	10395
503,53	2,5834	10237
504,03	2,5124	10079
504,53	2,5349	10155
505,03	2,6602	10626
505,53	2,5452	10170
506,03	2,5635	10232
506,53	2,5596	10253
507,03	2,4589	9777,2

507,53	2,5916	10497
508,03	2,7175	10880
508,53	2,6045	10407
509,03	2,503	9982,8
509,53	2,6198	10507
510,03	2,55	10194
510,53	2,6211	10513
511,03	2,6624	10649
511,53	2,5779	10267
512,03	2,5215	10122
512,53	2,5304	10170
513,03	2,5743	10261
513,53	2,5602	10226
514,03	2,6229	10479
514,53	2,5719	10282
515,03	2,6022	10364
515,53	2,5716	10248
516,03	2,5993	10519
516,53	2,5811	10307
517,03	2,655	10708
517,53	2,5138	9940,7
518,03	2,4756	9952,9
518,53	2,5957	10419
519,03	2,6669	10686
519,53	2,571	10259
520,03	2,6467	10631
520,53	2,6348	10562
521,03	2,6022	10394
521,53	2,5663	10238
522,03	2,5819	10330
522,53	2,4409	9692,2
523,03	2,5658	10437
523,53	2,7146	10767
524,03	2,6329	10592
524,53	2,6448	10547
525,03	2,5112	9949,8
525,53	2,4875	10036
526,03	2,5134	10032

Table E2: Thixotropic analysis for NCC-Bentonite sample with 0.2% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	6,5181	26059
10	6,2871	25152
15	6,1653	24653
20	6,0869	24350
25	6,081	24314
25,12	444,38	2249,5
25,22	234,39	239
25,32	28,374	28,29
25,42	44,336	44,403
25,52	40,243	40,223
25,62	38,561	38,545
25,72	39,577	39,586
25,82	39,071	39,058
25,92	36,745	36,73
26,02	37,441	37,447
26,53	0,44134	1729,7
27,03	0,70279	2881,1
27,53	1,0508	4314,7
28,03	1,4531	5964,9
28,53	1,9374	7944,2
29,03	2,309	9293
29,53	2,49	10107
30,03	2,8581	11619
30,53	3,1772	12820
31,03	3,3345	13447
31,53	3,5363	14143
32,03	3,6637	14769
32,53	3,8047	15264
33,03	3,9607	15944
33,53	3,9962	15965
34,03	4,0886	16477
34,53	4,1212	16464
35,03	4,2593	17141
35,53	4,4292	17773
36,03	4,5292	18104
36,53	4,4337	17686
37,03	4,4672	17930

37,53	4,5541	18227
38,03	4,5839	18389
38,53	4,8502	19449
39,03	4,8128	19235
39,53	4,7843	19190
40,03	4,8575	19427
40,53	4,7983	19110
41,03	4,8602	19503
41,53	4,9593	19962
42,03	5,2021	20807
42,53	5,1326	20499
43,03	5,0983	20397
43,53	5,0287	20181
44,03	5,2003	20780
44,53	5,1032	20418
45,03	5,1803	20771
45,53	5,2	20834
46,03	5,2004	20816
46,53	5,2833	21231
47,03	5,3121	21217
47,53	5,276	21150
48,03	5,3033	21286
48,53	5,3609	21413
49,03	5,3094	21208
49,53	5,321	21275
50,03	5,3286	21347
50,53	5,4084	21593
51,03	5,3873	21590
51,53	5,4213	21725
52,03	5,4401	21762
52,53	5,4977	21893
53,03	5,4119	21768
53,53	5,4597	21807
54,03	5,4496	21879
54,53	5,5281	22051
55,03	5,4671	21906
55,53	5,5847	22383
56,03	5,6589	22669
56,53	5,5716	22269
57,03	5,4745	21785
57,53	5,4719	21999

58,03	5,6154	22430
58,53	5,6786	22755
59,03	5,6069	22379
59,53	5,6608	22736
60,03	5,6526	22534
60,53	5,6376	22514
61,03	5,6319	22569
61,53	5,7021	22863
62,03	5,6555	22621
62,53	5,6793	22710
63,03	5,7386	22928
63,53	5,6703	22730
64,03	5,6175	22452
64,53	5,6904	22871
65,03	5,7261	22879
65,53	5,7035	22835
66,03	5,7943	23177
66,53	5,7074	22781
67,03	5,6824	22723
67,53	5,6731	22718
68,03	5,6674	22684
68,54	5,7457	22960
69,03	5,7203	22891
69,53	5,7397	22993
70,04	5,7571	22939
70,53	5,6662	22641
71,03	5,6653	22670
71,55	5,6569	22634
72,03	5,742	23032
72,53	5,7584	23011
73,07	5,7189	22846
73,53	5,7067	22790
74,03	5,6827	22690
74,53	5,7195	22831
75,03	5,64	22578
75,53	5,7141	22907
76,03	5,7148	22870
76,53	5,7092	22809
77,03	5,7079	22843
77,53	5,6544	22614
78,03	5,669	22662

78,53	5,6472	22610
79,03	5,6185	22435
79,53	5,6816	22818
80,03	5,8033	23188
80,53	5,7232	22822
81,03	5,6668	22663
81,53	5,7279	23013
82,03	5,7946	23134
82,53	5,7983	23244
83,03	5,6924	22767
83,53	5,7037	22887
84,03	5,7009	22758
84,53	5,7449	22961
85,03	5,7023	22800
85,53	5,6102	22421
86,03	5,7081	22775
86,53	5,6989	22829
87,03	5,7154	22905
87,53	5,6592	22550
88,03	5,5752	22360
88,53	5,7903	23197
89,03	5,7018	22768
89,53	5,7375	22876
90,03	5,6692	22633
90,53	5,6804	22741
91,03	5,7207	22924
91,53	5,7098	22867
92,03	5,7071	22787
92,53	5,6832	22696
93,03	5,5908	22320
93,53	5,7327	23012
94,03	5,6712	22602
94,53	5,7797	23191
95,03	5,7263	22881
95,53	5,5822	22339
96,03	5,7252	22913
96,53	5,7364	22900
97,03	5,7079	22819
97,53	5,6343	22503
98,03	5,6882	22750
98,53	5,7393	22986

99,03	5,7415	22997
99,53	5,7192	22866
100,03	5,76	23031
100,53	5,6808	22671
101,03	5,7066	22835
101,53	5,6618	22641
102,03	5,6862	22788
102,53	5,6725	22680
103,03	5,7696	23143
103,53	5,7203	22859
104,03	5,7507	22958
104,53	5,6298	22443
105,03	5,6054	22492
105,53	5,6853	22726
106,03	5,7078	22826
106,53	5,7463	22996
107,03	5,7216	22872
107,53	5,6954	22832
108,03	5,6734	22678
108,53	5,612	22502
109,03	5,7753	23110
109,53	5,7786	23108
110,03	5,7933	23177
110,53	5,7108	22810
111,03	5,7542	23075
111,53	5,6853	22659
112,03	5,6688	22661
112,53	5,8021	23242
113,03	5,7367	22916
113,53	5,7356	22954
114,03	5,699	22794
114,53	5,6212	22500
115,03	5,6754	22759
115,53	5,7	22770
116,03	5,6215	22500
116,53	5,7006	22829
117,03	5,7	22780
117,53	5,6523	22590
118,03	5,718	22860
118,53	5,6198	22499
119,03	5,6322	22558

119,53	5,4868	21885
120,03	5,6601	22746
120,53	5,6668	22669
121,04	5,6344	22505
121,54	5,5219	22014
122,04	5,5233	22098
122,54	5,5288	22127
123,04	5,5526	22267
123,54	5,6628	22662
124,03	5,5644	22217
124,53	5,6274	22591
125,03	5,6436	22528
125,53	5,4523	21739
126,03	5,4832	22001
126,53	5,5424	22253
127,03	5,7196	22911
127,53	5,6098	22427
128,03	5,5629	22231
128,53	5,5841	22374
129,03	5,5402	22030
129,53	5,5344	22152
130,03	5,5551	22180
130,53	5,4588	21819
131,03	5,5772	22358
131,53	5,5948	22431
132,03	5,5536	22170
132,53	5,5284	22117
133,03	5,5732	22340
133,53	5,5603	22207
134,03	5,5438	22174
134,53	5,4733	21861
135,03	5,4828	21959
135,53	5,5862	22355
136,03	5,4776	21897
136,53	5,5457	22182
137,03	5,445	21810
137,53	5,5585	22152
138,03	5,4623	21896
138,53	5,4148	21626
139,03	5,4922	22067
139,53	5,5097	21969

140,03	5,4733	21911
140,53	5,5177	22046
141,03	5,4894	21931
141,53	5,4233	21641
142,03	5,3551	21417
142,53	5,4185	21716
143,03	5,4505	21805
143,53	5,5048	22005
144,03	5,3306	21279
144,53	5,4885	21990
145,03	5,4501	21748
145,53	5,3553	21371
146,03	5,4325	21859
146,53	5,4506	21726
147,03	5,4156	21680
147,53	5,4687	21863
148,03	5,4419	21797
148,53	5,4295	21774
149,03	5,4051	21533
149,53	5,4214	21683
150,03	5,4407	21787
150,53	5,4012	21628
151,03	5,4526	21876
151,53	5,509	22060
152,03	5,3932	21579
152,53	5,4199	21661
153,03	5,3899	21553
153,53	5,3916	21553
154,03	5,3827	21502
154,53	5,4441	21864
155,03	5,5933	22380
155,53	5,4185	21572
156,03	5,3528	21399
156,53	5,5001	22067
157,03	5,4638	21811
157,53	5,4381	21656
158,03	5,4153	21723
158,53	5,353	21304
159,03	5,3523	21469
159,53	5,4617	21805
160,03	5,4228	21728

160,53	5,4632	21914
161,03	5,4446	21783
161,53	5,3585	21350
162,04	5,409	21673
162,53	5,3593	21450
163,03	5,4054	21619
163,55	5,4017	21562
164,03	5,2282	20911
164,53	5,4427	21872
165,05	5,406	21575
165,53	5,4115	21629
166,03	5,2768	21069
166,56	5,3533	21494
167,03	5,4084	21596
167,53	5,3865	21591
168,03	5,3609	21425
168,53	5,3252	21249
169,03	5,3828	21523
169,53	5,3171	21217
170,03	5,1822	20695
170,53	5,2596	21109
171,03	5,2767	21099
171,53	5,2788	21126
172,03	5,3032	21228
172,53	5,2453	21010
173,03	5,2677	21099
173,53	5,3185	21163
174,03	5,2949	21263
174,53	5,279	21066
175,03	5,1837	20789
175,53	5,2634	21042
176,03	5,3046	21284
176,53	5,3273	21283
177,03	5,2965	21192
177,53	5,2748	21068
178,03	5,2369	20934
178,53	5,2559	21083
179,03	5,2855	21061
179,53	5,2676	21116
180,03	5,2719	21066
180,53	5,2624	21043

181,03	5,1815	20711
181,53	5,3893	21601
182,03	5,2329	20882
182,53	5,2466	21008
183,03	5,1963	20748
183,53	5,2183	20984
184,03	5,2909	21044
184,53	5,1255	20515
185,03	5,2135	20886
185,53	5,2028	20736
186,03	5,2354	20985
186,53	5,1961	20743
187,03	5,2039	20933
187,53	5,3083	21256
188,03	5,1736	20578
188,53	5,1065	20456
189,03	5,0964	20308
189,53	5,0867	20358
190,03	5,0759	20340
190,53	5,1522	20627
191,03	5,133	20560
191,53	5,1309	20530
192,03	5,054	20113
192,53	5,0945	20410
193,03	5,0648	20256
193,53	5,1102	20504
194,03	5,1834	20741
194,53	5,1326	20526
195,03	5,1611	20637
195,53	5,1215	20480
196,03	5,165	20662
196,53	5,148	20553
197,03	5,1075	20424
197,53	5,1644	20630
198,03	5,1427	20537
198,53	5,1801	20774
199,03	5,0795	20219
199,53	5,1738	20832
200,03	5,3615	21420
200,53	5,1403	20463
201,03	5,1542	20624

201,53	5,18	20731
202,03	5,1133	20437
202,53	5,1954	20851
203,03	5,3161	21266
203,53	5,1281	20461
204,03	5,0922	20308
204,53	5,0588	20282
205,03	5,2214	20923
205,53	5,2348	20973
206,03	5,173	20669
206,53	5,1732	20676
207,03	5,0278	20051
207,53	5,067	20361
208,03	5,2532	21141
208,53	5,2732	20920
209,03	5,024	20075
209,53	5,1731	20738
210,03	5,08	20243
210,53	5,0617	20230
211,03	4,9761	19965
211,53	5,2194	20945
212,03	5,1725	20651
212,53	5,1501	20594
213,03	5,0997	20380
213,53	5,0919	20378
214,03	5,0574	20180
214,53	5,0286	20083
215,03	5,052	20254
215,53	5,0852	20355
216,03	4,9756	19859
216,53	5,1217	20547
217,03	5,1063	20444
217,53	5,1059	20332
218,03	5,0245	20138
218,53	5,1295	20479
219,03	4,9795	19953
219,53	5,127	20569
220,03	5,0818	20279
220,53	5,0174	20081
221,03	5,0879	20322
221,53	4,9824	19914

222,03	5,0787	20441
222,53	5,0603	20201
223,03	5,0234	20100
223,53	4,9573	19834
224,03	5,0805	20311
224,53	4,9593	19811
225,03	5,103	20513
225,53	5,1136	20446
226,03	5,0294	20061
226,53	5,0235	20100
227,03	4,9365	19738
227,53	4,9989	19938
228,03	5,0548	20264
228,53	5,0652	20222
229,03	4,9148	19700
229,53	5,025	20083
230,03	4,9912	19919
230,53	4,8672	19443
231,03	4,9072	19705
231,53	5,0435	20166
232,03	5,0128	20043
232,53	4,9814	19908
233,03	4,8808	19515
233,53	4,8866	19561
234,03	4,9452	19771
234,53	4,9989	20011
235,03	4,819	19280
235,53	4,9624	19825
236,03	4,9037	19575
236,53	4,9257	19709
237,03	4,8941	19604
237,53	4,9422	19743
238,03	4,8705	19484
238,53	4,9912	19989
239,03	4,9812	19883
239,53	4,9232	19689
240,03	4,9635	19927
240,53	4,9977	19934
241,03	4,7584	18985
241,53	4,9538	19902
242,03	5,001	19932

242,53	4,9227	19679
243,03	4,93	19795
243,53	4,8757	19394
244,03	4,874	19533
244,53	4,893	19568
245,03	4,8769	19540
245,53	4,9234	19646
246,03	4,9241	19689
246,53	4,8544	19388
247,03	4,8689	19502
247,53	4,9219	19699
248,04	4,8569	19386
248,53	4,8859	19540
249,03	4,9321	19768
249,55	5,0386	20166
250,03	4,8576	19375
250,53	4,8846	19588
251,07	4,8567	19442
251,53	5,05	20169
252,03	4,9798	19874
252,53	4,9536	19779
253,03	4,8998	19597
253,53	4,8746	19482
254,03	4,9236	19675
254,53	4,9185	19653
255,03	4,8565	19347
255,53	4,8107	19271
256,03	4,9121	19650
256,53	4,7523	18979
257,03	4,942	19785
257,53	4,8648	19425
258,03	4,9021	19664
258,53	4,9087	19688
259,03	4,9653	19847
259,53	4,8066	19082
260,03	4,8631	19530
260,53	4,8379	19385
261,03	4,9645	19930
261,53	4,9895	19956
262,03	4,851	19356
262,53	4,8004	19123

263,03	4,7754	19180
263,53	4,8908	19576
264,03	4,9429	19795
264,53	4,9011	19537
265,03	4,9241	19709
265,53	4,8998	19508
266,03	4,75	19045
266,53	4,8974	19615
267,03	4,8427	19392
267,53	4,821	19192
268,03	4,7802	19213
268,53	4,9167	19694
269,03	4,8454	19394
269,53	4,8802	19542
270,03	4,9191	19684
270,53	4,9363	19731
271,03	4,8591	19334
271,53	4,8453	19452
272,03	4,8702	19438
272,53	4,7828	19185
273,03	4,8814	19511
273,53	4,9225	19745
274,03	4,7881	19030
274,53	4,6548	18679
275,03	4,7908	19149
275,53	4,8558	19452
276,03	4,9078	19588
276,53	4,7734	19060
277,03	4,6929	18788
277,53	4,7916	19161
278,03	4,7361	18982
278,53	4,8951	19595
279,03	4,8474	19290
279,53	4,8439	19375
280,03	4,7912	19159
280,53	4,7767	19156
281,03	4,7505	18943
281,53	4,7617	19045
282,03	4,6983	18803
282,53	4,7392	18955
283,03	4,7279	18873

283,53	4,8352	19316
284,03	4,6646	18630
284,53	4,6609	18684
285,03	4,8092	19259
285,53	4,7645	19063
286,03	4,6445	18507
286,53	4,69	18855
287,03	4,8403	19374
287,53	4,7833	19108
288,03	4,7775	19047
288,53	4,638	18533
289,03	4,6395	18469
289,53	4,6837	18836
290,03	4,819	19266
290,53	4,672	18691
291,03	4,7416	18978
291,53	4,7473	19035
292,03	4,624	18439
292,53	4,67	18821
293,03	4,8087	19182
293,53	4,7105	18757
294,03	4,6679	18724
294,53	4,8089	19188
295,03	4,674	18593
295,53	4,6484	18609
296,03	4,6847	18759
296,53	4,8819	19491
297,03	4,6853	18682
297,53	4,6792	18729
298,03	4,7936	19150
298,53	4,6171	18407
299,03	4,6233	18489
299,53	4,7133	18830
300,03	4,6992	18755
300,53	4,6311	18544
301,03	4,7214	18955
301,53	4,7545	18990
302,03	4,6931	18767
302,53	4,6592	18610
303,03	4,7047	18804
303,53	4,7065	18821

304,03	4,6099	18372
304,53	4,6125	18405
305,03	4,7195	18945
305,53	4,7088	18827
306,03	4,699	18765
306,53	4,5563	18194
307,03	4,7148	18947
307,53	4,717	18889
308,03	4,6297	18441
308,53	4,6384	18668
309,03	4,7907	19143
309,53	4,6252	18439
310,03	4,6453	18543
310,53	4,7121	18911
311,03	4,7399	18890
311,53	4,58	18271
312,03	4,6254	18567
312,53	4,7366	18921
313,03	4,731	18952
313,53	4,6575	18631
314,03	4,5893	18335
314,53	4,6323	18493
315,03	4,6768	18729
315,53	4,5833	18379
316,03	4,6934	18767
316,53	4,7033	18832
317,03	4,6693	18680
317,53	4,6439	18527
318,03	4,6613	18728
318,53	4,7269	18878
319,03	4,7052	18870
319,53	4,7193	18790
320,03	4,6512	18649
320,53	4,6878	18675
321,03	4,6449	18598
321,53	4,6047	18449
322,03	4,7118	18901
322,53	4,6471	18509
323,03	4,6812	18824
323,53	4,7201	18838
324,03	4,6341	18549

324,53	4,7109	18789
325,03	4,7434	18970
325,53	4,5729	18269
326,03	4,6481	18634
326,53	4,7289	18915
327,03	4,7374	18926
327,53	4,6606	18706
328,03	4,6439	18546
328,53	4,555	18202
329,03	4,6424	18647
329,53	4,5942	18333
330,03	4,5787	18332
330,53	4,6853	18721
331,03	4,6078	18452
331,53	4,5412	18155
332,03	4,4997	17997
332,53	4,6442	18632
333,03	4,5505	18141
333,53	4,5041	17956
334,03	4,5661	18260
334,53	4,6708	18628
335,03	4,5513	18236
335,53	4,4307	17728
336,03	4,5632	18385
336,53	4,6589	18590
337,03	4,6304	18608
337,53	4,5422	18080
338,03	4,5916	18365
338,53	4,6027	18415
339,03	4,5837	18365
339,53	4,6012	18394
340,03	4,5217	18052
340,53	4,542	18148
341,03	4,5288	18087
341,53	4,6006	18384
342,03	4,5048	17977
342,53	4,5327	18116
343,03	4,6	18495
343,53	4,5969	18367
344,03	4,6132	18382
344,53	4,5297	18092

345,03	4,4434	17859
345,53	4,6368	18575
346,03	4,7005	18813
346,53	4,5093	18015
347,03	4,5539	18236
347,53	4,5196	18080
348,03	4,4875	17928
348,53	4,5906	18438
349,03	4,5813	18322
349,53	4,5808	18246
350,03	4,5251	18151
350,53	4,5501	18194
351,03	4,5884	18426
351,53	4,6342	18500
352,03	4,5671	18277
352,53	4,5843	18378
353,03	4,607	18447
353,53	4,4917	17863
354,03	4,438	17758
354,53	4,5808	18334
355,03	4,595	18457
355,54	4,6027	18455
356,03	4,5602	18176
356,53	4,4945	18002
357,03	4,6139	18523
357,53	4,5542	18150
358,03	4,5853	18386
358,53	4,6222	18454
359,03	4,4176	17582
359,53	4,4717	17936
360,03	4,5187	18084
360,53	4,6344	18605
361,03	4,5707	18244
361,53	4,5989	18437
362,03	4,4154	17628
362,53	4,4787	17896
363,03	4,5727	18341
363,53	4,6928	18804
364,03	4,5302	18115
364,53	4,6171	18460
365,03	4,5855	18359

365,53	4,5016	17941
366,03	4,5983	18451
366,53	4,6194	18508
367,03	4,5941	18363
367,53	4,5329	18099
368,03	4,594	18462
368,53	4,6074	18425
369,03	4,448	17797
369,53	4,5996	18482
370,03	4,6764	18693
370,53	4,5674	18229
371,03	4,513	18145
371,53	4,5147	18077
372,03	4,5332	18142
372,53	4,6917	18835
373,03	4,5797	18275
373,53	4,4811	17922
374,03	4,3857	17520
374,53	4,6028	18538
375,03	4,6195	18476
375,53	4,5736	18239
376,03	4,4965	17964
376,53	4,4837	17871
377,03	4,4215	17706
377,53	4,5628	18320
378,03	4,6561	18595
378,53	4,4869	17901
379,03	4,4988	18087
379,53	4,5248	18058
380,03	4,3874	17509
380,53	4,4618	17919
381,03	4,5768	18335
381,53	4,6129	18478
382,03	4,563	18249
382,53	4,4856	17932
383,03	4,468	17913
383,53	4,4848	17881
384,03	4,4165	17698
384,53	4,4852	17971
385,03	4,5172	18070
385,53	4,4743	17823

386,03	4,4638	17907
386,53	4,4388	17771
387,03	4,5136	18078
387,53	4,5199	18093
388,03	4,5969	18392
388,53	4,4422	17709
389,03	4,3744	17459
389,53	4,4853	18049
390,03	4,4575	17830
390,53	4,5769	18373
391,03	4,5219	18007
391,53	4,3732	17484
392,03	4,4952	17947
392,53	4,4743	17912
393,03	4,395	17545
393,53	4,5396	18296
394,03	4,4677	17830
394,53	4,4876	18034
395,03	4,5363	18072
395,53	4,4514	17829
396,03	4,471	17885
396,53	4,3527	17340
397,03	4,4369	17885
397,53	4,5014	17988
398,04	4,5267	18130
398,53	4,4381	17730
399,03	4,457	17822
399,54	4,4702	17890
400,03	4,4348	17702
400,53	4,4513	17901
401,03	4,3938	17525
401,53	4,4601	17869
402,03	4,5219	18135
402,53	4,4634	17766
403,03	4,4526	17804
403,53	4,4111	17619
404,03	4,4954	18045
404,53	4,4232	17642
405,03	4,4513	17807
405,53	4,547	18257
406,03	4,5353	18132

406,53	4,4407	17731
407,03	4,4226	17723
407,53	4,398	17543
408,03	4,5144	18048
408,53	4,4283	17756
409,03	4,54	18165
409,53	4,4839	17847
410,03	4,5446	18190
410,53	4,4719	17920
411,03	4,5302	18126
411,53	4,5354	18134
412,03	4,5497	18237
412,53	4,4454	17691
413,03	4,4786	17907
413,53	4,4322	17748
414,03	4,5505	18288
414,53	4,4736	17802
415,03	4,5769	18328
415,53	4,5806	18322
416,03	4,5609	18239
416,53	4,4763	17917
417,03	4,4804	17964
417,53	4,4633	17762
418,03	4,4264	17727
418,53	4,5348	18161
419,03	4,5778	18368
419,53	4,4067	17517
420,03	4,4081	17750
420,53	4,4811	17853
421,03	4,5771	18300
421,53	4,5615	18210
422,03	4,5598	18221
422,53	4,4327	17741
423,03	4,5199	18086
423,53	4,4918	17937
424,03	4,5165	18140
424,53	4,5555	18191
425,03	4,4049	17664
425,53	4,46	17880
426,03	4,4382	17690
426,53	4,4843	18000

427,03	4,4573	17852
427,53	4,4407	17803
428,03	4,4979	17960
428,53	4,5279	18068
429,03	4,4989	18013
429,53	4,3002	17163
430,03	4,4032	17631
430,53	4,5043	18020
431,03	4,4924	17938
431,53	4,4679	17899
432,03	4,4599	17857
432,53	4,3501	17355
433,05	4,5019	18071
433,53	4,4961	17915
434,03	4,4245	17670
434,55	4,369	17474
435,03	4,492	17989
435,53	4,3906	17557
436,05	4,4503	17829
436,53	4,4205	17713
437,03	4,4492	17833
437,53	4,3955	17542
438,03	4,4088	17672
438,53	4,4446	17776
439,03	4,3811	17581
439,53	4,4752	17818
440,03	4,4355	17686
440,53	4,3505	17388
441,03	4,3495	17418
441,53	4,4365	17777
442,03	4,43	17699
442,53	4,4585	17817
443,03	4,3607	17426
443,53	4,3522	17390
444,03	4,3222	17308
444,53	4,3064	17241
445,03	4,3328	17385
445,53	4,4522	17821
446,03	4,4717	17899
446,53	4,3562	17351
447,03	4,3869	17563

447,53	4,2658	17078
448,03	4,3842	17597
448,53	4,5195	18068
449,03	4,4283	17796
449,53	4,4187	17608
450,03	4,3438	17336
450,53	4,3569	17474
451,03	4,4076	17636
451,53	4,3352	17362
452,03	4,3625	17397
452,53	4,4479	17766
453,03	4,3912	17597
453,53	4,2822	17132
454,03	4,4389	17798
454,53	4,4437	17814
455,03	4,48	17862
455,53	4,4809	17924
456,03	4,4013	17602
456,53	4,391	17581
457,03	4,4371	17782
457,53	4,4185	17624
458,03	4,3532	17476
458,53	4,464	17846
459,03	4,3219	17288
459,53	4,3804	17574
460,03	4,4984	18029
460,53	4,4126	17594
461,03	4,2761	17038
461,53	4,4041	17688
462,03	4,449	17866
462,53	4,5391	18087
463,03	4,345	17335
463,53	4,3967	17673
464,03	4,418	17705
464,53	4,4364	17729
465,03	4,3888	17554
465,53	4,3379	17357
466,03	4,5483	18284
466,53	4,484	17869
467,03	4,4828	17900
467,53	4,4178	17662

468,03	4,4037	17608
468,53	4,3521	17398
469,03	4,4305	17690
469,53	4,3652	17528
470,03	4,3776	17472
470,53	4,4051	17607
471,03	4,4411	17733
471,53	4,4055	17644
472,03	4,4799	17862
472,53	4,3564	17399
473,03	4,3738	17532
473,53	4,4772	17928
474,03	4,3656	17468
474,53	4,3922	17611
475,03	4,4437	17747
475,53	4,3834	17577
476,03	4,3095	17195
476,53	4,439	17839
477,03	4,4988	17953
477,53	4,3385	17276
478,03	4,2597	17090
478,53	4,5253	18168
479,03	4,3788	17490
479,53	4,4863	18006
480,03	4,3568	17379
480,53	4,4314	17782
481,03	4,2872	17150
481,53	4,2865	17199
482,03	4,3575	17429
482,53	4,5238	18202
483,03	4,4017	17495
483,53	4,3043	17175
484,03	4,3834	17542
484,53	4,3903	17493
485,03	4,2224	16870
485,53	4,3463	17394
486,03	4,3444	17387
486,53	4,341	17367
487,03	4,4039	17588
487,53	4,2857	17171
488,03	4,3635	17489

488,53	4,3716	17445
489,03	4,3534	17443
489,53	4,2596	17065
490,03	4,3317	17306
490,53	4,379	17533
491,03	4,3094	17198
491,53	4,2862	17120
492,03	4,3287	17398
492,53	4,4033	17579
493,03	4,2904	17137
493,53	4,4024	17612
494,03	4,355	17390
494,53	4,4107	17691
495,03	4,3108	17268
495,53	4,3063	17201
496,03	4,339	17377
496,53	4,394	17572
497,03	4,3595	17405
497,53	4,3156	17329
498,03	4,2803	17066
498,53	4,2574	17132
499,03	4,3693	17476
499,53	4,3137	17261
500,03	4,3717	17463
500,53	4,3969	17541
501,03	4,2318	16887
501,53	4,382	17576
502,03	4,3549	17405
502,53	4,2436	16983
503,03	4,3865	17578
503,53	4,38	17470
504,03	4,3039	17141
504,53	4,2372	17014
505,03	4,3739	17484
505,53	4,3071	17279
506,03	4,3759	17471
506,53	4,368	17493
507,03	4,2824	17054
507,53	4,3238	17362
508,03	4,3649	17427
508,53	4,3942	17574

509,03	4,2983	17203
509,53	4,2745	17053
510,03	4,2302	16964
510,53	4,2398	16970
511,03	4,3353	17437
511,53	4,3854	17413
512,03	4,1885	16730
512,53	4,3492	17433
513,03	4,3797	17540
513,53	4,3215	17264
514,03	4,2748	17088
514,54	4,3292	17355
515,03	4,3864	17458
515,53	4,4167	17649
516,05	4,3039	17213
516,53	4,273	17101
517,03	4,3481	17322
517,56	4,2665	17125
518,03	4,2707	17030
518,53	4,2957	17310
519,03	4,5018	17937
519,53	4,2921	17120
520,03	4,3538	17444
520,53	4,249	16985
521,03	4,3772	17539
521,53	4,393	17572
522,03	4,2969	17178
522,53	4,3287	17323
523,03	4,359	17436
523,53	4,3697	17434
524,03	4,3891	17578
524,53	4,4084	17614
525,03	4,2651	16970
525,53	4,3333	17450
526,03	4,3233	17278

Table E3: Thixotropic analysis for NCC-Bentonite sample with 0.4% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	9,6943	38727
10	9,3237	37291
15	8,9984	35994
20	8,839	35343
25	8,7495	35000
25,12	444,4	2338,8
25,22	290,6	302,96
25,32	34,051	33,789
25,42	54,544	54,588
25,51	50,782	50,759
25,62	50,602	50,609
25,72	48,815	48,802
25,82	46,579	46,56
25,92	47,501	47,511
26,02	46,809	46,82
26,53	0,88144	3435,2
27,03	1,1784	4859,1
27,53	1,6938	7030,1
28,03	2,4692	10199
28,53	2,9689	12102
29,03	3,6985	15182
29,53	4,2186	17012
30,03	4,5918	18586
30,53	5,0017	20176
31,03	5,3116	21364
31,53	5,3967	21645
32,03	5,6324	22675
32,53	5,9779	24029
33,03	6,2389	25100
33,53	6,3601	25515
34,03	6,3175	25259
34,54	6,5446	26313
35,03	6,7536	27031
35,53	6,768	27139
36,05	6,9284	27760
36,53	7,0124	28100
37,03	7,0672	28256

37,55	7,2009	28817
38,03	7,3133	29289
38,53	7,309	29213
39,06	7,2982	29116
39,53	7,378	29644
40,03	7,5453	30262
40,53	7,5216	30018
41,03	7,6127	30537
41,53	7,7654	31037
42,03	7,5907	30365
42,53	7,6712	30743
43,03	7,6985	30759
43,53	7,8157	31243
44,03	7,8322	31414
44,53	7,899	31640
45,03	7,857	31358
45,53	7,9345	31717
46,03	7,8874	31585
46,53	7,9673	31899
47,03	8,081	32315
47,53	8,0768	32244
48,03	8,0465	32250
48,53	8,0002	32009
49,03	8,0508	32216
49,53	8,0834	32313
50,03	8,1536	32748
50,53	8,1774	32657
51,03	8,0942	32329
51,53	8,182	32730
52,03	8,1846	32760
52,53	8,1863	32835
53,03	8,1881	32690
53,53	8,1385	32528
54,03	8,169	32720
54,53	8,2416	33004
55,03	8,2192	32822
55,53	8,2399	33010
56,03	8,2213	32886
56,53	8,1561	32715
57,03	8,3923	33599
57,53	8,221	32866

58,03	8,3259	33382
58,53	8,323	33295
59,03	8,1702	32567
59,53	8,2361	33013
60,03	8,3093	33285
60,53	8,3564	33499
61,03	8,3598	33425
61,53	8,362	33406
62,03	8,2584	33047
62,53	8,2642	33135
63,03	8,4036	33550
63,53	8,3483	33387
64,03	8,3649	33495
64,53	8,4747	33917
65,03	8,4424	33720
65,53	8,3957	33561
66,03	8,308	33252
66,53	8,3882	33534
67,03	8,3272	33304
67,53	8,4523	33790
68,03	8,3187	33383
68,53	8,5241	34161
69,03	8,3488	33268
69,53	8,3282	33405
70,03	8,4692	33877
70,53	8,4077	33675
71,03	8,4227	33594
71,53	8,3527	33421
72,03	8,3923	33671
72,53	8,4235	33641
73,03	8,357	33342
73,53	8,408	33716
74,03	8,4558	33809
74,53	8,3346	33321
75,03	8,3823	33446
75,53	8,4055	33671
76,03	8,4677	33912
76,53	8,4786	33918
77,03	8,4482	33832
77,53	8,4793	33913
78,03	8,4835	33936

78,53	8,3726	33441
79,03	8,4587	33841
79,53	8,4547	33864
80,03	8,5672	34272
80,53	8,4714	33863
81,03	8,4945	33942
81,53	8,4824	33949
82,03	8,4825	33931
82,53	8,4103	33674
83,03	8,5891	34343
83,53	8,5153	34066
84,03	8,5188	34136
84,53	8,5811	34347
85,03	8,5021	33985
85,53	8,4664	33896
86,03	8,4677	33896
86,53	8,5165	34056
87,03	8,5519	34162
87,53	8,4934	34039
88,03	8,5386	34155
88,53	8,499	34003
89,03	8,5638	34264
89,53	8,4318	33750
90,03	8,463	33900
90,53	8,4716	33843
91,03	8,4584	33820
91,53	8,4858	34024
92,03	8,5155	34081
92,53	8,444	33696
93,03	8,3915	33569
93,53	8,4573	33887
94,03	8,5375	34171
94,53	8,542	34087
95,03	8,3453	33380
95,53	8,4151	33702
96,03	8,5332	34193
96,53	8,6751	34693
97,03	8,5091	33999
97,53	8,5452	34261
98,03	8,4942	33955
98,53	8,4082	33562

99,03	8,5076	34063
99,53	8,4954	33969
100,03	8,4874	34036
100,53	8,3982	33445
101,03	8,4055	33684
101,53	8,4947	34024
102,03	8,5437	34124
102,53	8,4158	33568
103,03	8,3811	33519
103,53	8,3631	33458
104,03	8,364	33356
104,53	8,3474	33405
105,03	8,5253	34181
105,53	8,4379	33754
106,03	8,3507	33347
106,53	8,3176	33233
107,03	8,3655	33501
107,53	8,3314	33388
108,03	8,3897	33548
108,53	8,3116	33240
109,03	8,3826	33522
109,53	8,3258	33330
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111,53	8,3129	33282
112,03	8,2365	32902
112,53	8,3855	33596
113,03	8,3965	33616
113,53	8,2423	32899
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115,03	8,2314	33035
115,53	8,3375	33393
116,03	8,3226	33250
116,53	8,2061	32719
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117,54	8,3283	33351
118,03	8,399	33576
118,53	8,3275	33170
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122,07	8,2236	32819
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124,53	8,1598	32711
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125,53	8,1942	32769
126,03	8,209	32810
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128,53	8,288	33182
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129,53	8,3108	33245
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131,03	8,1483	32631
131,53	8,2601	33137
132,03	8,3452	33387
132,53	8,3031	33157
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133,53	8,1564	32536
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137,53	8,2207	32821
138,03	8,1827	32734
138,53	8,1646	32645
139,03	8,1714	32720
139,53	8,2956	33218

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144,53	8,1681	32620
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145,53	8,2542	32858
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149,53	8,189	32726
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152,53	8,1629	32668
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155,53	8,1009	32477
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157,53	8,024	32052
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158,53	8,0325	32205
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163,53	7,9829	31859
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165,03	7,9777	31864
165,53	7,9078	31584
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166,53	7,9116	31656
167,03	7,9481	31817
167,53	7,9064	31553
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168,53	7,9572	31884
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169,53	7,9171	31572
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173,53	7,8697	31456
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174,53	7,8548	31378
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176,03	7,8564	31442
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179,53	7,8404	31371
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184,53	7,7543	30972
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206,53	7,6292	30533
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207,53	7,6079	30493
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208,53	7,6325	30456
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215,53	7,4782	29906
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218,53	7,5838	30282
219,03	7,4681	29942
219,53	7,5695	30248
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221,03	7,5024	30058
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223,53	7,407	29609
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226,53	7,4647	29866
227,03	7,4284	29669
227,53	7,3641	29469
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228,53	7,4289	29672
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232,53	7,395	29577
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238,53	7,4164	29644
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243,53	7,4261	29756
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244,53	7,3371	29418
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261,53	7,2395	28948
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262,53	7,1085	28431

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265,53	7,1678	28705
266,03	7,223	28880
266,53	7,255	28979
267,03	7,1908	28781
267,53	7,2736	29072
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268,53	7,2285	28919
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275,53	7,0989	28430
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425,03	6,5202	26029
425,55	6,4606	25857
426,03	6,5787	26329
426,53	6,456	25768

427,03	6,5551	26230
427,53	6,6325	26612
428,03	6,5198	25968
428,53	6,4562	25767
429,03	6,5116	26075
429,53	6,5588	26260
430,03	6,4928	25932
430,53	6,4486	25779
431,03	6,5349	26139
431,53	6,6099	26498
432,03	6,4814	25802
432,53	6,4385	25756
433,03	6,5685	26286
433,53	6,5716	26268
434,03	6,3846	25527
434,53	6,5879	26404
435,03	6,618	26497
435,53	6,6624	26733
436,03	6,7544	26981
436,53	6,5371	26020
437,03	6,6355	26633
437,53	6,5958	26345
438,03	6,542	26216
438,53	6,6094	26428
439,03	6,5521	26209
439,53	6,6083	26400
440,03	6,4738	25912
440,53	6,5934	26333
441,03	6,6275	26576
441,53	6,6148	26433
442,03	6,5611	26210
442,53	6,5514	26205
443,03	6,6027	26390
443,53	6,4027	25630
444,03	6,5645	26376
444,53	6,7064	26666
445,03	6,52	26048
445,53	6,5785	26356
446,03	6,4845	25927
446,53	6,5152	25991
447,03	6,5699	26355

447,53	6,5799	26303
448,03	6,5658	26295
448,53	6,5688	26157
449,03	6,5004	26047
449,53	6,4566	25772
450,03	6,4593	25856
450,53	6,5386	26131
451,03	6,5656	26298
451,53	6,5513	26130
452,03	6,6246	26461
452,53	6,5229	26122
453,03	6,4961	25947
453,53	6,5511	26162
454,03	6,5531	26159
454,53	6,5324	26230
455,03	6,6045	26381
455,53	6,5479	26145
456,03	6,5098	26038
456,53	6,6019	26460
457,03	6,6763	26735
457,53	6,6651	26685
458,03	6,6043	26296
458,53	6,4501	25838
459,03	6,5197	26163
459,53	6,6126	26524
460,03	6,6999	26789
460,53	6,5513	26054
461,03	6,4662	25924
461,53	6,5325	26187
462,03	6,5562	26250
462,53	6,506	25996
463,03	6,4573	25852
463,53	6,4591	25779
464,03	6,4922	25934
464,53	6,4886	25940
465,03	6,4954	25989
465,53	6,4959	25958
466,03	6,4463	25717
466,53	6,4986	26071
467,03	6,3627	25397
467,53	6,3396	25399

468,03	6,5302	26142
468,53	6,5972	26337
469,03	6,4358	25720
469,53	6,3606	25427
470,03	6,3718	25546
470,53	6,3984	25674
471,03	6,5271	26120
471,53	6,5238	26046
472,03	6,4887	25904
472,53	6,403	25667
473,03	6,4725	25939
473,53	6,3851	25537
474,03	6,5086	26067
474,53	6,4879	25906
475,03	6,3513	25422
475,53	6,4597	25872
476,03	6,4365	25698
476,53	6,4412	25797
477,03	6,4574	25883
477,53	6,4496	25751
478,03	6,3669	25519
478,53	6,4133	25691
479,03	6,5141	26019
479,53	6,4577	25787
480,03	6,3622	25341
480,53	6,4508	25927
481,03	6,5039	25993
481,53	6,396	25581
482,03	6,4665	25824
482,53	6,3655	25539
483,03	6,3272	25297
483,53	6,4936	26022
484,03	6,4036	25535
484,53	6,4741	25925
485,03	6,4097	25582
485,53	6,4148	25722
486,03	6,4123	25520
486,53	6,3861	25550
487,03	6,452	25826
487,53	6,5104	26022
488,03	6,4379	25692

488,53	6,371	25529
489,04	6,4706	25832
489,53	6,4561	25838
490,03	6,492	25953
490,55	6,4155	25645
491,03	6,4354	25767
491,53	6,4837	25933
492,05	6,3575	25382
492,53	6,3867	25654
493,03	6,4542	25821
493,56	6,4432	25795
494,03	6,5289	26114
494,53	6,4091	25626
495,06	6,4526	25752
495,53	6,4473	25839
496,03	6,4975	25938
496,53	6,4851	25978
497,03	6,4132	25592
497,53	6,3353	25322
498,03	6,5374	26187
498,53	6,5125	26013
499,03	6,3818	25537
499,53	6,4436	25709
500,03	6,4275	25710
500,53	6,4743	25877
501,03	6,411	25699
501,53	6,5034	26032
502,03	6,4826	25860
502,53	6,466	25921
503,03	6,4279	25653
503,53	6,4455	25784
504,03	6,5641	26265
504,53	6,4222	25680
505,03	6,5094	26093
505,53	6,4807	25899
506,03	6,4657	25838
506,53	6,5473	26313
507,03	6,4134	25546
507,53	6,4834	26054
508,03	6,5917	26354
508,53	6,5802	26348

509,03	6,502	25881
509,53	6,395	25589
510,03	6,4198	25681
510,53	6,4298	25650
511,03	6,3841	25523
511,53	6,491	26022
512,03	6,5404	26109
512,53	6,5021	26034
513,03	6,4219	25597
513,53	6,3834	25451
514,03	6,4012	25682
514,53	6,4761	25878
515,03	6,3402	25342
515,53	6,3767	25565
516,03	6,4755	25882
516,53	6,2778	25083
517,03	6,2821	25145
517,53	6,3013	25251
518,03	6,3102	25201
518,53	6,3169	25282
519,03	6,2825	25068
519,53	6,4222	25830
520,03	6,445	25780
520,53	6,4455	25852
521,03	6,461	25830
521,53	6,3683	25408
522,03	6,4058	25694
522,53	6,3865	25596
523,03	6,4074	25470
523,53	6,2721	25108
524,03	6,3361	25355
524,53	6,3404	25429
525,03	6,3548	25479
525,53	6,5026	26005
526,03	6,3742	25504

Table E4: Thixotropic analysis for NCC-Bentonite sample with 0.6% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	15,369	61448
10	14,781	59116
15	14,521	58068
20	14,219	56878
25	14,056	56202
25,22	385,75	427,99
25,32	70,91	70,275
25,42	87,827	87,901
25,51	85,633	85,597
25,62	82,625	82,597
25,72	79,562	79,529
25,82	80,219	80,238
25,92	78,056	78,028
26,01	75,683	75,658
26,53	3,7486	15341
27,03	6,531	28159
27,53	9,9942	41566
28,03	12,75	51662
28,53	13,883	55834
29,03	14,426	57811
29,53	14,9	59587
30,03	14,983	59964
30,53	15,117	60556
31,03	15,134	60555
31,53	15,194	60753
32,03	15,244	60966
32,53	15,17	60763
33,03	15,18	60784
33,53	15,107	60253
34,03	15,016	60076
34,53	14,986	59983
35,03	14,954	59840
35,53	15,065	60218
36,03	14,894	59566
36,53	14,894	59617
37,03	14,779	59030
37,53	14,804	59283

38,03	14,86	59502
38,53	14,839	59413
39,03	14,733	58887
39,53	14,725	58804
40,03	14,688	58766
40,53	14,586	58379
41,03	14,712	58872
41,53	14,717	58794
42,03	14,696	58788
42,53	14,642	58617
43,03	14,682	58733
43,53	14,616	58436
44,03	14,609	58538
44,53	14,635	58563
45,03	14,602	58368
45,53	14,546	58085
46,03	14,437	57793
46,53	14,509	58089
47,03	14,408	57615
47,53	14,498	57959
48,03	14,464	57841
48,53	14,36	57471
49,03	14,439	57711
49,53	14,313	57177
50,03	14,26	57087
50,53	14,331	57355
51,03	14,317	57180
51,53	14,232	56924
52,03	14,135	56588
52,53	14,234	57030
53,03	14,194	56671
53,53	14,189	56667
54,03	14,108	56598
54,53	14,203	56796
55,03	14,265	56998
55,53	14,186	56721
56,03	14,187	56806
56,53	14,127	56453
57,03	14,087	56319
57,53	14,079	56323
58,03	14,078	56382

58,53	13,972	55830
59,03	13,979	55894
59,53	14,189	56826
60,03	14,063	56290
60,53	13,988	55864
61,03	13,865	55370
61,53	14,06	56335
62,03	14,075	56293
62,53	13,985	55918
63,04	13,945	55684
63,53	13,9	55595
64,03	13,976	55956
64,54	13,867	55368
65,03	13,966	55867
65,53	13,839	55364
66,03	13,844	55379
66,53	13,804	55177
67,03	13,811	55207
67,53	13,877	55622
68,03	13,881	55533
68,53	13,745	54892
69,03	13,793	55114
69,53	13,8	55239
70,03	13,683	54744
70,53	13,655	54607
71,03	13,618	54400
71,53	13,612	54478
72,03	13,635	54567
72,53	13,657	54592
73,03	13,669	54661
73,53	13,644	54655
74,03	13,614	54488
74,53	13,653	54561
75,03	13,588	54374
75,53	13,551	54180
76,03	13,546	54241
76,53	13,628	54433
77,03	13,479	53793
77,53	13,44	53786
78,03	13,561	54290
78,53	13,473	53912

79,03	13,405	53629
79,53	13,502	54084
80,03	13,46	53838
80,53	13,45	53632
81,03	13,401	53691
81,53	13,423	53703
82,03	13,397	53578
82,53	13,402	53579
83,03	13,391	53584
83,53	13,34	53401
84,03	13,316	53259
84,53	13,305	53217
85,03	13,333	53300
85,53	13,322	53322
86,03	13,269	53093
86,53	13,376	53506
87,03	13,29	53147
87,53	13,312	53343
88,03	13,376	53473
88,53	13,331	53214
89,03	13,288	53225
89,53	13,291	53195
90,03	13,42	53611
90,53	13,353	53354
91,03	13,362	53499
91,53	13,337	53368
92,03	13,366	53447
92,53	13,345	53272
93,03	13,409	53655
93,53	13,32	53372
94,03	13,329	53323
94,53	13,291	53003
95,03	13,117	52473
95,53	13,111	52447
96,03	13,174	52696
96,53	13,369	53462
97,03	13,382	53615
97,53	13,428	53702
98,03	13,356	53384
98,53	13,339	53279
99,03	13,303	53283

99,53	13,331	53421
100,03	13,284	53034
100,53	13,219	52831
101,03	13,269	53149
101,53	13,309	53335
102,03	13,219	52799
102,53	13,31	53238
103,03	13,288	53209
103,53	13,186	52718
104,03	13,235	52925
104,53	13,295	53124
105,03	13,276	53174
105,53	13,197	52764
106,03	13,282	53143
106,53	13,346	53313
107,03	13,115	52508
107,53	13,226	53006
108,03	13,27	52986
108,53	13,242	52887
109,03	13,129	52527
109,53	13,16	52753
110,03	13,216	52806
110,53	13,262	53017
111,03	13,174	52728
111,56	13,198	52772
112,03	13,128	52402
112,53	13,196	52839
113,03	13,281	53179
113,53	13,2	52825
114,03	13,025	52058
114,53	13,083	52318
115,03	13,047	52279
115,53	13,034	52107
116,03	13,069	52194
116,53	12,972	51889
117,03	13,042	52284
117,53	13,035	52175
118,03	12,969	51773
118,53	12,995	52034
119,03	13,078	52353
119,53	12,951	51746

120,03	12,994	51987
120,53	13,048	52193
121,03	13,027	52121
121,53	12,952	51724
122,03	12,83	51249
122,53	12,84	51373
123,03	12,9	51717
123,53	12,971	51802
124,03	12,922	51622
124,53	12,854	51425
125,03	12,89	51672
125,53	12,849	51392
126,03	12,92	51616
126,53	12,854	51441
127,03	12,842	51389
127,53	12,9	51531
128,03	12,867	51437
128,53	12,785	51129
129,03	12,889	51648
129,53	12,915	51526
130,03	12,828	51306
130,53	12,861	51521
131,03	12,898	51650
131,53	12,797	51086
132,03	12,659	50602
132,53	12,823	51362
133,03	12,802	51228
133,53	12,84	51372
134,03	12,869	51474
134,53	12,703	50798
135,03	12,717	50898
135,53	12,78	51086
136,03	12,738	50880
136,53	12,675	50828
137,03	12,767	51006
137,53	12,716	50806
138,03	12,658	50646
138,53	12,731	50997
139,03	12,744	51007
139,53	12,828	51255
140,03	12,824	51258

140,53	12,718	50915
141,03	12,741	51035
141,53	12,737	50927
142,03	12,748	50986
142,53	12,79	51208
143,03	12,748	50908
143,53	12,764	50973
144,03	12,811	51264
144,53	12,893	51666
145,03	12,808	51191
145,53	12,707	50726
146,03	12,659	50696
146,53	12,97	52033
147,03	12,89	51470
147,53	12,801	51175
148,03	12,806	51233
148,53	12,792	51300
149,03	12,803	51209
149,53	12,872	51548
150,03	12,866	51439
150,53	12,831	51374
151,03	12,743	50870
151,53	12,759	51028
152,03	12,847	51442
152,53	12,829	51382
153,03	12,902	51563
153,53	12,776	50972
154,03	12,807	51289
154,53	12,901	51654
155,03	12,751	50867
155,53	12,674	50681
156,03	12,79	51210
156,53	12,783	51184
157,03	12,722	50903
157,53	12,808	51204
158,03	12,819	51270
158,53	12,751	51040
159,03	12,792	51148
159,53	12,9	51556
160,03	12,792	51189
160,53	12,74	50940

161,03	12,784	51117
161,53	12,878	51462
162,03	12,755	51078
162,53	12,672	50735
163,03	12,791	51080
163,53	12,725	50832
164,03	12,746	51024
164,53	12,759	51053
165,03	12,645	50565
165,53	12,687	50679
166,03	12,735	51004
166,53	12,664	50656
167,03	12,705	50788
167,53	12,674	50672
168,03	12,627	50514
168,53	12,563	50306
169,03	12,65	50531
169,53	12,577	50295
170,03	12,667	50738
170,53	12,59	50368
171,03	12,582	50259
171,53	12,512	50042
172,03	12,557	50299
172,53	12,609	50506
173,03	12,564	50159
173,53	12,579	50365
174,03	12,556	50265
174,53	12,526	50100
175,03	12,555	50170
175,53	12,558	50223
176,03	12,555	50284
176,53	12,513	50123
177,03	12,685	50614
177,53	12,478	49873
178,03	12,549	50253
178,53	12,484	49905
179,03	12,541	50144
179,53	12,494	49926
180,03	12,45	49865
180,53	12,432	49729
181,03	12,433	49716

181,53	12,46	49836
182,03	12,509	50145
182,53	12,471	49847
183,03	12,452	49760
183,53	12,472	49932
184,03	12,465	49896
184,53	12,507	49941
185,03	12,435	49682
185,53	12,273	49078
186,03	12,536	50276
186,53	12,446	49723
187,03	12,492	49906
187,53	12,474	49926
188,03	12,403	49620
188,53	12,4	49667
189,03	12,411	49522
189,53	12,315	49325
190,03	12,46	49893
190,53	12,395	49513
191,03	12,503	50021
191,53	12,512	50062
192,03	12,415	49694
192,53	12,408	49632
193,04	12,506	49994
193,53	12,403	49602
194,03	12,399	49678
194,55	12,47	49823
195,03	12,443	49728
195,53	12,574	50403
196,05	12,53	50128
196,53	12,451	49747
197,03	12,453	49785
197,53	12,454	49856
198,03	12,542	50302
198,53	12,528	49962
199,03	12,477	49894
199,53	12,51	50076
200,03	12,39	49579
200,53	12,536	50161
201,03	12,454	49790
201,53	12,459	49846

202,03	12,504	50035
202,53	12,461	49792
203,03	12,553	50137
203,53	12,431	49778
204,03	12,491	49991
204,53	12,487	49890
205,03	12,532	50124
205,53	12,487	49974
206,03	12,501	50065
206,53	12,441	49648
207,03	12,387	49556
207,53	12,513	50128
208,03	12,528	50082
208,53	12,463	49767
209,03	12,534	50145
209,53	12,443	49865
210,03	12,394	49508
210,53	12,426	49736
211,03	12,577	50275
211,53	12,572	50365
212,03	12,419	49659
212,53	12,367	49428
213,03	12,483	49931
213,53	12,493	50027
214,03	12,584	50327
214,53	12,459	49777
215,03	12,516	50053
215,53	12,458	49881
216,03	12,357	49418
216,53	12,392	49468
217,03	12,387	49603
217,53	12,477	49938
218,03	12,369	49399
218,53	12,386	49514
219,03	12,498	49943
219,53	12,269	49150
220,03	12,3	49187
220,53	12,378	49479
221,03	12,29	49125
221,53	12,37	49535
222,03	12,302	49161

222,53	12,265	48896
223,03	12,268	49173
223,53	12,258	49042
224,03	12,206	48800
224,53	12,37	49510
225,03	12,353	49391
225,53	12,232	48942
226,03	12,258	48991
226,53	12,222	48886
227,03	12,283	49141
227,53	12,297	49267
228,03	12,254	48961
228,53	12,103	48363
229,03	12,202	48869
229,53	12,351	49429
230,03	12,278	48956
230,53	12,158	48581
231,03	12,182	48758
231,53	12,321	49325
232,03	12,298	49154
232,53	12,176	48708
233,03	12,189	48775
233,53	12,128	48512
234,03	12,159	48624
234,53	12,198	48867
235,03	12,266	49105
235,53	12,143	48449
236,03	12,08	48284
236,53	12,108	48410
237,03	12,178	48791
237,53	12,072	48251
238,03	12,113	48407
238,53	12,167	48663
239,03	12,187	48810
239,53	12,136	48517
240,03	12,033	48060
240,53	12,081	48343
241,03	12,114	48486
241,53	12,079	48323
242,03	11,999	47932
242,53	12,117	48511

243,03	12,122	48538
243,53	12,139	48598
244,03	12,166	48632
244,53	12,206	48769
245,03	12,141	48576
245,53	12,173	48733
246,03	12,24	48866
246,53	12,111	48429
247,03	12,257	49125
247,53	12,167	48631
248,03	12,218	48813
248,53	12,196	48860
249,03	12,159	48579
249,53	12,185	48813
250,03	12,226	48794
250,53	12,096	48402
251,03	12,213	48947
251,53	12,103	48396
252,03	12,193	48805
252,53	12,273	49102
253,03	12,167	48704
253,53	12,132	48492
254,03	12,213	48851
254,53	12,1	48374
255,03	12,138	48637
255,53	12,091	48393
256,03	12,16	48535
256,53	12,046	48253
257,03	12,216	48928
257,53	12,149	48565
258,03	12,209	48773
258,53	12,181	48702
259,03	12,05	48238
259,53	12,177	48754
260,03	12,243	48878
260,53	12,102	48402
261,03	12,081	48420
261,53	12,193	48772
262,03	12,203	48706
262,53	12,106	48426
263,03	12,068	48309

263,53	12,113	48440
264,03	12,14	48514
264,53	12,036	48185
265,03	12,137	48644
265,53	12,058	48153
266,03	12,13	48520
266,53	12,042	48225
267,03	12,128	48576
267,53	12,103	48373
268,03	12,04	48124
268,53	12,105	48536
269,03	12,203	48865
269,53	12,034	47978
270,03	11,953	47784
270,53	11,99	48064
271,03	12,149	48588
271,53	11,98	47822
272,03	12,069	48259
272,53	12,005	48035
273,03	11,995	47980
273,53	11,971	47813
274,03	12,017	48108
274,53	11,984	47954
275,03	12,011	48070
275,53	11,965	47871
276,03	12,09	48293
276,53	11,921	47692
277,03	11,881	47597
277,53	11,967	47840
278,03	12,059	48250
278,53	11,954	47805
279,03	11,894	47604
279,53	11,934	47690
280,03	11,972	47914
280,53	12,003	48051
281,03	11,953	47738
281,53	11,92	47605
282,03	11,962	47879
282,53	11,948	47837
283,03	11,938	47740
283,53	11,924	47634

284,03	11,862	47396
284,53	11,836	47428
285,03	11,888	47563
285,53	11,872	47417
286,03	11,828	47309
286,53	11,725	46981
287,03	11,925	47732
287,53	11,865	47436
288,03	11,832	47338
288,53	11,866	47587
289,03	11,859	47384
289,53	11,789	47154
290,03	11,809	47265
290,53	11,789	47253
291,03	11,876	47460
291,53	11,765	47001
292,03	11,756	47133
292,53	11,943	47806
293,03	11,885	47513
293,53	11,825	47186
294,03	11,81	47266
294,53	11,76	47135
295,03	11,844	47350
295,53	11,915	47657
296,03	11,896	47598
296,53	11,881	47589
297,03	11,857	47336
297,53	11,877	47456
298,03	11,835	47384
298,53	11,967	47959
299,03	11,962	47841
299,53	11,923	47657
300,03	11,99	48017
300,53	11,942	47873
301,03	11,948	47763
301,53	11,824	47346
302,03	11,933	47796
302,53	11,948	47677
303,03	11,923	47767
303,53	11,953	47849
304,03	11,862	47370

304,53	11,863	47397
305,03	11,934	47763
305,53	11,924	47726
306,03	11,813	47307
306,53	11,851	47337
307,03	11,917	47656
307,53	11,816	47352
308,03	11,89	47482
308,53	11,81	47226
309,03	11,952	47817
309,53	11,974	47934
310,03	11,917	47597
310,53	11,835	47286
311,03	11,75	47112
311,53	12,034	48263
312,03	11,96	47805
312,53	11,899	47667
313,03	11,877	47459
313,53	11,839	47310
314,03	11,932	47860
314,53	12,032	48130
315,03	11,908	47491
315,53	11,734	46891
316,03	11,977	48078
316,53	11,957	47728
317,03	11,897	47549
317,53	11,87	47505
318,03	11,908	47670
318,53	11,885	47529
319,03	11,869	47452
319,53	11,938	47846
320,03	11,919	47732
320,53	11,781	47049
321,03	11,82	47277
321,53	11,897	47575
322,03	11,915	47746
322,53	11,873	47459
323,03	11,869	47384
323,53	11,778	47119
324,03	11,852	47468
324,53	11,802	47146

325,03	11,781	47136
325,53	11,786	47112
326,03	11,847	47386
326,53	11,714	46865
327,03	11,857	47417
327,53	11,725	46902
328,03	11,675	46721
328,53	11,722	46866
329,03	11,797	47134
329,53	11,799	47233
330,03	11,694	46767
330,53	11,721	46957
331,03	11,925	47633
331,53	11,687	46718
332,04	11,618	46526
332,53	11,707	46806
333,03	11,856	47379
333,55	11,695	46782
334,03	11,63	46527
334,53	11,653	46606
335,03	11,769	47043
335,53	11,685	46754
336,03	11,643	46532
336,53	11,663	46567
337,03	11,622	46445
337,53	11,741	47046
338,03	11,66	46646
338,53	11,663	46649
339,03	11,681	46647
339,53	11,623	46551
340,03	11,608	46430
340,53	11,711	46853
341,03	11,559	46286
341,53	11,666	46650
342,03	11,687	46738
342,53	11,622	46494
343,03	11,727	46987
343,53	11,674	46682
344,03	11,7	46701
344,53	11,643	46597
345,03	11,705	46886

345,53	11,684	46712
346,03	11,627	46480
346,53	11,8	47246
347,03	11,807	47301
347,53	11,658	46497
348,03	11,707	46908
348,53	11,791	47145
349,03	11,703	46823
349,53	11,639	46566
350,03	11,765	46978
350,53	11,657	46685
351,03	11,767	47091
351,53	11,77	47068
352,03	11,819	47161
352,53	11,782	47184
353,03	11,781	47155
353,53	11,727	46925
354,03	11,747	46913
354,53	11,741	46973
355,03	11,732	46978
355,53	11,722	46808
356,03	11,735	46904
356,53	11,78	47203
357,03	11,801	47230
357,53	11,761	46910
358,03	11,624	46424
358,53	11,747	47025
359,03	11,725	46907
359,53	11,697	46784
360,03	11,66	46613
360,53	11,778	47181
361,03	11,852	47429
361,53	11,731	46878
362,03	11,718	46842
362,53	11,804	47299
363,03	11,808	47228
363,53	11,705	46783
364,03	11,756	47022
364,53	11,737	46975
365,03	11,833	47380
365,53	11,796	47182

366,03	11,773	47084
366,53	11,719	46922
367,03	11,722	46864
367,53	11,852	47392
368,03	11,881	47447
368,53	11,655	46591
369,03	11,804	47270
369,53	11,633	46446
370,03	11,628	46587
370,53	11,692	46793
371,03	11,591	46294
371,53	11,688	46794
372,03	11,724	46880
372,53	11,641	46555
373,03	11,588	46338
373,53	11,576	46227
374,03	11,598	46448
374,53	11,646	46625
375,03	11,665	46640
375,53	11,593	46332
376,03	11,571	46268
376,53	11,591	46431
377,03	11,652	46622
377,53	11,644	46489
378,03	11,658	46685
378,53	11,557	46223
379,03	11,461	45810
379,53	11,487	45913
380,03	11,47	45914
380,53	11,619	46584
381,03	11,565	46190
381,53	11,554	46198
382,03	11,481	45916
382,53	11,62	46566
383,03	11,501	45969
383,53	11,663	46604
384,03	11,581	46326
384,53	11,582	46409
385,03	11,588	46305
385,53	11,406	45637
386,03	11,564	46269

386,53	11,567	46292
387,03	11,539	46096
387,53	11,642	46548
388,03	11,56	46217
388,53	11,556	46276
389,03	11,441	45710
389,53	11,587	46325
390,03	11,462	45887
390,53	11,438	45776
391,03	11,492	45897
391,53	11,466	45845
392,03	11,439	45803
392,53	11,516	46168
393,03	11,438	45712
393,53	11,429	45724
394,03	11,61	46532
394,53	11,55	46174
395,03	11,54	46110
395,53	11,456	45777
396,03	11,515	46166
396,53	11,618	46429
397,03	11,62	46382
397,53	11,406	45611
398,03	11,44	45865
398,53	11,615	46507
399,03	11,558	46137
399,53	11,608	46432
400,03	11,526	46151
400,53	11,535	46202
401,03	11,548	46129
401,53	11,563	46316
402,03	11,62	46496
402,53	11,567	46249
403,03	11,534	46065
403,53	11,577	46288
404,03	11,505	46111
404,53	11,672	46638
405,03	11,633	46457
405,53	11,481	45898
406,03	11,641	46659
406,53	11,603	46400

407,03	11,656	46627
407,53	11,631	46479
408,03	11,653	46694
408,53	11,681	46754
409,03	11,499	45871
409,53	11,623	46549
410,03	11,639	46530
410,53	11,528	46067
411,03	11,513	46056
411,53	11,621	46547
412,03	11,728	46951
412,53	11,542	46088
413,03	11,702	46802
413,53	11,671	46688
414,03	11,65	46695
414,53	11,737	46923
415,03	11,592	46291
415,53	11,721	46992
416,03	11,692	46754
416,53	11,566	46224
417,03	11,566	46294
417,53	11,687	46744
418,03	11,652	46651
418,53	11,639	46421
419,03	11,663	46668
419,53	11,689	46794
420,03	11,727	46951
420,53	11,674	46590
421,03	11,525	46084
421,53	11,541	46205
422,03	11,617	46622
422,53	11,681	46594
423,03	11,518	46038
423,53	11,623	46506
424,03	11,495	45950
424,53	11,407	45643
425,03	11,503	45951
425,53	11,485	45928
426,03	11,578	46350
426,53	11,501	45908
427,03	11,449	45748

427,53	11,468	45972
428,03	11,543	46195
428,53	11,429	45636
429,03	11,503	46091
429,53	11,565	46353
430,03	11,468	45847
430,53	11,455	45823
431,03	11,497	46013
431,53	11,5	46051
432,03	11,484	46003
432,53	11,475	45826
433,03	11,435	45752
433,53	11,512	46102
434,03	11,398	45578
434,53	11,343	45308
435,03	11,385	45576
435,53	11,538	46295
436,03	11,553	46204
436,53	11,509	45937
437,03	11,531	46167
437,53	11,537	46209
438,03	11,435	45709
438,53	11,492	45950
439,03	11,531	46092
439,53	11,325	45297
440,03	11,396	45628
440,53	11,588	46291
441,03	11,47	45832
441,53	11,441	45838
442,03	11,472	45833
442,53	11,417	45528
443,03	11,322	45384
443,53	11,504	46100
444,03	11,487	45847
444,53	11,349	45356
445,03	11,441	45818
445,53	11,503	46101
446,03	11,477	45798
446,53	11,347	45302
447,03	11,428	45744
447,53	11,456	45904

448,03	11,46	45781
448,53	11,29	45087
449,03	11,514	46095
449,53	11,464	45871
450,03	11,521	46042
450,53	11,57	46252
451,03	11,551	46254
451,53	11,468	45868
452,03	11,523	46083
452,53	11,604	46399
453,03	11,646	46589
453,53	11,534	46188
454,03	11,505	45977
454,53	11,507	46035
455,03	11,635	46630
455,53	11,505	46015
456,03	11,416	45648
456,53	11,492	46005
457,03	11,65	46603
457,53	11,565	46226
458,03	11,562	46252
458,53	11,535	46091
459,03	11,532	46171
459,53	11,628	46566
460,03	11,609	46329
460,53	11,596	46440
461,03	11,624	46564
461,53	11,543	46191
462,03	11,673	46689
462,53	11,733	46908
463,03	11,661	46643
463,53	11,501	45999
464,03	11,53	46144
464,53	11,543	46156
465,03	11,652	46671
465,53	11,695	46796
466,03	11,691	46714
466,53	11,603	46388
467,03	11,607	46490
467,53	11,603	46375
468,03	11,652	46580

468,53	11,675	46656
469,03	11,633	46599
469,53	11,687	46766
470,03	11,577	46256
470,53	11,604	46416
471,03	11,623	46537
471,53	11,558	46245
472,03	11,591	46311
472,53	11,64	46535
473,03	11,573	46339
473,53	11,654	46538
474,03	11,517	45968
474,53	11,449	45807
475,03	11,587	46407
475,53	11,542	46167
476,03	11,593	46268
476,53	11,441	45757
477,03	11,409	45654
477,53	11,516	46079
478,03	11,473	45845
478,53	11,439	45767
479,03	11,595	46494
479,53	11,563	46244
480,03	11,465	45795
480,53	11,527	46140
481,03	11,5	46045
481,53	11,455	45790
482,03	11,446	45757
482,53	11,432	45755
483,03	11,56	46334
483,53	11,554	46195
484,03	11,541	46095
484,53	11,6	46436
485,03	11,488	45968
485,54	11,518	46144
486,03	11,596	46296
486,53	11,552	46243
487,04	11,528	46133
487,53	11,472	45896
488,03	11,518	46031
488,56	11,483	45985

489,03	11,572	46348
489,53	11,592	46333
490,03	11,484	45844
490,53	11,483	46016
491,03	11,56	46205
491,53	11,504	45961
492,03	11,484	45836
492,53	11,448	45922
493,03	11,643	46645
493,53	11,518	45996
494,03	11,475	45863
494,53	11,4	45676
495,03	11,459	45827
495,53	11,382	45506
496,03	11,499	46011
496,53	11,438	45806
497,03	11,469	45893
497,53	11,426	45673
498,03	11,46	45800
498,53	11,511	46140
499,03	11,504	45975
499,53	11,483	45872
500,03	11,516	46084
500,53	11,6	46463
501,03	11,463	45833
501,53	11,476	45806
502,03	11,583	46355
502,53	11,554	46245
503,03	11,623	46520
503,53	11,516	46058
504,03	11,588	46368
504,53	11,578	46295
505,03	11,576	46338
505,53	11,625	46443
506,03	11,628	46475
506,53	11,577	46352
507,03	11,683	46752
507,53	11,632	46467
508,03	11,676	46711
508,53	11,591	46375
509,03	11,521	46165

509,53	11,637	46470
510,03	11,615	46538
510,53	11,611	46477
511,03	11,583	46451
511,53	11,661	46538
512,03	11,711	46866
512,53	11,631	46551
513,03	11,584	46282
513,53	11,592	46354
514,03	11,595	46377
514,53	11,595	46442
515,03	11,624	46493
515,53	11,646	46577
516,03	11,77	47069
516,53	11,586	46331
517,03	11,584	46341
517,53	11,614	46365
518,03	11,643	46586
518,53	11,588	46306
519,03	11,478	45954
519,53	11,621	46473
520,03	11,554	46176
520,53	11,608	46506
521,03	11,628	46484
521,53	11,643	46530
522,03	11,724	46934
522,53	11,616	46370
523,03	11,621	46457
523,53	11,658	46585
524,03	11,539	46016
524,53	11,523	46180
525,03	11,657	46657
525,53	11,641	46549
526,03	11,611	46455

Table E5: Thixotropic analysis for NCC-Bentonite sample with 1.0% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	18,848	75293
10	17,706	70825
15	17,415	69658
20	17,117	68401
25	17,113	68478
25,12	1405,6	5016,8
25,22	130,74	128,5
25,32	78,469	78,456
25,42	78,293	78,282
25,51	72,792	72,737
25,61	72,341	72,326
25,71	74,414	74,445
25,81	69,772	69,763
25,91	67,708	67,698
26,01	70,424	70,457
26,53	1,6633	6645,5
27,03	3,2553	13509
27,53	4,6006	18926
28,03	6,0535	24814
28,53	7,6604	31318
29,03	9,1866	37454
29,53	10,225	41038
30,03	10,695	42960
30,53	11,47	46026
31,03	12,083	48553
31,53	12,603	50242
32,03	12,483	49996
32,53	12,782	51406
33,03	13,269	53017
33,53	13,248	52892
34,03	13,293	53278
34,53	13,475	53905
35,03	13,538	54363
35,53	13,875	55647
36,03	13,838	55270
36,53	14,089	56335
37,03	14,381	57527

37,53	14,463	57745
38,03	14,203	56949
38,53	14,171	56737
39,03	14,599	58596
39,53	14,75	58999
40,03	14,727	58839
40,53	14,584	58307
41,03	14,667	58622
41,53	14,839	59414
42,03	14,897	59733
42,53	14,889	59457
43,03	14,728	58961
43,53	15,01	60172
44,03	15,433	61504
44,53	14,936	59754
45,03	15,072	60370
45,53	15,155	60766
46,03	15,063	60037
46,53	15,091	60491
47,03	15,349	61374
47,53	15,516	62337
48,03	15,804	63048
48,53	15,165	60520
49,03	15,538	62354
49,53	15,767	63053
50,03	15,543	61958
50,53	15,455	61804
51,03	15,513	61991
51,53	15,773	63323
52,03	15,762	63102
52,53	15,724	62909
53,03	16,084	64288
53,53	15,819	63253
54,03	15,575	62026
54,53	15,781	63486
55,03	16,298	64895
55,53	15,84	63317
56,03	16,095	64308
56,53	16,019	64091
57,03	16,206	65124
57,53	16,192	64537

58,03	15,906	63636
58,53	16,317	65468
59,03	16,066	63773
59,53	15,636	62783
60,03	16,43	65955
60,53	16,561	66346
61,03	16,217	64698
61,53	16,239	64959
62,03	16,323	65389
62,53	16,527	66025
63,03	15,961	63769
63,53	16,41	65734
64,03	16,224	64819
64,53	15,974	63785
65,03	16,276	65511
65,53	16,628	66334
66,03	16,218	65022
66,53	17,009	68176
67,03	16,688	66590
67,53	16,604	66313
68,03	16,435	65804
68,53	16,359	65491
69,03	16,77	67114
69,53	16,666	66639
70,03	16,463	65731
70,53	16,174	64523
71,03	16,39	65661
71,53	16,867	67626
72,03	16,975	67901
72,53	16,76	66878
73,03	16,645	66659
73,53	16,515	66081
74,03	16,679	66700
74,53	16,589	66398
75,03	16,77	67096
75,53	16,404	65631
76,03	16,615	66691
76,53	16,859	67466
77,03	16,782	67032
77,53	16,506	65901
78,03	16,597	66376

78,53	16,637	66509
79,03	16,54	66075
79,53	16,475	66094
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80,53	16,819	67277
81,03	16,471	65567
81,53	16,443	65879
82,03	16,618	66675
82,53	16,734	66801
83,03	16,436	65709
83,53	16,685	66743
84,03	16,657	66894
84,53	16,859	67402
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85,53	16,457	65954
86,03	16,746	67019
86,53	16,837	67328
87,03	16,696	66452
87,53	16,486	65743
88,03	16,922	67853
88,53	16,325	65052
89,03	16,592	66817
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92,03	16,483	65631
92,53	16,885	67757
93,03	16,458	65517
93,53	16,689	66769
94,03	16,705	66906
94,53	16,788	67315
95,03	17,017	68013
95,53	16,535	66019
96,03	16,585	66340
96,53	16,524	66146
97,03	16,892	67518
97,53	16,78	67131
98,03	16,917	67939
98,53	16,633	66164

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99,53	16,709	66819
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106,53	16,997	68162
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108,53	16,829	67223
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112,53	16,519	66181
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113,53	16,716	66867
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115,53	16,65	66875
116,03	17,175	68780
116,53	16,813	67181
117,03	16,8	67343
117,53	16,931	67751
118,03	17,223	68664
118,53	16,653	66501
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121,53	16,927	67756
122,03	17,316	69352
122,53	17,077	68123
123,03	16,938	67822
123,53	16,841	67352
124,03	17,131	68670
124,53	16,967	67553
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127,53	17,099	68387
128,03	17,055	68335
128,53	16,902	67425
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135,53	16,781	66798
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138,53	16,709	66618
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145,03	16,607	66487
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146,53	16,753	67035
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148,53	16,732	66824
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153,53	16,441	65688
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156,53	16,694	66816
157,03	16,327	65157
157,53	16,583	66431
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158,53	16,372	65301
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161,53	16,573	66366
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162,53	16,161	64568
163,03	16,31	65388
163,53	16,548	66208
164,03	16,12	64253
164,53	16,217	65101
165,03	16,432	65550
165,53	16,277	65085
166,03	16,054	63969
166,53	16,433	66006
167,03	16,383	65598
167,53	16,548	66207
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168,53	16,24	65014
169,03	16,282	65168
169,53	16,235	64857
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172,03	16,425	65562
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175,03	16,866	67222
175,53	15,946	63590
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176,53	16,352	65419
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185,03	16,438	65567
185,53	16,015	64124
186,03	16,021	64038
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187,53	15,827	63451
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188,53	16,013	64057
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191,53	16,073	64331
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192,53	16,08	64353
193,03	16,285	65151
193,53	16,152	64394
194,03	15,77	62990
194,53	16,03	64271
195,03	16,077	64237
195,53	15,966	63830
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239,53	15,75	63094
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273,53	15,534	62174
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367,53	14,941	59387
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395,03	15,465	62159
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405,53	15,098	60593
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407,53	15,098	60319
408,03	14,844	59278
408,53	15,042	60323
409,03	14,796	59162
409,53	15,075	60508
410,03	15,262	60997
410,53	15,127	60456
411,03	14,774	59129
411,53	15,373	61513
412,03	15,263	61279
412,53	15,156	60378
413,03	14,898	59803
413,53	14,752	58978
414,03	15,19	61000
414,53	14,914	59478
415,03	15,235	61049
415,53	14,905	59568
416,03	14,665	58689
416,53	15,412	61854
417,03	14,986	59557
417,53	14,991	60038
418,04	14,852	59587
418,53	15,171	60596
419,03	15,194	60634
419,54	15,044	60230
420,03	15,006	60089
420,53	14,994	59957
421,05	14,829	59183
421,53	14,942	59757
422,03	15,177	60831
422,55	15,538	62145
423,03	15,051	60106
423,53	15,21	60880
424,03	15,105	60482
424,53	15,22	61180
425,03	15,353	61255
425,53	15,084	60396
426,03	15,351	61437
426,53	15,449	61911

427,03	15,264	61032
427,53	15,028	60103
428,03	15,175	60946
428,53	15,311	61185
429,03	15,166	60761
429,53	15,553	62349
430,03	15,612	62313
430,53	14,988	59487
431,03	15,188	61051
431,53	15,476	61974
432,03	15,034	59930
432,53	15,312	61373
433,03	15,278	60867
433,53	15,169	60529
434,03	15,424	61840
434,53	15,497	62108
435,03	15,314	61035
435,53	15,264	60945
436,03	15,2	60896
436,53	15,036	59971
437,03	15,288	61197
437,53	15,131	60618
438,03	15,494	61866
438,53	15,013	59928
439,03	14,737	58986
439,53	15,269	61348
440,03	15,214	60904
440,53	15,426	61493
441,03	14,925	59714
441,53	14,93	59885
442,03	15,191	60809
442,53	15,063	60052
443,03	15,092	60577
443,53	15,258	60805
444,03	14,834	59367
444,53	15,176	60969
445,03	15,271	61097
445,53	14,849	59125
446,03	14,571	58509
446,53	15,38	61838
447,03	15,338	61026

447,53	14,924	59807
448,03	15,107	60143
448,53	15,153	60531
449,03	15,091	60428
449,53	15,29	60997
450,03	15,276	61076
450,53	14,983	59798
451,03	14,945	59851
451,53	15,122	60634
452,03	15,205	60732
452,53	14,92	59593
453,03	15,244	61306
453,53	15,237	60747
454,04	15,106	60143
454,53	14,711	58577
455,03	14,741	59119
455,55	15,01	60027
456,03	15,127	60613
456,53	15,025	60169
457,03	15,17	60714
457,53	15,063	60057
458,03	15,019	60177
458,53	14,911	59653
459,03	15,117	60713
459,53	14,952	59381
460,03	15,023	60334
460,53	15,1	60330
461,03	15,166	60730
461,53	14,991	59849
462,03	15,271	61072
462,53	15,275	61124
463,03	14,907	59592
463,53	15,181	60585
464,03	14,88	59527
464,53	15,433	61866
465,03	15,462	61685
465,53	14,93	59421
466,03	14,975	60064
466,53	15,247	61022
467,03	15,222	60774
467,53	15,301	60986

468,03	14,957	59923
468,53	15,221	60944
469,03	15,271	61033
469,53	15,173	60714
470,03	14,961	59815
470,53	15,341	61461
471,03	15,517	61751
471,53	14,858	59370
472,03	15,025	60204
472,53	15,529	62439
473,03	15,474	61726
473,53	15,118	60555
474,03	15,622	62476
474,53	15,116	60534
475,03	15,307	61334
475,53	15,439	61831
476,03	15,199	60740
476,53	15,231	60915
477,03	15,039	60188
477,53	15,338	61563
478,03	15,68	62832
478,53	15,236	60676
479,03	15,141	60621
479,53	14,821	59302
480,03	15,501	62437
480,53	16,064	64244
481,03	15,233	60593
481,53	15,037	60183
482,03	15,435	61971
482,53	15,627	62244
483,03	15,343	61669
483,53	15,483	62121
484,03	15,262	61035
484,53	14,998	60001
485,03	15,205	60865
485,53	15,763	63177
486,03	15,592	62345
486,53	15,48	61856
487,03	15,101	60333
487,53	14,978	59934
488,03	15,459	62026

488,53	15,227	60920
489,03	15,26	60897
489,53	14,987	59892
490,03	15,174	60831
490,53	15,35	61373
491,03	15,238	61376
491,53	15,616	62069
492,03	14,999	60168
492,53	15,524	62221
493,03	15,082	60253
493,53	15,198	61034
494,03	15,326	61298
494,53	15,189	60532
495,03	15,291	61436
495,53	15,076	60206
496,03	15,083	60329
496,53	15,413	61698
497,03	15,219	60980
497,53	15,408	61723
498,03	15,262	61221
498,53	15,025	60003
499,03	15,212	61050
499,53	15,383	61815
500,03	15,365	61381
500,53	15,006	59762
501,03	15,126	60636
501,53	15,262	61139
502,03	15,247	60967
502,53	15,086	60460
503,03	15,027	60005
503,53	14,985	60422
504,03	15,383	61188
504,53	14,87	59459
505,03	15,133	60563
505,53	14,95	59752
506,03	14,821	59220
506,53	15,05	60414
507,03	15,22	60971
507,53	15,057	60229
508,03	15,282	61154
508,53	15,276	61193

509,03	15,024	59835
509,53	15,263	61307
510,03	15,102	60013
510,53	15,079	60616
511,03	15,283	61152
511,53	15,238	60858
512,03	15,155	60567
512,53	14,941	59825
513,03	15,104	60518
513,53	15,307	61296
514,03	15,266	61105
514,53	15,484	62055
515,03	15,372	61402
515,53	15,112	60287
516,03	14,961	60131
516,53	15,434	61722
517,03	15,055	60125
517,53	15,467	61796
518,03	15,167	60464
518,53	15,356	61670
519,03	15,437	61471
519,53	15,182	60844
520,03	15,454	61897
520,53	15,373	61386
521,03	15,252	61321
521,53	15,199	60615
522,03	15,393	61730
522,53	15,229	61015
523,03	15,71	62828
523,53	15,193	60715
524,03	15,078	60174
524,53	15,417	61860
525,03	15,499	62024
525,53	15,467	61904
526,03	15,315	61242

Table E6: Thixotropic analysis for NCC-Bentonite sample with 1.2% NCC at 25 °C

Time [s]	Shear Stress [Pa]	Viscosity [mPa·s]
5	15,153	60583
10	14,681	58721
15	14,598	58387
20	14,519	58081
25	14,444	57751
25,12	444,43	2631,6
25,22	418,43	482,67
25,32	128,75	126,67
25,42	107,79	107,81
25,51	107	106,95
25,62	104,02	103,98
25,72	98,92	98,863
25,82	98,317	98,325
25,91	97,219	97,182
26,01	94,658	94,615
26,53	3,9393	15714
27,03	4,8522	20116
27,53	6,4988	26855
28,03	8,035	32697
28,53	9,2119	37269
29,03	10,197	41109
29,53	10,798	43356
30,03	11,315	45511
30,53	11,755	47188
31,03	11,97	47877
31,53	12,264	49114
32,03	12,514	50190
32,54	12,693	50911
33,03	12,876	51592
33,53	13,02	52099
34,05	13,076	52295
34,53	13,105	52479
35,03	13,254	53090
35,55	13,261	52988
36,03	13,291	53163
36,53	13,447	53936
37,06	13,519	54081

37,53	13,578	54286
38,03	13,566	54274
38,53	13,626	54598
39,03	13,595	54357
39,53	13,62	54392
40,03	13,743	55030
40,53	13,832	55362
41,03	13,766	55043
41,53	13,848	55344
42,03	13,898	55586
42,53	13,928	55789
43,03	13,876	55487
43,53	14,016	56052
44,03	13,982	55913
44,53	14,011	56128
45,03	14,097	56409
45,53	14,132	56492
46,03	14,069	56232
46,53	14,03	56178
47,03	14,167	56673
47,53	14,104	56326
48,03	14,152	56663
48,53	14,201	56869
49,03	14,158	56608
49,53	14,138	56501
50,03	14,204	56845
50,53	14,112	56508
51,03	14,136	56522
51,53	14,207	56728
52,03	14,223	56905
52,53	14,187	56773
53,03	14,185	56701
53,53	14,286	57179
54,03	14,325	57335
54,53	14,14	56602
55,03	14,216	56874
55,53	14,246	56882
56,03	14,284	57248
56,53	14,252	57024
57,03	14,157	56654
57,53	14,283	57125

58,03	14,393	57602
58,53	14,269	57163
59,03	14,35	57350
59,53	14,302	57072
60,03	14,267	57183
60,53	14,298	57245
61,03	14,279	57010
61,53	14,271	57075
62,03	14,254	57075
62,53	14,293	57204
63,03	14,262	56956
63,53	14,219	56857
64,03	14,401	57708
64,53	14,258	57037
65,03	14,206	56750
65,53	14,27	57041
66,03	14,317	57307
66,53	14,276	57159
67,03	14,307	57179
67,53	14,224	56849
68,03	14,314	57325
68,53	14,149	56575
69,03	14,238	57013
69,53	14,178	56699
70,03	14,146	56650
70,53	14,266	57065
71,03	14,252	56863
71,53	14,176	56717
72,03	14,187	56742
72,53	14,128	56520
73,03	14,175	56663
73,53	14,166	56701
74,03	14,112	56511
74,53	14,098	56401
75,03	14,073	56351
75,53	14,083	56306
76,03	14,121	56603
76,53	14,118	56502
77,03	14,14	56555
77,53	14,178	56759
78,03	14,109	56388

78,53	13,999	55942
79,03	14,004	55904
79,53	14,192	56853
80,03	14,151	56670
80,53	14,094	56419
81,03	14,156	56580
81,53	14,09	56376
82,03	14,031	56148
82,53	14,099	56405
83,03	14,223	56774
83,53	14,016	56040
84,03	14,052	56240
84,53	14,027	56031
85,03	14,033	56144
85,53	14,102	56449
86,03	14	55961
86,53	13,886	55525
87,03	14,082	56262
87,53	14,037	56194
88,03	13,991	56019
88,53	13,978	55861
89,03	13,991	55952
89,53	14,03	56166
90,03	14,103	56474
90,53	13,979	55787
91,03	13,973	55885
91,53	14,012	56107
92,03	14,133	56581
92,53	14,076	56277
93,03	14,122	56499
93,53	14,06	56259
94,03	14,029	56164
94,53	14,071	56162
95,03	14,059	56233
95,53	14,224	56965
96,03	14,131	56545
96,53	14,089	56361
97,03	14,239	56918
97,53	14,171	56678
98,03	14,196	56869
98,53	14,209	56722

99,03	14,076	56253
99,53	14,178	56742
100,03	14,11	56436
100,53	14,135	56422
101,03	14,09	56349
101,53	14,093	56496
102,03	14,119	56461
102,53	14,158	56633
103,03	14,095	56277
103,53	14,21	56949
104,03	14,179	56745
104,53	14,163	56647
105,03	14,144	56550
105,53	14,072	56345
106,03	14,093	56435
106,53	14,116	56321
107,03	14,081	56360
107,53	14,032	56163
108,03	14,151	56679
108,53	14,25	56902
109,03	14,081	56320
109,53	14,096	56455
110,03	14,1	56382
110,53	14,071	56203
111,03	14,197	56819
111,53	14,151	56679
112,03	14,159	56560
112,53	14,067	56246
113,03	14,201	56775
113,53	14,123	56581
114,03	14,123	56479
114,53	14,124	56399
115,03	13,989	56014
115,53	14,086	56375
116,03	14,056	56210
116,53	14,067	56164
117,03	13,994	56061
117,53	14,076	56359
118,03	13,987	55892
118,53	14,093	56365
119,03	14,051	56168

119,53	13,916	55699
120,03	13,971	55906
120,53	13,955	55745
121,03	13,832	55356
121,53	13,974	55999
122,03	13,999	55917
122,53	13,974	55897
123,03	13,931	55749
123,53	13,918	55741
124,03	13,881	55429
124,53	13,85	55447
125,03	14,016	56183
125,53	13,961	55828
126,03	13,842	55301
126,53	13,903	55605
127,03	13,897	55594
127,53	13,811	55350
128,03	13,907	55601
128,53	13,844	55250
129,03	13,766	55176
129,53	13,895	55643
130,03	13,907	55558
130,53	13,967	55834
131,03	13,827	55338
131,53	13,769	55095
132,03	13,891	55530
132,53	13,749	54993
133,03	13,816	55411
133,53	13,909	55683
134,03	13,756	54908
134,53	13,775	55084
135,03	13,739	55070
135,53	13,764	55080
136,03	13,732	54893
136,53	13,836	55297
137,03	13,765	55078
137,53	13,711	54815
138,03	13,707	54762
138,53	13,775	55161
139,03	13,734	54925
139,53	13,675	54742

140,03	13,806	55165
140,53	13,737	54953
141,03	13,779	55213
141,53	13,737	54937
142,03	13,735	54853
142,53	13,825	55359
143,03	13,836	55376
143,53	13,727	54937
144,03	13,784	55110
144,53	13,813	55185
145,03	13,776	55130
145,53	13,83	55321
146,03	13,782	55104
146,53	13,9	55617
147,03	13,807	55237
147,53	13,79	55145
148,03	13,811	55176
148,53	13,77	55163
149,03	13,892	55645
149,53	13,807	55145
150,03	13,768	55052
150,53	13,926	55796
151,03	13,833	55370
151,53	13,819	55271
152,03	13,926	55641
152,53	13,8	55185
153,03	13,892	55625
153,53	13,808	55171
154,03	13,823	55228
154,53	13,805	55276
155,03	13,793	55229
155,53	13,899	55489
156,03	13,845	55410
156,53	13,922	55757
157,03	13,81	55271
157,53	13,767	55031
158,04	13,952	55743
158,53	13,807	55244
159,03	13,828	55392
159,55	13,835	55349
160,03	13,776	55012

160,53	13,871	55577
161,05	13,822	55296
161,53	13,81	55198
162,03	13,883	55523
162,56	13,838	55409
163,03	13,779	55100
163,53	13,788	55099
164,03	13,833	55293
164,53	13,908	55733
165,03	13,864	55465
165,53	13,79	55144
166,03	13,885	55472
166,53	13,802	55250
167,03	13,838	55424
167,53	13,882	55561
168,03	13,885	55415
168,53	13,741	55014
169,03	13,854	55498
169,53	13,762	54906
170,03	13,74	54974
170,53	13,798	55268
171,03	13,671	54654
171,53	13,592	54283
172,03	13,748	55059
172,53	13,693	54766
173,03	13,723	54964
173,53	13,722	54779
174,03	13,706	54824
174,53	13,656	54657
175,03	13,71	54933
175,53	13,695	54694
176,03	13,57	54255
176,53	13,675	54801
177,03	13,692	54781
177,53	13,722	54894
178,03	13,652	54653
178,53	13,68	54763
179,03	13,63	54476
179,53	13,585	54280
180,03	13,655	54682
180,53	13,69	54825

181,03	13,638	54522
181,53	13,604	54356
182,03	13,688	54789
182,53	13,628	54529
183,03	13,628	54563
183,53	13,62	54425
184,03	13,657	54609
184,53	13,523	54138
185,03	13,699	54747
185,53	13,583	54261
186,03	13,508	54070
186,53	13,609	54527
187,03	13,573	54216
187,53	13,546	54139
188,03	13,524	54176
188,53	13,604	54452
189,03	13,603	54390
189,53	13,604	54325
190,03	13,515	54127
190,53	13,573	54398
191,03	13,559	54213
191,53	13,54	54082
192,03	13,509	54110
192,53	13,436	53755
193,03	13,527	54127
193,53	13,632	54443
194,03	13,476	53959
194,53	13,604	54481
195,03	13,533	54022
195,53	13,549	54232
196,03	13,645	54600
196,53	13,631	54596
197,03	13,642	54447
197,53	13,578	54269
198,03	13,474	53969
198,53	13,674	54810
199,03	13,737	54874
199,53	13,549	54147
200,03	13,612	54490
200,53	13,647	54616
201,03	13,559	54115

201,53	13,668	54634
202,03	13,598	54469
202,53	13,662	54693
203,03	13,668	54545
203,53	13,717	54857
204,03	13,677	54742
204,53	13,557	54259
205,03	13,656	54538
205,53	13,64	54610
206,03	13,544	54216
206,53	13,648	54647
207,03	13,645	54572
207,53	13,692	54791
208,03	13,712	54911
208,53	13,632	54524
209,03	13,552	54117
209,53	13,517	54115
210,03	13,767	55176
210,53	13,639	54517
211,03	13,626	54433
211,53	13,683	54777
212,03	13,709	54875
212,53	13,628	54456
213,03	13,576	54215
213,53	13,644	54598
214,03	13,605	54513
214,53	13,683	54771
215,03	13,682	54653
215,53	13,681	54710
216,03	13,542	54178
216,53	13,627	54514
217,03	13,663	54535
217,53	13,565	54319
218,03	13,736	55054
218,53	13,638	54462
219,03	13,583	54294
219,53	13,553	54241
220,04	13,536	54185
220,53	13,512	54085
221,03	13,574	54263
221,55	13,656	54628

222,03	13,531	54179
222,53	13,459	53826
223,05	13,384	53452
223,53	13,612	54547
224,03	13,561	54191
224,55	13,451	53840
225,03	13,557	54135
225,53	13,497	54058
226,03	13,547	54226
226,53	13,438	53638
227,03	13,502	53973
227,53	13,487	54027
228,03	13,53	54167
228,53	13,443	53695
229,03	13,45	53752
229,53	13,435	53792
230,03	13,461	53872
230,53	13,477	53830
231,03	13,448	53741
231,53	13,472	53908
232,03	13,46	53865
232,53	13,414	53563
233,03	13,371	53410
233,53	13,4	53765
234,03	13,511	53978
234,53	13,344	53255
235,03	13,393	53652
235,53	13,515	54098
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