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Behaviour of polymer muds under high pressure – high temperature conditions

Diploma thesis spring 2007

by

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MASTEROPPGAVEN

Kandidatens navn: **Håvard Larsen**

Oppgavens tittel: **Behaviour of polymer mud under high pressure – high temperature conditions**

Utfyllende tekst:

It is a known fact that fluid viscosity changes with temperature, and to a less degree with pressure. At IPT the HPHT viscometer will be applied through this thesis in two ways.

1. **Determine the influence of temperature and pressure on some selected drilling fluid compositions.**

2. **Suggest, test and evaluate a potential student exercise on the HPHT viscometer.**

In task 1 we initially select some polymers for investigation, but the literature survey will reveal if there are other interesting materials to be tested with respect to temperature and pressure response.

In task 2 the combined effect of applying obtained results in a frictional pressure simulator will be investigated. This task must define exercise goal, procedure/ user manual/ instruction and example exercises with results and discussion.

Studieretning: Petroleumsteknologi

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Faglærer

Abstract

A well is classified as a HPHT (High Pressure High Temperature) well if the static bottomhole temperatures are greater than 350 °C and when the formation pressures exceed 1800 kg/m^3 ECD. Mud weights as high as 2400 kg/m^3 may be required to maintain a proper well control. The temperature of the drilling fluid when circulating in the well may range from 0 °C to 150 °C and it is important that the drilling fluid maintain acceptable rheological properties within the whole range. The rheological properties of the mud will strongly depend on the temperature and the pressure variations. The problems regarding HPHT wells are mostly due to ECD and cuttings transport.

In order to control and measure the viscosity for deep HPHT wells we have conducted laboratory experiments that deal with aging at different temperatures on a polymer mud, as well as pressure and temperature effects on a field mud. We have also calculated the annular pressure using Landmark Wellplan software. To calibrate the instruments, i.e. the Physica HPHT viscometer and a Fann viscometer, we used ubelohde, known to give an exact value of the viscosity of a fluid. The calibration liquid was a 2-stroke motor oil with different amounts of Exxsol-D60 added.

The aging experiments were conducted in a mixture of water and HEC that were put in three different incubators at 20 °C, 60 °C and 90 °C for 1, 3, 8, 11, 15 and 20 days. The results showed that the viscosity decreased rapidly in the solutions that were aged at the highest temperatures and that most of the decrease took place during the first day of aging.

In the experiments on real (field) mud exposed to high pressures and temperatures the Physica viscometer was used. The results showed that the pressure effects were negligible compared to the temperature effects. During the measurements we experienced that the viscosity decreased as the temperature increased and that the decrease in the viscosity was more significant from 20 to 60 °C than from 60 to 90 °C.

Based on the results obtained in the laboratory and an evaluation of fluid implication on well pressure, we were able to draw the following main conclusions:

- Laboratory experiments are very educational. To learn that reality is not straight forward to measure was enlightening.
- The viscosity is very dependant on the temperature.
- The combined effect of pressure on the viscosity of a field mud is negligible.
- The annular pressure differences calculated in Landmark Wellplan did not show any significant differences for the different well temperatures.

Acknowledgment

This diploma thesis has been carried out on the Norwegian University of Science and Technology at Department of Petroleum Engineering and Applied Geophysics.

I would like to thank my supervisors Pål Skalle and Knut Backe who has been an accommodating support during the whole project as well as Roger Overå for being helpful to show where to find the equipment and to demonstrate how the apparatus work in the laboratory.

Håvard Larsen

Trondheim, June 2007

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1 Introduction

The development of deep offshore operations gives new and more technical challenges due to the harsh conditions encountered at these water depths. The extreme conditions that exist require an adaption and a particular design of the drilling and cementing fluids. One of the most challenging problems of deep offshore drilling is the range of temperatures and pressures. The temperature of the drilling fluid when circulating in the well may range from 0 °C to 150 °C and it is important that the drilling fluid maintain acceptable rheological properties within the whole range. The rheological properties of the mud will strongly depend on the temperature and the pressure variations.

To solve the problems with the mud properties it is often necessary to use several additives either separately or concurrently. The major drawback of the conventional additives is that they are generally unstable at high temperatures normally encountered in deep wells. The rheological properties of traditional water- and oil-based muds may change, often dramatically, when regions of high temperature and/or pressure are encountered in a deep well. Alternatively, there are several natural and synthetic polymers available which exhibit better resistance to thermal, bacterial and even mechanical degradiation. For these reasons are the new polymers increasingly replacing conventional additives as rheology modifiers in the drilling industry.

In this diploma thesis we will take a closer look and find out more about rheological properties of drilling fluids in HPHT conditions as well as to find out what effect these conditions have on polymers (HEC). In addition to a literature survey the goal of the work is to evaluate the problem through laboratory measurements in a HPHT viscometer and thereby find which implications it can have on annular pressure with different values for temperature and pressure. The program we are using in the pressure measurements is Landmark Wellplan, which is a commercial tool. The viscosity measurements will be conducted using Physica Rheolab MC 1 HPHT viscometer which is a rotational, shear stress and creep rheometer and the results will be compared by measuring the viscosity using a Fann viscometer. A capillary viscometer (ubehlode) will be used to calibrate the other two instruments.

2 HPHT Drilling Fluid Challenges

A well is known as a HPHT (High Pressure High Temperature) well if the formation pressures exceed 1800 kg/m^3 ECD and when the static bottomhole temperatures are greater than 350 °C. Mud weights as high as 2400 kg/m^3 may be required to maintain a proper well control[1].

To be able to know the behaviour of drilling fluids under actual HPHT conditions is it required to minimize the costs and risks related to the drilling fluids as well as to maximize the operational efficiency[2].

Due to the increased demands for energy in the world is the oil industry forced to explore areas previously unexplored or minimally explored. A subset of this activity is HPHT drilling. HPHT drilling is not a profitable option during times with high price uncertainty or low commodity pricing due to the relatively high lifting costs. The resurgence of HPHT drilling stretches globally and includes areas such as the Deep Gulf of Mexico Continental Shelf, northern India, Saudi Arabia and Brunei. Historical HPHT basins such as Indonesia, Thailand and northern Malaysia have also seen an increase in the HPHT activity[2].

The development of HPHT prospects can require overcoming very large drilling challenges. The rigs required for HPHT drilling are larger due to the requirements such as hook load, mud pumps, drill pipe and surface mud capacity. Due to the requirements mentioned, are these rigs more expensive than conventional rigs. HPHT wells require a higher density fluid which usually demands high solids loading. High solids loading and the resulting higher pressures combined with the competency of rock at depth, lead to low penetration rates, extending time on location and added drilling costs[2].

The drilling of deep, hot wells depends very much on the rheological properties of the drilling fluids for specific downhole conditions. The rheological properties of water-based drilling fluids under downhole conditions may be very different from the properties measured at surface conditions. This is observed because the temperature and shearing affect the drilling fluid properties. An increase in the temperature will reduce the effectiveness of the most drilling fluid additives that would maintain the rheological, fluid loss and electrochemical properties. Problems according to increased temperatures are accelerated when high chemical contaminants, such as salt of calcium, magnesium and sodium are encountered. The problem of elevated temperatures itself is considered as one of the drilling fluid contaminants that can not be treated with any additives[3].

In the lower parts of the hole might the drilling fluids become too thick when there is no circulation in the borehole. Excessive heating may cause solidification of drilling fluids. If a case of stuck pipe is encountered, circulation may continue for a long time and aging of the drilling fluid comes under consideration. Aging affects the rheology of drilling fluids along with temperature, and investigation shows that the effect of dynamic aging is greater than static aging[3].

When drilling a well it is very important to know the exact pressure drop for many reasons. Some of the reasons might be[4]:

- To optimize the pressure drop on the drilling bit in order to get a maximum impact on the formation, and thereby increase the rate of penetration.
- For optimizing the flow rate in the annulus, the area between the borehole wall and the drillpipe, to get a better transport of drilled cuttings to the surface as well as to maintain a proper hole cleaning.
- To avoid fracture of the formation crossed due to the underestimation of the annular pressure drop.
- To detect any unexpected changes of the standpipe pressure, due to changes in the hydraulic drilling circuit (i.e., washout, plugged nozzles and fluid kick) and make opportune decisions to restore the original conditions.
- To better design the mud pumps available on the drilling rig.

In addition to the reasons mentioned above might the drilling of ultradeep wells with high temperatures and pressures influence the rheological properties of the drilling fluids in several ways[4].

Physically, decreases in temperature and increases in pressure both affect the mobility of the system and lead to an increase of apparent viscosities and viscoelastic relaxation times[5]. The effect of pressures is expected to be greater with oil-based systems due to the oil phase compressibility[6].

Electrochemically, an increase in temperature will increase the ionic activity of electrolytes and the solubility of any partially soluble salt that may be present in the mud. This could change the balance between the interparticle attractive and repulsive forces and also the degree of dispersion and flocculation in the mud systems. In some occasions this can also affect the emulsion stability of oil-based muds[7]. All these phenomena have a big impact on rheological properties, especially as far as viscoelasticity and thixotropy are concerned.

Chemically, all hydroxides react with clay minerals at temperatures above 90 °C and for many kinds of muds this can result in a change in the structure and also a change in the rheological properties[4].

Due to the large number of variables involved, the behaviour of the drilling mud at high pressures and temperatures may be very difficult to explain because of the complexity. It can be very difficult to set general guidelines for each group of muds (oil-based muds, water-based muds, etc.) or even for the same kind of mud as small differences in composition may result in large differences in the rheological behaviour[4].

2.1 Rheology in general

Rheology is described as the science of deformation and flow of materials in response to stress, while viscosity is defined as the internal resistance of fluid to flow. The equation used for describing deformation is given by[8]:

$$\tau = \mu\gamma , \qquad (2.1)$$

where T is the shear stress, γ is the shear rate defined as $\delta v_x/\delta y$, and μ is the viscosity[8]. The term T can be defined as F/A where F is the force required to keep the upper plate moving at constant velocity v in the x-direction and A is the area of the plate in contact with the fluid, as seen in Figure 2. 1. A shear force has to be applied to the upper plate in order to keep it in motion relative to the lower plate with velocity v in the x-direction. By fluid viscosity, the force is transmitted through the fluid to the lower plate in such a way that the x-component of the fluid velocity linearly depends on the distance from the lower plate[9]. It is implicit assumed as well as verified experimentally that the fluid does not slip at the plate surface[8].

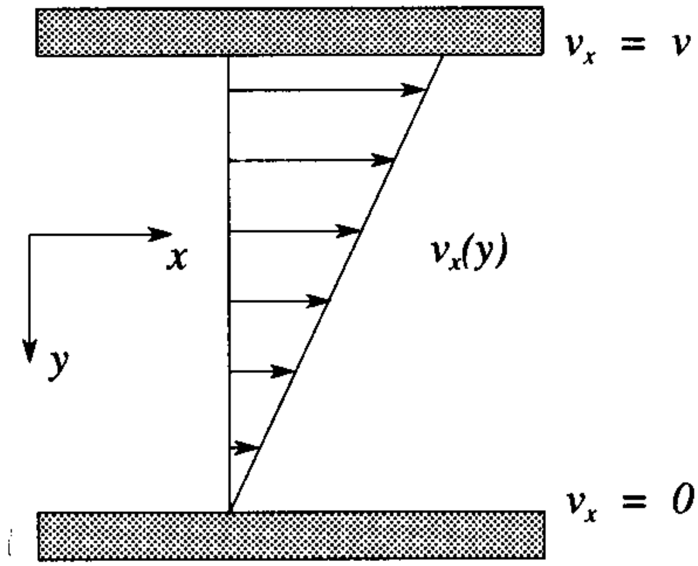

Figure 2. 1: Velocity profile of a fluid between two flat surfaces where one is moving.

Rheology makes a big importance in deep HTHP wells where the hole diameter is normally smaller than in conventional wells resulting in an increase in the ECD pressures. Correspondingly, the abnormal pressures experienced in HPHT wells require higher mud densities. The increasing solids concentration of even the non-reactive weight material will also reduce the thermal stability of the fluid amount of available base liquid and reduce the surface area of the solids. Excessive viscosity and gelation increase the possibility of lost circulation[1].

2.1.1 Newtonian and non-Newtonian fluids

Fluids may generally be divided into two main groups depending on their rheological properties, known as Newtonian fluids and non-Newtonian fluids. Newtonian fluids, such as water, have shear-independent viscosity and the shear stress is proportional to the shear rate[8]. Newtonian fluids exhibit a linear relationship between shear stress (green graphs) and shear strain, while non-Newtonian fluids exhibit a non-linear relationship between shear stress and shear strain (red graphs), as seen from Figure 2. 2[1].

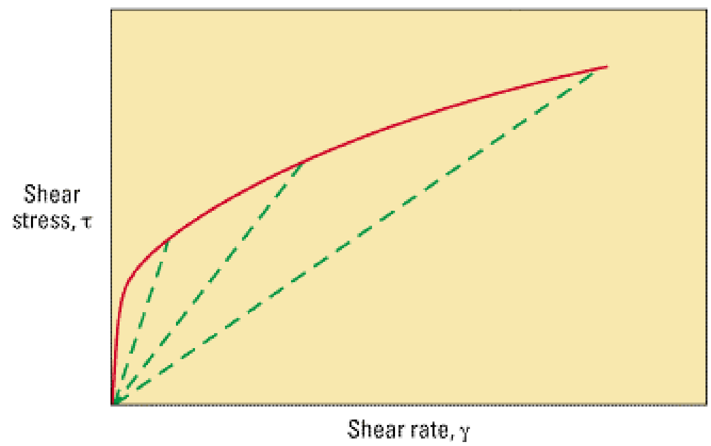

Figure 2. 2: Rheogram, non-Newtonian and Newtonian fluid.

Newtonian behaviour in experiments conducted at constant pressure and temperature has the following characteristics[10]:

- The only stress generated in simple shear flow is the shear stress σ, the two normal stress differences is equal to zero.
- The shear viscosity does not vary with shear rate.
- The viscosity is constant with respect to the time of shearing, and the stress in the liquid falls to zero immediately when shearing is stopped. The viscosity is constant even if there is a long time between the different measurements, i.e. the viscosity is as previously measured.
- The viscosities measured in different types of deformation are always in simple proportion to one another.

2.1.2 Rheological models

In addititon to the Newtonian model described above are there other rheological models that are used in the drilling industry.

The viscosity of non-Newtonian fluids varies with shear rate, as shown by the red curve in Figure 2. 3: Newtonian vs. non-Newtonian effective viscosity comparison.[1]

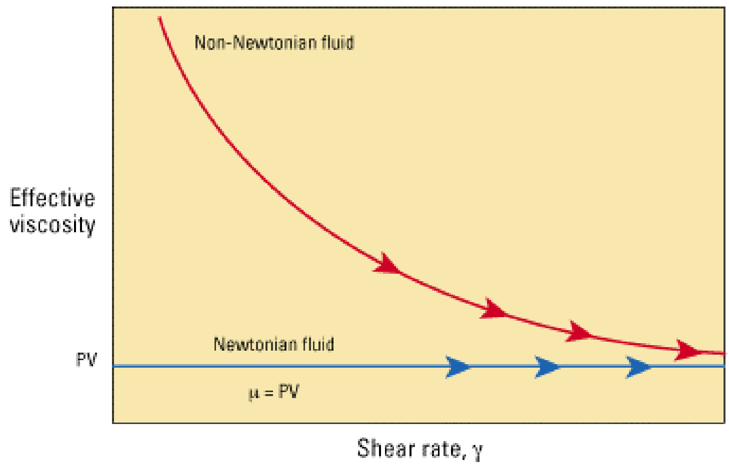

Figure 2. 3: Newtonian vs. non-Newtonian effective viscosity comparison.

Most drilling fluids are non-Newtonian fluids, with viscosity decreasing as shear rate is increasing. Other examples of non-Newtonian fluids might be gels and polymer melts. Non-Newtonian fluids are characterized as pseudoplastic, Bingham plastic, thixotropic etc. EOR (enhanced oil recovery) polymers are pseudoplastic, meaning that the viscosity is decreasing with increasing shear rate. Fluids that have an increase in viscosity with an increase in shear rate are called dilatants. The behaviour of different kinds of fluids is shown in Figure 2. 4[8]. The four main rheological models are shown in Figure 2. 5[1].

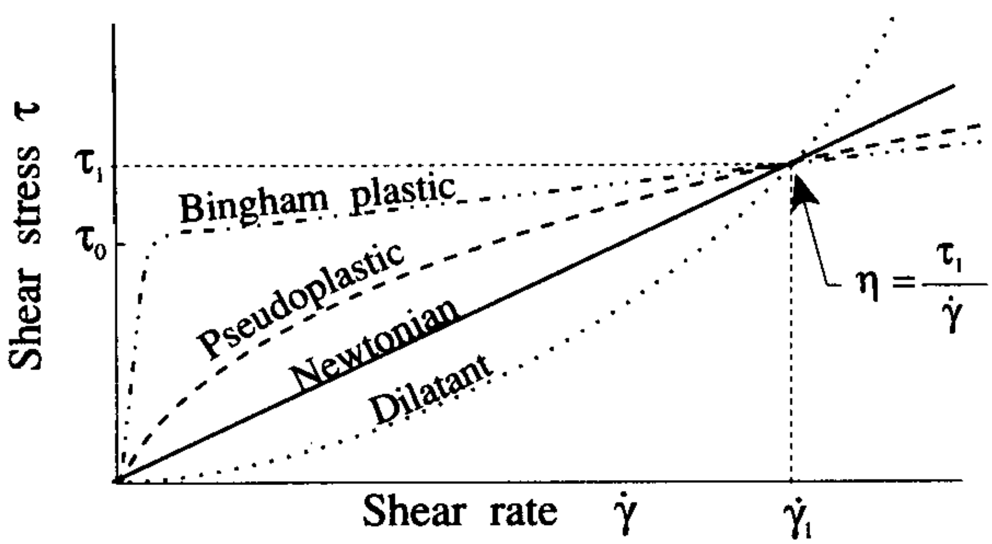

Figure 2. 4: Relationship between shear stress and shear rate, different rheological models.

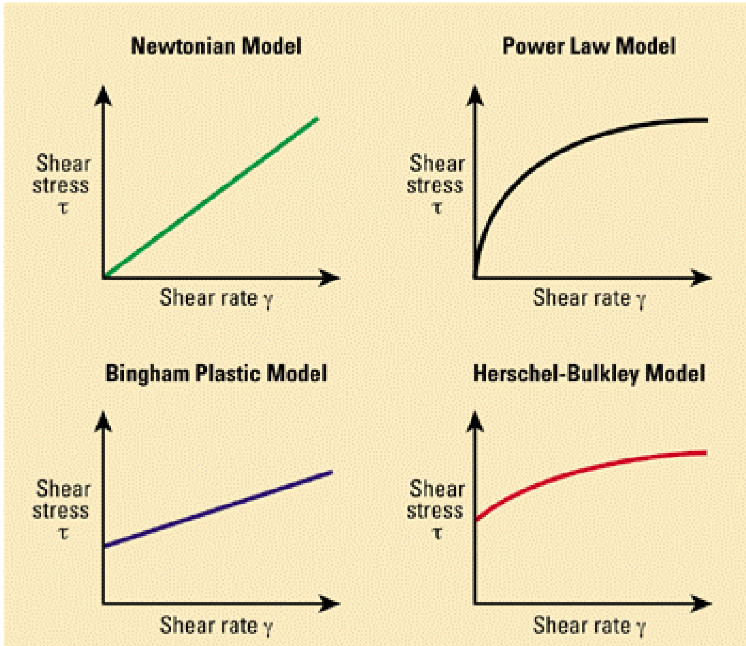

Figure 2. 5: The four major rheological models.

Some fluids have a time-dependant viscosity; they are known as thixotropic if the viscosity is decreasing with increasing time at a constant shear rate; and rheopetric if the viscosity is increasing with increasing time, see Figure 2. 6[4].

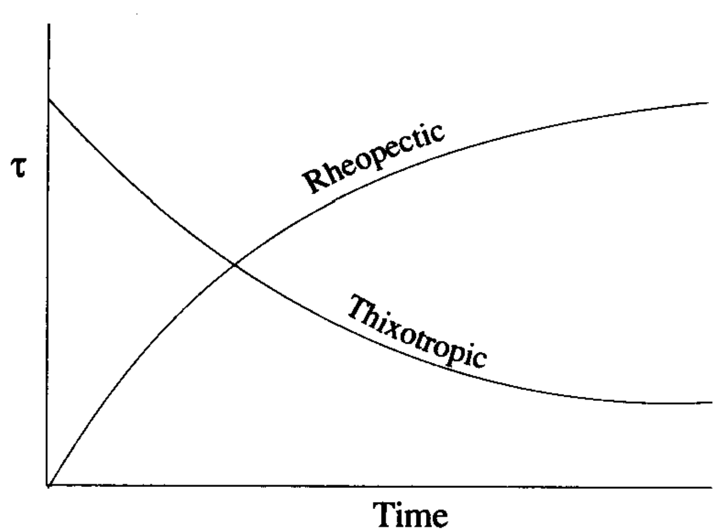

Figure 2. 6: Relationship between shear stress and time.

2.1.2.1 The Bingham plastic fluid model

The Bingham plastic model is a two-parameter rheological model that is widely used in industry to describe flow characteristics of many types of muds. The model is described mathematically as follows:

$$T = T_0 + \mu_{pl} * \gamma \qquad (2.2)$$

where T_0 is the yield point and μ_{pl} is the plastic viscosity. Fluids that behave according to this model are called Bingham plastic fluids and exhibit a linear shear-stress, shear-rate behaviour after an initial shear-stress threshold has been reached. μ_{pl} is the slope of the line and T_0 is the threshold stress. μ_{pl} should be as low as possible for fast drilling and is best achieved by minimizing colloidal solids. The value for T_0 must be high enough to be able to transport cuttings out of the hole, but not too large as a high yield point results in excessive pump pressure when starting mud flow[1].

2.1.2.2 The Power Law model

A Power-Law fluid is described by the two-parameter rheological model of a pseudoplastic fluid or as a fluid whose viscosity decreases as shear rate increases. Water-base polymer muds, especially those made with XC polymer, fit the Power Law, mathematical equation better than the Bingham plastic or any other two-parameter model[11]. Power Law fluids may be described mathematically as follows:

$$T = K * \gamma^n \qquad (2.3)$$

where K is the fluid consistency index and n is the flow behaviour index[1].

2.1.2.3 The Herschel-Bulkley model

The Herschel-Bulkley equation is preferred to Power Law or Bingham plastic relationships because it results in more accurate models of rheological behaviour when adequate experimental data are available[12]:

$$T = T_0 + K * \gamma^n \qquad (2.4)$$

where K is the fluid consistency index and n is the flow behaviour index.

The yield stress used is normally the 3 RPM reading in the Fann viscometer, with the n and K values then calculated from the 600 or 300 RPM values or graphically. The Herschel-Bulkley fluid model requires a certain stress to initiate flow, but less stress with increasing shear[1].

2.2 Viscosity

Viscosity is a property of fluids and slurries that indicates their resistance to flow, defined as the ratio of shear stress to shear rate. Viscosity, μ, might be expressed mathematically as follows:

$$\mu = T/\gamma \qquad (2.5)$$

The unit for viscosity is Poise, equivalent to dyne-sec/cm^2. As one Poise represents a high viscosity, 1/100 poise, or one centipoise (cP), is used for measuring the viscosity of drilling fluids. One centipoise equals one millipascal-second. Viscosity must have a stated or an understood shear rate in order to give a meaningful value. Measurement temperature and pressure must also be stated or understood[1].

The viscosity of fluids varies with pressure and temperature. The viscosity of most fluids is rather sensitive to changes in temperature, but relatively insensitive to pressure variations until they are exposed to high pressures. The viscosity of liquids usually rises with pressure at a constant temperature. An exception to this rule is water; the viscosity of water decreases with increasing pressure at constant temperature. In practical experiments is the effect of pressure, on the viscosity of liquids, usually ignored[9].

The effect of molecular weight on the viscosity of liquids is; the liquid viscosity increases with increasing molecular weight[9].

2.2.1 Effects of temperature

The effect of temperature has different impact on viscosity of liquids and gases. A decrease in temperature causes the viscosity of a liquid to rise[9]. For most industrial applications involving aqueous systems, is the most interesting temperature range from 0 to 100 °C. Lubricating oils are used from about -50 °C to 300 °C. Polymer melts are usually in the range from 150-300 °C, whilst molten glass is processed around 500 °C[10].

Most of the available laboratory viscometers can handle temperatures in the range from -50 to 150 °C by using an external temperature controller or an immersion bath. If higher temperatures are required, air baths are used[10].

The viscosity of Newtonian liquids decreases with increase in temperature, approximately by the Arrhenius relationship[10],

$$\eta = Ae^{-B/T}, \tag{2.6}$$

where T is the absolute temperature and A and B are constants of the liquid. In general, for Newtonian liquids, the greater the viscosity, the stronger is the dependence of the temperature. The strong dependence of the temperature variations means that great care has to be taken with temperature control in viscometry in order to get accurate results in the laboratory. For instance, the temperature sensitivity for water is 3 % for each °C at room temperature, so that ± 1 % accuracy requires the sample temperature to be maintained within ± 0,3 °C. For liquids of higher viscosity, given their stronger viscosity dependence on temperature, even greater care has to be taken[10].

In viscometry it is important to note that it is not sufficient to simply maintain control of the thermostat temperature; the act of shearing itself generates heat within the liquid and may change the temperature enough to decrease the viscosity unless there are practises involved that remove the generated heat[10].

Another important factor is the rate of heat extraction, which depends on two things in viscometry; 1) the kind of apparatus: in one class the test liquid flows through and out of the apparatus whilst, in the other, test liquid is permanently contained within the apparatus. In the first case, for instance in slits and capillaries, the liquid flow itself convects some of the heat away. On the other hand, in instruments like the concentric cylinder and cone-and-plate viscometers, the conduction of heat to the surfaces is the only significant heat-transfer process. 2) The heat extraction depends on the dimensions of the viscometers: For slits and capillaries is the channel width the controlling parameter, whilst the gap width is important for concentric cylinders and cone-and-plate devices. In general, one wants these slips to be as small as possible[10].

2.2.2 Effects of pressure

The viscosity of liquids increases exponentially with isotropic pressure. Water below 30 °C is the only exception, in which case it is found that the viscosity first decreases before eventually increasing exponentially. For pressures that differ from atmospheric pressures with about one bar are the changes quite small. Therefore, in most practical experiments, is the pressure effect ignored in viscometry measurements. There are, however, situations where this would not be justified. In the oil industry, for example, one requires measurements of the viscosity of lubricants and drilling fluids at elevated pressures. Lubricants in gears can often experience pressures that exceed 1 GPa while oil-well drilling fluids have to operate at depths with pressures up to 20 MPa[10].

2.2.3 Effects of the shear- thinning on non-Newtonian liquid

The general shape of the curve representing the variations of viscosity with shear stress for shear-thinning materials is shown in Figure 2. 7. The corresponding graphs of shear stress vs. shear rate and viscosity vs. shear rate are plotted as well. The curves indicate that in the limit of very low shear rates or shear stresses is the viscosity constant, whilst in the limit of high shear rates or shear stresses is the viscosity again constant but at a lower level. These two areas are known as the lower and upper Newtonian regions where lower and upper refers to shear rate and not viscosity. The lower and upper areas where the viscosity is constant are also called “first Newtonian region” and “second Newtonian region” respectively[10].

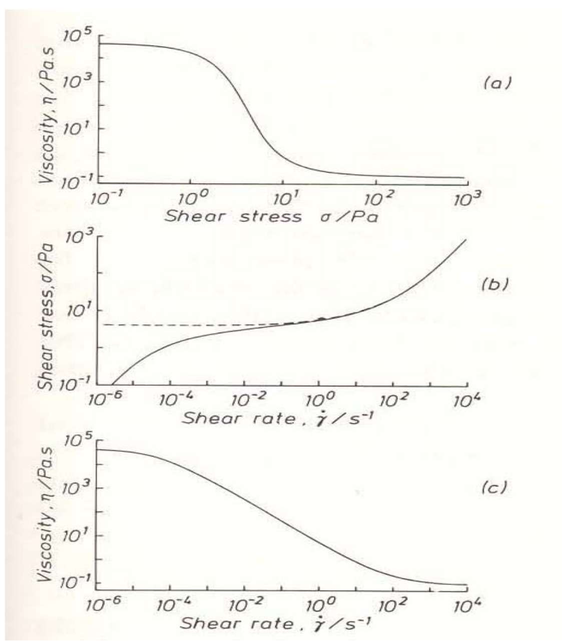

Figure 2. 7: Behaviour of a non-Newtonian liquid and the interrelation between parameters.

3 Prior laboratory studies

As we will take a closer look on the viscosity variations in liquids at different pressures and temperatures as well as for different liquid aging times in the laboratory, some of the experiments that have been conducted by others in the past will be discussed. In our experiments we will only look at water-based muds, but in the prior laboratory studies will also the use of oil-based drilling fluids be discussed.

The subject of this study is the viscosity dependence of different factors including;

- Temperature effects
- Pressure effects
- Effect of time

The effects of these different variables on the viscosity will be tested in the laboratory and presented later in the thesis.

To study the mud rheology at high pressure and high temperature conditions (HPHT) one might use several different types of rheometers. Annis[14] and Hiller[15] studied the effects of high temperatures (up to 150 °C) and high pressures (up to 500 bar) on the rheology of water-based muds, considering them to have plastic behaviour.

At the same period, 1960's, Combs and Whitmore[16] performed experiments with high pressures and temperatures on all invert emulsion muds, and measured variations in the effective viscosity using a capillary viscometer. Sinha[17] studied oil-based muds and water-based clay suspensions using a falling bob consistometer. He concluded that the equivalent viscosity of water-based muds, compared to inverted emulsion muds and oil-based muds, is not affected to the same extent by the variations of temperature and pressure. Another conclusion he found was that the temperature is the dominant variable in the case of water-based muds. McMordie[18] performed experiments with temperatures up to 180 °C and pressures up to 965 bar on colloidal suspensions of asphalt in oil-based muds. He proved[19] that at constant pressure and temperature might the viscosity of water-based muds be described well by modification of the power law expression.

Bailey et al.[20] studied, by the use of the Huxley and Bertram HPHT rheometer, the behaviour of viscosity of low toxicity inverted oil emulsions at high temperature (up to 200 °C) and high pressure (up to 1000 bar). The conclusion they drew was that the Bingham model is not accurate for predicting the rheological behaviour of low toxicity oil muds at high temperatures.

At the same time, other experiments on the same kind of muds were performed at high temperatures (from 32 °C to 150 °C) and pressures (from 69 to 1034 bar) in a coaxial viscometer, by Politte[21]. He found that oil-based muds behave as plastic fluids, and concluded that the plastic viscosity is much related to the viscosity of the oil at high pressures and temperatures. The yield point is on the other hand weakly affected by pressure and mostly dependant on temperature in a complex way.

Other authors, i.e. Briscoe et al.[22], see chapter 3.3, did also select a Bingham model. They studied aqueous bentonite suspensions and muds using rolling ball rheometers for pressures up to 1400 bar and temperatures up to 140 °C. The observations they made were that high pressures modify the Bingham rheological parameters in a way which is strongly temperature and mud formulation dependant.

However, the Herschel and Bulkley rheological model was chosen by Alderman et al.[23] and by Kenny et al.[24] respectively, to describe the performance of water-based mud and oil-based mud under HPHT conditions. Alderman et al.[23] observed that high shear viscosity decrease with increasing temperature in a similar way for all the examined water-based muds, increasing with pressure to an extent which depends on the mud density. Kenny et al. studied the yield stress changes of emulsion-based muds pointing out different trends depending on the temperature and pressure ranges.

Ali and Al-Marhoun[3], see chapter 3.1, investigated the effect of high pressure, high temperature and long aging on the rheological properties of water-based drilling fluids. The experimental method included two different equipments, a Baroid roller oven and a Fann 70 HTHP Viscometer. The aging of the drilling fluids was up to 30 days at a temperature of 254,4 °C.

Later Kennedy[25] studied the behaviour of pseudoplastic and yield pseudoplastic fluids. He experimented with two rheological models for predicting the effective viscosity of the drilling fluids. One of the models, named the first order model, was developed for power-law fluids, and the other model, named the second order model, was studied for polymer melts. These models do only take into account the temperature effect on the effective viscosity.

Maglione et al.[4] performed laboratory measurements at high pressures and temperatures using Huxley and Bertram HPHT rheometers, assuming the Herschel and Bulkley rheological model. The model they made was applied to monitor stand pipe pressure, and very low errors were found with respect to rheological models used in practice today (Bingham, Ostwald and de Waele and Herschel and Bulkley models using Fann viscometer readings). It can be used to study variations of the circulating drilling fluid rheology vs. pressure and temperature in the well by applying it to field data sets of circulation tests carried out at different depths.

3.1 Ali and Al-Marhoun: Effect of HPHT and aging on water-based muds

Below are a description and the results of the experiment carried out by Ali and Al-Marhoun[25]. The results from the study are evaluated taking into consideration effective viscosity, plastic viscosity, yield point, gel strength and shear stress vs. shear rate relationships.

3.1.1 Procedure

The procedures of the experiment of the drilling fluid properties followed the API recommendations as best as possible, as some of the recommendations were not representative for the actual bottom hole conditions in this experiment. The test procedures used to simulate bottom-hole conditions included equipment such as a) Baroid Roller Oven and b) Fann Model 70 HTHP Viscometer[25].

The optimum drilling fluid samples for this water-based drilling system under the conditions of elevated bottom-hole temperatures and pressures were made with the use of a mixture of bentonite (2 g), attapulgite (3 g), vinylsulfonate/vinylamide (VSVA) (1,5 g), NaCl (3 g), Lime (0,28 g) and gypsum in 100 g of distilled fresh water[17]. The samples were aged in the roller oven for 0, 1, 3, 7, 10, 15, 20 and 30 days in room temperature (25 °C), and then tested in Fann 70 HTHP Viscometer after a specific aging time. All data were collected at temperatures of 25, 50, 100, 150, 200 and 254 °C and at pressures of 207 and 690 bar[25].

3.1.2 Results and discussion

1) Effects of temperature

In the experiments they saw that the effective viscosity, plastic viscosity, yield point and gel strengths decreased gradually with the increase in temperature for all values of aging time. The changes in the rheological properties are explained according to the investigation done by Al-Marhoun and Rahman[26]. According to them are the differences in the rheological properties due to the effect of lime and gypsum added to the mud system. When exposed to heat will lime and gypsum release a large amount of calcium ions in aqueous solutions. Ali and Al-Marhoun experienced that a) for a particular temperature, shear stress increased with shear rate, b) for the same shear rate, shear stress decreased with increasing temperature, and temperature effects were diminishing as the temperature increased.

The results from the data at different temperatures; 25, 50, 100, 150, 200 and 254 °C, showed that the temperature effect is decreasing as the temperature is increasing and that the effect on shear rate vs. shear stress was very small for temperatures over 200 °C.

2) Effects of aging

In addition to temperature effects did Ali and Al-Marhoun[25] study the effect of aging on the properties of the drilling fluids. The experiment showed that the viscosity at a particular temperature increased with the increase in aging time and that the aging effects were diminishing with the increase in time, see Figure 3. 1. This might be explained from the fact that the degree of dispersion and flocculation increase when muds are aged dynamically. Rheological properties of mud seemed to increase at both high and low shear rates after the muds were rolled dynamically in the oven[25].

Another result was that the yield point and gel strength increased with aging time and the aging effects were, as mentioned above, diminishing with the increase in aging time[25]. This might be explained by the fact that as the particle numbers are increasing there will be greater attractive and larger interparticle forces which will lead to an increase in the yield point and gel strengths[25].

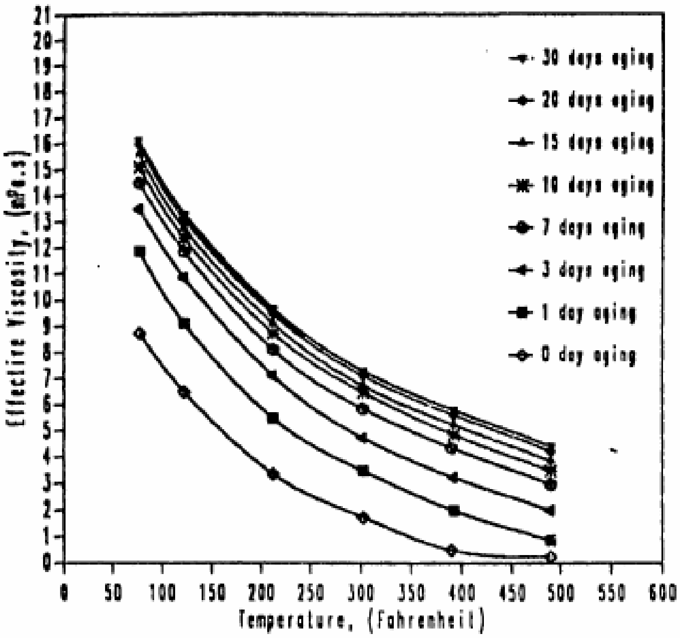

Figure 3. 1: Eff. viscosity as a function of temperature for different aging time at 3000 psig.

In Figure 3. 2 is the shear stress as a function of shear rate plotted for different aging times. One can see that the shear stress at a given shear rate is increasing with aging time. This might be explained by the dispersion and flocculation effects of the drilling fluid. Viscosity is directly proportional to shear stress. As viscosity increases with aging time, so is the shear stress increasing with aging time[25]. The effect of aging on shear stress- shear rate relationships has good agreement with the result obtained by Annis[14] where he dynamically aged the mud for 24 and 48 hours at 148,9 °C and observed that shear stress at a given shear rate increased with aging time.

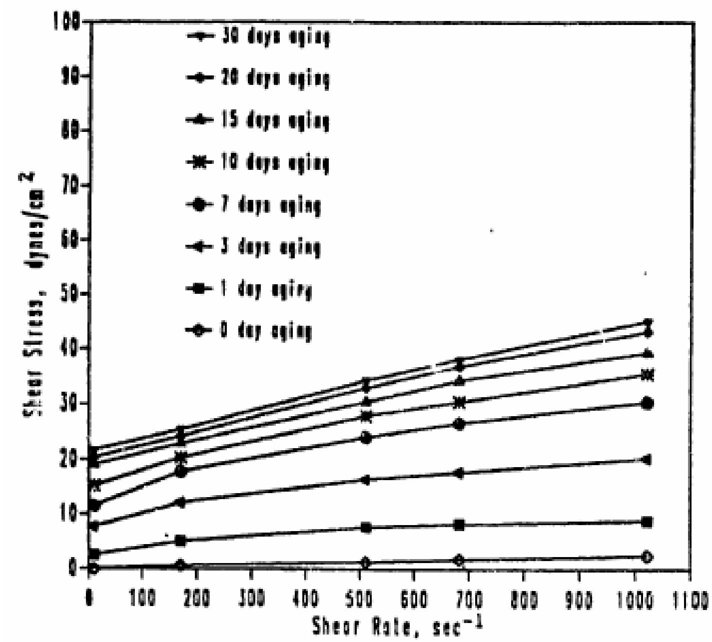

Figure 3. 2: Shear stress vs shear rate for different aging time at 490°F and 3000 psig.

3) Effects of pressure

The results showed that viscosity and shear stress at a given shear rate increased with increase in pressure. This was due to the fact that as pressure increases, the density of the liquid phase increases which leads to that the rheological properties of the fluid increases.

3.2 Salimi et al: Rheological behaviour of polymer-extended water-based drilling muds at high pressures and temperatures

3.2.1 Procedure

Salimi at al.[27] investigated the rheological behaviour of several polymer-extended water-based drilling muds at different temperatures and pressures simulating their true working conditions in a deep oil well. The base mud used was 21 grams of bentonite in 350 cm^3 distilled water, mixed 20 minutes at 12000 rpm. The different polymers used were PHPA (Partially-Hydrolysed Poly-Acrylamide), XC (Xhantan Gum), and CMC (Carboxy Methyl Cellulose). The test fluids were obtained by dissolving 1, 2 and 3 grams of each of the polymers in the base mud, giving 10 different test-muds. The mixing of the polymer muds were conducted in 15 minutes at low rpm to avoid mechanical degradiation of the polymer chains[27].

A Fann 50C commercial viscometer was used to obtain the flow curve of all test fluids. This instrument allows temperatures up to 273,9 °C and pressures up to 72,4 bar, at shear rates up to 1000 s^{-1}. In practice, all experiments were done at five distinctive pressures of 6.9, 13.8, 20.7, 27.6 and 34.5 bar, and at four temperatures of 43.4, 68.3, 93.3, 123.9 and 148.9 °C respectively[27].

3.2.2 Results and discussion

The experiments showed that at any given pressure and temperature, did the shear stress increase nonlinearly with shear rate for all test fluids, see Figure 3. 3.

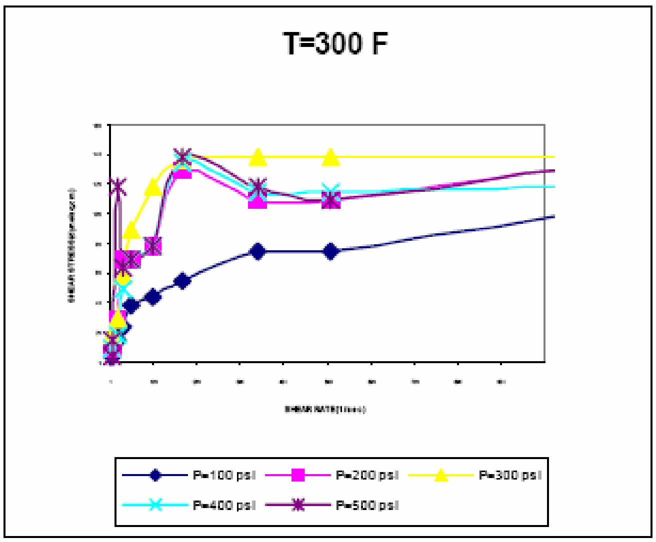

Figure 3. 3: Shear rate vs shear stress for the test fluids at different pressures at 300°F.

However, when the flow curves at different pressure and temperature were compared with each other it was realized that, at a given shear rate, only for the base mud an increase in pressure and temperature was accompanied with an increase in shear stress. The increase was also found to be more pronounced at higher shear rates. In contrast, for all nine polymer-extended muds, a decrease in shear stress was observed when either the temperature or the pressure was increased, see Figure 3. 4. It was found that the effect of temperature on flow curve was more severe than the effect of pressure[27].

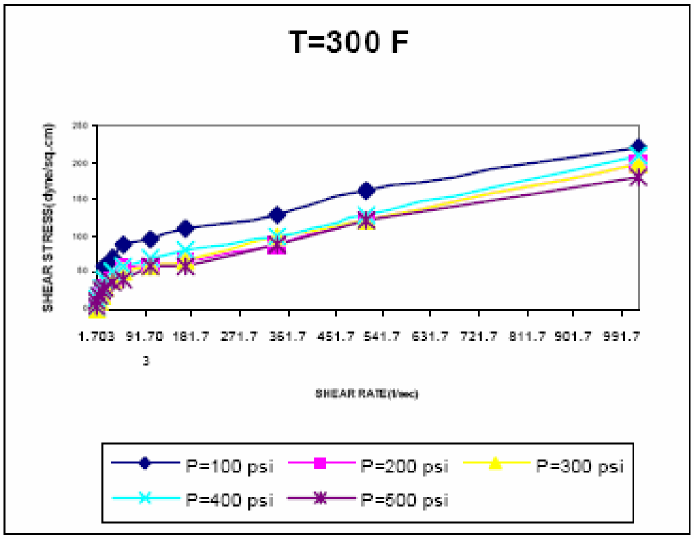

Figure 3. 4: Shear rate vs shear stress polymer-extended muds, at 300°F and different P.

The next sets of experiments were conducted to find the effects of pressure and temperature on the apparent viscosity. For the base mud, see Figure 3. 5, did the apparent viscosity increase with an increase in pressure and temperature.

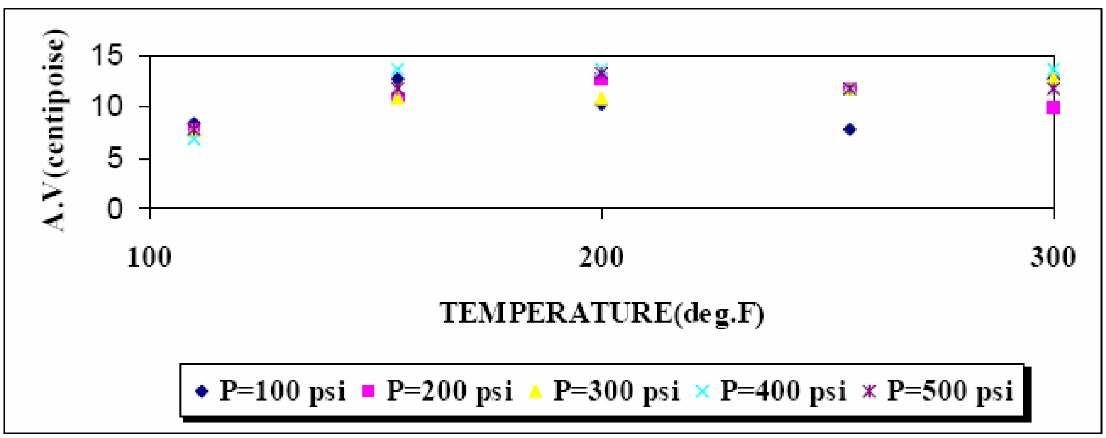

Figure 3. 5: Apparent viscosity base mud, different pressures and temperatures.

In contrast, for muds with polymer additives, see Figure 3. 6, a drop in apparent viscosity was observed at all three concentrations used.

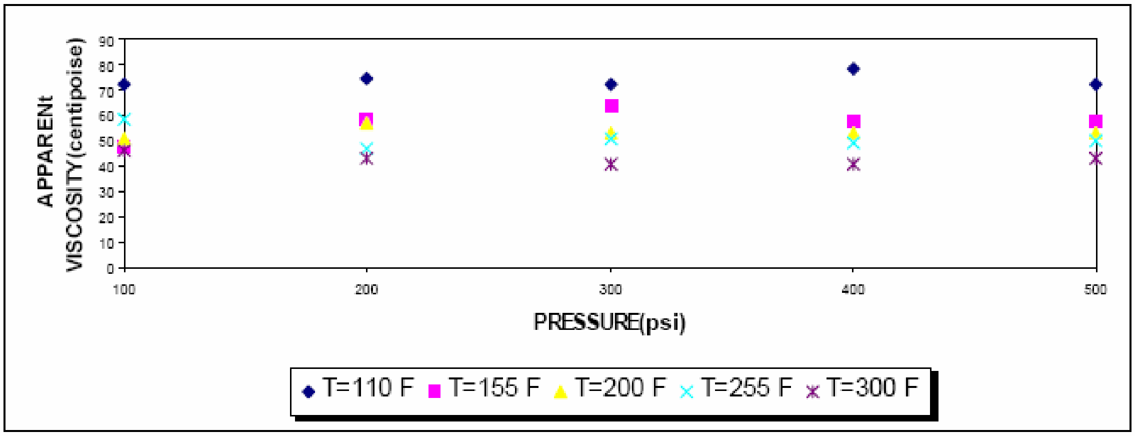

Figure 3. 6: Apparent viscosity mud with polymer additives, different P and T.

3.3 Briscoe, B.J. et al.: Experimental study of the rheological properties of various aqueous bentonite suspension

Briscoe B.J. et al.[28] studied the rheological properties of various aqueous bentonite suspensions which resemble those oil-well drilling fluids, or muds, which are encountered in practice.

3.3.1 Procedure

They used a rolling-ball type rheometer, for performing rheological measurements at pressures up to 1400 bar and at temperatures up to 140 °C. The HPHT rolling-ball rheometer consists mainly of three parts; the high pressure cell, the pressure and temperature control system and the rolling ball velocity measuring system.

The materials used were bentonite, a clay suspension (initial pH = 10 ± 0.5), barite powder and distilled water. The different muds were mixed in a high shear mixer for ten minutes[28].

3.3.2 Results

The types of bentonite mud studied involved pure bentonite – water suspensions, $CaCl_2$-treated muds and barite– loaded clay suspensions. The concentration of the bentonite clay ranged from 3 % to 12 % (mass). The rheological data are presented in two sections ((a) and b)) where the different sections deal with concentrated muds at ambient and elevated temperatures.

a. Concentrated muds at room temperature, about 20 °C

As they experienced minimum mud properties change in the range 10 to 30 °C they did not have to control the room temperature. The rolling ball measurements were conducted at each pressure level from 1 bar up to 1350 bar. The equivalent rheological properties were calculated based on equations for Bingham fluids (not mentioned here) for the rolling ball apparatus. The results are shown in Table 3. 1[28].

Table 3. 1: Pressures at room temperature a) Normalized yield stress, b) plastic viscosity

	mud (mass %)	T/°C	$P = 1$	$P = 700$	$P = 1000$	$P = 1350$
(a)	7	16	1.00	0.96	0.98	—
	8	26	1.00	1.03	0.95	1.00
	9	20	1.00	1.00	—	—
	10	20	1.00	1.03	1.05	1.08
	12 + 0.5 Ca^{2+}	21	1.00	0.95	0.95	1.00
(b)	7	16	1.00	1.05	1.12	—
	8	26	1.00	1.05	1.07	1.08
	9	20	1.00	1.04	—	—
	10	20	1.00	1.00	1.02	1.13
	12 + 0.5 Ca^{2+}	21	1.00	1.04	1.07	1.07

From the table it is clear that as the pressure increased from 1 bar to 1350 bar, the normalized yield stress fluctuated as much as ± 5 % except perhaps the 10 % mud where the yield stress increased gradually as the pressure increased. On the other hand, the plastic viscosity values tended to increase for all the muds studied as the pressure increased, although the magnitude of the changes were small.

b. Concentrated muds at higher temperatures, 50- 120 °C.

The effect of the applied pressure on the rheological properties of muds was found to be much larger at higher temperatures. Figure 3. 7 and Figure 3. 8 presents two typical experimental results plotted as the rheograms of the HPHT rolling-ball rheometer; the equivalent shear stress parameter, λ, against the equivalent shear rate, γ_e. Figure 3. 7 presents the data for an 8 % clay mud at various pressures and at a temperature of 65 °C compared with the results obtained at 22 °C. It is clear that, at higher temperatures, the mud is "thickened" and the apparent yield stress increases with the elevation of the pressure. This is in contrast to the response of the mud at room temperature where the pressure effect (from 1 bar to 1350 bar) is insignificant. The variation of the equivalent plastic viscosity, visually seen as the slope of the curves, as a function of pressure was insignificant in this case showing that it is not a sensitive parameter with respect to pressure[28].

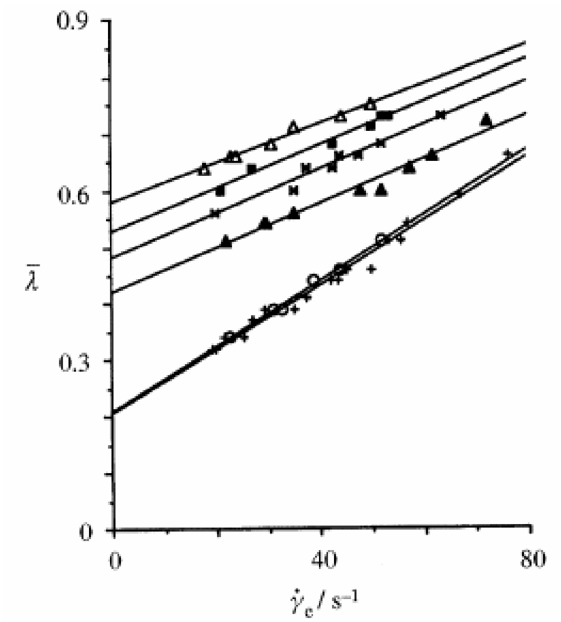

Figure 3. 7: Equivalent shear stress vs shear rate for 8% clay mud in HPHT rheometer.

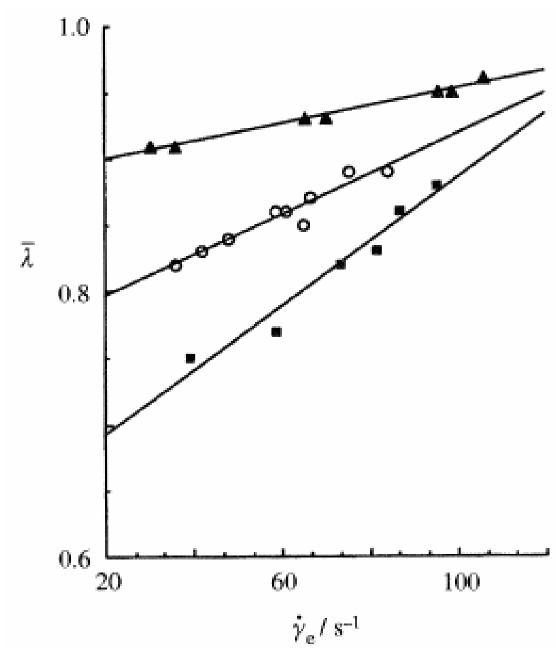

Figure 3. 8: Equivalent shear stress vs shear rate for 12 % clay mud in HPHT rheometer.

Similar results for the pressure effects on the same mud sample were also obtained at various temperatures, this is shown in Table 3. 2. They experienced that when the temperature was increased to 100 °C, the 8 % mud became too thick for the rheometer. In the case of the 12 %

clay mud containing 0.5 % calcium chloride, Figure 3. 8, the measurement was carried out up to 115 °C because calcium ions inhibited the temperature sensitivity of the suspension. Again one can see that the apparent yield stress is enhanced at high pressures and, in addition, the equivalent plastic viscosity now tends to decrease as the pressure increases. This suggests that the system becomes more "gelled" in character at high pressures and temperatures[28].

Table 3. 2: a) Normalized yield stress and b) plastic viscosity of muds at high P and T.

	muds (mass%)	T/°C	$P = 1$	$P = 700$	$P = 1000$	$P = 1350$
(a)	7	50	1.54	1.62	1.72	—
	7	70	1.79	1.95	2.04	—
	8	40	1.25	1.50	—	1.65
	8	65	2.1	2.35	2.65	2.90
	8	80	3.05	3.29	3.39	3.60
	10	40	1.38	—	1.62	1.84
	Ca^{+2} mud	70	1.15	1.47	—	1.89
	Ca^{+2} mud	115	1.64	1.97	—	2.28
(b)	7	50	0.57	0.67	0.67	—
	7	70	0.67	0.55	0.48	—
	8	40	0.86	0.79	—	0.70
	8	65	0.68	0.68	0.67	0.61
	8	80	0.54	0.54	0.63	0.61
	10	40	0.80	—	0.83	0.60
	Ca^{+2} mud	70	1.29	0.89	—	0.54
	Ca^{+2} mud	115	0.86	0.54	—	0.23

4 Background laboratory experiment

Chapter four take up preparatory issues of laboratory investigations. This includes what kind of apparatus used and recommended practices.

4.1 Methods for measuring viscosity

Principle of rotational viscometers

To measure the viscosity a rotational viscometer is used, such as a Fann viscometer, which uses the idea that the force required to turn an object in a fluid, can indicate the viscosity of that fluid. The fluid or mud is sheared at a constant rate between the inner bob and the outer rotating sleeve. As it is difficult to build a viscometer that is based on the relative movement of two parallel plates, one has found that the rotation of an outer sleeve about an inner cylinder is quite similar to the movement of two parallel plates. The principle is sketched in Figure 4. 1[29].

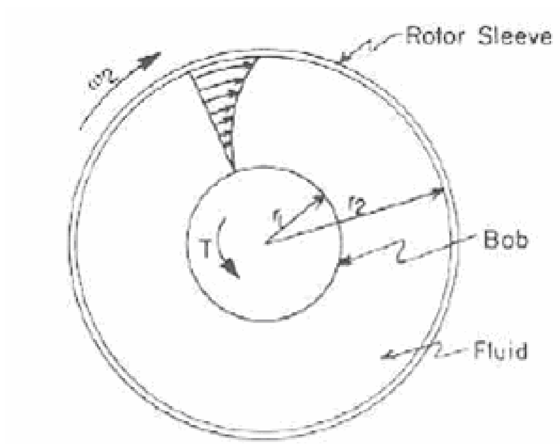

Figure 4. 1: **Cross sectional view of rotational viscometer[29].**

4.1.1 Rotational viscometer: *Physica viscometer, RHEOLAB MC1*

The Physica MC 1 is a rotational, shear stress and creep rheometer. The apparatus is shown in Figure 4. 2.

Measuring cones, concentric cylinders and parallel plates are used as measuring systems. The fluid sample is positioned in the measuring gap between the stationary measuring cup and the rotating measuring bob, respectively, the rotating cone or plate and the stationary lower plate.

The measuring drive developed for the Physica instrument series works with a dynamic system consisting of a measuring drive and an optical encoder without gearing and without mechanical force transducer where the torque is measured without deflection.

The Physica measuring drive is suited for carrying out rotational tests where the desired speed is pre-set and the torque acting on the measuring bob from the flow resistance of the sample is measured. In addition, in the creep or shear stress test it is possible to pre-set the desired shear stress and measure the shear deformation of the sample via the angle deflection. If one wants to determine the flow behaviour of plastic substances, shear stress tests can be carried out with the Physica which enables a precise measurement of the yield point without shearing the sample[30].

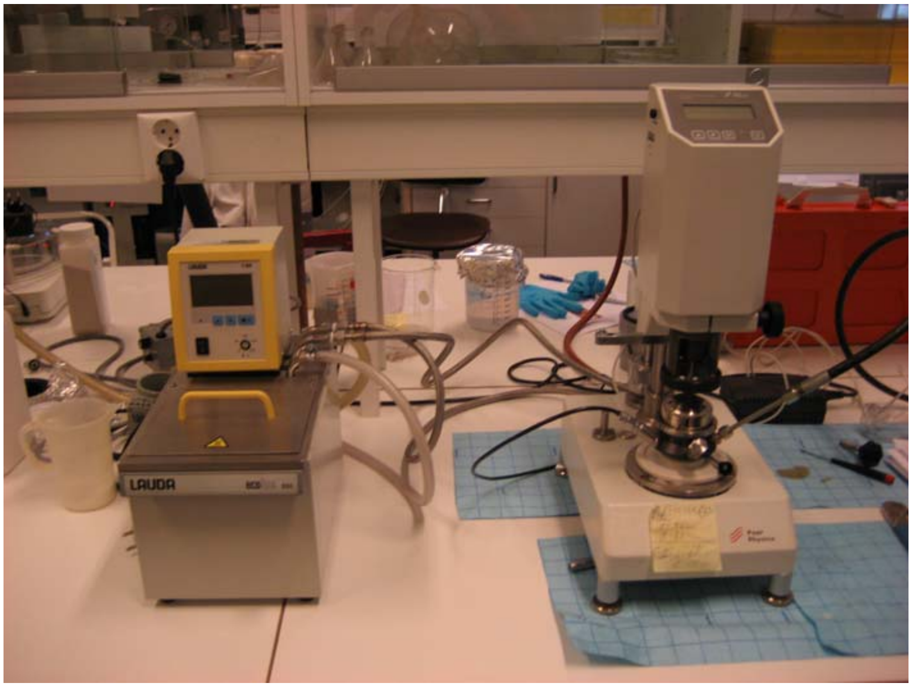

Figure 4. 2: Physica viscometer to the right, water bath to the left.

It is possible to run the Physica viscometer both manually on the apparatus as well as connected to a computer with a certified program. The computer program used in this laboratory is Physica US200. By running the viscometer from a computer one have several options when it comes to what kind of measurements that are to be done. The computer program record each measurement point and can plot the points continuously as they are recorded during a measurement series.

The cup and bob that is available in the laboratory today do have some limiting factors when it comes to measurements on liquids with low viscosities. Two examples are presented below on typical measurements of poor and good values, Table 4. 1 and Table 4. 2. The column for Status should be empty (as in Table 4. 2) and not give M- an M+ (as in Table 4. 1). The reason for the M- and M+ is that the torque is too low. Jan Schaffer[1], a representative from the company that delivered the apparatus (Houm AS), told that the torque should be in the range of 0,5 – 50 mNm. As one can see is the torque too low in Table 4. 1 and therefore are the values for shear stress and thereby viscosity very inconsistent in contrast to the values in Table 4. 2 where the measurements for shear stress and viscosities give rather consistent values. When the value for the torque is too low, that is when the liquid is very thin, the contribution from the mechanics in the apparatus become larger and the measured values will be inaccurate due to the contribution from the instrument.

Table 4. 1: Example of poor measurements in Physica viscometer.

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	21,2	0	M-M+
2	800	2,19	2,73	21,2	0,0775	M-
3	800	4,22	5,28	21,2	0,15	M-
4	800	0	0	21,2	0	M-
5	800	1,88	2,35	21,2	0,0667	M-
6	800	2,19	2,73	21,2	0,0775	M-
7	800	1,97	2,46	21,2	0,0698	M-
8	800	1,7	2,13	21,2	0,0603	M-
9	800	0	0	21,2	0	M-
10	800	1,91	2,39	21,2	0,0677	M-

Table 4. 2: Example of good values from the Physica viscometer.

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	50,8	36,3	22,9	1,8	
2	1 400	51,7	36,9	22,9	1,83	
3	1 400	50,6	36,1	22,9	1,79	
4	1 400	51,3	36,7	22,9	1,82	
5	1 400	50,5	36,1	22,9	1,79	
6	1 400	49,3	35,2	22,9	1,75	
7	1 400	51,2	36,5	22,9	1,81	
8	1 400	50,2	35,8	22,9	1,78	
9	1 400	51,7	36,9	22,9	1,83	
10	1 400	50,4	36	22,9	1,79	

[1] Personal communication with Jan Schaffer, Houm AS, Trondheim (April 2007)

4.1.2 Rotational viscometer: *Fann viscometer*

The Fann viscometer is the most commonly used instrument to measure viscosity and shear rate of drilling mud. The direct-indicating viscometer is a rotational cylinder and bob instrument, also known as a V-G meter. Direct-indicating viscometers are rotational types of instruments powered by an electric motor or a hand crank[1].

In the Fann viscometer one have the opportunity to choose different rotational speeds, ranging from 3 to 600 RPM. For the different RPMs one get different values known as readings, Φ, which can be read on a scale on the top of the viscometer, see Figure 4. 3. In order to get the desired values to use in the plot of shear rate vs. shear stress one has to convert the readings to shear stress in the unit Pascal. The conversion factors are as follows:

$$\gamma = RPM * 1{,}703 \tag{4.1}$$

$$\tau_{OFU} = \phi * 1{,}06 \tag{4.2}$$

$$\tau_{SI} = \tau_{OFU} * 0{,}4788 \tag{4.3}$$

$$\mu_{eff} = \frac{\tau_{SI}}{\gamma} \tag{4.4}$$

In the viscometer you first record the values at the highest speed, 600 RPM and then 300 RPM and down to the lowest value that is for 3 RPM. The RPM-values is then multiplied by a constant (1,703) in order to get the shear rate with the unit s^{-1}. To include the readings into oil field units (OFU) a conversion factor of 1,06 is used. This factor, 1,06, is usually neglected and 1,0 is used instead in a standard so that the dial reading of a viscometer containing a standard torsion spring is numerically equal to the gel strength in pounds force per 100 sq ft. As the dial reading generally cannot be made very precisely, the factor 1,06 is not considered very significant[40]. Conversion between OFU and SI is 0,4778 to get the values into SI-units. The effective viscosity is found from eqn. 4.4.

In addition is it possible to heat the liquid measured in the Fann viscometer. This gives the user the opportunity to vary the temperature between 20 °C and ~100 °C.

The Fann viscometer is not a very good viscosity indicator when it comes to measuring relatively thin liquids at low shear rates (especially 3 rpm and 6 rpm readings). If the liquid is too thin, i.e. the viscosity is too low, will the needle in the display move back and forth and not give a constant value making it difficult to get a good value.

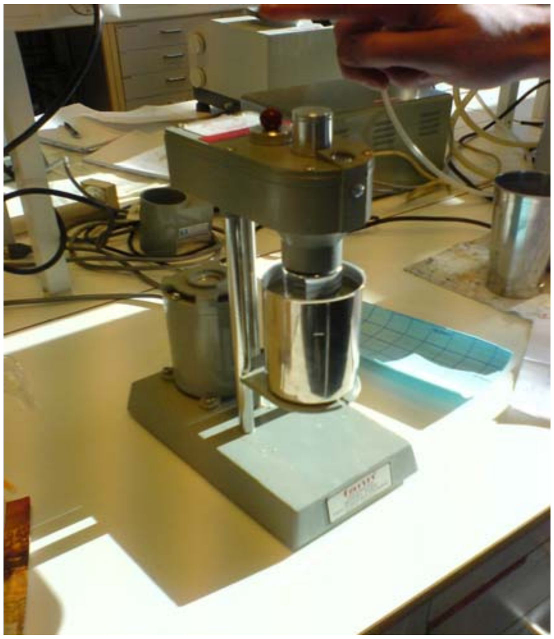

Figure 4. 3: Fann viscometer apparatus.

4.1.3 Principle of capillary viscometer, ubelohde

The capillary type viscometers are used to determine the viscosity of liquids. One type of viscometer for liquids is the Ostwald Viscometer, see Figure 4. 5. Another type is the ubelohde viscometer, Figure 4. 4. In this type of viscometer is the viscosity deduced from the comparison of the times required for a given volume of the tested liquids and the reference liquid to flow through a given capillary tube under specified initial head conditions. The temperature should be kept constant during the experiment by immersing the instrument in a temperature-controlled water bath[9].

Figure 4. 4: A capillary viscometer, ubelohde.

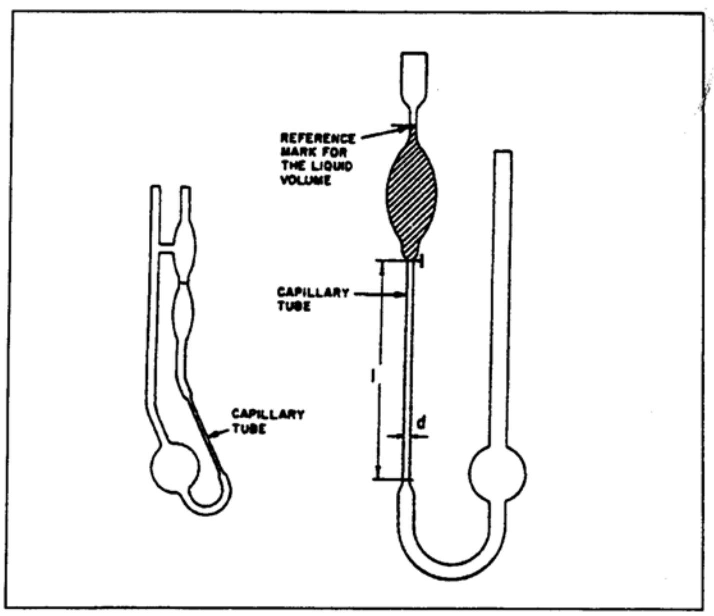

Figure 4. 5: Two types of Ostwald viscometers.

In this method the Poiseuilles law for a capillary tube with a laminar flow regime is used[9]:

$$Q = \frac{V}{t} = \frac{\Delta P \pi r^4}{8\mu l} \quad (4.5)$$

where t is the time required for a given volume V of liquid with density ρ and viscosity of μ to flow through the capillary tube of length l and radius r by means of pressure gradient ΔP. In this instrument is the driving force for ΔP = ρgl. This leads to[9]:

$$\frac{V}{t} = \frac{\pi r^4 \rho g l}{8\mu l} \quad (4.6)$$

or

$$\mu = \frac{\pi r^4 \rho g l}{8V} = Const.\, \rho * t \quad (4.7)$$

The capillary constant is determined from a liquid with known viscosity[9].

The ubelohde is filled with the liquid using a pyreusball until the liquid fills the desired amount of the capillary viscometer. Then the ubelohde is placed vertically in a stand waiting for the liquid to flow through the capillary tubes and into the spheres, first K1 and then K2. K1 and K2 have different constants measured by the manufacturer. The time used for the liquid to fill the spheres is measured and then the kinematic viscosity may be calculated. The dynamic viscosity can be calculated from the kinematic viscosity and the liquid density. A pycnometer or mud balance is used to calculate the density of the liquid.

4.2 API Recommended practice: Standard Procedure for Field Testing Drilling Fluids

The need of a systematic standard procedure is recommended to avoid individual methods of solving problems and to be able to compare results from laboratory measurements conducted by different people.

"*The American Petroleum Institute (API) Recommended Practices are published to facilitate the broad availability of proven, sound, engineering and operating practices. These recommended practices are not intended to obviate the need for applying sound judgment as* *to when and where these Recommended Practices should be utilized*.", API recommended Practices (1984)[31].

4.2.1 Viscosity- water based drilling fluids[35]

Description:

The following instruments are used to measure viscosity and/or gel strength of drilling fluids:

- Marsh funnel - a simple device for indication of viscosity on a routine basis (description in appendix).
- Direct- indicating viscometer – a mechanical device for measurement of viscosity at varying shear rates.

Viscosity and gel strengths are measurements that relate to the flow properties of muds. The study of deformation and flow of matter is rheology. An in-depth discussion of rheology is made in API Bulletin 13D: The Rheology of Oil-Well Drilling Fluids.

DIRECT- INDICATING VISCOMETER

Equipment:

a. Direct-indicating viscometers are rotational types of instruments powered by an electric motor or hand crank. Drilling fluid is contained in the annular space between two concentric cylinders. The outer cylinder or rotor sleeve is driven at a constant rotational velocity (rpm). The rotation of the rotor sleeve in the fluid produces a torque on the inner cylinder or bob. A torsion spring restrains the movement of the bob, and a dial attached to the bob indicates displacement of the bob.

The constants in the instrument have been adjusted so that plastic viscosity and yield point are obtained by using readings from rotor sleeve 300 rpm and 600 rpm.

b. Stop watch.
c. Suitable container, e.g., the cup provided with the viscometer.
d. Thermometer.

Procedure:

a. Place a sample in container and immerse the rotor sleeve exactly to the scribed line. Measurements in the field should be made with minimum delay (within five minutes, if possible), and at a temperature as near as practical to that of the mud at the place of sampling (not to differ more than 6 °C). The place of sampling should be stated on the report.

b. Record the temperature of the sample.
c. With the sleeve rotating at 600 rpm, wait for dial reading to reach a steady value (the required time depends on the mud). Record the dial reading for 600 rpm.
d. Shift to 300 rpm and wait for dial reading to reach steady value. Record the dial reading for 300 rpm (and the other values 200, 100, 6, 3).

For gel strength measurements:

e. Stir drilling fluid sample for 10 seconds at high speed.
f. Allow mud to stand undisturbed for 10 seconds. Start the viscometer at 3 rpm, the maximum read value is the initial gel strength. Record the initial gel strength (10 sec gel) in Pa.
g. Re-stir the mud at high speed for 10 seconds and then allow the mud to stand undisturbed for 10 minutes. Repeat the readings as in point f. and report the maximum reading as 10 minute gel in Pa.

5 Laboratory experiment

The laboratory experiment is the main part of the thesis, and is divided in 3:

1. Calibration of the test equipment
2. Rheology test of the drill- in mud exposed to pressure and temperature
3. Rheology test of a polymer (HEC + water)

A presentation of the equipment used is done in chapter 4.1.

5.1 Calibration of test equipment

As for any experimental investigation is it important that the equipment is calibrated. We need to make sure the input to any evaluation have high quality. Therefore will calibration of the equipment be the first task in the laboratory experiment.

5.1.1 Test procedure

The calibration liquid used is Statoil Aquaway, which is a 2-stroke motor oil. We looked up the rheological properties for the given oil in a data-sheet from the manufacturer and in cooperation with the supervisor we found that this oil covered our needs. The oil was used in the calibration of the Fann viscometer and the Physica HPHT viscometer.

The test matrix for the calibration liquid is shown in Table 5. 1.

Table 5. 1: Test matrix for the calibration liquid.

	Temperature [°C]	Pressure [Bar]	Cap. viscometer ubelohde	Fann viscometer	Physica viscometer
Calibration liquid	20	1	6	6	3
	90	1	-	6	3
Total # of experiments:					24

The calibration is done by mixing the calibration liquid with a thinner oil, Exxsol D-60, in order to still have a Newtonian liquid and to be able to make a plot of the viscosity measured from the Physica viscometer vs ubelohde and from the Fann viscometer vs ubelohde. The oil solutions used are as follows:

1. Calibration oil without any Exxsol D-60 added
2. Calibration oil + approximately 8 vol-% Exxsol D-60 added
3. Calibration oil + approximately 10 vol-% Exxsol D-60 added
4. Calibration oil + approximately 20 vol-% Exxsol D-60 added
5. Calibration oil + approximately 30 vol-% Exxsol D-60 added

The viscosities of these solutions are measured in an ubelohde, Physica viscometer and Fann viscometer. The results will be plotted to be able to compare the different measured viscosities and to find a function to convert the read values from Physica and Fann viscometer into "real values" from the ubelohde.

5.1.2 Test equipment

- Calibration liquid, Statoil Aquaway 2-stroke motor oil
- Pycnometer
- Exxsol D-60

  A thin oil used to make the viscosity of the calibration liquid less
- Stop watch

  Used in the viscosity measurements in the capillary viscometer
- Ubelohde
- Fann viscometer
- Physica viscometer

5.1.3 Test results

We wanted a liquid with some special rheological properties, i.e. a stable Newtonian liquid with a viscosity in a certain range, as well as it was cheap. Another limitation was that the viscosity should be as high as possible, but not higher than 100 cSt at our operating conditions (~20 °C) because the ubelohde available could only measure on liquids up to 100 cSt. The oil used, called Statoil Aquaway 2-stroke[32], had most of the properties that we looked for, i.e. a viscosity of 34,8 and 6,2 cSt at 40 and 100 °C respectively, see Table 5. 2. From these values we made a plot to find the viscosity at laboratory conditions (~23 °C) and this was found to be approximately 55 cP, Figure 5. 1.

Table 5. 2: Information from manufacturer on the rheological properties of aquaway.

Given density, 15 °C	869	kg/m^3

T, Celsius	cSt	cP
40	34,8	30,2412
100	6,2	5,3878

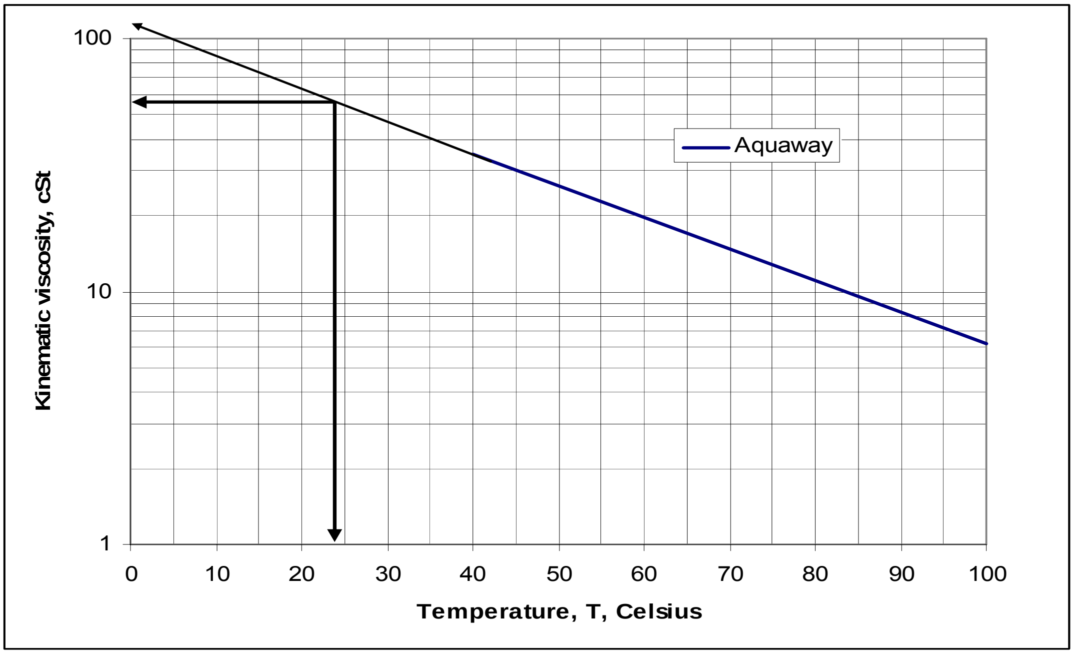

Figure 5. 1: Rheological properties of calibration liquid, given data from manufacturer.

The density of the oil was measured using different pycnometers. The volumes of the pycnometers were in the range of 50,006 to 50,783 cm^3. The weight was tare by the pycnometers alone and then oil was added. The liquid densities were then calculatd to be in the range of 861,7 to 865,6 kg/m^3. The values from the measurements from the pycnometer are shown in Table 5. 3. The temperature of the liquid as well as the room was measured to be 23,5 °C ± 0,2 °C using a digital thermometer.

Table 5. 3: Densities of the calibration liquid from pycnometer measurements.

Experiment No.	Temperature [°C]	V pycnometer [cm^3]	Weight oil [g]	Density [g/cm^3]	Density [kg/m^3]
1	23,5	50,582	43,782	0,8656	865,6
2	23,5	50,783	43,772	0,8619	861,9
3	23,5	50,235	43,364	0,8632	863,2
4	23,5	50,783	43,760	0,8617	861,7
5	23,5	50,006	43,103	0,8620	862,0
Average density:				862,9	kg/m^3

5.1.3.1 Viscosity of the calibration liquid from the capillary viscometer, ubelohde

The density of the calibration liquid is calculated in order to be able to calculate the dynamic viscosity from the kinematic viscosity measurements. The measured data from the different experiments with the ubelohde is shown in Table 5. 4. In the table are the following parameters:

- The constant K, i.e. K1 and K2, is given on each individual ubelohde from the manufacturer,
- The time column is the time used to fill up the "spheres" K1 and K2 in the ubelohde,
- The kinematic viscosity is the product of the constant K multiplied by the time,
- The dynamic viscosity is calculated from multiplying the kinematic viscosity with the density.

Table 5. 4: Measured viscosities of the calibration liquid from ubelohde.

Experiment No.	T_{start} oil [°C]	T_{end} oil [°C]	Constant, K [mm^2/s^2]	Time [s]	Kinematic μ [mm^2/s], [cSt]	Dynamic μ [cP]
1	23,6	23,6	0,2683	276	74,05	63,90
2	23,6	23,6	0,2592	290	75,17	64,86
3	23,6	23,6	0,2028	376	76,25	65,80
4	23,5	23,5	0,2683	288	77,27	66,67
5	23,5	23,5	0,2592	297	76,98	66,43
6	23,5	23,5	0,2028	381	77,27	66,67
Average dyn. Visc					65,72 cP	

The measured dynamic viscosity of the calibration liquid from the ubelohde is in the range of 63,9 cP to 66,7 cP. Two different ubelohdes were used two times each. The average dynamic viscosity for the calibration liquid is 65,72 cP which is a bit larger than expected from the data from Table 5. 2 and Figure 5. 1 where the viscosity at 23,5 °C was calculated to be approximately 55 cP. The room-temperature was 23,5 °C ± 0,2 °C. It is important to measure the temperature as the viscosity of the oil depends very much on the temperature. It is also important to know the temperature when the viscosity-calculations are to be compared with the viscosity measured using other viscometers.

In addition was the viscosity of the calibration liquid with different amounts of Exxsol D-60 added measured in an ubelohde. The density was measured using a pycnometer. The results from these measurements are shown below in Table 5. 5.

Table 5. 5: Viscosity ubelohde 8 vol-%, 10 vol-% and 20 vol-% Exxsol D-60.

8 vol-% Exxsol D-60

T liquid start	22,7	°C
Volume pycno	50,235	cm^3
Weight pycno	43,19	g
Density	859,76	kg/m3

Constant K [m m/s^2]	Time [sec]	Kin visc [cP]	Dyn visc [cP]
0,09295	415	38,57	33,16
0,07346	511	37,54	32,27

Average dyn visc 32,72 cP

10 vol-% Exxsol D-60

T liquid start	23,3	°C
Volume pycnometer	24,721	cm^3
Weight pycnometer	21,118	g
Density	854,25	kg/m3

Constant K [m m/s^2]	Time [sec]	Kin visc [cP]	Dyn visc [cP]
0,09295	352	32,72	27,95
0,07346	455	33,42	28,55

Average dyn visc 28,25 cP

20 vol-% Exxsol D-60

T liquid start	23,1	°C
Volume pycnometer	24,721	cm^3
Weight pycnometer	20,713	g
Density	837,87	kg/m3

Constant K [m m/s^2]	Time [sec]	Kin visc [cP]	Dyn visc [cP]
0,09295	188	17,47	14,64
0,07346	247	18,14	15,20

Average dyn visc 14,92 cP

30 vol-% Exxsol D-60

T liquid start	22,7	°C
Volume pycnometer	50,783	cm^3
Weight pycnometer	42,18	g
Density	830,59	kg/m3

Constant K [m m/s^2]	Time [sec]	Kin visc [cP]	Dyn visc [cP]
0,03503	321	11,24	9,42
0,02617	431	11,28	9,45

Average dyn visc 9,44 cP

5.1.3.2 Readings of the calibration liquid in Fann viscometer

When calculating the viscosity of the calibration liquid by using Fann viscometer it is important that the liquid and surroundings have the same temperature as for the ubelohde measurements. The temperatures are shown in Table 5. 6. The average measured data as well as calculated values of the effective viscosity from six experiments in the Fann viscometer is shown in Table 5. 7.

Table 5. 6: Liquid temperature and room temperature Fann viscometer.

Temp air start	23,6	°C
Temp air end	23,7	°C
Temp oil start	23,5	°C
Temp oil end	23,8	°C

Table 5. 7: Fann Viscometer: Average values from 6 experiments, calibration liquid.

RPM	γ	Reading Φ	T_{OFU}	T_{SI}	mju eff
-	[s^{-1}]	[-]	[lb/100ft^2]	[Pa]	[cP]
600	1022	133,17	141,16	67,59	66,14
300	511	67,50	71,55	34,26	67,05
200	341	45,17	47,88	22,92	67,30
100	170	22,83	24,20	11,59	68,05
6	10	3,67	3,89	1,86	182,12
3	5	1,50	1,59	0,76	149,01

The average values for shear rate and shear stress are plotted in Figure 5. 2. By the use of the linear add-trendline function in Microsoft Excel we get the following equations:

$$y = 0{,}0654x + 0{,}7039 \quad (5.1)$$

$$R^2 = 0{,}9999 \quad (5.2)$$

where the slope 0,0654x indicates a viscosity of 65,4 cP. The regression constant R^2 is 0,9999 which mean that the linear trendline is very close to the line from the measured data from the Fann viscometer, this can also be seen visually in the plot where the red line fits the blue line almost perfect.

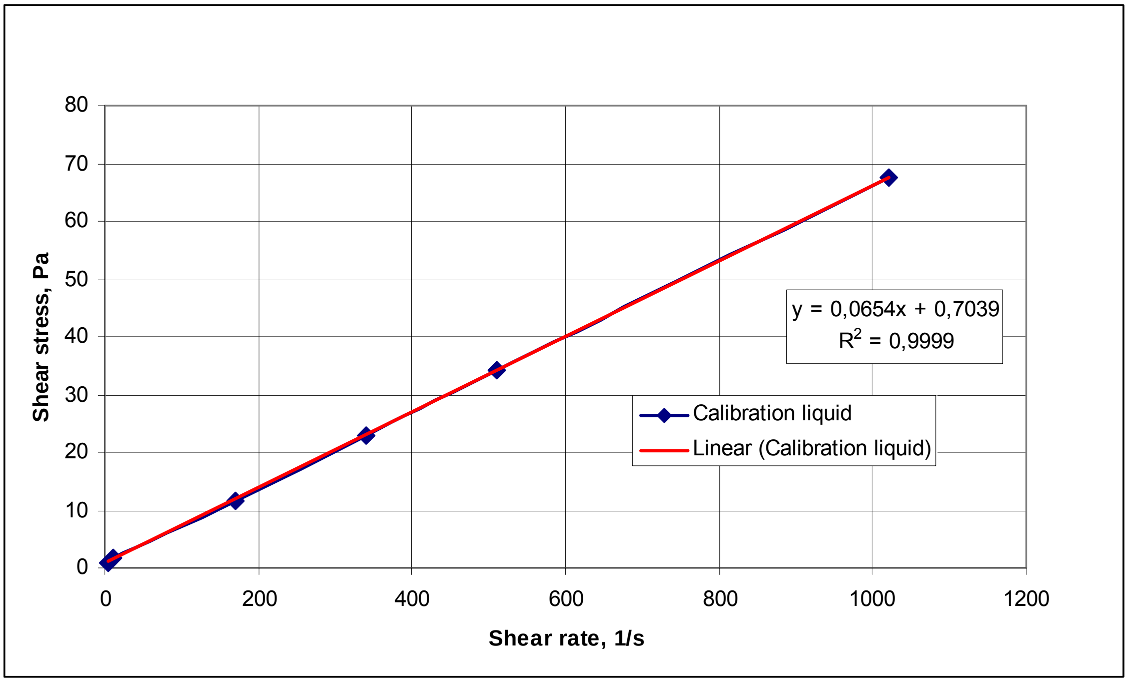

Figure 5. 2: Plot of average shear rate vs shear stress for 6 experiments, calibration liquid.

The results from the viscosity measurements in the Fann viscometer compared to the results from the ubelohde measurements show that the calculated viscosity is almost equal. The average viscosity from the ubelohde is 65,72 cP, see Table 5. 4, while the viscosity from the Fann viscometer is 65,4 cP when the liquid temperature is 23,5 °C ± 0,3 °C. These measured values are very close and indicate that the Fann viscometer shows more or less the correct values due to that the ubelohde is supposed to be a very good viscosity indicator at least for liquids with relatively high viscosities.

In order to get a plot of $\mu_{ubelohde}$ vs. μ_{Fann}, did we measure the viscosity of the four other calibration liquid solutions were Exxsol D-60 was added to the calibration liquid as well. By plotting the readings from the Fann viscometer and using the add trendline function in Microsoft Excel to get the slope, we got the following results for the viscosity for the ubelohde and Fann viscometer respectively, Table 5. 8.

Table 5. 8: Fann viscometer. Viscosity calibration oil with diff amounts Exxsol D-60.

Solution	Temperature [°C]	$\mu_{ubelohde}$ [cP]	μ_{Fann} [cP]
1) Calibration oil	23,5	65,7	65,4
2) Calibration oil + ~8 vol-% Exxsol D-60	22,7	32,72	35,2
3) Calibration oil + ~10 vol-% Exxsol D-60	22,9	28,2	30,7
4) Calibration oil + ~20vol-% Exxsol D-60	23	14,92	16,3
4) Calibration oil + ~30vol-% Exxsol D-60	22,7	9,44	9,5

We suppose that the viscosity measured in the ubelohde is more accurate. In order to find an equation to use for conversion of the measurements from the Fann viscometer in to more accurate measurements are the viscosities from ubelohde and Fann viscometer from Table 5. 8 plotted in the same plot, Figure 5. 3. By doing this one can find a trendline so that the measured values are adjusted to be closer to a reference value. In this case are the values from the ubelohde used as a reference.

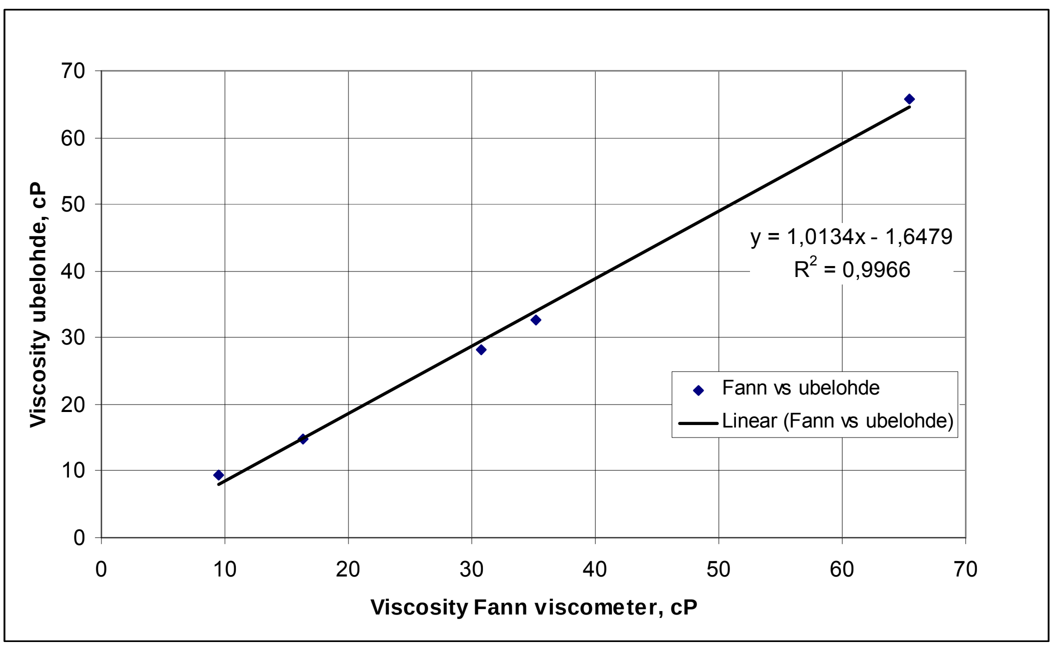

Figure 5. 3: Calibrating the Fann viscometer. Fann readings vs ubelohde.

By using the add trendline function to the data-points, we get the following equations for the linear trendline:

$$y = 1{,}0134x - 1{,}6479 \tag{5.3}$$

$$R^2 = 0{,}9966 \tag{5.4}$$

which means:

$$\mu_{ubelohde} = 1{,}0134 * \mu_{Fann} - 1{,}6479 \tag{5.5}$$

This means that all measurements in the Fann viscometer should be put into this equation in order to get a value for the viscosity that is more accurate.

In addition to a linear trendline is a Power- approximation in Microsoft Excel conducted as well. The result is shown in Figure 5. 4.

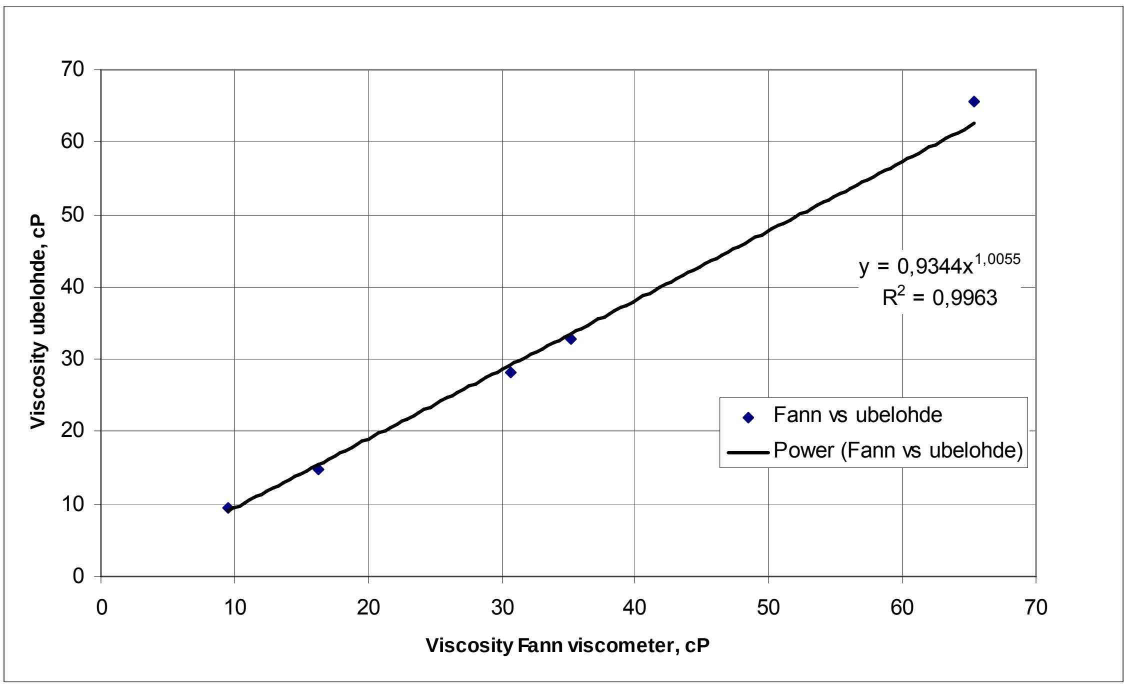

Figure 5. 4: Fann viscometer calibration, Power- approximation.

As one may see from the plot is the calculated equation as follows:

$$\mu_{ubelohde} = 0{,}9344 * \mu_{Fann} \string^ 1{,}0055 \tag{5.6}$$

$$R^2 = 0{,}9963 \tag{5.7}$$

The regression constant is almost the same as for the linear trendline (0,9966 vs 0,9963). This means that we may choose randomly one of the two equations because both approximations give more or less the same regression constant. We have chosen to use the equation from the power- trendline in the calculations to come because this line visually fits better at low viscosities.

5.1.3.3 Readings of the calibration liquid in Physica HPHT viscometer

The third and last viscosity measurement apparatus is the Physica HPHT viscometer. The temperature in the water bath is set so that the temperature of the oil in the measuring cell is as close to 23,5 °C as possible. The same calibration liquids are measured in this experiment as for the ubelohde and Fann viscometer. The result from the shear rate vs shear stress for the calibration liquid is shown below in Figure 5. 5. The linear add trendline function gave the following equations:

$$y = 0{,}0642x - 0{,}87 \quad (5.8)$$

$$R^2 = 0{,}9999 \quad (5.9)$$

The viscosity is calculated to be 64,2 cP for the calibration liquid. This result is in the same range as for both the ubelohde (μ = 65,72 cP) and Fann viscometer (μ = 65,4 cP).

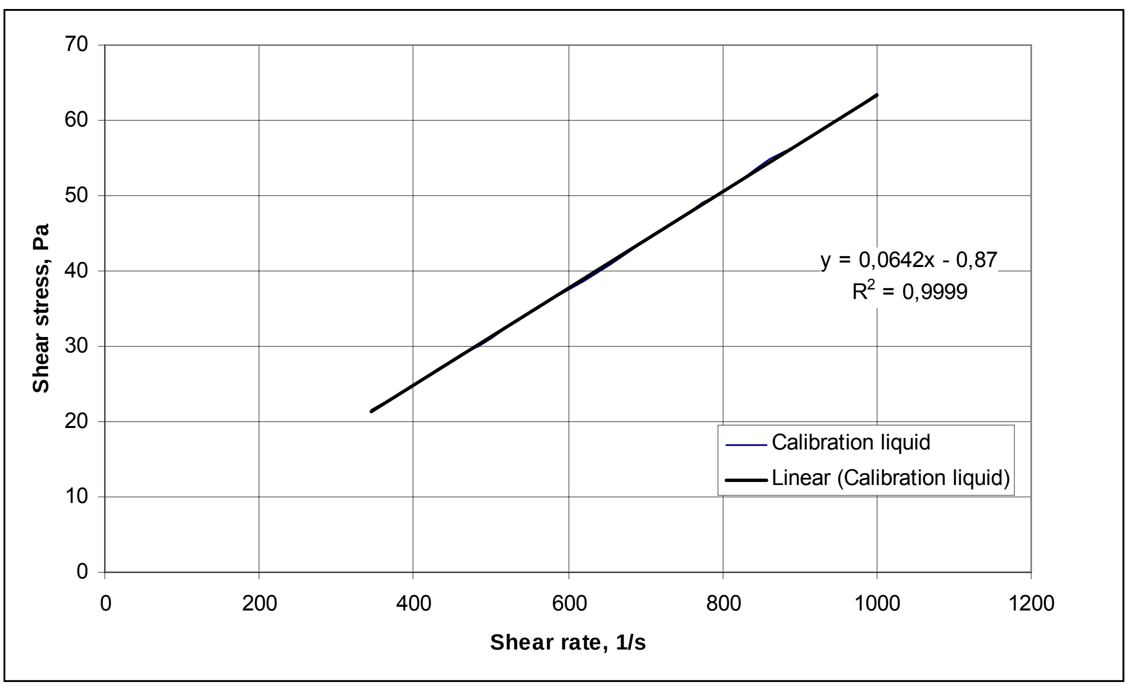

Figure 5. 5: Calibration liquid. Shear rate vs shear stress from Physica viscometer.

The viscosities of the solutions of calibration liquid with different amounts of exxsol D-60 are measured as well. The measurements are conducted by making a method in the computer program that measures 15 points for each of the following shear rates, 800, 900, 1000, 1100 and 1200 s^{-1}. Then the average shear stress from the 15 measured values for each shear rate is calculated.

The results from the measurements of the calibration liquid with different amounts of Exxsol D-60 added for the ubelohde, Physica and Fann viscometer is shown in Table 5. 9 and a plot of the Physica values are shown in Figure 5. 6.

Table 5. 9: Viscosity calibration liquid with different amounts of Exxsol D-60.

Solution	Temperature [°C]	$\mu_{ubelohde}$ [cP]	μ_{Fann} [cP]	$\mu_{Physica}$ [cP]
1) Calibration oil	23,5	65,7	65,4	64,2
2) Calibration oil + ~8 vol-% Exxsol D-60	22,7	32,72	35,2	35,3
3) Calibration oil + ~10 vol-% Exxsol D-60	22,9	28,2	30,7	31,6
4) Calibration oil + ~20vol-% Exxsol D-60	23	14,92	16,3	17,6
4) Calibration oil + ~30vol-% Exxsol D-60	22,7	9,44	9,5	10,7

We made the same plot as for the Fann viscometer and ubelohde and used the add trendline function in Microsoft Excel. First we used a linear trendline and then a Power- approximation. The linear trendline, plotted in the Appendix, showed that the measured points indicated a straight line. This is a good sign, indicating that the liquid is Newtonian. The plot of each of the oil solutions as well as the linear- approximation is shown in the appendix. The Power- approximation is plotted in Figure 5. 6. The functions from this approximation are as follows:

$$\mu_{ubelohde} = 0,6866 * \mu_{Physica}\hat{}1,0866 \quad (5.10)$$

$$R^2 = 0,9971 \quad (5.11)$$

The calculated regression constant ($R^2 = 0,9971$) is better, that means closer to 1, than the one calculated with a linear trendline approximation ($R^2 = 0,9956$ in Appendix), but both of the trendlines give good values as is also seen visually in the plot. In the following calculations we will use the trendline with the best regression constant, which is the power- trendline approximation.

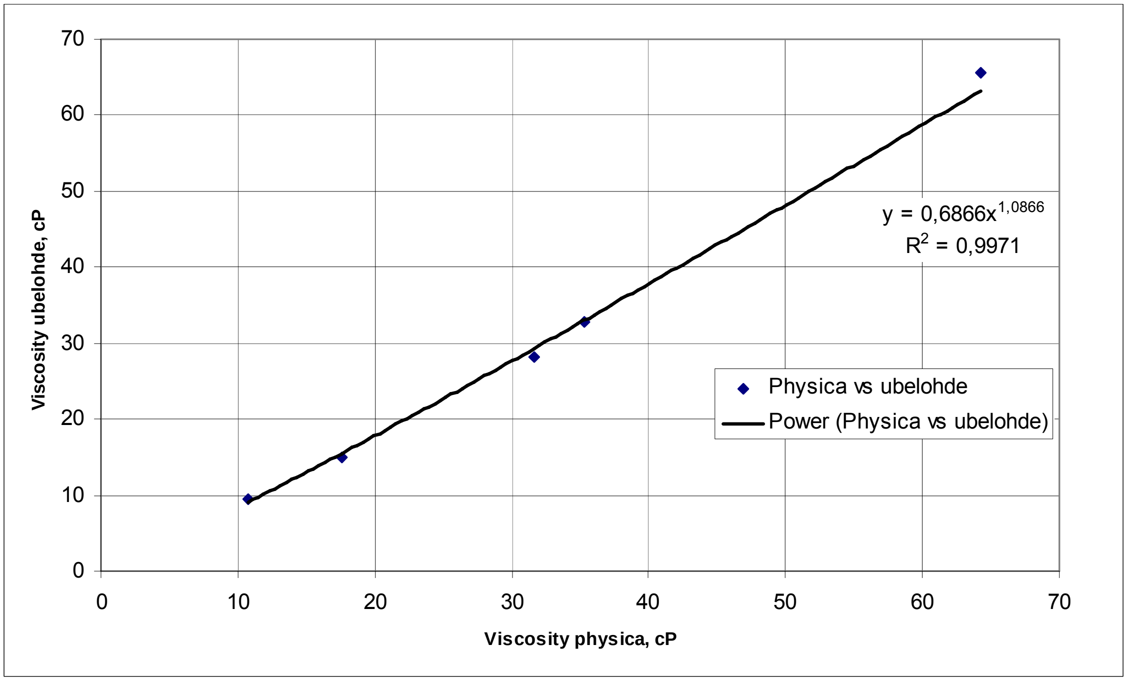

Figure 5. 6: Physica viscometer. Power- approximation.

The results from the different calibration liquid measurements are shown in Table 5. 9. As one can see are the results from 1) the calibration oil quite similar for the three experiments with an error ±1 cP compared with the ubelohde that we use as the reference value. For experiment 2) are the results obtained both from the Fann viscometer and Physica viscometer approximately 2,5- 3,5 cP higher compared to the ubelohde. The same trend is observed in experiment 3) and 4) where the ubelohde shows a viscosity at 14,92 cP in experiment 3) while the Fann viscometer and Physica viscometer indicated a viscosity of 16,3 cP and 17,6 cP respectively. It is difficult to draw any conclusions with just these few measurements but at least they indicate that the Fann viscometer and the Physica viscometer give too high viscosity when the liquid is thinned. This result is in agreement with information that Jan Schaffer* from the manufacturer (Houm AS) gave us about the Physica viscometer. He told that the Physica viscometer would most likely give more inaccurate values for shear rates in liquids with low viscosities.

* Personal communication with Jan Schaffer, Houm AS, Trondheim (April 2007)

5.2 Rheology testing of field mud exposed to P and T

The rheological properties of one water-based drilling fluid will be tested in the Physica viscometer by exposing the mud to different pressures and temperatures. A water bath and a nitrogen pressure bottle are connected to the viscometer in order to be able to control the temperature and pressure. Both the temperature and pressure are adjusted directly on the respective apparatuses.

5.2.1 Test matrix- pressure and temperature experiment

Table 5. 10 shows the test matrix for the laboratory experiments regarding the effects of pressure and temperature on a water-based field mud, a drill- in fluid. The measurements are only conducted by the use of the Physica viscometer as it is the only instrument available in the laboratory that can measure both different pressures and temperatures at the same time. For each of the chosen temperatures (20 °C, 60 °C and 90 °C) is it performed two measurements with the selected measurement method on the computer in order to minimize the source of error. Only the data from one of the two series will be used, the second series will act as a control to see if it matches the first series in a way that give more or less reliable measurements.

Table 5. 10: Test matrix for the P and T experiments.

	Temperature [°C]	Pressure [Bar]	Physica # experiments
Drill- in mud	20	1	2
	20	40	2
	20	80	2
	60	1	2
	60	40	2
	60	80	2
	90	1	2
	90	40	2
	90	80	2
Number of experiments:			18

The total number of experiments in this part of the laboratory is 18.

5.2.2 Test procedure and equipment

The mud used is a drill-in mud, which means that is a type of mud that is used to drill the last section of the hole in to the reservoir. 1 liter mud consists of the following:

- 2 % Starch
- 5 % CaCO3 – Calciumcarbonat
- 0,6 % Xanthan Gum
- 250 g salt- used as weight material and clay stabilizer
- 1 liter of water

In addition to the mud are the following equipment used:

- Thermometer
- A mixer
- Physica viscometer
- Pressure bottle with Nitrogen
- Water bath

The following method was used in the computer- program of the Physica viscometer in the measurements:

- Shear rate: 100, 200, ……, 1300, 1400 s^{-1}
- One measuring point each 3 seconds
- 10 measuring points for each shear rate, the average value of the viscosity from the program is calculated. The real viscosity is then calculated by using the equation obtained from the add trendline function in the $\mu_{Physica}$ vs $\mu_{ubelohde}$ plot. To be able to compare for different shear rates and shear stress, is the shear stress calculated by:
    - $\tau = \frac{\mu_{real} * \gamma}{1000}$
- Temperature: 21,5 ± 0,4 °C

When conducting the measurements will all of the experiments involving a temperature of 20 °C be implemented first. This means that the first experiment is at 20 °C at 1 bar, then 20 °C at 40 bar and at last 20 °C at 80 bar. The measuring cell is then heated to 60 °C and the measurements are implemented in the same order as for 20 °C. Finally, the water bath is heated up to 90 °C. The same mud is used in all of the experiments. There will be conducted sampling tests on a specific temperature and pressure with a new mud with the same properties to see if the mud that is exposed to higher pressure and temperature changes its properties so much so that the data recorded is incorrect.

5.2.3 Results Physica, T = 20 °C

The lowest shear rate = 400 s^{-1} because anything less gives too much inaccuracy in the measurements from the Physica viscometer (as commented above in chapter 4.1.1).

The results from the measurements conducted at 20 °C at the three different pressures are presented in Table 5. 11 and Figure 5. 7. the column *Visc. Calc.* in Table 5. 11 is the "real" viscosity, a result from adjusting the measured viscosity by the use of the equation $\mu_{ubelohde}$ that we found earlier.

Table 5. 11: T=20 °C. Shear rate, shear stress and viscosity at different pressures.

T = 20 °C, P = 1 bar

Shear rate [1/s]	Visc. Calc. [cP]	Shear stress [Pa]
400	42,34	16,94
500	36,54	18,27
600	32,25	19,35
700	28,91	20,24
800	26,27	21,02
900	24,76	22,28
1000	22,96	22,96
1100	22,08	24,29
1200	21,50	25,81
1300	20,66	26,86
1400	19,79	27,71

T = 20 °C, P = 40 bar

Shear rate [1/s]	Visc. Calc. [cP]	Shear stress [Pa]
400	37,80	15,12
500	32,38	16,19
600	28,85	17,31
700	27,10	18,97
800	24,80	19,84
900	23,47	21,13
1000	21,91	21,91
1100	20,73	22,81
1200	20,33	24,39
1300	19,63	25,52
1400	19,21	26,89

T = 20 °C, P = 80 bar

Shear rate [1/s]	Visc. Calc. [cP]	Shear stress [Pa]
400	39,02	15,61
500	34,13	17,07
600	30,27	18,16
700	27,68	19,38
800	25,55	20,44
900	23,96	21,56
1000	22,06	22,06
1100	21,56	23,71
1200	20,65	24,79
1300	20,03	26,04
1400	19,62	27,47

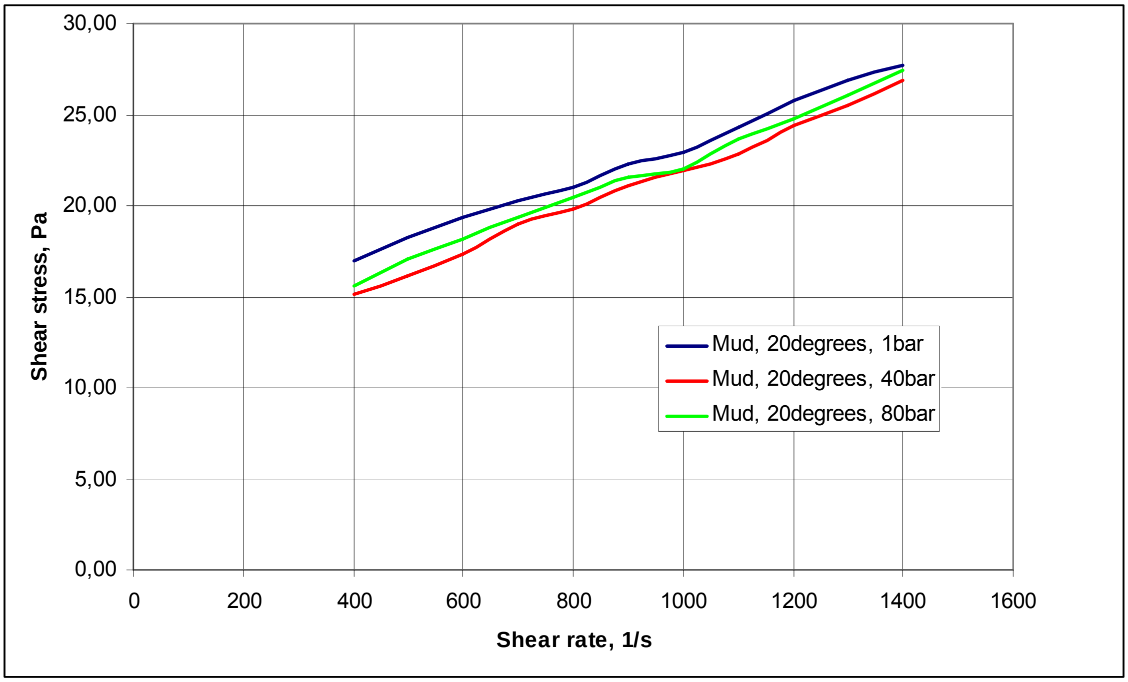

Figure 5. 7: Field mud, T=20 °C, for all three different pressures.

In Figure 5. 7 it is seen that the results from the measurements at different pressures at 20 °C give almost the same values for all pressures. The slope of the lines appears to be, at least visually, the same. The differences in the calculated viscosity seem to be in the range of 2 cP at any given shear rate. The results from the measurements at 1 bar give somewhat higher values than for the other pressures for all shear rates indicating that the pressure does have an impact. Another explanation might be that as the same mud was used at all measurements and that the first experiment was done at 1 bar, might the mud have shear thinning properties which makes the viscosity less as the mud is rotated in the apparatus.

5.2.4 Results Physica, T = 60 °C

At a temperature of 60 °C we also use 400 s^{-1} as the lowest shear rate although the results might be somewhat more inaccurate than at 20 °C as it is expected that the viscosity decreases when the temperature increases.

We have chosen only to include the table of shear rate, shear stress and viscosity, and the results from all the different pressures in the same plot. The measured data are presented in Table 5. 12 and the plot in Figure 5. 8.

Table 5. 12: T=60 °C. Shear rate, shear stress and viscosity at different pressures.

T = 60 °C, P = 1 bar

Shear rate [1/s]	Visc.calc. [cP]	Shear stress [Pa]
400	27,55	11,02
500	22,71	11,36
600	20,64	12,39
700	18,29	12,80
800	17,17	13,74
900	16,04	14,43
1000	14,36	14,36
1100	14,00	15,40
1200	13,64	16,36
1300	12,84	16,69
1400	12,54	17,56

T = 60 °C, P = 40 bar

Shear rate [1/s]	Visc. calc. [cP]	Shear stress [Pa]
400	26,57	10,63
500	23,88	11,94
600	20,74	12,44
700	18,17	12,72
800	17,10	13,68
900	16,06	14,45
1000	14,80	14,80
1100	14,15	15,56
1200	13,35	16,02
1300	13,01	16,91
1400	12,83	17,96

T = 60 °C, P = 80 bar

Shear rate [1/s]	Visc. calc. [cP]	Shear stress [Pa]
400	27,79	11,12
500	23,16	11,58
600	20,79	12,48
700	18,02	12,61
800	17,66	14,13
900	15,74	14,16
1000	15,27	15,27
1100	13,85	15,23
1200	13,32	15,98
1300	13,16	17,11
1400	12,84	17,97

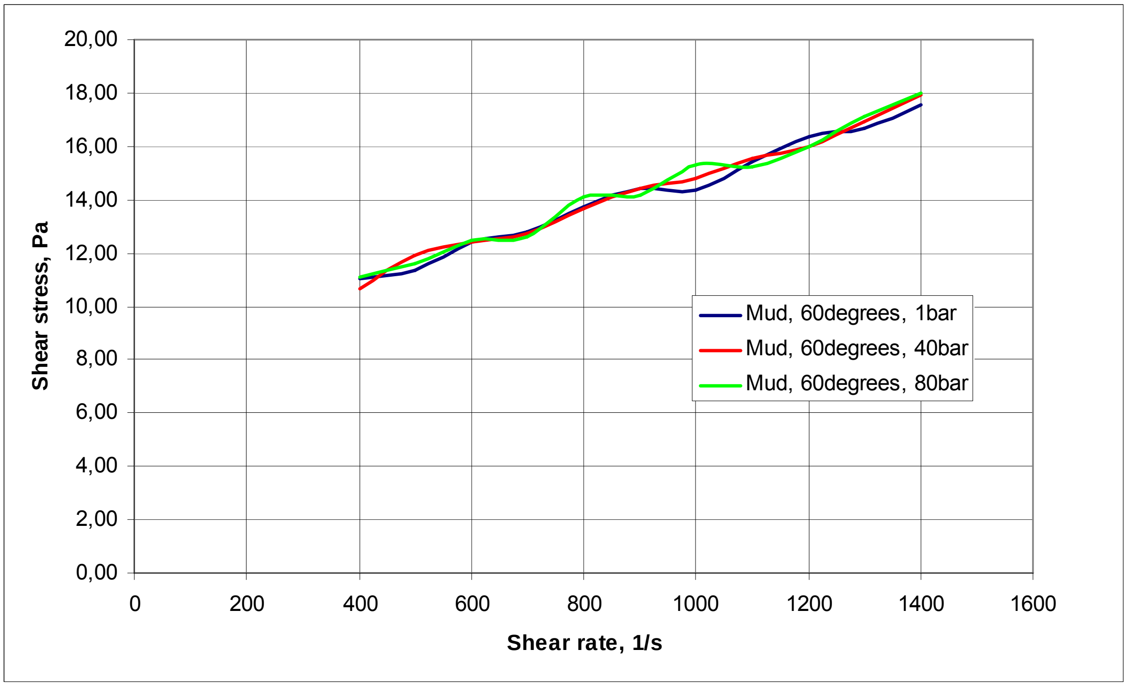

Figure 5. 8: Drill- in mud, T=60 °C, for all three different pressures.

As one can see from Figure 5. 8 is it very difficult to sort out the different lines from each other as they are almost covering one another totally. No clear conclusion can be drawn except that the measured data give more or less the same shear stress for any given shear rate for all the different pressures. This indicates that the pressure effects are insignificant when it comes to measuring at this specific mud at 60 °C.

5.2.5 Results Physica, T = 90 °C

The lowest shear rate measured is at 400 s^{-1}, which is the same as for the measurements conducted at 20 °C and 60 °. For the measurements at 90 °C are the expected viscosity even lower because the temperature is higher than in the previous experiments. Therefore it might be difficult to get good values for the shear stress and viscosity, at least for the lowest shear rates. The results of the measurements at 90 °C are shown in Table 5. 13 and Figure 5. 9.

Table 5. 13: T=90 °C. Shear rate, shear stress and viscosity at different pressures.

T = 90 °C, P = 1 bar			T = 90 °C, P = 40 bar			T = 90 °C, P = 80 bar		
Shear rate [1/s]	Visc. calc. [cP]	Shear stress [Pa]	Shear rate [1/s]	Visc. calc. [cP]	Shear stress [Pa]	Shear rate [1/s]	Visc. calc. [cP]	Shear stress [Pa]
400	25,01	10,00	400	24,63	9,85	400	24,63	9,85
500	20,10	10,05	500	20,54	10,27	500	21,49	10,75
600	19,14	11,48	600	18,98	11,39	600	19,17	11,50
700	18,07	12,65	700	16,82	11,77	700	18,07	12,65
800	15,71	12,57	800	15,81	12,65	800	16,30	13,04
900	14,25	12,83	900	14,69	13,22	900	15,40	13,86
1000	13,96	13,96	1000	13,82	13,82	1000	14,23	14,23
1100	12,73	14,01	1100	12,74	14,02	1100	13,34	14,67
1200	12,17	14,60	1200	12,73	15,28	1200	12,62	15,14
1300	11,84	15,39	1300	12,12	15,75	1300	12,20	15,86
1400	11,41	15,97	1400	12,16	17,02	1400	12,15	17,01

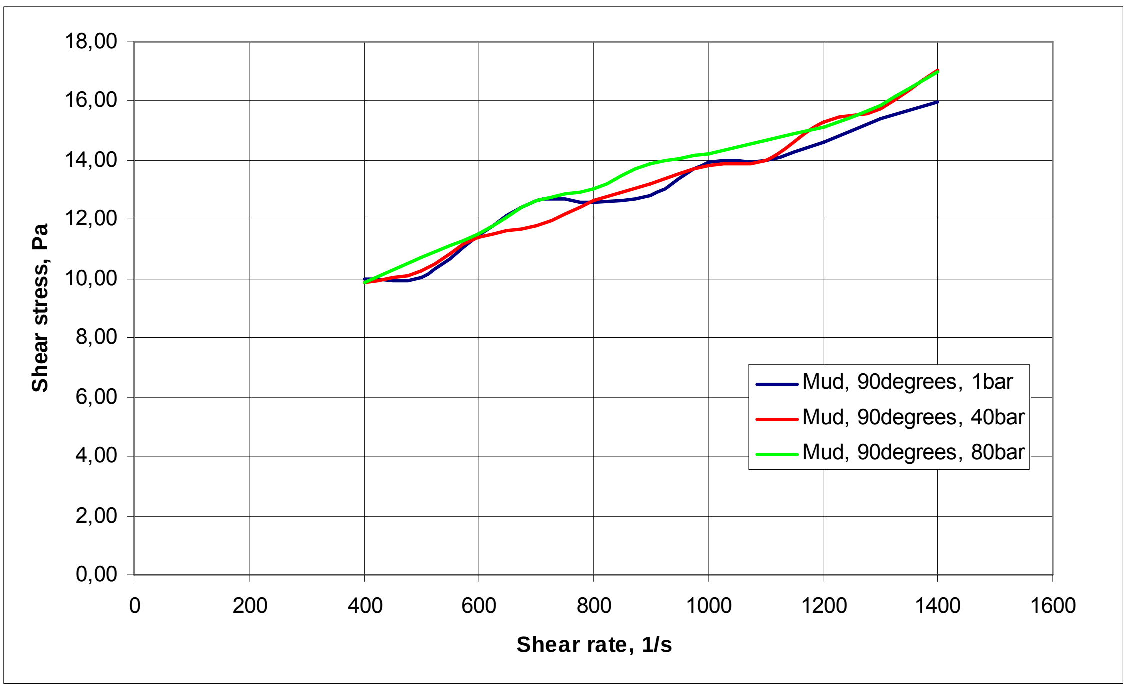

Figure 5. 9: Drill- in mud, T=90 °C, for all three different pressures.

As one can see from the plot is it very difficult to divide the different lines from one another and it is also difficult to draw any conclusions when it comes to if the pressure has an impact on the viscosity. The green line (90 degrees, 80 bar) is though almost largest or similar to the largest value at almost any values. This might be a coincident or indicate that the shear stress is increasing as the pressure is increasing. The trend is though so unclear and insignificant that it is most likely not a clear conclusion to draw.

5.2.6 Discussion P and T experiment, drill- in mud

In addition to the measurements presented above were there conducted measurements on a "new mud" that had not been exposed to heating or pressure increments. The results from these measurements did not give any significant differences from the one recorded the first time and we have concluded that this effect is negligible.

From the plot of all three pressures at 20 °C, Figure 5. 7, one might say that the shear stress and thereby the viscosity is decreasing, at least in some degree, as the pressure is increasing above 1 bar. The 80 bar – line is a bit above the 40 – bar line but beneath the 1 bar – line.

The same trend is not seen for the two other temperatures, 60 °C and 90 °C in Figure 5. 8 and Figure 5. 9 where the lines for the different pressures are almost covering one another totally, making it impossible to draw any other conclusions than that the pressure effect seems to be insignificant.

If one compare the results for the viscosity in each of the three tables, Table 5. 11, Table 5. 12 and Table 5. 13 one can see that the viscosity is decreasing as the temperature is increasing. As one example we see that at 20 °C, 40 bar and 1000 s^{-1} shear rate is the viscosity 21,91 cP. At 60 °C and 90 °C at the same pressure and shear rate are the viscosity 14,80 cP and 13,82 cP, respectively. The same trend is seen for the other pressures and shear rates as well but it seems that the effect of temperature is decreasing as the temperature is increasing (at least for temperatures above 60 °C) because the difference in viscosity is less between 60 °C and 90 °C than between 20 °C and 60 °C. It is though clear that it is larger difference between 20 and 60 °C (ΔT = 40 °C) and 60 and 90 °C (ΔT = 30 °C) but the difference in viscosity is more significant at lower temperatures.

5.3 Rheology test of HEC+water exposed to aging

The next part of the laboratory work is to measure the effect of aging on a polymer, a solution of 0,5 wt-% HEC and water.

5.3.1 Test matrix- aging experiment

The test matrix for the aging experiment is shown below in Table 5. 14. The aging effect on the viscosity will be measured both in a Fann viscometer and the Physica viscometer and aging effect after 1, 3, 8, 11, 15 and 20 days will be measured. In the Fann viscometer experiments will there be done three continuously separate measurements on the same liquid sample to minimize the source of error. The average reading for the three measurements will be used as the reading value. In the measurements in the Physica viscometer will there be conducted two experiments for each liquid sample using a method in the computer program. This is done to be able to combine and see if there are any differences between the first and second run and to see if there are any differences according to shear thinning properties.

Table 5. 14: Test matrix aging experiment.

	Aging temperature [°C]	Aging time [days]	Fann viscometer # experiments	PHYSICA # experiments
Water + HEC	20	1	3	2
	20	3	3	2
	20	8	3	2
	20	11	3	2
	20	15	3	2
	20	20	3	2
	60	1	3	2
	60	3	3	2
	60	8	3	2
	60	11	3	2
	60	15	3	2
	60	20	3	2
	90	1	3	2
	90	3	3	2
	90	8	3	2
	90	11	3	2
	90	15	3	2
	90	20	3	2
Number of experiments:				90

5.3.2 Test procedure aging experiment

The experiment is done by measuring the viscosity of 0,5 wt-% HEC at three different temperatures. HEC and water is mixed in a high-speed mixer for 10 minutes. Then the solutions are divided in to three different metal-cylinders (from a roller oven), see Figure 5. 10, and placed in different incubators that hold different temperatures. One cylinder is placed in an incubator that holds 90 °C, another in 60 °C and the last one is placed in room-temperature (20 °C). The solutions are aged for a predetermined length of time, as one can see from the test matrix. After one day are the first sets of measurements conducted. In order to be able to compare the results from the different aging temperatures are all of the solutions cooled in a water bath that holds approximately 21,5 °C. The cylinders are opened and the temperature of the solution is measured. The solution is then calmly stirred by the use of a fork or similar to mix. The viscosity of the solutions are measured both by using a Fann viscometer and the Physica viscometer. The same solutions are used for the different aging times, which means that after one set of measurement is finished are the solutions put back in the incubators for further aging.

Figure 5. 10: Metal cylinders from a roller oven.

5.3.3 Test equipment

- HEC

  HEC (Hydroxyethylcellulose) is a derivative from nonionic cellulose with hydroxyethyl groups attached to the polymer structure. HEC is used as a viscosifier in many different fluids, e.g. brines and saline fracturing fluids, completion fluids, workover fluids and drill-in fluids. The rheology becomes pseudoplastic, but there is almost no gel-strength development. HEC gives little fluid-loss control, except from its rheological effects. A high degree of substitution (from 1.5 to 2.5 out of 3 maximum) gives HEC superior solubility in water and various brines[33].
- Water
- Fann viscometer
- Physica viscometer
- Thermometer

- Metal-cylinders from a roller oven

5.3.4 Results 20 °C aging temperature

The first set of measurements conducted in the HEC + water aging experiment was done at 20 °C after some hours of settling time, until the foam that had grown on the top of the solution was gone.

5.3.4.1 Physica viscometer

The recorded values at the time = 0 at 20 °C are used as the initial shear stress and viscosity for the experiments at 60 and 90 °C as well. We will use a shear rate of 1000 s^{-1} and the effective viscosity at this rate as the value to compare for the different aging times and temperatures. The experiments are conducted at shear rates from 800 to 1400 s^{-1} in the Physica viscometer, but the recorded data are not shown in this part (but in the appendix).

In Figure 5. 11 is the viscosity at a shear rate of 1000 s^{-1} vs aging time plotted. The temperature at the solutions are 21,5 ± 0,5 °C.

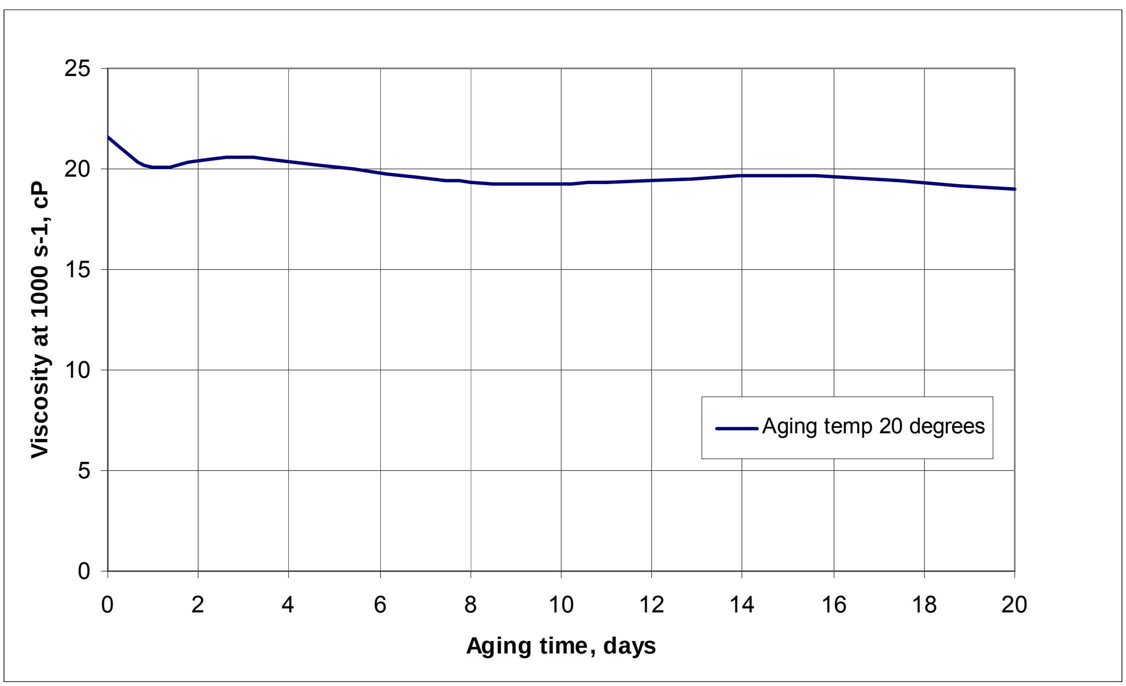

Figure 5. 11: Physica, aging effects at 20 °C.

As one can see from the plot is the viscosity rather constant at all of the aging times, with a small decrease in the viscosity at least if you compare the initial viscosity and the viscosity after 20 days of aging. The decrease from zero days to one day is most significant.

5.3.4.2 Fann viscometer

In addition to Physica were the mud properties tested in the Fann viscometer as well. The values from Physica and Fann are not comparable because the mud is not Newtonian and the plotted shear rate is not the same. In the plots from the Fann viscometer are the values at 300 rpm = 511 s^{-1} plotted vs aging time. The results from the experiments at the three different aging temperatures are shown in Figure 5. 12.

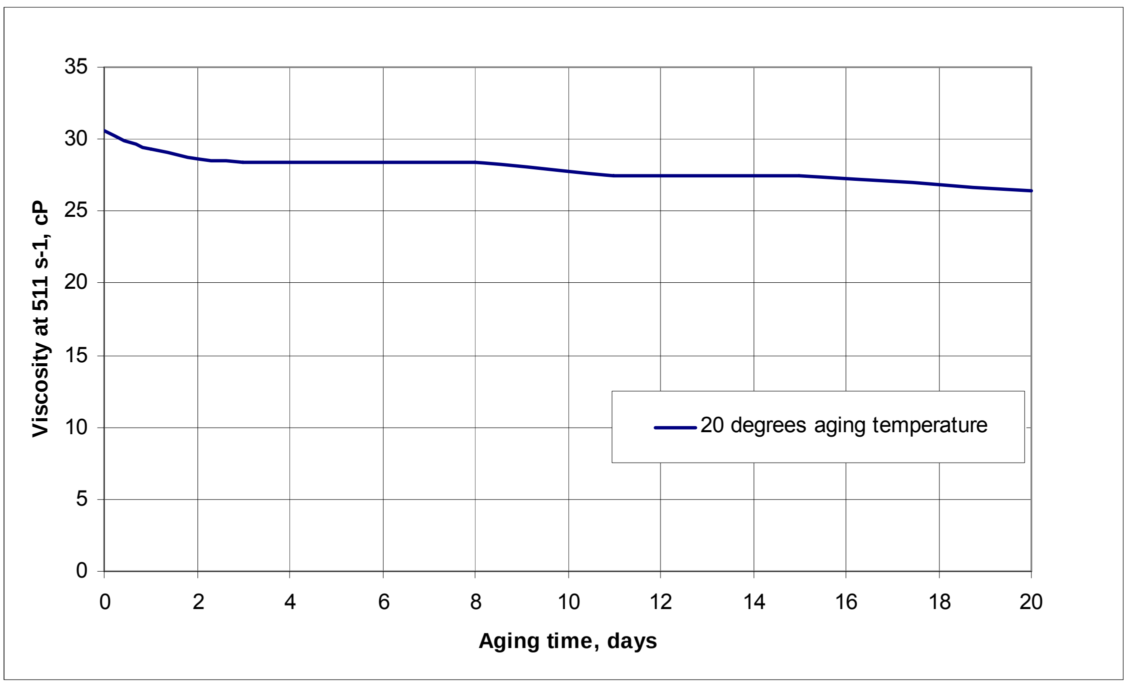

Figure 5. 12: Fann viscometer, aging effects at 20 °C.

From the figure we can see that the trend is more or less the same as for the Physica measurement. It seems to be a little decrease in the viscosity as the aging time is increasing with an initial viscosity at approximately 30 cP and a final viscosity at approximately 26-27 cP. The decreasing viscosity trend is more pronounced in the Fann viscometer measurements compared to the Physica measurements.

5.3.5 Results 60 °C and 90 °C aging temperature

The next sets of experiments are done at 60 °C and then 90 °C. As mentioned earlier are the values from the 20 °C measurement used as the initial value. The HEC + water solutions are placed in incubators at 60 °C and 90 °C for the predefined length of time (1, 3, 8, 11, 15 and 20 days). All measurements are done at room temperature (21,5 ± 0,5 °C).

5.3.5.1 Physica viscometer

A plot of the results from the three different aging temperatures is shown in Figure 5. 13.

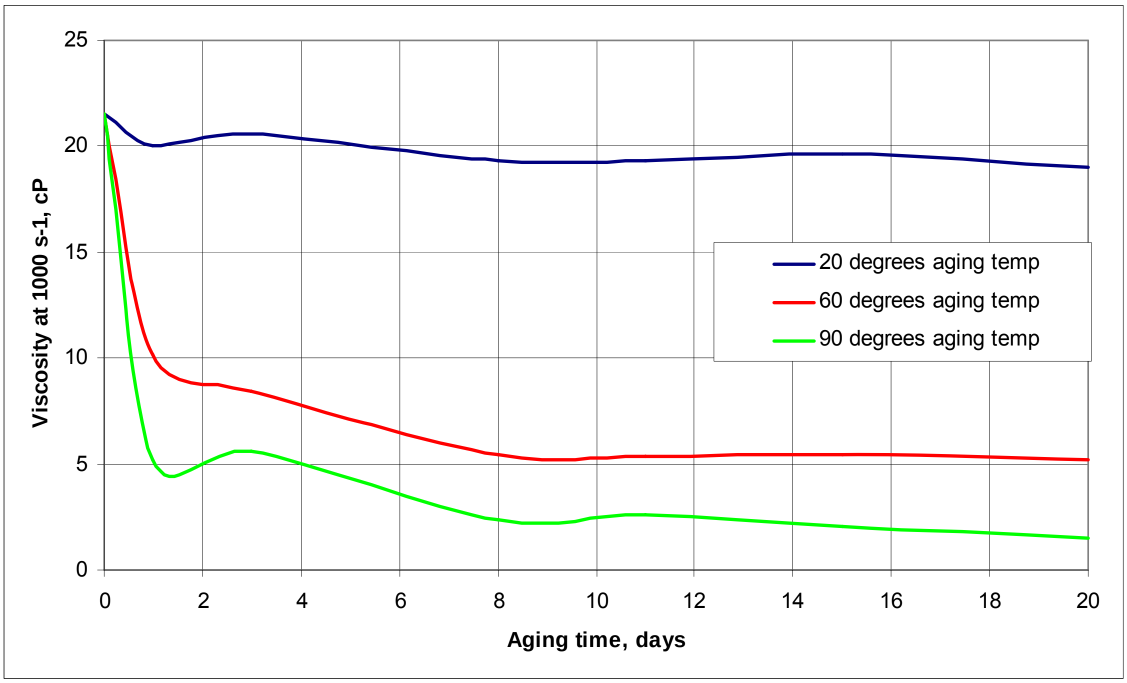

Figure 5. 13: Physica, aging effects at 20, 60 and 90 °C.

The data for 20 °C in the Physica has been commented earlier. At 60 °C aging temperature is it seen visually that the viscosity is decreasing a lot after only one day of aging, decreasing from approximately 21 cP to 8 cP. This is seen from the steep fall of the line from 0 to 1 day of aging. From 1 day to approximately 8 days of aging is there also a decrease, but not as steep as at the first day. After 8 days does it seem like the viscosity is more or less constant at about 5 cP. For 90 °C is the viscosity decreasing rapidly from 0 to 1 day of aging, starting at an initial value of 22 cP and decreasing to about 4 cP after 1 day. The viscosity is then increasing from 1 – 3 days, until it is decreasing till about 8 days and becoming more or less constant at approximately 2 – 3 cP after 8 days of aging.

The initial value for the viscosity is the same (22 cP) for all temperatures. A clear trend is that as the aging temperature increases, is the viscosity decreasing. The viscosity is more or less constant after approximately 11 days for all three cases.

5.3.5.2 Fann viscometer

A plot of the results for all the different aging temperatures is shown below in Figure 5. 14. For plots at 20, 60 and 90 °C temperature alone, see appendix.

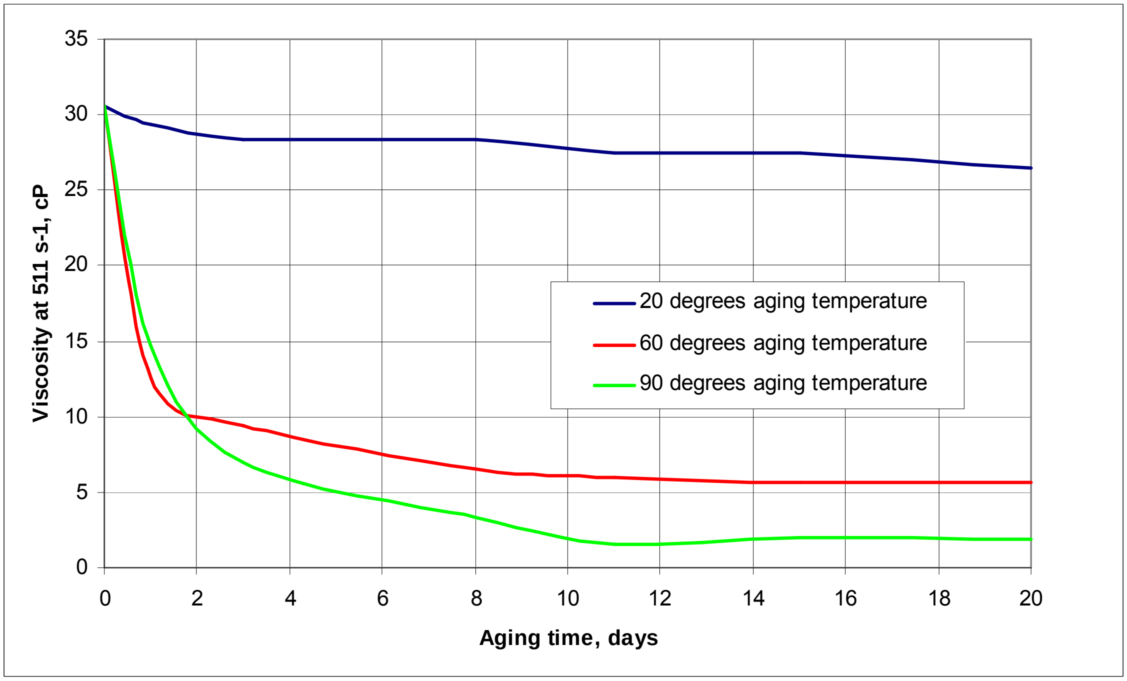

Figure 5. 14: Fann viscometer, aging effects at 20, 60 and 90 °C.

From the plot is it seen that the viscosity is decreasing quite rapidly between 0 and 1 days of aging at 60 °C and 90 °C aging temperature. In the range from 1 day to approximately 11 days is the decrease rather constant until the viscosity is constant at approximately 5 – 6 cP for the rest of the measurements for 60 °C aging. At 90 °C aging temperature does it seem like the viscosity stabilizes at approximately 2 – 3 cP after 11 days of aging.

A clear trend can be seen, as the aging temperature is increasing is the viscosity of the HEC + water- solution decreasing. The viscosity of the solution aged at 20 °C is also decreasing a little, but it is negligible compared to the 60 and 90 °C solutions.

5.3.6 Discussion HEC + water aging experiment

The results from Physica and Fann viscometer give more or less the same trends for the different aging temperatures. This indicates that the results are reliable.

When conducting measurements at 60 and 90 °C aging temperature we experienced that it was difficult to read the value on the dial in the Fann viscometer at least at the lowest RPM’s (3 and 6 RPM). This resulted in that the readings at the lowest RPM’s were neglected. A similar problem was experienced in the Physica recordings as well, where the readings at the lower RPM’s where unreliable as they fluctuated a lot. The trend for the different aging temperatures are nevertheless obvious if one look at the different plots. As the aging temperature increase is the viscosity decreasing quite rapidly. The plot of the aging at 20 °C shows a little decrease in the viscosity as the aging time increases, but it is negligible compared to the viscosity decrease in the 60 and 90 °C experiments. The plot of 60 °C aging temperature shows a rapid decrease in the viscosity after one day of aging and then a more or less constant decrease until about 11 days of aging. When the aging is longer than 11 days is the viscosity more or less constant at approximately 6 cP for both the Physica and Fann viscometer measurements. The result from the 90 °C aging temperature measurement give the same trend, but in this case is the viscosity approximately 2 – 3 cP in both Physica and Fann viscometer. The increase in the viscosity at 90 °C between 1 and 3 days is difficult to explain but may be due to liquid or room conditions (temperature).

6 Evaluation of lab results through conventional simulator

In this part we will evaluate the results from the laboratory measurements and see if the pressure and temperature effects have any practical importance. The calculations will be done by measuring the annular pressure in three ways:

- Based on the 20 °C readings
- Based on the 60 °C readings
- As a function of viscosity at the measured pressures and temperatures in Physica

The program that is used is Landmark Wellplan which is a drilling engineering software system to assist with solving engineering problems during the design and operational phases of drilling and completing wells. Wellplan is comprised of several modules including Torque Drag Analysis, Hydraulics, Well Control, Surge, OptiCem-Cementing, Bottom Hole Assembly, Critical Speed, Stuck Pipe, and Notebook[34].

In this work has the Hydraulics Analysis mode in the software been used.
"Landmark's Wellplan Hydraulics application delivers all of the analysis tools engineers need to study and design well hydraulics. Wellplan Hydraulics software enables accurate circulation system analysis. The application can be used to study ECDs with regards to pore pressure and fracture pressure problems, to select jet sizes for optimum ROP over a given depth range, and to select flowrates to optimize hole cleaning.
Wellplan Hydraulics software performs pressure-loss analysis for all parts of the circulating system, including pressure losses through pipe and annular sections, pressure losses in rig surface equipment including coiled tubing units, and pressure drop across the bit.
Wellplan Hydraulics technology is deployed on Landmark's Engineer's Data Model™ (EDM), the platform for a fully integrated suite of well engineering and data analysis products. EDM software provides one-time data entry, a system to promote best practices, and an environment for managing and accessing operational knowledge and lessons learned"; Landmark Wellplan Hydraulics[35].

Below, see Table 6. 1, is the well- properties used in the Landmark Wellplan calculations presented.

Table 6. 1: Well properties in Landmark Wellplan calculations.

Well data in Landmark			
Casing length	2000 m	**Drill collar**	
Casing ID	228,63 m m	Length	70 m
Open hole length	1000 m	OD	139,7 m m
Open hole ID	215,9 m m	ID	44,45 m m
Drill pipe		**Bit**	
Length	2928,7 m	Length	0,3 m
OD	139,7 m m	OD	215,9 m m
ID	121,36 m m		

The Landmark Wellplan calculations are divided in to four different cases with different fluid properties (measured in the Physica viscometer) and temperatures. The well property values are valid for all the cases, at least case 1, case 2 and case 3. Case 4 is a bit different and is discussed later in the chapter. The well is vertical with 3000 m MD and TVD. The density used is 1150 kg/m^3 for all four cases.

6.1 Case 1: Constant temperature 20 °C

- Constant density = 1150 kg/m^3
- Constant temperature = 20 °C in the whole well
- Physica/ Fann readings at 20 °C
- Pump rate: 0,5 m^3/min

6.2 Case 2: Constant temperature 60 °C

- Constant density = 1150 kg/m^3
- Constant temperature = 60 °C in the whole well
- Physica/Fann readings at 60 °C
- Pump rate: 0,5 m^3/min

6.3 Case 3: Temperature gradient 20 – 90 °C

- Constant density = 1150 kg/m^3

- Temperature gradient 20 – 90 °C in the well
- Fann readings at 60 °C because this is closest to the average temperature in the well
- Pump rate: 0,5 m^3/min

6.4 Case 4: Use of real values of the viscosity

- Use readings measured in Physica at different depths and temperatures
- 12 different wells with a depth of 250 m (3000 m total depth) with their own properties in Landmark
- Constant density = 1150 kg/m^3. The density variations due to compressibility and pressure differences is neglected.
- Pump rate = 0,5 m3/min

6.5 Results

In Figure 6. 1 is the results from all four cases plotted in the same plot.

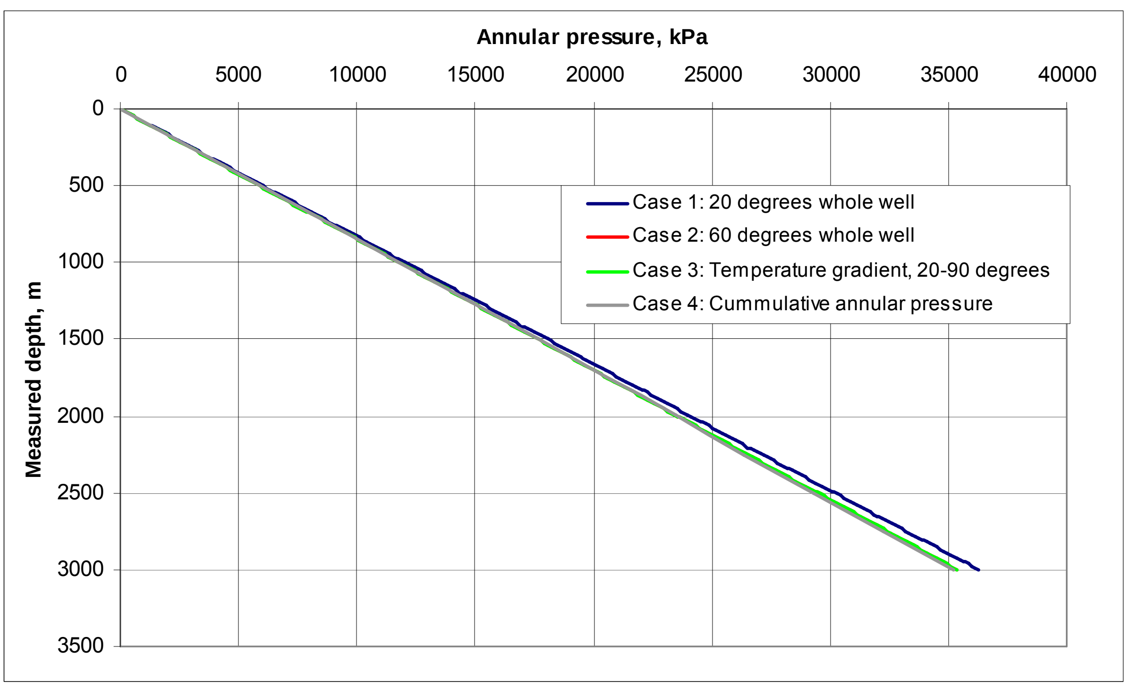

Figure 6. 1: All cases in the same plot.

As one can see is the difference between each case minimal. The highest annular pressure is seen for case 1 (constant temperature at 20 °C in the whole well). The line for case 2 is not shown because it is behind the line representing case 3. It is difficult to separate the other cases from one another as well and therefore one can conclude that the temperature in the well has little effect on the calculated annular pressure. A plot of each case (case 1, case 2 and case 3) alone is shown in the appendix.

The procedure and calculations for case 4 is shown in the following.
The temperature profile in a well is shown below in Figure 6. 2. This plot is used as the basic to know what temperature that exists at what depth. The straight line from 10 °C at surface to 100 °C at 3000 m measured depth is the static temperature gradient. The thick curved line from 40 °C at surface to 50 °C at 3000 m measured depth is the temperature in the annulus during drilling.

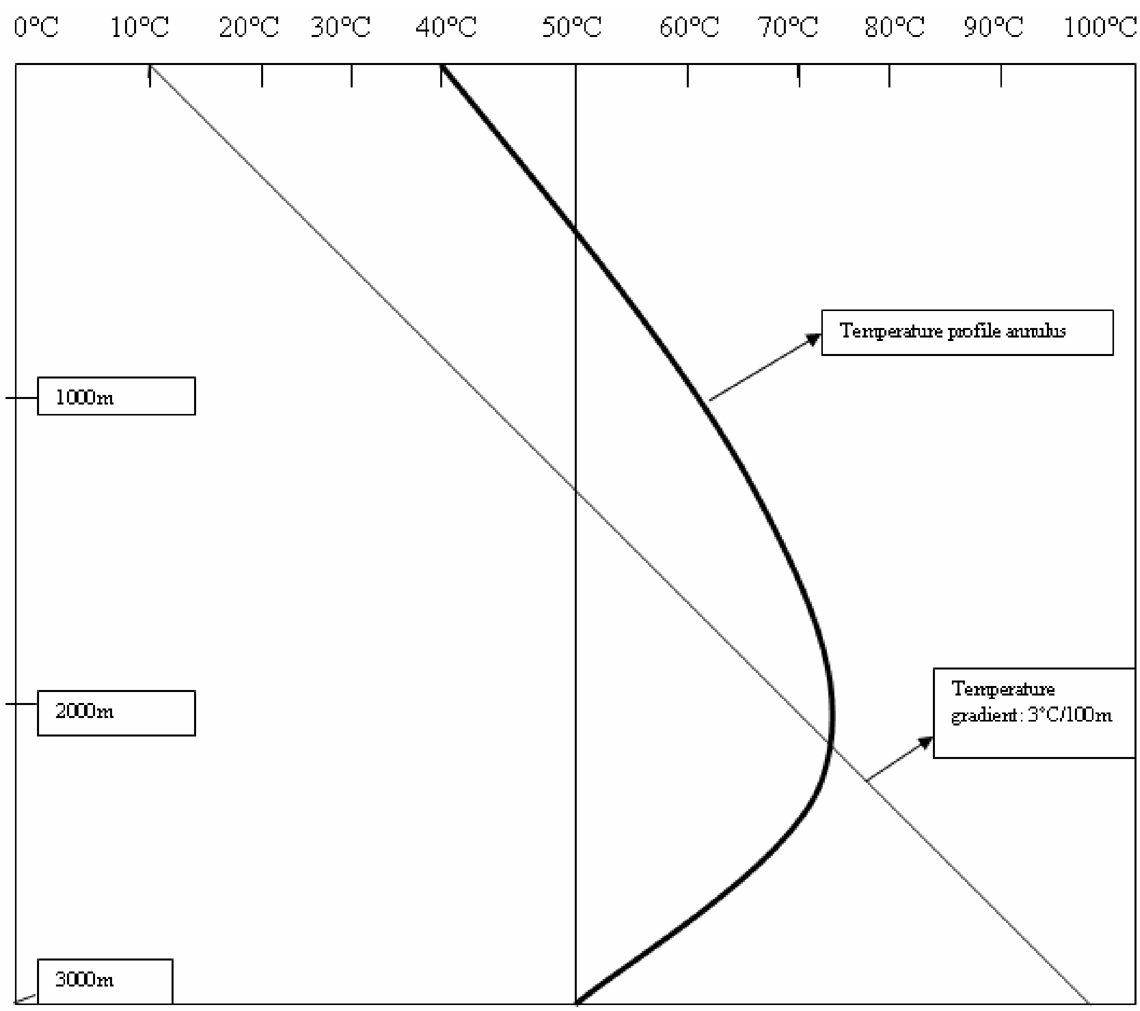

Figure 6. 2: Temperature profile in a well.

By using a similar plot as the one in Figure 6. 2 one can find the temperature at each 250 meters in the well. This is done by dividing the well in to 12 zones, each zone 250 m MD, and read the average temperature at every 250 m depth. The *MD-column* in Table 6. 2 is the average depth in each zone, while the *Temp-column* is the corresponding temperature in this zone. The last four columns are the calculated dial readings from the recorded data in the Physica viscometer in to Fann readings. This calculation is done in order to be able to type Fann readings in the fluid editor in the Landmark Wellplan program. By doing this we take into account that the fluid changes its properties as it is exposed to different temperatures in the well.

Table 6. 2: Temperature and reading values at different depths in the well.

Interval [m]	MD [m]	Temp [°C]	Readings			
			235RPM	352RPM	528RPM	705RPM
0 - 250	125	43	27,4	32	38,7	45,5
250 - 500	375	48	25,9	30,4	36,7	43,1
500 - 750	625	53	24,8	28,9	35	41
750 - 1000	875	58	23,5	27,5	33,4	39,2
1000 - 1250	1125	61	23	26,9	32,8	38,3
1250 - 1500	1375	65	22,4	26,2	31,8	37,3
1500 - 1750	1625	68	22	25,9	31,3	36,8
1750 - 2000	1875	69	22	25,8	31,1	36,6
2000 - 2250	2125	70	21,9	25,7	31	36,5
2250 - 2500	2375	66	22,2	26	31,7	37
2500 - 2750	2625	63	22,8	26,5	32,2	37,7
2750 - 3000	2875	55	24,2	28,2	34,3	40,2

The reading values from Table 6. 2 is plotted in Figure 6. 3. We see that all of the four lines have the same trend, which indicates that the readings are concurrent in representing the properties of the mud at different temperatures.

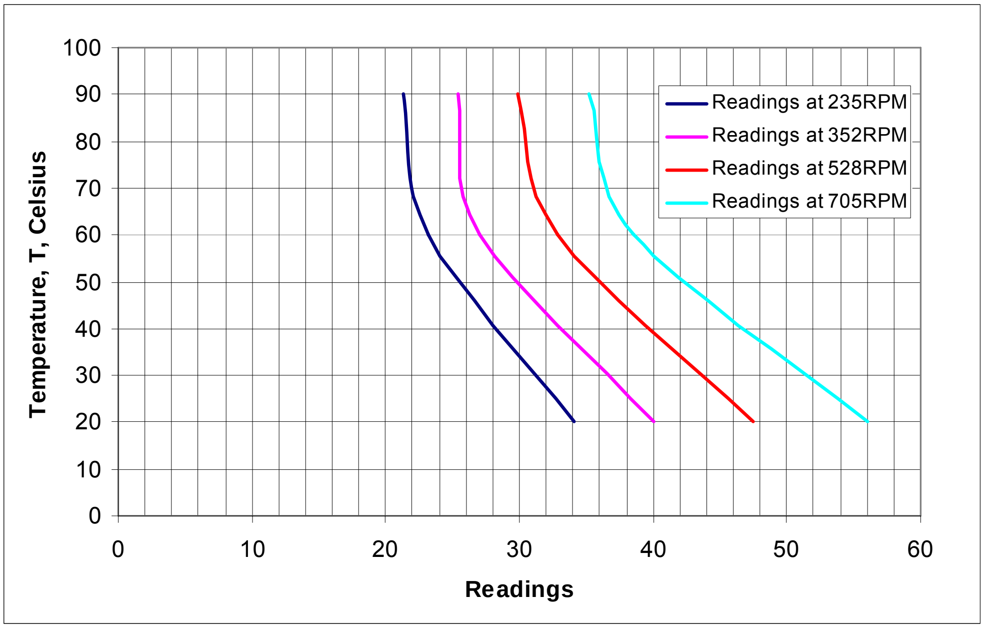

Figure 6. 3: Plot of readings at different RPMs vs. temperature.

In Figure 6. 4 is a plot of the viscosity at 1000 s-1 plotted vs. temperature. The data used to make the plot is presented in Table 6. 3, recorded in the Physica viscometer. The values have been converted in to "real" values for the viscosity by using the function found in the calibration part of the experiment. The viscosity at different depths is found by the corresponding temperature at the specific depth and then the viscosity is read from the plot. The viscosity is important in order to find the Reynolds number which is supposed to be less than ~1800, in order to have a laminar flow.

Table 6. 3: Data for the plot of viscosity at 1000 s^{-1} vs. temperature.

Temp [°C]	Eff viscosity, 1000 s-1 [cP]
20	37,86
60	24,84
90	22,06

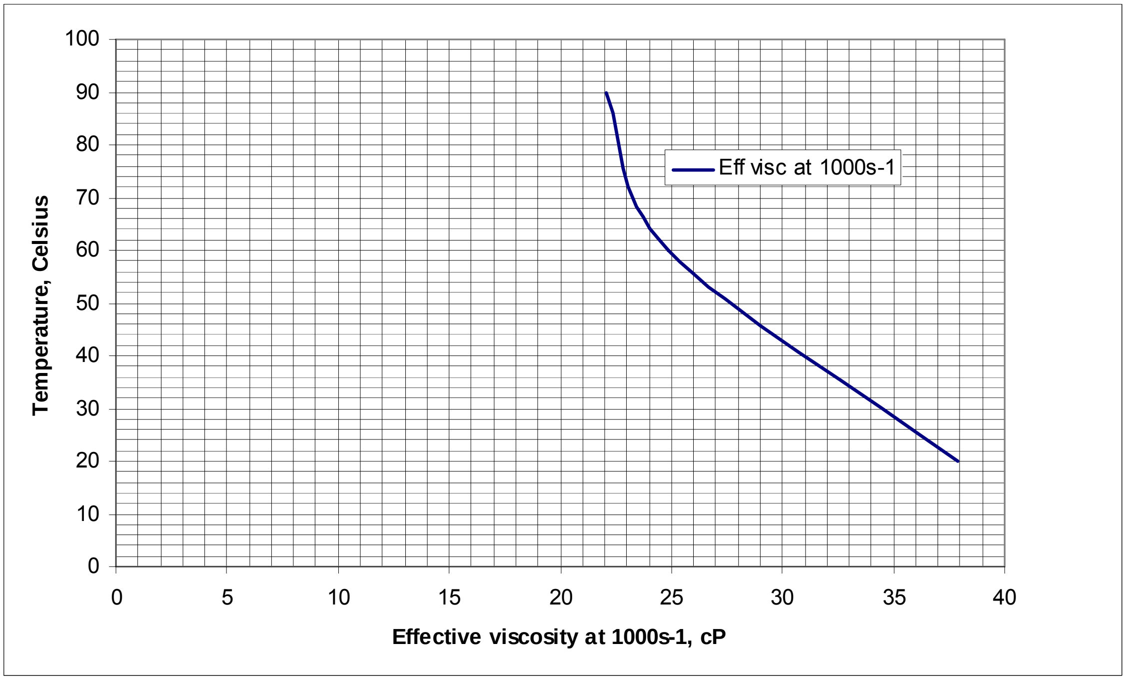

Figure 6. 4: Effective viscosity at 1000 s^{-1} vs. temperature.

Below is the different formulas used to find the necessary parameters been listed in eqn 6.1 – 6.7.

$$A = \pi \frac{(d_o^2 - d_i^2)}{4} \tag{6.1}$$

$$N_{Re} = \frac{\rho v(d_o - d_i)}{\mu_{eff}} \tag{6.2}$$

$$q = A * v \tag{6.3}$$

$$v = goal \text{ seek in order for q} = 0{,}5 \frac{m^3}{\min} \tag{6.4}$$

$$N_{Re} < 1800 \tag{6.5}$$

$$d_o = outer \text{ diameter (casing or open hole)} \tag{6.6}$$

$$d_i = inner \text{ diameter (drill string or drill collar)} \tag{6.7}$$

In Table 6. 4 different calculated values for some of the parameters used in case 4 are shown. As one can see from the column N_{Re} are all the values below 1800. The pump rate has to be the same in all zones. The values that varies for each zone is the effective viscosity (because of the temperature variations), Reynold's number and in some occasions the OD (outer diameter), ID (inner diameter), annular area and annular velocity. The table is made to be sure that the flow is within the criteria for laminar flow in all of the zones. The fixed pump rate at 0,5 m^3/min is the maximum rate because a higher rate would have increased the Reynold's number too much, leading to that the flow would become turbulent instead of laminar.

Table 6. 4: Calculating table for different parameters used.

Interval [m]	Temperature [°C]	N_{Re} [-]	OD [m]	ID [m]	A annulus [m^2]	v annulus [m/s]	Eff viscosity [Pas]	Density [kg/m^3]	Pump rate [m^3/s]	Pump rate [m^3/min]
0 - 250 m	43	1165,2	0,22441	0,127	0,0269	0,30996	0,030	1150	0,00833	0,5
250 - 500 m	48	1226,9	0,22441	0,127	0,0269	0,30996	0,028	1150	0,00833	0,5
500 - 750 m	53	1310,3	0,22441	0,127	0,0269	0,30996	0,027	1150	0,00833	0,5
750 - 1000 m	58	1367,0	0,22441	0,127	0,0269	0,30996	0,025	1150	0,00833	0,5
1000 - 1250 m	61	1417,3	0,22441	0,127	0,0269	0,30996	0,025	1150	0,00833	0,5
1250 - 1500 m	65	1458,9	0,22441	0,127	0,0269	0,30996	0,024	1150	0,00833	0,5
1500 - 1750 m	68	1477,6	0,22441	0,127	0,0269	0,30996	0,024	1150	0,00833	0,5
1750 - 2000 m	69	1483,9	0,22441	0,127	0,0269	0,30996	0,023	1150	0,00833	0,5
2000 - 2250 m	70	1562,1	0,20825	0,127	0,0214	0,38953	0,023	1150	0,00833	0,5
2250 - 2500 m	66	1535,7	0,20825	0,127	0,0214	0,38953	0,024	1150	0,00833	0,5
2500 - 2750 m	63	1497,8	0,20825	0,127	0,0214	0,38953	0,024	1150	0,00833	0,5
2750 - 3000 m	55	1399,9	0,20825	0,127	0,0214	0,38953	0,026	1150	0,00833	0,5

6.6 Discussion Landmark Wellplan simulator experiment

As one can see from Figure 6. 1 is the difference between each case minimal. The highest annular pressure is seen for case 1 (constant temperature at 20 °C in the whole well). The line for case 2 is not shown because it is behind the line representing case 3. It is difficult to separate the other cases from one another as well and therefore one can conclude that the temperature in the well has little effect on the calculated annular pressure.

When running case 4, we have used the same mud density in the whole well. This might be wrong, but if we were to calculate a new density for each of the 250 m intervals we would have to take both the compressibility and volume changes into account. We found that this would be too much in this thesis and neglected these effects. It is though obvious that it might be a potential source of error.

7 Discussion

We thought it would be easier than expected to implement the laboratory experiment. It was more parameters to take into account than we realized before the experiment was started. We experienced some challenges, e.g. how much HEC to add to the water, readings on the differerent viscometers and to know what values that should be used for the viscosity in the calculations.

Some of the results from our laboratory measurements are compared to others work below. The main conclusion is that the trend in our results is more or less the same as the one experienced in earlier studies.

Ali and Al- Marhoun[25] found that the effective viscosity, plastic viscosity, yield and gel strengths decreased gradually with the increase in temperature for different values of aging time. The changes in the rheological properties are explained by the adding of lime and gypsum to the mud system. The experiments showed that the aging effects were diminishing with the increase in time. This is in agreement with what we observed in our experiments.

Salimi et al.’s[27] first set of experiments conducted at different pressures and temperatures showed that for all nine polymer- extended muds were a decrease in shear stress observed when either the pressure or the temperature was increased. It was found that the effect of temperature was more severe than the effect of pressure. The third set of measurements by Salimi et al. was done to find the effects of pressure and temperature on the apparent viscosity. For the polymer extended muds was a drop in the apparent viscosity observed at all three concentrations used. These results are comparable to what we found in the laboratory measurements conducted at the student laboratory at NTNU. The pressure effects were negligible compared to the effect of temperature. As the temperature increased did the shear stress (and thereby the viscosity) decrease in the experiments on the drill- in mud.

The results from Briscoe et al.’s[28] laboratory work showed that the plastic viscosity values tended to increase as the pressure increased for all of the different muds studied at 20 °C. The changes were though small. At higher temperatures (50 – 120 °C) they did find that the effect of applied pressure on the rheological properties to be much larger. In our experiments we did not find any clear relations between pressure and higher temperatures. What we experienced was that the effect of pressure seemed to be more significant at low temperatures (at 20 °C).

The differences between published findings and our, can be related to sources of error in the laboratory work, and might be summarized as follows:

- Inaccurate measurements:
    - Regarding the temperature of the solutions and differences in room temperature.
    - The use of stop watch to measure the migration time for the oil in the ubelohde.
- Temperature measurements:
    - For the experiments at 20 °C, 60 °C and 90 °C. The temperature differences at each temperature might be small but we are not absolutely sure on what effects the small temperature differences have on the rheological properties.
    - The temperature in the measuring cell is measured outside the Physica viscometer itself. The indicator on the water bath is not reliable as the heat loss in the water- tubes are significant.
- Internal friction in the apparatuses at very low shear rates. Mostly in the Physica viscometer but also in the Fann viscometer.
- Readings. Both in the Fann viscometer- the needle goes back and forth, especially for low RPMs, and in Physica where the recorded shear stress varies a lot at the same shear rate.
- The calculations of the “real” viscosities from the measurements in Physica and Fann viscometer by the use of the equations found from the plots of $\mu_{Physica}$ vs $\mu_{ubelohde}$ and μ_{Fann} vs. $\mu_{ubelohde}$, due to poor fit at some of the ranges.

Improvements that can be made in order to obtain more realistic results may be:

a) To use solutions with higher viscosities. By doing this it would be easier both to measure in the Fann viscometer as well as in the Physica viscometer.
b) Perform measurements inside an incubator or a room where the temperature is constant.

c) To use a commercial calibration liquid with a known viscosity in order to calibrate the viscometer readings according to the values from this liquid. The measurements used as calibration from the ubelohde were mixed by us and are not absolutely correct.

8 Conclusion

Based on the results obtained in the laboratory and an evaluation of fluid implication on well pressure, the following conclusions can be drawn:

1. Laboratory experiments are very educational. To learn that reality is not straight forward to measure was enlightening.
2. There were too many sources of error involved to draw final conclusions, especially the uncertainty in the rheology.
3. The viscosity is very dependant on the temperature.
4. In the aging experiments is the viscosity decreasing more rapidly when the temperature is high (naturally).
5. Most of the viscosity decrease takes place during the first day of aging. After one day is the viscosity decrease much less.
6. The effect of pressure on the rheological properties is negligible. We did not experience any differences in the viscosity at 1, 40 or 80 bar at any of the temperatures.
7. The annular pressure differences calculated with Landmark Wellplan did not show any significant differences for the different well temperatures. It is difficult to separate the different cases from one another in the plot of annular pressure vs. depth.

9 Nomenclature

A	Area	[m^2]
D	Diameter	[m], [μm]
ECD	Equivalent circulating density	[kg/m^3]
G	Gravity constant	[m/s^2]
Q	Flow rate	[m^3/s]
r	radius	[m], [μm]
V	Volume	[m^3]
γ	Shear rate	[s^{-1}]
ρ_m	Density fluid	[kg/m^3]
T	Tau, shear stress	[Pa]
T_y	Yield stress	[Pa]
μ	Viscosity	[cP], [Pas]
μ_{pl}	Plastic viscosity	

10 Abbrevations

ERD	Extended Reach Drilling	
HEC	Hydroxyethylcellulose, Viscosifier	
HPHT	High Pressure High Temperature	
MW	Mudweight	[kg/m^3]
N_{Re}	Reynold's number	
OBM	Oil Based Mud	
WBM	Water Based Mud	
MD	Measured depth	[m]
TVD	Total vertical depth	[m]
RPM	Rotations per minute	
VSVA	vinylsulfonate/vinylamide	
XC	Xanthan Gum	
NaCl	Natrium Chloride	
PHPA	Partially-Hydrolysed Poly Acrylamide	
CMC	Carboxy Methyl Cellulose	
OFU	Oil Field Units	

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Appendix

In this appendix we have implemented some of the tables and plots that we did not include in the main part of the diploma thesis. The plots and tables are mainly from the laboratory work and from the Landmark Wellplan calculations. Two manuals on the Physica HPHT viscometer have been included, as well as a student exercise based on the laboratory and Landmark calculations in this diploma thesis. The appendix is divided in different sections named A.1 to A6.

A.1 Manuals for the Physica viscometer
A.2 Recorded data aging experiment
A.3 HPHT experiment on drill- in mud
A.4 Landmark
A.5 API Recommended Practices
A.6 Student exercise on the HPHT viscometer and Landmark calculations

A.1 Manuals for the PHYSICA viscometer

In this part we have implemented two manuals that we have made during the thesis work regarding the use of the Physica viscometer. The laboratory did not have any useful manuals on this apparatus. We have made one manual on Manually operation and another on PC operation of the Physica HPHT viscometer

A.1.1 Manually operation of the PHYSICA viscometer

General information:
The viscometer should be turned on for at least 30 minutes at 1000rpm before measurements are started in order for the engine to get its desired temperature due to the need for minimizing the mechanic friction. This is a minimum when liquids with viscosity in the range of 0 – 50 cP is used.

The viscometer is not very accurate when it comes to viscosity- measurements of liquids with low viscosities (<50cP). It is though no problem to measure on liquids down to 10 cP.

R_a = radius bob
R_i = radius cup

When the shear rate, D, increase will the torque, M, increase and the viscosity will decrease for a non-Newtonian liquid (mud).
For a Newtonian fluid (like 2-stroke oil) will the viscosity be constant when the shear rate is increased. This will be shown as a straight line in a plot of shear stress vs. shear rate.

With the current bob and cup (called CC23PR) available in the student laboratory one can perform measurements of liquids (also with particles) with effective viscosities above a certain (maybe 10cP) threshold.

The possibilities mentioned below are extras and not currently available in the laboratory:

If you want to conduct measurements with EXXSOL D-60 (1,5cP), then another bob has to be used. This bob (CC26, b1) is not currently available in the student laboratory at NTNU. With this bob is the gap between the cup and the bob smaller which makes it more suitable for viscosity measurements in low-viscosity-liquids without particles. This bob might be used to measure the viscosity at T=90ºC and P=200bar. If you change the bob you have to change the shear stress (and maybe shear rate) factors in both the viscometer and in the software of the PC.

Another possibility is to remove the pressure cell and replace it with a larger cup and bob. This might be done to get accurate measurements of low-viscosity-liquids without pressure and temperature.

Checking of parameters and adjusting the instrument

Mount the apparatus as described in the manual from the manufacturer.
Turn on the PHYSICA-viscometer with the on/off- button on the back of the instrument. Then it is shown some information in the display for a few seconds until the main menu is shown:

-----------------MAIN MENU-----------------------

PROGRAM	MANUAL
REMOTE	PROG. INPUT
SETUP	DOWNLOAD

One may switch between the different options by using the ▶- button. This button is also used to move one step to the right when different parameters are adjusted.

The ▲-button is normally used to either scroll in a menu or to go back to the previous menu (one step "up" in windows). It is also used to change values when editing shear rate, speed, parameters etc.

The OK- button is used to confirm the values you set. It is also used as to "move to the next step" and confirm parameters.

The ST-button is used to start and stop measurements and sometimes to "move a step up".

Measurement system MS1 CC 23PR is used for the cup and bob that is available in the laboratory. Each measurement system consists of two factors, one shear stress and one shear rate respectively. The factors for MC1 CC 23PR are:

Shear stress, T, [Pa] = 1,4099534
Shear rate, D, [1/s] = 1,2854875

n * shear rate factor = D [1/s]
M (torque) * shear stress factor = T [Pa]

$$\frac{\tau}{D} = viscosity$$

NOTE: The viscometer should be turned on for at least 30 minutes at 1000rpm before measurements are started in order for the engine to get its desired temperature and to minimize the mechanic friction. This is a minimum when liquids with viscosity in the range of 0 – 50 cP is used.

If the viscometer indicate a viscosity that has to be wrong for a liquid with a known viscosity, it is possible to adjust the shear stress factor T = 1,4099534 [Pa] manually on the viscometer. This is done by (it is though not a recommended practice and should only be done if it is the last option):

- Choose SETUP in the MAIN MENU (click the OK-button)

MEAS.SYS	ADJUST
POW.CHECK	ID-NO.
DATE/TIME	SERVICE

- Then choose Meas. Sys. (click OK)
- Enter the password 0987 (click OK)
- Then click OK (then the factors will be displayed)

------------MEAS. SYSTEMS--------

MS-No. :	01
MS-Name:	CC23PR

- The factors for the different measurement systems can be displayed and corrected by simply using the ▲-button. MS 01 is the system that is most used and these factors are the one you may want to correct.

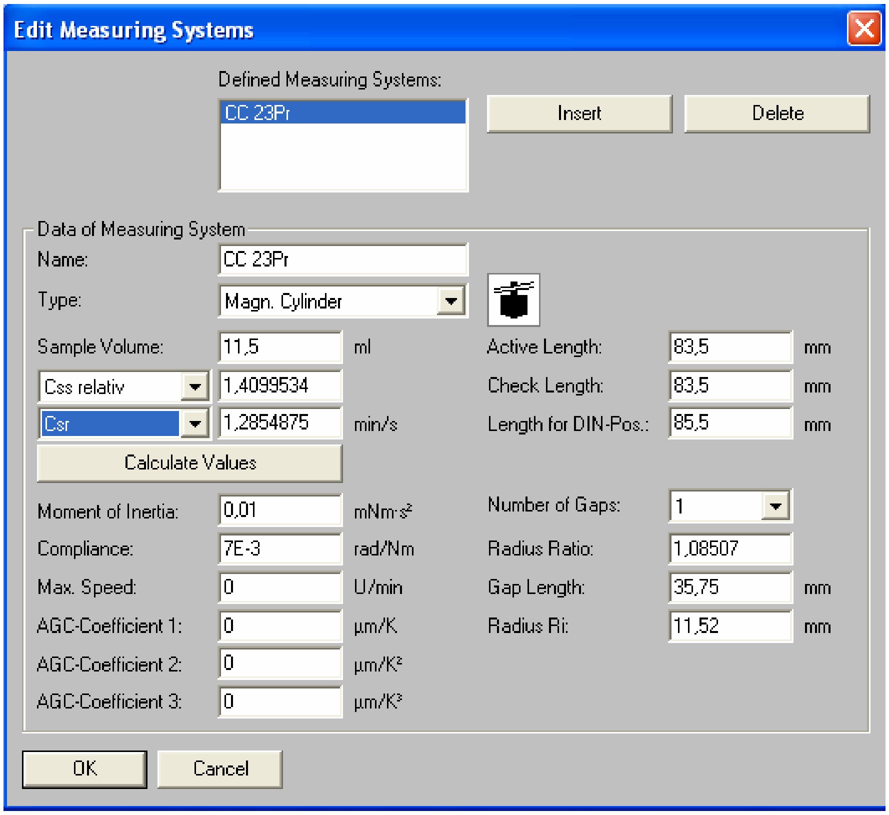
  In this mode is it possible to create new measurement systems with different factors for the shear stress and the shear rate.
  Click OK to display the factors of the chosen measurement system.

  The following window will then be displayed if you choose MS 01:

MS-No.:	01
MS-Name:	CC23PR
[Pa]	0001,40995
[min/s]	0001,28548

These values are given from the manufacturer and are valid for MS 01, CC23PR only.
If you want to change the viscosity-measurements, that is if you believe that the instrument give wrong values then you can change the shear stress factor T = 1,40995 Pa to be either higher or lower.

The factors are also found in the software (see the manual for “operation of the PHYSICA viscometer from PC” to see how they are found in the software.



- To get back to the main menu click OK a number of times until the following is shown in the display:

----------MEAS. SYSTEMS--------

MS-No. :	01
MS-Name:	CC23PR

- Then click ST and the SETUP menu will appear:

-----------------SETUP----------------

MEAS.SYS	ADJUST
POW.CHECK	ID-NO.
DATE/TIME	SERVICE

<u>Internal friction- Adjustment of the apparatus</u>

The adjustment should be done approximately every 3 months.
Make sure that the bob and cup is connected as if measurements were to be conducted, but do not have any liquid in the cup.

- Select SETUP from the MAIN MENU

-----------------SETUP----------------

MEAS.SYS	ADJUST
POW.CHECK	ID-NO.
DATE/TIME	SERVICE

- Then choose ADJUST (click OK)

Then the following message will appear in the display:
"See MC1 manual for correct handling! Press OK to continue"
Then click OK. The following will be displayed:

-------ADJUST---------

Act.: 9‰ / 28‰ Press OK to start friction adjustment

Then follow the procedure given in the display. The internal friction adjustment last for about 15 minutes.

<u>Cleaning of the bob, cup ad pressure cell</u>

Dismount the pressure cell by using an Allen key (umbraco). Wipe off the visible dirt from the parts. If the bob is moving too slow, it might be necessary to dismount the two ball-bearings. The ball-bearings might be cleaned by the use of toluene or soap/ water. After cleaning it can be a tips to lubricate the ball-bearings with a thin oil.

How to perform measurements in the PHYSICA viscometer

As said earlier is it important to run the instrument for at least 30 minutes at 1000rpm in order for the engine to get is "working temperature" and to minimize the friction in the engine.

There are different parameters that you can choose from to give the measurements you want. The parameter that is most commonly used is the shear rate. An instruction of how to measure the viscosity by adjusting the shear rate is given below:

In the main menu:

-----------------MAIN MENU----------------------

PROGRAM	MANUAL
REMOTE	PROG. INPUT
SETUP	DOWNLOAD

Choose MANUAL. Then the following window will show:

-----------------MANUAL----------------------

START	INPUT
DISPLAY	MEMORY
PRINT	

Choose INPUT. Then the following is displayed:

-----------------MANUAL INPUT-------------------	
T	M
D	n
Select Set Variable	

Choose D as set variable (click OK).

-----------------MANUAL INPUT-------------------
MS : 01 CC23PR
Time t: 00028 s
Rate D: 01000,00 1/s

In this menu one may change measurement system, the time for the measurement, and the shear rate. The time and the shear rate have limitations according to maximum and minimum value. If too high or too low value is selected the viscometer will make a sound that indicate that the value is out of boundary.
With the values given above will the measurement last for 28 seconds at a shear rate of 1000 1/s and measuring system MS 01 CC23PR.

When the desired values are chosen (by clicking OK) a question of what the sample should be saved as appears.

---------MANUAL INPUT------

Sample: "G1R1D T"

Click OK to confirm the sample name. Then the MANUAL-menu will be displayed again.

-----------------MANUAL-----------------------

START	INPUT
DISPLAY	MEMORY
PRINT	

Choose DISPLAY. In this menu one choose the parameters that should be displayed during the measurements. One may chose up to 4 different parameters. As a rule of thumb should always M (torque) be chosen because this indicates if the measurements is in the range for "reliable measurements", meaning that the torque always should be in the range of 0,05-50 mNm. If the torque is less the measurements may be inaccurate. The DISPLAY.window is looks like this (click OK when the following message occurs: Select display vars with OK, clear with ST, leave with ▲.)

T [Pa]	M [‰]
D [1/s]	N [rpm]
t [s]	ή [mPas]
T [ºC]	ή [Pas]

To delete all selected variables click ST. To choose the desired variables click OK. The one you choose will have a number 1-4 beside. When you have chosen up to 4 variables you leave the menu by clicking ▲. The MANUAL menu will be displayed.

Choose START (click OK), then the following will be displayed:

-------------FREE MEMORY--------------------

Memory needed: 2

```
Memory free:                    1868 (example)
Press OK to continue
```

Press OK to start the measurements. The following window will be displayed.

```
--------MANUAL----------------
PR OFF/ME ON  /PI ON
MS    : 01       CC23PR
Press ST to start
```

Press ST to start the measurements. A typical measuring-widow will be as follows, but it depends on what variables chosen:

```
D    : 1000,00 1/s
M   :     48,9   ‰
ή    :    68,9   mPas
T    :     22,1   ºC
```

This test shows that the viscosity of the liquid in the cup is 68,9 mPas at a shear rate of 1000 1/s and a temperature of 22,1 ºC.

Temperature regulation

- Start the water bath and set the desired temperature.
- Heat up the measurement-cell by mounting the electrical cable to the contact beneath the measurement cell
- The temperature in the measurement cell is shown in the display of the PHYSICA viscometer. Start the PHYSICA viscometer manually by choosing:

```
->MANUAL
   -> INPUT (click OK)
      -> D (click OK)
         -> MS 01, t =10000s, Rate=10001/s (clickOK)
            ->sample: G1R1D  T (click OK)
                -> START (click OK)
                    ->FREE MEMORY…  (click OK)
                        ->-----------MANUAL----------------
                          PR OFF/ME ON  /PI ON
                          MS    : 01       CC23PR
                          Press ST to start

                              ->Click [ST] to start
```

Then the temperature (and other parameters will be displayed)

Wait until the desired temperature is achieved and then move the electrical cable from beneath to the connector that is mounted on the measuring cell.

Pressure regulation

Before conducting experiments at elevated pressures make sure that all parts of the apparatus is mounted properly and that all connections are screwed accurately. To perform measurements using pressure one has to have a pressure bottle (nitrogen) available. The high pressure cable is connected to the pressure bottle and the pressure cell on the apparatus. The pressure is adjusted by the manometer on the pressure bottle.

Pressure limitations: 100 bar at 300ºC
150 bar at 20ºC

A.1.2 PC-control of PHYSICA HPHT viscometer

The software that is installed on the computer today (April 2007) is called **US200, v-2.30.** By using this software you are able to run the PHYSICA viscometer from a computer.

For temperature and pressure regulation, see in the Manually operation of the PHYSICA viscometer paper.

How to start the program

Start up the computer:

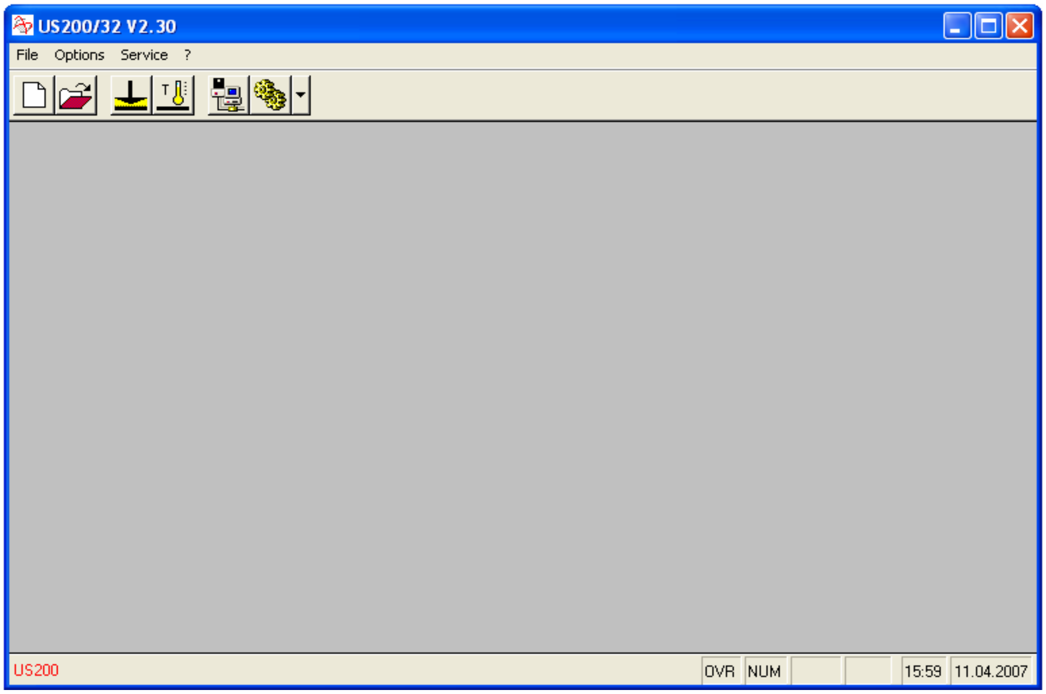
Username: Administrator
Password: physica
Log on to: IPT-…..(This computer)

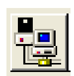
In the desktop-mode:
START
-> Programs -> Physica -> US200

How to connect the PHYSICA viscometer to computer:

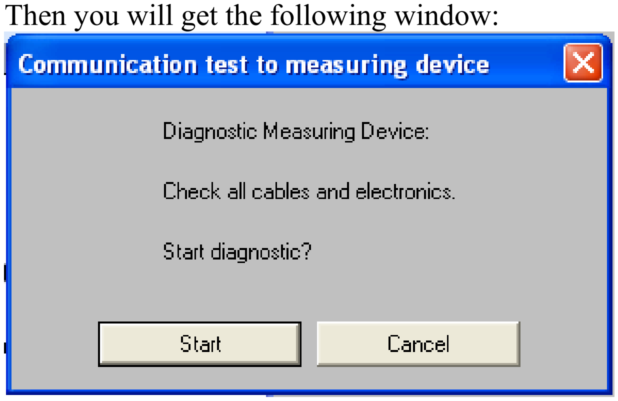
Turn on the viscometer and make sure it is in it in REMOTE –mode.

From the US200 menu in the PC:



Click on the symbol:  (Communication test to measuring device)

Then you will get the following window:



Click on the Start-button. If everything is OK with the connection between the PC and the viscometer, then the following message will be shown:

Click the OK- button.

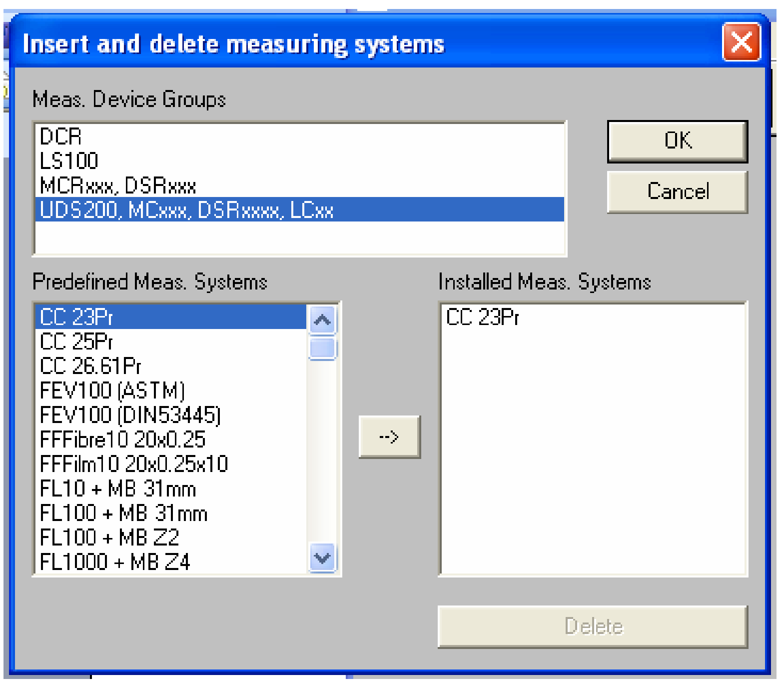
To choose the desired measuring system

Different measuring systems are used depending on the diameter and type of bob and cup that is mounted on the PHYSICA viscometer. By now (April 2007) there is only one kind of cup and bob available in the laboratory, called the CC 23PR.

To install the desired measurement system for the bob and cup, one might do as follows:

Note: This is most likely not necessary to do as the proper measurement system is already installed on the computer! It might be necessary if the software has been reinstalled or if different cups and bobs are available etc.

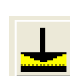
In the main window of US200/32 V2.30 click on the ***Service***- button. Then choose ***Measuring systems*** and ***Install.*** Then the following window will be displayed:

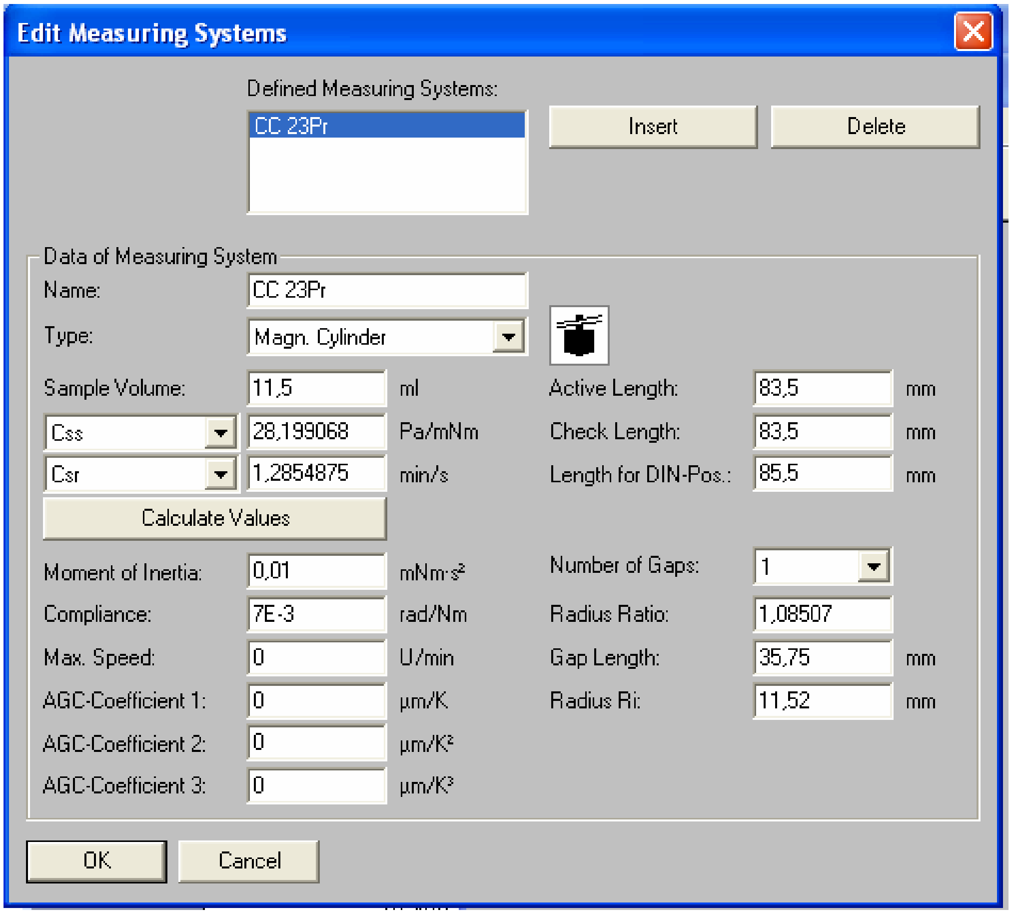


Choose ***UDS200, MCxxx, DSRxxxx, LCxx*** in the *Meas. Device Groups* and then choose ***CC23Pr*** from the *Predefined Meas. Systems* and click on the arrow so that the ***CC23Pr*** appears in the window *InstalledMeas. Systems.* Then click OK in the top right corner.

As the desired measurement system is installed, one can check and correct the predefined values given from the manufacturer as follows:

Edit measuring system

In the main window of the US200/32 V2.30 click on the icon  (Edit Measuring System). Then the following window will be displayed:

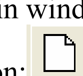


Note: As it is only one measuring system installed by now, there is only one Defined Measuring System, CC23Pr. If other measurement systems are installed there will be more Defined Measurement Systems to choose from.

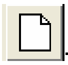
The values shown here is only valid when you run the PHYSICA viscometer from the computer. If you are to run the PHYSICA viscometer manually the value for Css (shear stress) is different. To find out how to check the values for shear stress and shear rate on the viscometer take a look in the manual for operating PHYSICA viscometer manually.

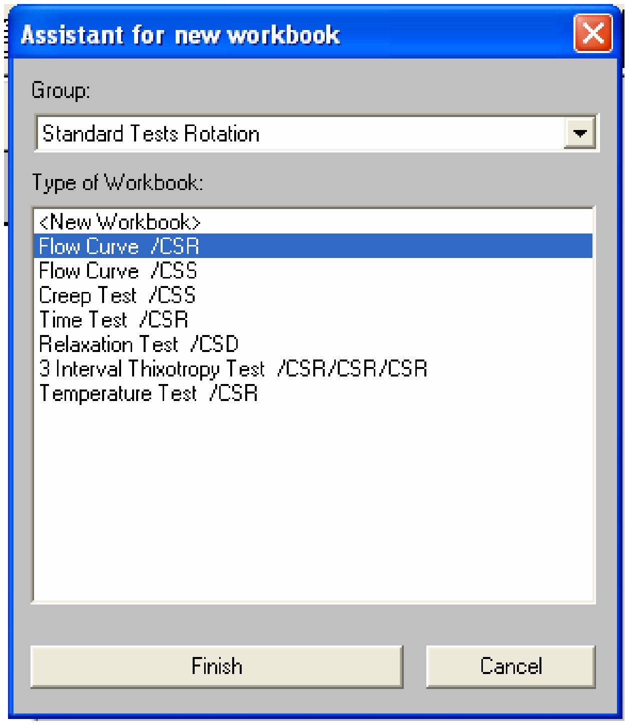
Note: If you find out that the viscometer is giving too high or too low viscosities when measuring the viscosity of a known liquid, then you may correct the Css-constant either higher or lower depending on the measurements. The values shown above are the values from the manufacturer and they are predefined for the specific cup and bob, CC23Pr, in the laboratory.

Create or open an existing workbook:

There are two options according to what you want to do from the main window in the computer program. One opportunity is to create a new workbook (icon: ), the other one is to open an existing workbook (icon: ).

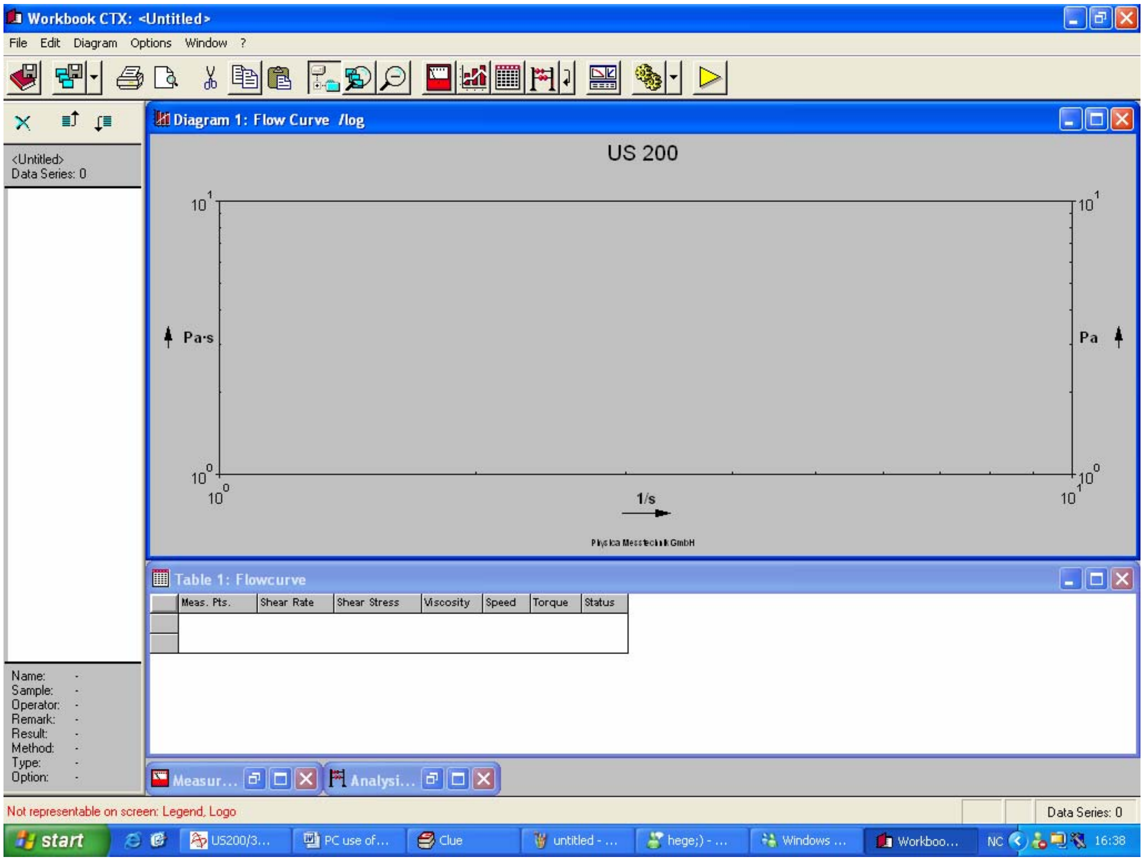
To create a workbook:

Click on the -icon. Then the window shown below will be displayed. The different options are basic workbooks depending on what to measure. The typical setup to choose is either **Flow curve /CSR** or **Flow curve /CSS.**
Flow curve /CSR is used when shear rate is the defining parameter, meaning that the shear stress is measured while **Flow curve /CSS** is chosen when shear stress is defined and the corresponding shear rate is to be calculated.



Example: Choose **Flow curve /CSR and click** 

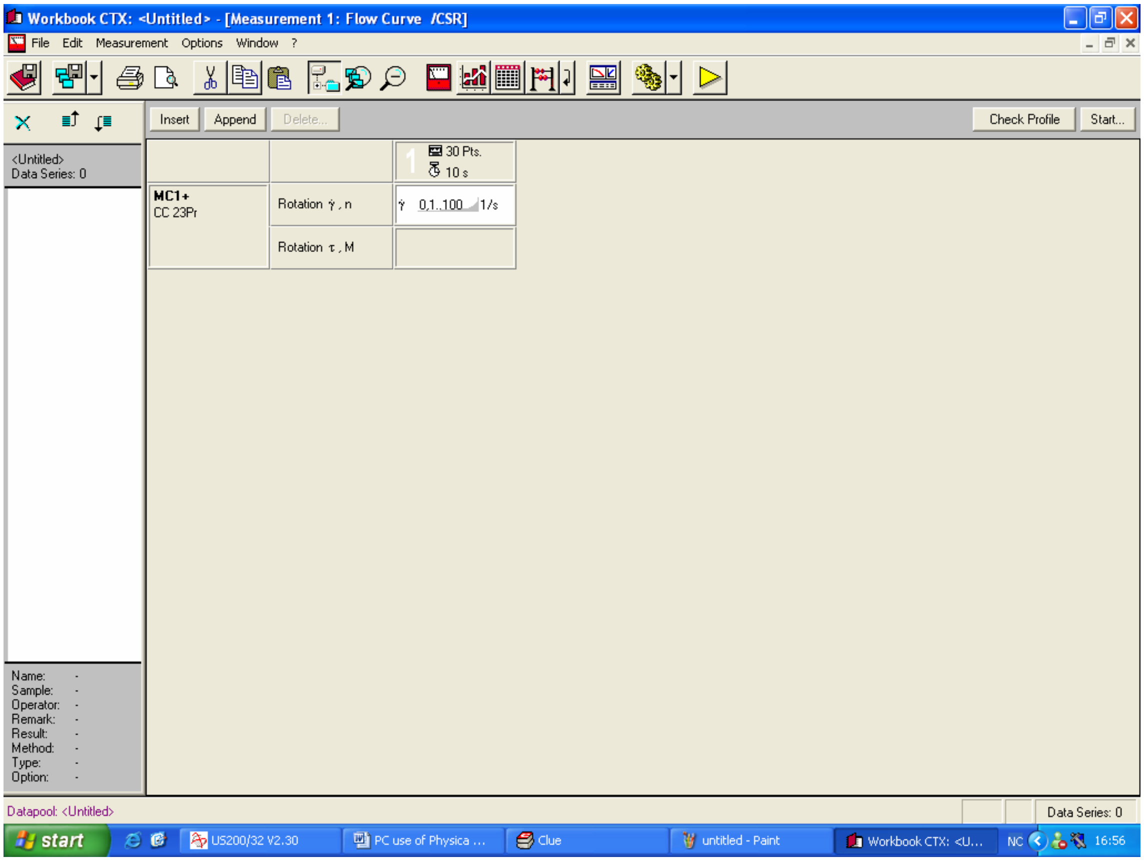
. Then the following window displays.



Open the **Measurement 1: Flow Curve /CSR**-window. This can be done in (at least) two ways:

1. Click on the -icon in the bottom left corner.
2. Click Window and then **Measurement 1: Flow Curve /CSR**

This window will be displayed independently of which of the two options that were chosen:

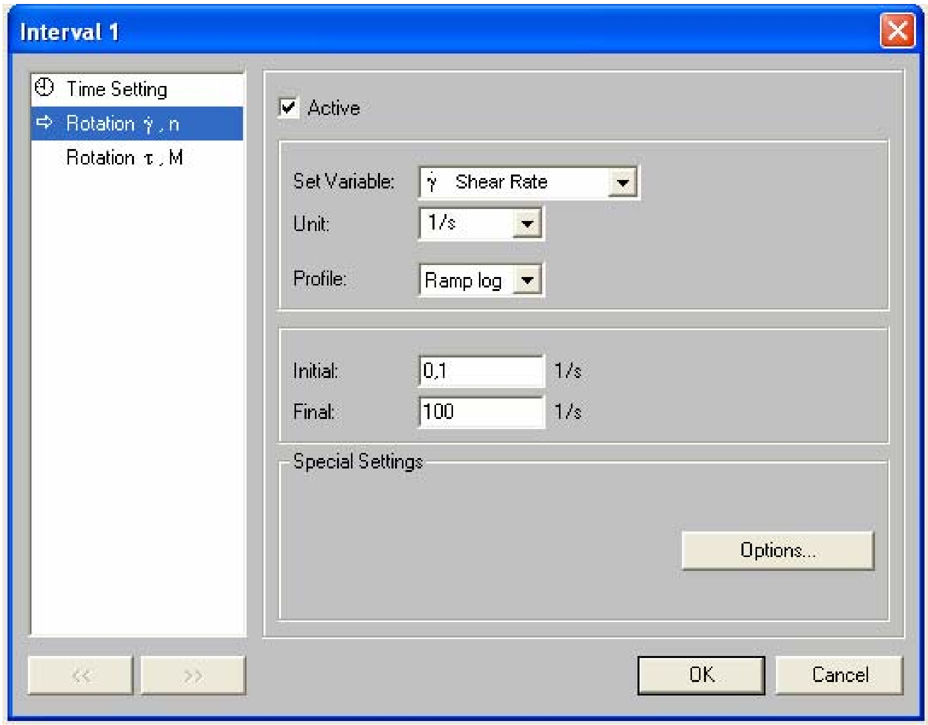


Note: Make sure that the correct measurement system is chosen, in this case MC1+ and CC 23Pr is chosen (as seen in the figure above).

Click on the 

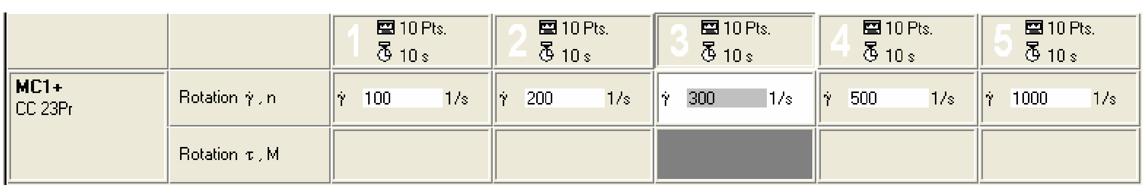
-symbol. In this mode one can set the shear rate, the number of measuring points, shear stress, the duration between each measuring point etc. One can choose whether to use the shear rate or the shear stress as the set variable depending on what to measure. By clicking Profile it is possible to choose between:

- Const: The shear rate is set at a constant value.
- Ramp lin: Choose an initial and a final value for the shear rate. Equal distance between all of the measurement-points from the lowest to the highest selected value.
- Ramp log: Many measurement points at low shear rates and fewer as the shear rate is increasing. The computer program decides what values to measure.

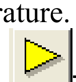


It is possible to do more than one measurement at the time. The most likely time to do this is if you want to measure the shear stress at predefined shear rates, for instance 100, 500, 800 and 1200 s^{-1}. It is done by clicking the Append- button the same number of times as the number of different shear rates to measure. It is possible to copy the properties of the interval and paste it into the next interval if the shear rate, for instance, is the only parameter that is to be changed. One can make an interval inactive by removing the mark on Active in the Interval- properties. Another option is to choose not to record data, this can only be done in the Interval-properties.

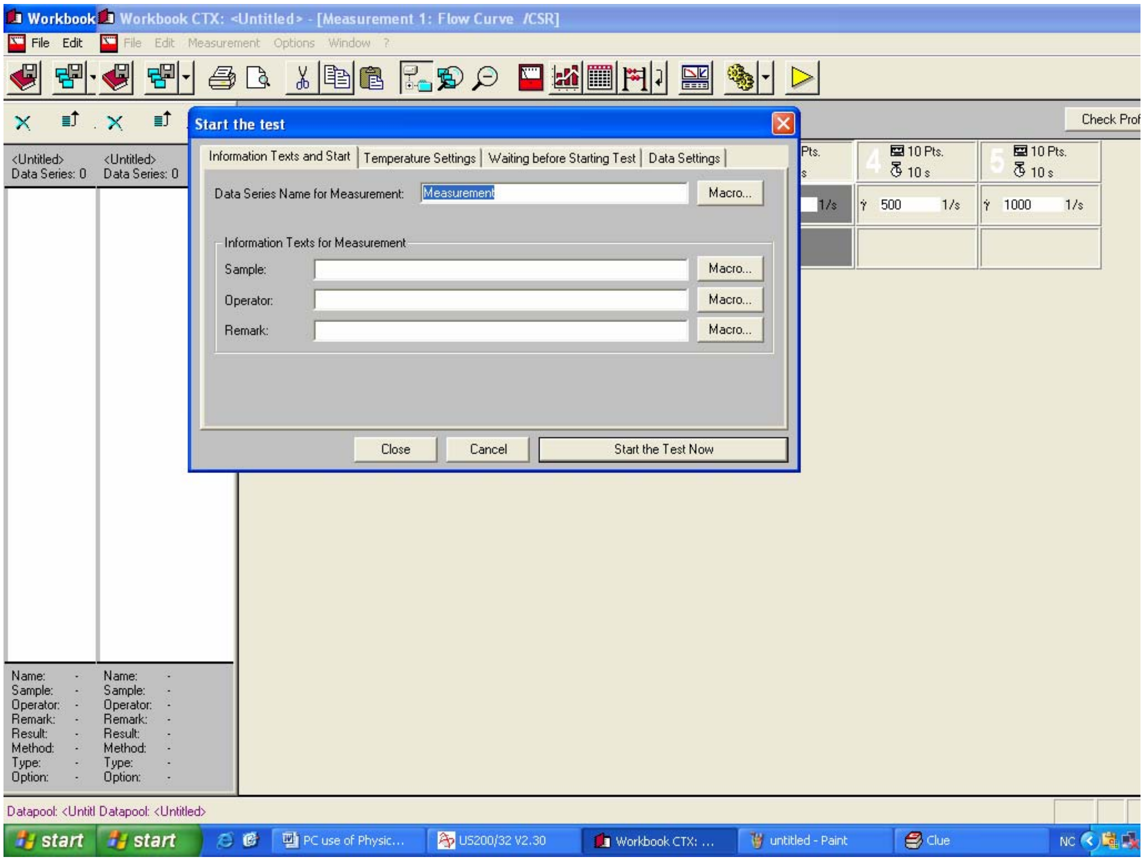
In the figure below is a method that record 10 measurement points, one measurement point every 10 seconds and shear rates ranging from 100, 200, 300, 500 and 1000 s^{-1} shown.



The liquid used is a Newtonian fluid with a viscosity of approximately 70 cP at room-temperature. Measurements are started by either:

1. -button.
2. Start...- button

By clicking one of these buttons the following window applies:



Then one choose a Name for Measurement. The next thing is to choose name and where to save the active datapool. The datapool is where the recorded data are saved. When this is done, the measurements starts. One can see a plot of the measured data so far or by the recorded values continuously as the measurements are done. To do this click Window and choose either 2 Table 1: Flow Curve or 3 Diagram 1: Flow curve/ log.

Example of a table of the recorded data by using the method above is pasted below. The parameters to be shown can be changed by clicking anywhere in the column of the parameter that is to be changed and then choose the desired parameter. A plot of the diagram is also shown.

Data Series Information
Name: Measurement 1
Sample:
Operator:
Remarks:
Number of Intervals: 5
Application: US200/32 V2.30 21001138-33024
Device: MC1+ SN305006
Measurement Date: ########
Measurement Time: 13:42
Measuring Systems: CC 23Pr

Calculating Constants:
- Csr: 1,285488
- Css: 28,19907
- Start Delay Time [s]: 0,265
- Measurement Type: 7

Interval: 1
Number of Data Points: 10

Time Setting: 10 Meas. Pts.
Meas. Pt. Duration 10 s
Measuring Profile:
Shear Rate d(gamma)/dt = 100 1/s

Meas. Pts.	Shear Rate [1/s]	Shear Stre [Pa]	Viscosity [cP]	Temperatu [°C]	Torque [mNm]	Status []
1	100	8,85	88,5	21,9	0,314	M-
2	100	8,56	85,6	21,8	0,303	M-
3	100	8,41	84,1	21,9	0,298	M-
4	100	8,29	82,9	21,8	0,294	M-
5	100	8,19	81,9	21,9	0,29	M-
6	100	8,2	82	21,9	0,291	M-
7	100	7,95	79,5	21,9	0,282	M-
8	100	7,79	77,9	21,9	0,276	M-
9	100	7,69	76,9	21,9	0,273	M-
10	100	7,54	75,4	21,9	0,267	M-

Interval: 2
Number of Data Points: 10

Time Setting: 10 Meas. Pts.
Meas. Pt. Duration 10 s
Measuring Profile:
Shear Rate d(gamma)/dt = 200 1/s

Meas. Pts.	Shear Rate [1/s]	Shear Stre [Pa]	Viscosity [cP]	Temperatu [°C]	Torque [mNm]	Status []
1	200	14,7	73,3	21,9	0,52	M-
2	200	14,6	73	21,9	0,518	M-
3	200	14,4	72	21,9	0,511	M-
4	200	14,3	71,5	21,9	0,507	M-
5	200	14,2	70,9	21,9	0,503	M-
6	200	14,1	70,6	21,9	0,501	M-
7	200	14,1	70,5	21,9	0,5	M-
8	200	14	70	21,9	0,496	M-
9	200	14	69,9	21,9	0,496	M-
10	200	13,9	69,6	21,9	0,493	M-

Interval: 3
Number of Data Points: 10

Time Setting: 10 Meas. Pts.
Meas. Pt. Duration 10 s
Measuring Profile:
Shear Rate d(gamma)/dt = 300 1/s

Meas. Pts.	Shear Rate [1/s]	Shear Stre [Pa]	Viscosity [cP]	Temperatu [°C]	Torque [mNm]	Status []
1	300	21,3	71	21,9	0,755	M-
2	300	21,2	70,8	21,9	0,753	
3	300	21,1	70,4	21,9	0,749	
4	300	21,1	70,4	21,9	0,749	
5	300	21	69,9	21,9	0,744	
6	300	21,1	70,2	21,9	0,747	
7	300	21	70	21,9	0,745	
8	300	20,9	69,7	21,9	0,741	
9	300	20,9	69,7	21,9	0,742	
10	300	21,1	70,2	21,9	0,747	

Interval: 4
Number of Data Points: 10

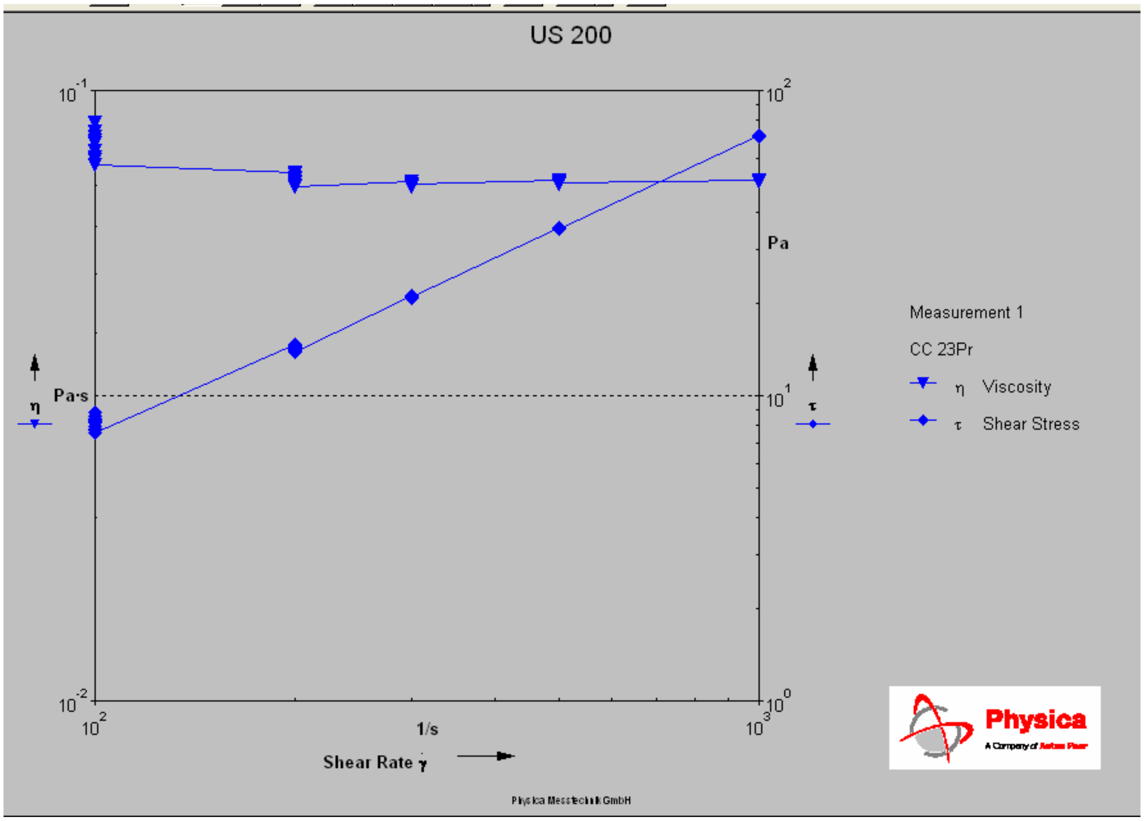
Time Setting: 10 Meas. Pts.
Meas. Pt. Duration 10 s
Measuring Profile:
Shear Rate d(gamma)/dt = 500 1/s

Meas. Pts.	Shear Rate [1/s]	Shear Stre [Pa]	Viscosity [cP]	Temperatu [°C]	Torque [mNm]	Status []
1	500	35,6	71,1	21,9	1,26	
2	500	35,4	70,8	21,9	1,26	
3	500	35,3	70,6	21,9	1,25	
4	500	35,2	70,5	21,9	1,25	
5	500	35,3	70,6	21,9	1,25	
6	500	35,2	70,3	21,9	1,25	
7	500	35,3	70,5	21,9	1,25	
8	500	35,3	70,5	21,9	1,25	
9	500	35,2	70,5	21,9	1,25	
10	500	35,2	70,5	21,9	1,25	

Interval: 5
Number of Data Points: 10

Time Setting: 10 Meas. Pts.
Meas. Pt. Duration 10 s
Measuring Profile:
Shear Rate d(gamma)/dt = 1E+3 1/s

Meas. Pts.	Shear Rate [1/s]	Shear Stre [Pa]	Viscosity [cP]	Temperatu [°C]	Torque [mNm]	Status []
1	1 000	71,4	71,4	21,9	2,53	
2	1 000	71,2	71,2	21,9	2,53	
3	1 000	71,2	71,2	21,9	2,52	
4	1 000	71	71	21,9	2,52	
5	1 000	71	71	21,9	2,52	
6	1 000	70,8	70,8	21,9	2,51	
7	1 000	70,9	70,9	21,9	2,51	
8	1 000	70,9	70,9	21,9	2,51	
9	1 000	70,8	70,8	21,9	2,51	
10	1 000	70,9	70,9	21,9	2,51	



It is possible to change the axis and scales.

When closing the program make sure that you have saved the files you need!

A.2 Recorded data Aging experiment

A.2.1 Fann viscometer readings

In this part are the tables from the measured values (readings) at different aging times in the Fann viscometer presented in tables. All the readings at 20 °C (at 1, 3, 8. 11, 15 and 20 days of aging) are shown. Then the measured values at 60 °C and 90 °C aging temperature are presented.

20 °C aging temperature

Table A. 1: Fann. 20 °C, no aging.

RPM	γ	Reading Φ			Average reading	T, $_{OFU}$	T, $_{SI}$	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	48	48	48	48,00	50,88	24,36	23,84
300	510,9	32,5	32	32,5	32,33	34,27	16,41	32,12
200	340,6	25	25	25	25,00	26,50	12,69	37,25
100	170,3	16	16	16	16,00	16,96	8,12	47,68
6	10,2	2	2	1	1,67	2,12	1,02	99,34
3	5,1	1	1	1	1,00	1,06	0,51	99,34

Table A. 2: Fann. 20 °C, 1 day aging.

RPM	γ	Reading Φ			Average reading	T, $_{OFU}$	T, $_{SI}$	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	46	46	46	46,0	48,76	23,35	22,85
300	510,9	31	31	30,5	30,8	32,86	15,73	30,80
200	340,6	24	24	24	24,0	25,44	12,18	35,76
100	170,3	14	14	14	14,0	14,84	7,11	41,72
6	10,2	3	4	3	3,3	3,18	1,52	149,01
3	5,1	1	1	1	1,0	1,06	0,51	99,34

Table A. 3: Fann. 20 °C, 3 days aging.

RPM	γ	Reading Φ			Average reading	T, $_{OFU}$	T, $_{SI}$	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	46	46	46	46,00	48,76	23,35	22,85
300	510,9	30	30	30	30,00	31,80	15,23	29,80
200	340,6	24	23	23	23,33	25,44	12,18	35,76
100	170,3	15	14	15	14,67	15,90	7,61	44,70
6	10,2	2	2	2	2,00	2,12	1,02	99,34
3	5,1	1	1	1	1,00	1,06	0,51	99,34

Table A. 4: Fann. 20 °C, 8 days aging.

RPM	γ	Reading Φ			Average reading	T, $_{OFU}$	T, $_{SI}$	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	45	45	45	45,00	47,70	22,84	22,35
300	510,9	30	30	30	30,00	31,80	15,23	29,80
200	340,6	23	23	23	23,00	24,38	11,67	34,27
100	170,3	14	14	14	14,00	14,84	7,11	41,72
6	10,2	2	1	1	1,33	1,41	0,68	66,23
3	5,1	0	0,5	1	0,50	0,53	0,25	49,67

Table A. 5: Fann. 20 °C, 11 days aging.

RPM	γ	Reading Φ			Average reading	T, $_{OFU}$	T, $_{SI}$	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	44	44	44	44,00	46,64	22,33	21,85
300	510,9	29	29	29	29,00	30,74	14,72	28,81
200	340,6	22	22	22	22,00	23,32	11,17	32,78
100	170,3	14	13,5	13	13,50	14,31	6,85	40,23
6	10,2	1	1,5	1,5	1,33	1,41	0,68	66,23
3	5,1	0	0,5	0,5	0,33	0,35	0,17	33,11

Table A. 6: Fann. 20 °C, 15 aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	44	44	44,5	44,17	46,82	22,42	21,94
300	510,9	29	29	29	29,00	30,74	14,72	28,81
200	340,6	23	22	22	22,33	23,67	11,33	33,28
100	170,3	14	13	14	13,67	14,49	6,94	40,73
6	10,2	1,5	1,5	2	1,67	1,77	0,85	82,78
3	5,1	0,5	0,5	0,5	0,50	0,53	0,25	49,67

Table A. 7: Fann. 20 °C, 20 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	43	43	43	43,00	45,58	21,82	21,36
300	510,9	28	28	28	28,00	29,68	14,21	27,82
200	340,6	21	21	21	21,00	22,26	10,66	31,29
100	170,3	13	13	13	13,00	13,78	6,60	38,74
6	10,2	1	1	1	1,00	1,06	0,51	49,67
3	5,1	0	0	0	0,00	0,00	0,00	0,00

60 °C aging temperature

Table A. 8: Fann. 60 °C, 1 day aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	24	24	24	24,00	25,44	12,18	11,92
300	510,9	13	14	13	13,33	14,13	6,77	13,25
200	340,6	9	10	10	9,67	10,25	4,91	14,40
100	170,3	6	6	5	5,67	6,01	2,88	16,89
6	10,2	1	1	1	1,00	1,06	0,51	49,67
3	5,1	1	1	1	1,00	1,06	0,51	99,34

Table A. 9: Fann. 60 °C, 3 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	19	19	18	18,67	19,79	9,47	9,27
300	510,9	10	10	9	9,67	10,60	5,08	9,93
200	340,6	7	7	7	7,00	7,42	3,55	10,43
100	170,3	3	4	3	3,33	3,18	1,52	8,94
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 10: Fann. 60 °C, 8 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	14	14	14	14,00	14,84	7,11	6,95
300	510,9	7	7	7	7,00	7,42	3,55	6,95
200	340,6	5	5	5	5,00	5,30	2,54	7,45
100	170,3	2	3	2,5	2,50	2,65	1,27	7,45
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 11:Fann. 60 °C, 11 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	13	13	13	13,00	13,78	6,60	6,46
300	510,9	6,5	6	6,5	6,33	6,71	3,21	6,29
200	340,6	4,5	4	4,5	4,33	4,59	2,20	6,46
100	170,3	2	2,5	2,5	2,33	2,47	1,18	6,95
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 12: Fann. 60 °C, 15 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	12	12	11	11,67	12,37	5,92	5,79
300	510,9	6	6	6	6,00	6,36	3,05	5,96
200	340,6	4	4	4	4,00	4,24	2,03	5,96
100	170,3	2	2	2	2,00	2,12	1,02	5,96
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 13: Fann. 60 °C, 20 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	11,5	11	11	11,17	11,84	5,67	5,55
300	510,9	6	6	6	6,00	6,36	3,05	5,96
200	340,6	4	4	4	4,00	4,24	2,03	5,96
100	170,3	2	2	2	2,00	2,12	1,02	5,96
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

<u>90 °C aging temperature</u>

Table A. 14: Fann. 90 °C, 1 day aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	11	11	11	11,00	11,66	5,58	5,46
300	510,9	6	6	7	6,33	6,36	3,05	5,96
200	340,6	4	5	4	4,33	4,24	2,03	5,96
100	170,3	3	2	3	2,67	3,18	1,52	8,94
6	10,2	1	1	1	1,00	1,06	0,51	49,67
3	5,1	0	0	0	0,00	0	0	0

Table A. 15: Fann. 90 °C, 3 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s^{-1}]	[-]	[-]	[-]	[-]	[lb/100ft^2]	[Pa]	cP
600	1021,8	8	8	8	8,00	8,48	4,06	3,97
300	510,9	4	4	4	4,00	4,24	2,03	3,97
200	340,6	3	3	2	2,67	3,18	1,52	4,47
100	170,3	2	1	1	1,33	2,12	1,02	5,96
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 16: Fann. 90 °C, 8 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s⁻¹]	[-]	[-]	[-]	[-]	[lb/100ft²]	[Pa]	cP
600	1021,8	6	5	6	5,67	6,01	2,88	2,81
300	510,9	3	3	3	3,00	3,18	1,52	2,98
200	340,6	2	2	2	2,00	2,12	1,02	2,98
100	170,3	1	1	1	1,00	1,06	0,51	2,98
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 17: Fann. 90 °C, 11 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s⁻¹]	[-]	[-]	[-]	[-]	[lb/100ft²]	[Pa]	cP
600	1021,8	4	4,5	4,5	4,33	4,59	2,20	2,15
300	510,9	2	2,5	2	2,17	2,30	1,10	2,15
200	340,6	1,5	1,5	1	1,33	1,41	0,68	1,99
100	170,3	1	1	0,5	0,83	0,88	0,42	2,48
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 18: Fann. 90 °C, 15 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s⁻¹]	[-]	[-]	[-]	[-]	[lb/100ft²]	[Pa]	cP
600	1021,8	4	4	4	4,00	4,24	2,03	1,99
300	510,9	2,5	2	2	2,17	2,30	1,10	2,15
200	340,6	1	1,5	1,5	1,33	1,41	0,68	1,99
100	170,3	0,5	1	1	0,83	0,88	0,42	2,48
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

Table A. 19: Fann. 90 °C, 20 days aging.

RPM	γ	Reading Φ			Average reading	T, OFU	T, SI	mju eff
-	[s⁻¹]	[-]	[-]	[-]	[-]	[lb/100ft²]	[Pa]	cP
600	1021,8	4	3,5	4	3,83	4,06	1,95	1,90
300	510,9	2	2	2	2,00	2,12	1,02	1,99
200	340,6	1	1	1	1,00	1,06	0,51	1,49
100	170,3	0,5	0,5	0,5	0,50	0,53	0,25	1,49
6	10,2	-	-	-	0,00	-	-	-
3	5,1	-	-	-	0,00	-	-	-

A.2.2 Physica viscometer recordings

The recorded data for all aging times at 20 °C aging temperature are presented first, then the results for 60 °C and 90 °C are presented.
The tables show the following parameters:

- Number of measuring points
- Shear rate [1/s]
- Shear stress at the given shear rate [Pa]
- Calculated viscosity [cP] from the measured shear rate and shear stress
- Temperature of the measuring cell [°C]
- Measured torque in the apparatus [mNm]
- Status

<u>20 °C aging temperature</u>

Table A. 20: Physica. 20 °C, no aging.

Name: HEC+water. 0day aging. rampLin 400-1200. T=20degrees. P=1bar 1

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	14,5	36,3	23,1	0,514	M-
2	400	12,3	30,7	23,1	0,435	M-
3	400	13,2	33	23,1	0,468	M-
4	400	13,9	34,7	23,1	0,492	M-
5	400	13,3	33,2	23	0,471	M-
6	400	13,9	34,6	23,1	0,491	M-
7	400	13,9	34,7	23,1	0,492	M-
8	400	12,4	31,1	23,1	0,441	M-
9	400	13,2	32,9	23	0,467	M-
10	400	12,4	31	23,1	0,439	M-
1	500	15,6	31,3	23,1	0,554	M-
2	500	15,4	30,7	23,1	0,544	M-
3	500	15	30	23,1	0,532	M-
4	500	15,6	31,2	23	0,553	M-
5	500	15,4	30,9	23	0,547	M-
6	500	15,7	31,4	23,1	0,557	M-
7	500	15,8	31,5	23	0,559	M-
8	500	15,6	31,2	23	0,552	M-
9	500	15,5	31,1	23	0,551	M-
10	500	13,8	27,6	23	0,49	M-
1	600	17,6	29,3	23	0,623	M-
2	600	17,1	28,4	23	0,605	
3	600	18,3	30,5	23	0,648	M-
4	600	17,4	29	23	0,616	
5	600	17,5	29,2	23	0,621	
6	600	17,3	28,9	23	0,615	
7	600	17,5	29,2	23	0,622	M-
8	600	17	28,4	23	0,604	
9	600	18,3	30,5	23	0,65	M-
10	600	18,9	31,5	23	0,671	M-
1	700	19,3	27,6	23	0,685	M-
2	700	19	27,2	23	0,675	
3	700	20,6	29,5	23	0,732	
4	700	19,1	27,3	23	0,678	
5	700	17	24,3	23	0,603	
6	700	18,3	26,1	23	0,649	
7	700	19,4	27,7	23	0,687	
8	700	20,6	29,5	23	0,732	
9	700	20,8	29,7	23	0,738	
10	700	18,6	26,6	23	0,661	
1	800	21,7	27,1	23	0,77	M-
2	800	20,6	25,7	23	0,729	
3	800	21	26,2	23	0,744	
4	800	21,3	26,6	23	0,756	
5	800	20,8	26	23	0,737	
6	800	19,7	24,6	23	0,698	
7	800	20,4	25,5	23	0,723	
8	800	19,3	24,1	23	0,684	
9	800	19,5	24,4	23	0,692	
10	800	20,6	25,7	23	0,73	
1	900	23	25,5	23	0,815	M-
2	900	23,4	26	23	0,83	
3	900	23,9	26,6	23	0,848	
4	900	24,2	26,9	23	0,86	
5	900	22,7	25,3	23	0,807	
6	900	22	24,5	23	0,781	
7	900	23,4	26	23	0,83	
8	900	21	23,3	23	0,743	
9	900	23,6	26,2	23	0,837	
10	900	23,2	25,8	23	0,823	
1	1 000	23,7	23,7	23	0,84	M-
2	1 000	24,2	24,2	23	0,858	
3	1 000	23,2	23,2	23	0,821	
4	1 000	24,5	24,5	23	0,868	
5	1 000	24,3	24,3	23	0,861	
6	1 000	23	23	23	0,816	
7	1 000	23,8	23,8	23	0,842	
8	1 000	23,9	23,9	22,9	0,847	
9	1 000	24,1	24,1	23	0,853	
10	1 000	23,9	23,9	22,9	0,847	
1	1 100	25,7	23,4	23	0,912	M-
2	1 100	25,8	23,5	22,9	0,916	
3	1 100	24,9	22,7	23	0,885	
4	1 100	25,7	23,4	23	0,911	
5	1 100	26,2	23,8	22,9	0,93	
6	1 100	24,7	22,5	22,9	0,876	
7	1 100	26,5	24,1	22,9	0,941	
8	1 100	24,8	22,6	22,9	0,88	
9	1 100	25,9	23,5	23	0,917	
10	1 100	25	22,8	22,9	0,888	
1	1 200	27,8	23,2	23	0,987	
2	1 200	27,1	22,6	22,9	0,962	
3	1 200	28,6	23,8	23	1,01	M-
4	1 200	27,8	23,2	23	0,985	
5	1 200	26,6	22,2	23	0,944	
6	1 200	28,4	23,7	22,9	1,01	
7	1 200	28	23,4	23	0,994	
8	1 200	27,4	22,9	23	0,973	
9	1 200	27,4	22,9	22,9	0,973	
10	1 200	27,6	23	22,9	0,978	

Table A. 21: Physica. 20 °C, 1 day aging to the left, 3 days aging to the right.

Name: aging HEC+water- 20degrees aging 1 day | Name: HEC+water- 20grader aging. Aging 3 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	22	27,5	22	0,779	M-M+
2	800	18,5	23,1	22	0,655	
3	800	19,8	24,8	22	0,704	
4	800	19,5	24,3	22	0,69	
5	800	19,1	23,9	22	0,677	
6	800	18,2	22,8	22	0,646	
7	800	19,2	24	22	0,681	
8	800	19	23,8	21,9	0,675	
9	800	20,2	25,2	21,9	0,715	
10	800	18,9	23,6	22	0,669	
11	800	18,1	22,7	22	0,644	
12	800	19,2	24	22	0,682	
13	800	19,6	24,5	22	0,694	M-
14	800	19,4	24,3	21,9	0,689	
15	800	18,4	23	21,9	0,653	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	21	23,4	22	0,746	M-
2	900	22	24,4	22	0,78	
3	900	21,4	23,8	22	0,76	
4	900	21,4	23,7	22	0,757	
5	900	20,3	22,6	21,9	0,721	
6	900	20,6	22,9	21,9	0,732	
7	900	17,9	19,9	21,9	0,637	
8	900	18,4	20,5	21,9	0,654	
9	900	19,5	21,6	22	0,69	
10	900	21,1	23,5	21,9	0,748	
11	900	20,9	23,3	21,9	0,742	
12	900	20,1	22,4	21,9	0,714	
13	900	21,5	23,9	21,9	0,762	
14	900	20	22,2	22	0,708	
15	900	20,4	22,7	22	0,724	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	22,4	22,4	21,9	0,796	M-
2	1 000	22,7	22,7	21,9	0,805	
3	1 000	22,3	22,3	21,9	0,789	
4	1 000	21,9	21,9	21,9	0,776	
5	1 000	22,4	22,4	21,9	0,793	
6	1 000	22,8	22,8	21,9	0,808	
7	1 000	23,2	23,2	21,9	0,824	
8	1 000	21,8	21,8	21,9	0,773	
9	1 000	22,2	22,2	21,9	0,787	
10	1 000	21,9	21,9	21,9	0,778	
11	1 000	21,3	21,3	21,9	0,755	
12	1 000	22,3	22,3	21,9	0,791	
13	1 000	23	23	21,9	0,817	
14	1 000	21,8	21,8	21,9	0,772	
15	1 000	22,9	22,9	21,9	0,812	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	24,6	22,4	21,9	0,872	M-
2	1 100	23,8	21,6	21,9	0,844	
3	1 100	24	21,8	21,9	0,849	
4	1 100	23,3	21,2	21,9	0,826	
5	1 100	23,7	21,5	21,9	0,839	
6	1 100	24,2	22	21,9	0,856	
7	1 100	23,9	21,7	21,9	0,848	
8	1 100	24,5	22,3	21,9	0,869	
9	1 100	23	20,9	21,9	0,816	
10	1 100	23,3	21,2	21,9	0,825	
11	1 100	22,9	20,8	21,9	0,811	
12	1 100	23	21	21,9	0,817	
13	1 100	23,9	21,8	21,9	0,848	
14	1 100	24,9	22,6	21,9	0,882	
15	1 100	25	22,7	21,9	0,885	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	24,8	20,7	21,9	0,88	M-
2	1 200	27,2	22,7	21,9	0,966	
3	1 200	25,9	21,6	21,9	0,92	
4	1 200	26,9	22,4	21,9	0,953	
5	1 200	25,3	21,1	21,9	0,899	
6	1 200	27,2	22,7	21,9	0,965	
7	1 200	24,6	20,5	21,9	0,871	
8	1 200	25,9	21,6	21,9	0,919	
9	1 200	25,8	21,5	21,9	0,914	
10	1 200	25,6	21,3	21,9	0,907	
11	1 200	25,7	21,4	21,9	0,911	
12	1 200	25,9	21,5	21,9	0,917	
13	1 200	25,2	21	21,9	0,894	
14	1 200	26,4	22	21,9	0,937	
15	1 200	25,3	21	21,9	0,896	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	27,6	21,3	21,9	0,98	M-
2	1 300	26,8	20,6	21,9	0,949	
3	1 300	27,5	21,1	21,9	0,974	
4	1 300	27,4	21,1	21,9	0,973	
5	1 300	26,6	20,5	21,9	0,945	
6	1 300	27,5	21,2	21,9	0,976	
7	1 300	26,6	20,5	21,9	0,945	
8	1 300	26,6	20,5	21,9	0,944	
9	1 300	26,8	20,6	21,9	0,949	
10	1 300	27,6	21,2	21,9	0,977	
11	1 300	25,9	19,9	21,9	0,917	
12	1 300	26,5	20,4	21,9	0,941	
13	1 300	26,5	20,4	21,9	0,941	
14	1 300	27	20,7	21,9	0,956	
15	1 300	26,2	20,2	21,9	0,929	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	29,5	21,1	21,9	1,05	M-
2	1 400	28,8	20,6	21,9	1,02	
3	1 400	27,9	19,9	21,9	0,989	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	18,5	23,2	23,1	0,657	M-M+
2	800	20,4	25,5	23,1	0,722	
3	800	19,9	24,9	23,1	0,707	
4	800	19,8	24,8	23,1	0,703	
5	800	20	25	23,1	0,71	
6	800	19,5	24,3	23,1	0,691	
7	800	19,4	24,2	23	0,687	
8	800	19,5	24,4	23,1	0,692	
9	800	19,7	24,6	23,1	0,697	
10	800	20,1	25,1	23,1	0,712	
11	800	19,9	24,8	23,1	0,704	
12	800	19,9	24,9	23,1	0,706	
13	800	19,2	24	23,1	0,682	
14	800	18,9	23,6	23,1	0,671	
15	800	19,4	24,3	23	0,688	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	20,9	23,2	23	0,741	M-
2	900	18,3	20,3	23	0,648	
3	900	20	22,2	23,1	0,709	
4	900	21	23,4	23	0,746	
5	900	20,2	22,4	23	0,715	
6	900	21,3	23,6	23,1	0,755	
7	900	21,9	24,4	23	0,778	
8	900	21,6	24	23	0,767	
9	900	19,9	22,1	23	0,706	
10	900	19,4	21,5	23,1	0,686	
11	900	20,9	23,3	23	0,743	
12	900	21,1	23,5	23	0,749	
13	900	21,2	23,6	23	0,752	
14	900	22	24,4	23	0,779	
15	900	22,2	24,7	23	0,788	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	24,5	24,5	23	0,869	M-
2	1 000	22	22	23	0,782	
3	1 000	21,8	21,8	23	0,774	
4	1 000	23	23	23	0,815	
5	1 000	21,3	21,3	23	0,755	
6	1 000	23,2	23,2	23	0,824	
7	1 000	22,5	22,5	23	0,799	
8	1 000	23,2	23,2	23	0,822	
9	1 000	23,7	23,7	23	0,839	
10	1 000	22,8	22,8	23	0,809	
11	1 000	23,4	23,4	23	0,831	
12	1 000	22,4	22,4	23	0,795	
13	1 000	22,7	22,7	23	0,804	
14	1 000	23,2	23,2	23	0,821	
15	1 000	23,4	23,4	23	0,829	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	24	21,8	23	0,851	M-
2	1 100	23,9	21,8	23	0,849	
3	1 100	25,7	23,4	23	0,911	
4	1 100	24,6	22,3	23	0,871	
5	1 100	23,9	21,7	23	0,846	
6	1 100	24,3	22,1	23	0,86	
7	1 100	24,3	22,1	23	0,861	
8	1 100	24,2	22	23	0,856	
9	1 100	23,5	21,3	23	0,832	
10	1 100	25	22,7	23	0,887	
11	1 100	24,3	22,1	23	0,862	
12	1 100	24,4	22,2	23	0,867	
13	1 100	24	21,8	23	0,851	
14	1 100	24,9	22,6	23	0,883	
15	1 100	23,4	21,3	23	0,83	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	26,4	22	23	0,936	M-
2	1 200	25,3	21,1	23	0,898	
3	1 200	26,8	22,3	23	0,949	
4	1 200	26,2	21,8	23	0,928	
5	1 200	26,3	21,9	23	0,934	
6	1 200	25,1	20,9	23	0,889	
7	1 200	27,5	22,9	23	0,976	
8	1 200	25,8	21,5	23	0,913	
9	1 200	26	21,7	23	0,921	
10	1 200	25,6	21,3	23	0,907	
11	1 200	26,1	21,7	23	0,924	
12	1 200	26,3	21,9	23	0,931	
13	1 200	26	21,7	23	0,923	
14	1 200	26,8	22,3	23	0,949	
15	1 200	26,5	22,1	23	0,939	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	28,2	21,7	23	1	M-
2	1 300	28	21,6	23	0,994	
3	1 300	28,6	22	23	1,01	
4	1 300	27,8	21,4	23	0,986	
5	1 300	27,7	21,3	23	0,984	
6	1 300	27,1	20,8	23	0,96	
7	1 300	27,9	21,5	23	0,991	
8	1 300	28,1	21,6	23	0,998	
9	1 300	27,8	21,4	23	0,986	
10	1 300	27	20,8	23	0,957	
11	1 300	27,3	21	23	0,967	
12	1 300	27	20,7	23	0,957	
13	1 300	28,9	22,3	23	1,03	
14	1 300	26,9	20,7	23	0,956	
15	1 300	28,1	21,6	23	0,995	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	29,4	21	23	1,04	M-
2	1 400	28,7	20,5	22,9	1,02	
3	1 400	29,8	21,3	22,9	1,06	

4	1 400	30,1	21,5	21,9	1,07
5	1 400	28,2	20,2	21,9	1
6	1 400	27,3	19,5	21,9	0,968
7	1 400	29,6	21,2	21,9	1,05
8	1 400	27,3	19,5	21,9	0,969
9	1 400	28,5	20,4	21,9	1,01
10	1 400	28	20	21,9	0,991
11	1 400	27,5	19,6	21,9	0,974
12	1 400	28,7	20,5	21,9	1,02
13	1 400	27,7	19,8	21,9	0,982
14	1 400	27,5	19,6	21,9	0,975
15	1 400	28,3	20,2	21,9	1

4	1 400	29,9	21,4	23	1,06
5	1 400	29,4	21	22,9	1,04
6	1 400	29,5	21,1	23	1,05
7	1 400	29,3	20,9	23	1,04
8	1 400	30	21,4	23	1,06
9	1 400	29,7	21,2	23	1,05
10	1 400	29,4	21	23	1,04
11	1 400	29,6	21,1	23	1,05
12	1 400	30,5	21,8	22,9	1,08
13	1 400	29,2	20,9	23	1,04
14	1 400	29,5	21	23	1,04
15	1 400	29,1	20,8	22,9	1,03

Table A. 22: Physica. 20 °C, 8 days to the left, 11 days to the right.

Name: HEC+water- 20degrees. Aging 8 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	18,4	23	21,3	0,651	M-M+
2	800	20,4	25,5	21,3	0,723	
3	800	18,8	23,5	21,3	0,668	
4	800	18,2	22,8	21,3	0,646	M-
5	800	17,4	21,8	21,3	0,619	
6	800	18,6	23,2	21,3	0,66	
7	800	17,4	21,8	21,3	0,619	M-
8	800	19,6	24,5	21,3	0,696	M-
9	800	18,3	22,9	21,3	0,651	
10	800	18,3	22,9	21,3	0,65	M-
11	800	19,1	23,9	21,3	0,679	
12	800	18,9	23,6	21,3	0,67	M-
13	800	18,1	22,7	21,3	0,644	M-
14	800	17,6	22	21,3	0,624	M-
15	800	18,9	23,6	21,3	0,67	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	20,5	22,8	21,3	0,727	M-
2	900	20,5	22,8	21,3	0,728	
3	900	21,4	23,8	21,3	0,758	
4	900	21,4	23,7	21,3	0,758	
5	900	20	22,2	21,3	0,708	
6	900	18,9	21	21,3	0,67	
7	900	20,1	22,3	21,3	0,713	
8	900	19,8	22	21,3	0,701	
9	900	19,6	21,8	21,3	0,694	
10	900	20	22,3	21,3	0,71	
11	900	20,7	23	21,3	0,735	
12	900	20,3	22,6	21,3	0,721	
13	900	22,1	24,6	21,3	0,784	
14	900	19,7	21,9	21,3	0,699	
15	900	19,9	22,1	21,3	0,706	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	21,9	21,9	21,3	0,777	M-
2	1 000	21,8	21,8	21,3	0,774	
3	1 000	21,9	21,9	21,3	0,776	
4	1 000	21,3	21,3	21,3	0,756	
5	1 000	21,5	21,5	21,3	0,763	
6	1 000	21,6	21,6	21,3	0,765	
7	1 000	20,5	20,5	21,2	0,726	
8	1 000	22	22	21,3	0,781	
9	1 000	21,5	21,5	21,3	0,762	
10	1 000	21,7	21,7	21,3	0,768	
11	1 000	21,2	21,2	21,3	0,753	
12	1 000	22,3	22,3	21,3	0,791	
13	1 000	21,6	21,6	21,2	0,767	
14	1 000	20,9	20,9	21,2	0,741	
15	1 000	21,4	21,4	21,2	0,76	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	23	20,9	21,3	0,817	M-
2	1 100	22,5	20,4	21,3	0,796	
3	1 100	23,1	21	21,3	0,819	
4	1 100	23,1	21	21,3	0,82	
5	1 100	25,2	22,9	21,2	0,893	
6	1 100	23,3	21,1	21,2	0,825	
7	1 100	24	21,8	21,3	0,85	
8	1 100	23,1	21	21,3	0,819	
9	1 100	22,6	20,6	21,2	0,803	
10	1 100	22,7	20,6	21,2	0,804	
11	1 100	23,5	21,3	21,2	0,832	
12	1 100	23,6	21,5	21,2	0,837	
13	1 100	23	20,9	21,2	0,817	
14	1 100	23,5	21,4	21,3	0,835	
15	1 100	23,3	21,2	21,2	0,828	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	25	20,8	21,2	0,886	M-
2	1 200	24,6	20,5	21,3	0,872	
3	1 200	25,2	21	21,2	0,893	
4	1 200	26,2	21,8	21,2	0,928	
5	1 200	25,6	21,3	21,2	0,908	
6	1 200	25,5	21,2	21,2	0,904	
7	1 200	25,5	21,2	21,2	0,903	
8	1 200	26	21,6	21,3	0,921	
9	1 200	25,1	20,9	21,2	0,89	
10	1 200	26,4	22	21,3	0,938	
11	1 200	25,4	21,2	21,2	0,901	
12	1 200	25,4	21,2	21,2	0,902	
13	1 200	25,1	20,9	21,2	0,89	
14	1 200	25,5	21,2	21,2	0,903	
15	1 200	25,1	20,9	21,2	0,888	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	26	20	21,2	0,921	M-
2	1 300	27,5	21,1	21,2	0,975	

Name: HEC+water- 20degrees. Aging 11 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	800	22,6	28,2	21,4	800	M-M+
2	800	18,5	23,2	21,4	658	
3	800	18,3	22,8	21,4	647	
4	800	18,9	23,6	21,4	669	
5	800	18,9	23,6	21,4	669	
6	800	18,2	22,7	21,4	644	
7	800	17,5	21,8	21,4	619	
8	800	18,6	23,2	21,4	659	
9	800	18,6	23,3	21,4	661	
10	800	18,8	23,5	21,4	665	
11	800	19,1	23,9	21,4	677	
12	800	18,2	22,7	21,4	644	
13	800	19,3	24,1	21,4	684	
14	800	19,7	24,6	21,4	699	M-
15	800	19,4	24,2	21,4	688	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	900	19	21,1	21,4	674	M-
2	900	20,1	22,3	21,4	711	
3	900	20,2	22,4	21,4	715	
4	900	20,8	23,2	21,4	739	
5	900	20,7	23	21,4	735	
6	900	20,6	22,9	21,4	731	
7	900	18,9	21	21,4	671	
8	900	20,3	22,6	21,4	722	
9	900	19,5	21,7	21,4	691	
10	900	18,6	20,6	21,4	658	
11	900	20,8	23,1	21,4	738	
12	900	21,9	24,3	21,4	776	
13	900	19,4	21,5	21,4	687	
14	900	19,9	22,1	21,4	704	
15	900	19,7	21,9	21,4	698	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 000	22,4	22,4	21,4	793	M-
2	1 000	21,6	21,6	21,4	768	
3	1 000	21,4	21,4	21,4	758	
4	1 000	21,3	21,3	21,4	754	
5	1 000	22,6	22,6	21,3	801	
6	1 000	21,4	21,4	21,4	759	
7	1 000	21,6	21,6	21,4	767	
8	1 000	20,9	20,9	21,4	743	
9	1 000	21,3	21,3	21,4	757	
10	1 000	22	22	21,4	781	
11	1 000	20,9	20,9	21,4	740	
12	1 000	21,5	21,5	21,4	764	
13	1 000	21,6	21,6	21,4	767	
14	1 000	22,2	22,2	21,4	787	
15	1 000	21,3	21,3	21,4	756	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 100	23,7	21,5	21,4	840	M-
2	1 100	23,3	21,2	21,4	826	
3	1 100	23,2	21,1	21,4	823	
4	1 100	23,2	21,1	21,4	824	
5	1 100	23,6	21,5	21,4	839	
6	1 100	23,1	21	21,4	821	
7	1 100	24,1	21,9	21,4	853	
8	1 100	23,7	21,5	21,4	839	
9	1 100	23,1	21	21,4	818	
10	1 100	23,4	21,3	21,4	830	
11	1 100	23,4	21,2	21,4	829	
12	1 100	23,8	21,6	21,4	843	
13	1 100	23,7	21,5	21,4	840	
14	1 100	24,4	22,2	21,4	864	
15	1 100	24	21,8	21,4	851	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 200	26,1	21,7	21,4	925	M-
2	1 200	25,7	21,5	21,4	913	
3	1 200	25,6	21,3	21,4	908	
4	1 200	26	21,7	21,4	922	
5	1 200	24,3	20,2	21,4	861	
6	1 200	24,3	20,2	21,4	862	
7	1 200	26,2	21,9	21,4	931	
8	1 200	25,7	21,5	21,4	913	
9	1 200	24,7	20,6	21,4	876	
10	1 200	26,2	21,8	21,4	927	
11	1 200	24,9	20,8	21,4	883	
12	1 200	26,3	21,9	21,4	934	
13	1 200	25	20,8	21,4	885	
14	1 200	25,1	20,9	21,4	891	
15	1 200	25,9	21,6	21,4	920	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 300	27,7	21,3	21,4	983	M-
2	1 300	27	20,8	21,4	958	

3	1 300	27,4	21,1	21,3	0,971	
4	1 300	25,9	19,9	21,2	0,918	
5	1 300	26,7	20,5	21,2	0,946	
6	1 300	26,3	20,2	21,2	0,931	
7	1 300	26,9	20,7	21,2	0,955	
8	1 300	26,5	20,4	21,2	0,939	
9	1 300	27,7	21,3	21,3	0,981	
10	1 300	27	20,7	21,2	0,956	
11	1 300	27,1	20,9	21,2	0,962	
12	1 300	26,5	20,4	21,2	0,941	
13	1 300	27,3	21	21,2	0,967	
14	1 300	26,9	20,7	21,2	0,954	
15	1 300	27,1	20,8	21,2	0,961	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	28,7	20,5	21,2	1,02	M-
2	1 400	28,4	20,3	21,2	1,01	
3	1 400	28,7	20,5	21,3	1,02	
4	1 400	29,4	21	21,2	1,04	
5	1 400	28,2	20,2	21,2	1	
6	1 400	28,2	20,2	21,2	1	
7	1 400	27,2	19,4	21,2	0,965	
8	1 400	27,5	19,6	21,2	0,976	
9	1 400	29,2	20,9	21,2	1,04	
10	1 400	28,6	20,4	21,3	1,02	
11	1 400	27,9	19,9	21,2	0,989	
12	1 400	28,6	20,5	21,2	1,02	
13	1 400	27,3	19,5	21,2	0,967	
14	1 400	29,1	20,8	21,3	1,03	
15	1 400	27,1	19,4	21,3	0,961	

3	1 300	26,8	20,6	21,4	951	
4	1 300	26,3	20,2	21,4	933	
5	1 300	26,7	20,5	21,4	946	
6	1 300	27,4	21,1	21,4	971	
7	1 300	26,3	20,3	21,4	934	
8	1 300	26,8	20,6	21,4	949	
9	1 300	25,7	19,7	21,4	910	
10	1 300	26,5	20,4	21,4	940	
11	1 300	26,5	20,4	21,4	940	
12	1 300	26,6	20,5	21,4	943	
13	1 300	26,8	20,6	21,4	951	
14	1 300	27,2	20,9	21,4	965	
15	1 300	27,9	21,5	21,4	990	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 400	29,4	21	21,4	1 040	M-
2	1 400	28,5	20,4	21,4	1 010	
3	1 400	28,9	20,6	21,4	1 020	
4	1 400	29	20,7	21,4	1 030	
5	1 400	28,8	20,6	21,4	1 020	
6	1 400	29,1	20,8	21,4	1 030	
7	1 400	27,6	19,7	21,4	980	
8	1 400	28,6	20,4	21,4	1 010	
9	1 400	29,5	21,1	21,4	1 050	
10	1 400	28,1	20,1	21,4	996	
11	1 400	28,3	20,2	21,4	1 000	
12	1 400	28,8	20,6	21,4	1 020	
13	1 400	28,1	20,1	21,4	998	
14	1 400	28,9	20,6	21,4	1 030	
15	1 400	27,5	19,6	21,4	975	

Table A. 23: Physica. 20 °C, 15 days to the left, 20 days to the right.

Name: HEC+water. 20 degrees, aging 15 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	invalid point					
2	800	20,9	26,1	21,9	0,741	
3	800	19,7	24,7	21,9	0,7	
4	800	19,5	24,3	21,9	0,69	
5	800	19,9	24,9	21,9	0,706	
6	800	19	23,7	21,9	0,673	
7	800	20	24,9	21,9	0,707	
8	800	19,9	24,9	21,9	0,707	
9	800	19,7	24,6	21,9	0,698	
10	800	19,6	24,4	21,9	0,693	
11	800	18,7	23,4	21,9	0,664	
12	800	17,8	22,2	21,9	0,631	
13	800	20	25	21,9	0,711	
14	800	20,2	25,3	21,9	0,718	
15	800	20,3	25,4	21,9	0,722	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	21,8	24,3	21,9	0,775	M-
2	900	21,9	24,3	21,9	0,776	
3	900	22,5	25	21,9	0,798	
4	900	21,4	23,7	21,9	0,757	
5	900	21,3	23,7	21,9	0,757	
6	900	20,3	22,6	21,9	0,72	
7	900	18,6	20,6	21,9	0,658	
8	900	19,2	21,3	21,9	0,681	
9	900	19,3	21,4	21,9	0,684	
10	900	21,4	23,8	21,9	0,759	
11	900	21,7	24,1	21,9	0,769	
12	900	20,5	22,7	21,9	0,726	
13	900	21	23,4	21,9	0,746	
14	900	20,1	22,4	21,9	0,714	
15	900	19,5	21,7	21,9	0,693	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	23,5	23,5	21,9	0,833	M-
2	1 000	22,5	22,5	21,9	0,797	
3	1 000	22,7	22,7	21,9	0,804	
4	1 000	23	23	21,9	0,817	
5	1 000	21,8	21,8	21,9	0,773	
6	1 000	21,8	21,8	21,9	0,771	
7	1 000	22,3	22,3	21,9	0,792	
8	1 000	21	21	21,9	0,746	
9	1 000	21,1	21,1	21,9	0,747	
10	1 000	21,6	21,6	21,9	0,766	
11	1 000	21,9	21,9	21,9	0,778	
12	1 000	21,9	21,9	21,9	0,777	
13	1 000	21,8	21,8	21,9	0,774	
14	1 000	20,6	20,6	21,9	0,731	
15	1 000	20,8	20,8	21,9	0,737	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	23,9	21,7	21,9	0,847	M-
2	1 100	23,6	21,4	21,9	0,837	
3	1 100	23,3	21,2	21,9	0,827	
4	1 100	22,2	20,2	21,9	0,788	
5	1 100	22,6	20,6	21,9	0,802	
6	1 100	24	21,8	21,9	0,851	
7	1 100	23,8	21,6	21,9	0,843	
8	1 100	23,4	21,2	21,9	0,829	
9	1 100	23,8	21,6	21,9	0,844	
10	1 100	22,3	20,3	21,9	0,792	
11	1 100	22,6	20,6	21,9	0,802	
12	1 100	21,6	19,6	21,9	0,766	
13	1 100	23,7	21,6	21,9	0,842	
14	1 100	22,6	20,5	21,9	0,801	
15	1 100	23,7	21,5	21,9	0,84	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	25,2	21	21,9	0,895	M-
2	1 200	25,3	21,1	21,9	0,897	
3	1 200	25,1	20,9	21,9	0,889	
4	1 200	24,2	20,2	21,9	0,858	
5	1 200	24,2	20,2	21,9	0,859	
6	1 200	24,9	20,7	21,9	0,882	

Name: HEC+water. 20 degrees, aging 20 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	23,1	28,8	19,6	0,818	M-M+
2	800	20,4	25,4	19,7	0,722	
3	800	20	24,9	19,8	0,708	
4	800	19,6	24,5	19,8	0,695	
5	800	20	25	19,9	0,71	
6	800	19,4	24,3	19,9	0,689	
7	800	18,9	23,7	20	0,671	
8	800	19,2	23,9	20	0,679	
9	800	19,4	24,2	20	0,687	
10	800	20,4	25,5	20,1	0,723	
11	800	19,5	24,4	20,1	0,693	
12	800	18,7	23,4	20,1	0,663	
13	800	18,4	23	20,1	0,652	
14	800	17,4	21,7	20,1	0,617	
15	800	18,1	22,6	20,2	0,64	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	21,3	23,7	20,2	0,756	M-
2	900	20,8	23,1	20,2	0,738	
3	900	20,4	22,6	20,2	0,722	
4	900	20,9	23,2	20,3	0,74	
5	900	20,8	23,2	20,3	0,739	
6	900	22	24,5	20,3	0,781	
7	900	20,4	22,7	20,3	0,725	
8	900	19,6	21,8	20,3	0,696	
9	900	20,6	22,9	20,3	0,731	
10	900	19,5	21,7	20,4	0,692	
11	900	20,3	22,6	20,4	0,721	
12	900	21,5	23,9	20,4	0,764	
13	900	20,5	22,8	20,4	0,727	
14	900	21,5	23,8	20,4	0,761	
15	900	20,3	22,5	20,4	0,718	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	22	22	20,4	0,779	M-
2	1 000	20,5	20,5	20,4	0,726	
3	1 000	21,1	21,1	20,4	0,748	
4	1 000	21,7	21,7	20,4	0,771	
5	1 000	21,2	21,2	20,5	0,751	
6	1 000	21,2	21,2	20,5	0,753	
7	1 000	20,3	20,3	20,5	0,718	
8	1 000	22,1	22,1	20,5	0,785	
9	1 000	21,3	21,3	20,5	0,755	
10	1 000	21,6	21,6	20,5	0,765	
11	1 000	21,9	21,9	20,5	0,775	
12	1 000	21,2	21,2	20,5	0,753	
13	1 000	20,6	20,6	20,5	0,731	
14	1 000	20,8	20,8	20,5	0,738	
15	1 000	21,5	21,5	20,5	0,762	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	23,4	21,3	20,5	0,831	M-
2	1 100	22,8	20,7	20,5	0,809	
3	1 100	23,6	21,5	20,6	0,837	
4	1 100	23,8	21,7	20,6	0,846	
5	1 100	24,1	21,9	20,6	0,856	
6	1 100	22,9	20,8	20,6	0,813	
7	1 100	23,2	21,1	20,6	0,824	
8	1 100	24,4	22,2	20,6	0,867	
9	1 100	23,1	21	20,6	0,818	
10	1 100	23,1	21	20,6	0,819	
11	1 100	23,3	21,2	20,6	0,826	
12	1 100	23	20,9	20,6	0,817	
13	1 100	21,2	19,3	20,6	0,752	
14	1 100	22,9	20,8	20,6	0,812	
15	1 100	24	21,8	20,6	0,851	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	26,2	21,8	20,6	0,929	M-
2	1 200	25,2	21	20,6	0,895	
3	1 200	24,2	20,1	20,6	0,857	
4	1 200	26,1	21,8	20,6	0,927	
5	1 200	25,2	21	20,6	0,895	
6	1 200	24,1	20	20,7	0,853	

7	1 200	24,6	20,5	21,9	0,873	
8	1 200	24,7	20,6	21,9	0,875	
9	1 200	24,1	20,1	21,9	0,853	
10	1 200	25	20,9	21,9	0,888	
11	1 200	24,6	20,5	21,9	0,873	
12	1 200	24,6	20,5	21,9	0,872	
13	1 200	24,2	20,2	21,9	0,86	
14	1 200	24,4	20,3	21,9	0,865	
15	1 200	24,8	20,6	21,9	0,879	

7	1 200	23,2	19,4	20,6	0,824	
8	1 200	24,4	20,3	20,7	0,864	
9	1 200	24,8	20,6	20,7	0,879	
10	1 200	24,5	20,4	20,6	0,87	
11	1 200	24,3	20,3	20,7	0,862	
12	1 200	24,5	20,4	20,7	0,87	
13	1 200	24,8	20,7	20,7	0,881	
14	1 200	23,4	19,5	20,7	0,83	
15	1 200	25,5	21,3	20,7	0,905	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	26,9	20,7	21,9	0,953	M-
2	1 300	26,1	20	21,9	0,924	
3	1 300	25,5	19,6	21,9	0,904	
4	1 300	26,2	20,2	21,9	0,929	
5	1 300	25,4	19,6	21,9	0,902	
6	1 300	26,6	20,4	21,9	0,942	
7	1 300	25,8	19,9	21,9	0,915	
8	1 300	25,9	19,9	21,9	0,917	
9	1 300	26,6	20,4	21,9	0,942	
10	1 300	26,5	20,4	21,9	0,939	
11	1 300	26,7	20,5	21,9	0,947	
12	1 300	25,1	19,3	21,9	0,889	
13	1 300	25,5	19,6	21,9	0,903	
14	1 300	25,9	19,9	21,9	0,918	
15	1 300	25,2	19,4	21,9	0,894	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	27	20,8	20,7	0,958	M-
2	1 300	27,2	20,9	20,7	0,963	
3	1 300	27,5	21,2	20,7	0,976	
4	1 300	26,8	20,6	20,7	0,951	
5	1 300	26,9	20,7	20,7	0,953	
6	1 300	27,4	21,1	20,7	0,971	
7	1 300	26	20	20,7	0,923	
8	1 300	26,7	20,6	20,7	0,949	
9	1 300	26,7	20,6	20,7	0,948	
10	1 300	26,4	20,3	20,7	0,938	
11	1 300	27,6	21,3	20,7	0,98	
12	1 300	26,9	20,7	20,7	0,954	
13	1 300	27,1	20,9	20,7	0,961	
14	1 300	26,1	20	20,7	0,924	
15	1 300	26,5	20,4	20,7	0,939	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	27,9	20	21,9	0,991	M-
2	1 400	27,5	19,7	22	0,976	
3	1 400	27,1	19,3	22	0,959	
4	1 400	28,4	20,3	21,9	1,01	
5	1 400	27,1	19,3	21,9	0,96	
6	1 400	27,7	19,8	21,9	0,982	
7	1 400	27	19,3	21,9	0,956	
8	1 400	26,2	18,7	22	0,929	
9	1 400	26,8	19,1	22	0,951	
10	1 400	27,2	19,5	22	0,966	
11	1 400	26,4	18,9	21,9	0,938	
12	1 400	27,4	19,5	21,9	0,97	
13	1 400	27	19,3	21,9	0,956	
14	1 400	27	19,3	22	0,958	
15	1 400	28,8	20,6	22	1,02	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	29	20,7	20,7	1,03	M-
2	1 400	28,2	20,1	20,7	0,999	
3	1 400	27,5	19,6	20,7	0,976	
4	1 400	28,5	20,3	20,7	1,01	
5	1 400	27,1	19,4	20,7	0,963	
6	1 400	29	20,7	20,7	1,03	
7	1 400	25,3	18,1	20,7	0,896	
8	1 400	28	20	20,7	0,993	
9	1 400	29	20,7	20,7	1,03	
10	1 400	27,9	19,9	20,7	0,99	
11	1 400	28,7	20,5	20,7	1,02	
12	1 400	27,9	19,9	20,7	0,99	
13	1 400	28,3	20,2	20,7	1,01	
14	1 400	27,9	20	20,8	0,991	
15	1 400	26,6	19	20,7	0,944	

60 °C aging temperature

Table A. 24: Physica. 60 °C, 1 day to the left, 3 days to the right.

Name: HEC+water. 60 degrees, aging 1 day

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	invalid point					
2	800	9,6	12	23,6	0,341	M-
3	800	9,86	12,3	23,5	0,349	M-
4	800	9,33	11,7	23,5	0,331	M-
5	800	9,12	11,4	23,4	0,324	M-
6	800	10,9	13,7	23,4	0,387	M-
7	800	10,7	13,4	23,4	0,38	M-
8	800	10,2	12,8	23,3	0,363	M-
9	800	9,66	12,1	23,3	0,342	M-
10	800	9,27	11,6	23,3	0,329	M-
11	800	9,07	11,3	23,2	0,322	M-
12	800	8,76	11	23,2	0,311	M-
13	800	9,52	11,9	23,2	0,337	M-
14	800	9,73	12,2	23,2	0,345	M-
15	800	9,33	11,7	23,1	0,331	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	11,4	12,6	23,1	0,403	M-
2	900	10,9	12,1	23,1	0,386	M-
3	900	10,5	11,6	23,1	0,371	M-
4	900	10,2	11,4	23,1	0,363	M-
5	900	10,3	11,5	23,1	0,366	M-
6	900	10,9	12,1	23,1	0,386	M-
7	900	10	11,2	23	0,356	M-
8	900	10,5	11,7	23	0,373	M-
9	900	11,4	12,6	23	0,403	M-
10	900	11,8	13,1	22,9	0,418	M-
11	900	10,8	12	23	0,384	M-
12	900	9,96	11,1	23	0,353	M-
13	900	9,95	11,1	22,9	0,353	M-
14	900	9,09	10,1	22,9	0,322	M-
15	900	11	12,2	22,9	0,391	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	12	12	22,9	0,426	M-
2	1 000	12,6	12,6	22,9	0,448	M-
3	1 000	10,5	10,5	22,9	0,374	M-
4	1 000	12,5	12,5	22,9	0,442	M-
5	1 000	11,3	11,3	22,9	0,4	M-
6	1 000	11,7	11,7	22,9	0,414	M-
7	1 000	12,8	12,8	22,9	0,455	M-
8	1 000	12	12	22,8	0,427	M-
9	1 000	12,4	12,4	22,8	0,441	M-
10	1 000	11,5	11,5	22,8	0,409	M-
11	1 000	12	12	22,8	0,426	M-
12	1 000	11,9	11,9	22,8	0,423	M-
13	1 000	11,4	11,4	22,8	0,404	M-
14	1 000	12,8	12,8	22,8	0,453	M-
15	1 000	12,2	12,2	22,8	0,434	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	14,5	13,1	22,8	0,513	M-
2	1 100	13,6	12,4	22,8	0,483	M-
3	1 100	13,8	12,6	22,7	0,491	M-
4	1 100	13,8	12,6	22,8	0,49	M-

Name: HEC+water. 60degrees, aging 3 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	6,78	8,48	23	0,24	M-M+
2	800	8,13	10,2	23	0,288	M-
3	800	8,81	11	23	0,312	M-
4	800	8,61	10,8	23	0,305	M-
5	800	8,84	11	23	0,313	M-
6	800	7,72	9,65	22,9	0,274	M-
7	800	7,97	9,96	23	0,283	M-
8	800	8,3	10,4	23	0,294	M-
9	800	7,56	9,45	23	0,268	M-
10	800	8,35	10,4	23	0,296	M-
11	800	9,08	11,4	23	0,322	M-
12	800	8,47	10,6	22,9	0,3	M-
13	800	9,23	11,5	22,9	0,327	M-
14	800	9,58	12	22,9	0,34	M-
15	800	8,27	10,3	22,9	0,293	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	9,56	10,6	22,9	0,339	M-
2	900	8,66	9,63	22,9	0,307	M-
3	900	8,76	9,73	22,9	0,311	M-
4	900	9,13	10,1	22,9	0,324	M-
5	900	8,7	9,67	22,9	0,308	M-
6	900	9,44	10,5	22,9	0,335	M-
7	900	8,73	9,7	22,9	0,31	M-
8	900	10,1	11,2	22,9	0,358	M-
9	900	10	11,1	22,9	0,356	M-
10	900	8,18	9,09	22,9	0,29	M-
11	900	7,87	8,74	22,9	0,279	M-
12	900	9,08	10,1	22,9	0,322	M-
13	900	9,38	10,4	22,9	0,333	M-
14	900	8,97	9,96	22,9	0,318	M-
15	900	9,34	10,4	22,9	0,331	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	9,47	9,47	22,9	0,336	M-
2	1 000	11,6	11,6	22,9	0,411	M-
3	1 000	8,53	8,53	22,9	0,303	M-
4	1 000	10,2	10,2	22,9	0,362	M-
5	1 000	11	11	22,9	0,39	M-
6	1 000	10,6	10,6	22,9	0,375	M-
7	1 000	10,3	10,3	22,9	0,366	M-
8	1 000	9,37	9,37	22,9	0,332	M-
9	1 000	10,1	10,1	22,9	0,357	M-
10	1 000	10	10	22,9	0,355	M-
11	1 000	9,92	9,92	22,9	0,352	M-
12	1 000	10,2	10,2	22,9	0,363	M-
13	1 000	10,7	10,7	22,9	0,38	M-
14	1 000	8,8	8,8	22,9	0,312	M-
15	1 000	10,3	10,3	22,9	0,365	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	11,2	10,2	22,9	0,396	M-
2	1 100	11,5	10,5	22,9	0,408	M-
3	1 100	11,5	10,4	22,9	0,406	M-
4	1 100	11	10	22,9	0,391	M-

5	1 100	12,7	11,6	22,7	0,452	M-
6	1 100	12,3	11,2	22,7	0,436	M-
7	1 100	12,7	11,6	22,7	0,451	M-
8	1 100	13,2	12	22,7	0,469	M-
9	1 100	13,7	12,5	22,7	0,486	M-
10	1 100	13,8	12,5	22,7	0,488	M-
11	1 100	12,4	11,2	22,7	0,439	M-
12	1 100	12,4	11,3	22,7	0,44	M-
13	1 100	13,3	12,1	22,7	0,471	M-
14	1 100	11,1	10,1	22,7	0,393	M-
15	1 100	13,7	12,5	22,7	0,487	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	13,4	11,1	22,7	0,474	M-
2	1 200	15,1	12,6	22,7	0,535	M-
3	1 200	14,7	12,2	22,7	0,521	M-
4	1 200	13,9	11,6	22,7	0,495	M-
5	1 200	13,7	11,4	22,7	0,487	M-
6	1 200	15,1	12,6	22,6	0,535	M-
7	1 200	14,2	11,8	22,7	0,503	M-
8	1 200	14,7	12,2	22,7	0,52	M-
9	1 200	14	11,7	22,6	0,496	M-
10	1 200	14,9	12,4	22,6	0,529	M-
11	1 200	14,1	11,8	22,7	0,501	M-
12	1 200	13,4	11,2	22,6	0,476	M-
13	1 200	13,6	11,3	22,6	0,481	M-
14	1 200	14,5	12,1	22,6	0,513	M-
15	1 200	14,7	12,3	22,6	0,522	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	17	13,1	22,6	0,602	M-
2	1 300	16,3	12,5	22,6	0,578	M-
3	1 300	16,5	12,7	22,6	0,585	M-
4	1 300	15,8	12,2	22,6	0,56	M-
5	1 300	15,5	11,9	22,6	0,549	M-
6	1 300	16,2	12,5	22,6	0,575	M-
7	1 300	16,1	12,4	22,6	0,571	M-
8	1 300	14,7	11,3	22,6	0,521	M-
9	1 300	15,8	12,2	22,6	0,561	M-
10	1 300	16,2	12,4	22,6	0,573	M-
11	1 300	16,3	12,5	22,6	0,577	M-
12	1 300	15,3	11,8	22,6	0,543	M-
13	1 300	15,9	12,3	22,6	0,565	M-
14	1 300	17,3	13,3	22,6	0,613	M-
15	1 300	16,2	12,5	22,6	0,574	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	18,1	12,9	22,6	0,642	M-
2	1 400	17,7	12,7	22,6	0,629	
3	1 400	16,9	12,1	22,6	0,601	
4	1 400	16,6	11,9	22,6	0,589	M-
5	1 400	18,6	13,3	22,6	0,661	
6	1 400	16,4	11,7	22,6	0,583	
7	1 400	19	13,6	22,6	0,675	
8	1 400	17,5	12,5	22,6	0,621	
9	1 400	15,8	11,3	22,6	0,561	M-
10	1 400	17,9	12,8	22,6	0,634	
11	1 400	16,8	12	22,6	0,594	
12	1 400	17,3	12,3	22,6	0,612	
13	1 400	17,6	12,6	22,5	0,624	
14	1 400	17,1	12,2	22,5	0,607	M-
15	1 400	17,8	12,7	22,5	0,63	

5	1 100	11,2	10,2	22,9	0,397	M-
6	1 100	10,6	9,61	22,9	0,375	M-
7	1 100	11	9,96	22,9	0,389	M-
8	1 100	10	9,13	22,9	0,356	M-
9	1 100	10,7	9,7	22,9	0,379	M-
10	1 100	12,6	11,4	22,9	0,446	M-
11	1 100	11,1	10,1	22,9	0,392	M-
12	1 100	11,1	10,1	22,9	0,393	M-
13	1 100	12	11	22,9	0,427	M-
14	1 100	9,22	8,38	22,9	0,327	M-
15	1 100	9,69	8,81	22,9	0,344	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	12,9	10,8	22,9	0,458	M-
2	1 200	11,7	9,74	22,9	0,415	M-
3	1 200	12	10	22,9	0,427	M-
4	1 200	11,3	9,41	22,9	0,4	M-
5	1 200	12,8	10,7	22,9	0,455	M-
6	1 200	11,2	9,35	22,9	0,398	M-
7	1 200	12,3	10,3	22,9	0,437	M-
8	1 200	13,8	11,5	22,9	0,491	M-
9	1 200	12,1	10,1	22,9	0,429	M-
10	1 200	12	10	22,9	0,426	M-
11	1 200	12,7	10,5	22,9	0,449	M-
12	1 200	15,5	12,9	22,9	0,55	M-
13	1 200	11,9	9,96	22,9	0,424	M-
14	1 200	13,5	11,3	22,9	0,479	M-
15	1 200	12,4	10,3	22,9	0,438	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	14	10,8	22,9	0,497	M-
2	1 300	14,5	11,2	22,9	0,515	M-
3	1 300	13,8	10,6	22,9	0,49	M-
4	1 300	13,8	10,6	22,9	0,488	M-
5	1 300	14,8	11,4	22,9	0,526	M-
6	1 300	13,6	10,5	22,9	0,483	M-
7	1 300	13,1	10	22,9	0,463	M-
8	1 300	14,3	11	22,9	0,506	M-
9	1 300	13,8	10,6	22,9	0,491	M-
10	1 300	13,4	10,3	22,9	0,476	M-
11	1 300	13,6	10,5	22,9	0,483	M-
12	1 300	14,2	10,9	22,9	0,502	M-
13	1 300	14	10,8	22,9	0,498	M-
14	1 300	14	10,8	22,9	0,497	M-
15	1 300	15,1	11,6	22,9	0,536	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	17,1	12,2	22,9	0,608	M-
2	1 400	16,9	12,1	22,9	0,599	M-
3	1 400	16,5	11,8	22,9	0,586	
4	1 400	16,4	11,7	22,9	0,582	
5	1 400	17,7	12,7	22,9	0,629	
6	1 400	17,8	12,7	22,9	0,63	M-
7	1 400	16,8	12	22,9	0,597	M-
8	1 400	16,9	12,1	22,9	0,6	
9	1 400	15,9	11,4	22,9	0,566	
10	1 400	16,6	11,8	22,9	0,588	
11	1 400	17,4	12,4	22,9	0,617	M-
12	1 400	16,6	11,8	22,9	0,588	
13	1 400	16,9	12,1	22,9	0,601	
14	1 400	17,2	12,3	22,9	0,611	M-
15	1 400	15,8	11,3	22,9	0,561	

Table A. 25: Physica. 60 °C, 8 days to the left, 11 days to the right.

Name: HEC+water. 60 degrees, aging 8 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	5,43	6,78	21,3	0,192	M-M+
2	800	5,96	7,46	21,3	0,211	M-
3	800	1,91	2,38	21,3	0,0677	M-
4	800	5,69	7,11	21,3	0,202	M-
5	800	5,79	7,24	21,3	0,205	M-
6	800	2,67	3,34	21,3	0,0947	M-
7	800	5,08	6,35	21,3	0,18	M-
8	800	3,63	4,54	21,3	0,129	M-
9	800	3,3	4,13	21,3	0,117	M-
10	800	2,98	3,73	21,3	0,106	M-
11	800	3,64	4,56	21,3	0,129	M-
12	800	3	3,75	21,2	0,106	M-
13	800	3,15	3,94	21,3	0,112	M-
14	800	2,38	2,97	21,2	0,0843	M-
15	800	3,84	4,79	21,3	0,136	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	6,11	6,79	21,3	0,217	M-
2	900	5,9	6,56	21,3	0,209	M-
3	900	6,05	6,73	21,2	0,215	M-
4	900	2,65	2,94	21,2	0,0938	M-
5	900	4,32	4,8	21,2	0,153	M-
6	900	3,43	3,81	21,2	0,122	M-
7	900	4,9	5,44	21,2	0,174	M-
8	900	2,39	2,66	21,2	0,0848	M-
9	900	5,63	6,26	21,2	0,2	M-
10	900	4,39	4,88	21,2	0,156	M-
11	900	5,97	6,64	21,2	0,212	M-
12	900	5,32	5,91	21,2	0,189	M-
13	900	3,01	3,34	21,2	0,107	M-
14	900	5,64	6,27	21,2	0,2	M-
15	900	4,62	5,13	21,2	0,164	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	6,63	6,63	21,2	0,235	M-
2	1 000	7,13	7,13	21,2	0,253	M-
3	1 000	6,98	6,98	21,2	0,248	M-
4	1 000	7,22	7,22	21,2	0,256	M-
5	1 000	6,35	6,35	21,2	0,225	M-
6	1 000	6,22	6,22	21,2	0,221	M-
7	1 000	6,26	6,26	21,2	0,222	M-
8	1 000	6,75	6,75	21,2	0,239	M-
9	1 000	7,69	7,69	21,2	0,273	M-

Name: HEC+water. 60degrees, aging 11 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	800	7,01	8,76	21,6	249	M-M+
2	800	5,91	7,39	21,6	210	M-
3	800	2,44	3,05	21,6	86,5	M-
4	800	4,91	6,14	21,6	174	M-
5	800	3,38	4,23	21,6	120	M-
6	800	4,81	6,01	21,6	171	M-
7	800	3,72	4,65	21,6	132	M-
8	800	1,75	2,19	21,6	62,2	M-
9	800	2,02	2,52	21,6	71,5	M-
10	800	3,94	4,92	21,6	140	M-
11	800	2,13	2,67	21,6	75,7	M-
12	800	4,82	6,02	21,6	171	M-
13	800	2,77	3,46	21,6	98,3	M-
14	800	4,98	6,23	21,6	177	M-
15	800	2,4	3	21,6	85,2	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	900	5,96	6,63	21,6	212	M-
2	900	7,56	8,4	21,6	268	M-
3	900	5,06	5,62	21,6	179	M-
4	900	4,43	4,92	21,6	157	M-
5	900	4,32	4,8	21,6	153	M-
6	900	2,79	3,1	21,6	98,8	M-
7	900	5,1	5,67	21,6	181	M-
8	900	3,31	3,67	21,6	117	M-
9	900	2,44	2,71	21,6	86,5	M-
10	900	6,03	6,71	21,6	214	M-
11	900	3,97	4,41	21,6	141	M-
12	900	3,65	4,06	21,6	130	M-
13	900	5,46	6,06	21,6	194	M-
14	900	5,87	6,53	21,5	208	M-
15	900	3,02	3,36	21,6	107	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 000	6,82	6,82	21,6	242	M-
2	1 000	7,54	7,54	21,6	267	M-
3	1 000	7,05	7,05	21,5	250	M-
4	1 000	6,73	6,73	21,5	239	M-
5	1 000	6,94	6,94	21,6	246	M-
6	1 000	6,44	6,44	21,6	228	M-
7	1 000	7,85	7,85	21,6	279	M-
8	1 000	6,27	6,27	21,6	222	M-
9	1 000	4,39	4,39	21,6	156	M-

10	1 000	6,85	6,85	21,2	0,243	M-
11	1 000	6,5	6,5	21,2	0,23	M-
12	1 000	5,87	5,87	21,2	0,208	M-
13	1 000	7,21	7,21	21,2	0,256	M-
14	1 000	6,83	6,83	21,2	0,242	M-
15	1 000	6,61	6,61	21,2	0,234	M-

10	1 000	6,77	6,77	21,6	240	M-
11	1 000	6,77	6,77	21,5	240	M-
12	1 000	6,61	6,61	21,5	234	M-
13	1 000	5,89	5,89	21,5	209	M-
14	1 000	6,83	6,83	21,5	242	M-
15	1 000	6,68	6,68	21,6	237	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	8,84	8,03	21,2	0,313	M-
2	1 100	8,97	8,15	21,2	0,318	M-
3	1 100	7,44	6,76	21,2	0,264	M-
4	1 100	8,14	7,4	21,2	0,289	M-
5	1 100	8,26	7,5	21,2	0,293	M-
6	1 100	8,11	7,37	21,2	0,287	M-
7	1 100	9,24	8,4	21,2	0,328	M-
8	1 100	8,61	7,83	21,2	0,305	M-
9	1 100	8,76	7,96	21,2	0,311	M-
10	1 100	9,04	8,22	21,2	0,321	M-
11	1 100	8,71	7,92	21,2	0,309	M-
12	1 100	8,39	7,63	21,2	0,298	M-
13	1 100	7,42	6,74	21,2	0,263	M-
14	1 100	8,74	7,95	21,2	0,31	M-
15	1 100	8,8	8	21,2	0,312	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 100	8,8	8	21,5	312	M-
2	1 100	8,16	7,42	21,6	290	M-
3	1 100	8,77	7,98	21,5	311	M-
4	1 100	7,03	6,39	21,5	249	M-
5	1 100	7,34	6,67	21,5	260	M-
6	1 100	7,31	6,65	21,5	259	M-
7	1 100	7,59	6,9	21,5	269	M-
8	1 100	8,44	7,67	21,5	299	M-
9	1 100	8,34	7,58	21,5	296	M-
10	1 100	7,97	7,25	21,5	283	M-
11	1 100	7,55	6,87	21,5	268	M-
12	1 100	7,72	7,02	21,5	274	M-
13	1 100	8,68	7,89	21,6	308	M-
14	1 100	8	7,27	21,5	284	M-
15	1 100	7,49	6,81	21,5	266	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	10,2	8,49	21,2	0,361	M-
2	1 200	10,8	9	21,2	0,383	M-
3	1 200	10,5	8,73	21,2	0,372	M-
4	1 200	10,7	8,95	21,2	0,381	M-
5	1 200	9,9	8,25	21,2	0,351	M-
6	1 200	10,4	8,63	21,2	0,367	M-
7	1 200	9,91	8,26	21,2	0,351	M-
8	1 200	9,3	7,75	21,2	0,33	M-
9	1 200	10,4	8,63	21,2	0,367	M-
10	1 200	10,2	8,48	21,2	0,361	M-
11	1 200	10,9	9,05	21,1	0,385	M-
12	1 200	9,13	7,61	21,2	0,324	M-
13	1 200	10	8,37	21,2	0,356	M-
14	1 200	10,2	8,47	21,2	0,36	M-
15	1 200	10,4	8,68	21,2	0,369	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 200	9,6	8	21,5	341	M-
2	1 200	9,88	8,23	21,5	350	M-
3	1 200	9,47	7,9	21,5	336	M-
4	1 200	9,79	8,16	21,5	347	M-
5	1 200	9,26	7,72	21,5	329	M-
6	1 200	9	7,5	21,5	319	M-
7	1 200	9,26	7,72	21,5	329	M-
8	1 200	9,22	7,68	21,5	327	M-
9	1 200	8,97	7,48	21,5	318	M-
10	1 200	9,88	8,23	21,5	350	M-
11	1 200	9,95	8,29	21,5	353	M-
12	1 200	9,66	8,05	21,5	343	M-
13	1 200	9,13	7,61	21,5	324	M-
14	1 200	8,76	7,3	21,5	311	M-
15	1 200	10,2	8,5	21,5	362	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	11,8	9,1	21,2	0,42	M-
2	1 300	12	9,25	21,2	0,426	M-
3	1 300	11,4	8,81	21,2	0,406	M-
4	1 300	11,9	9,16	21,2	0,423	M-
5	1 300	12,6	9,72	21,2	0,448	M-
6	1 300	12,2	9,37	21,2	0,432	M-
7	1 300	11,5	8,87	21,2	0,409	M-
8	1 300	11,8	9,06	21,2	0,418	M-
9	1 300	12,8	9,81	21,2	0,452	M-
10	1 300	12,6	9,68	21,2	0,446	M-
11	1 300	11,6	8,93	21,2	0,412	M-
12	1 300	12,5	9,63	21,2	0,444	M-
13	1 300	12,3	9,43	21,2	0,435	M-
14	1 300	12,9	9,93	21,2	0,458	M-
15	1 300	12,3	9,45	21,2	0,435	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 300	11,9	9,13	21,5	421	M-
2	1 300	11,2	8,62	21,5	397	M-
3	1 300	10,9	8,38	21,5	386	M-
4	1 300	10,9	8,4	21,5	387	M-
5	1 300	12	9,22	21,5	425	M-
6	1 300	11,5	8,82	21,5	406	M-
7	1 300	11	8,45	21,5	390	M-
8	1 300	11	8,49	21,5	391	M-
9	1 300	11,7	8,97	21,5	414	M-
10	1 300	11,8	9,08	21,5	419	M-
11	1 300	11,2	8,61	21,5	397	M-
12	1 300	12,9	9,91	21,5	457	M-
13	1 300	12,3	9,48	21,5	437	M-
14	1 300	10,9	8,41	21,5	388	M-
15	1 300	11,8	9,05	21,5	417	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	13,8	9,83	21,2	0,488	M-
2	1 400	13,4	9,54	21,2	0,474	M-
3	1 400	14,4	10,3	21,2	0,512	M-
4	1 400	13,7	9,8	21,2	0,486	M-
5	1 400	14,5	10,3	21,2	0,513	M-
6	1 400	14,1	10,1	21,2	0,501	M-
7	1 400	15,2	10,9	21,2	0,539	M-
8	1 400	13,4	9,55	21,2	0,474	M-
9	1 400	14,8	10,6	21,2	0,525	M-
10	1 400	13,5	9,66	21,2	0,48	M-
11	1 400	13,6	9,71	21,2	0,482	M-
12	1 400	14	9,97	21,2	0,495	M-
13	1 400	13,3	9,48	21,2	0,471	M-
14	1 400	13,2	9,43	21,2	0,468	M-
15	1 400	13,1	9,35	21,2	0,464	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 400	12,9	9,19	21,5	456	M-
2	1 400	13,1	9,39	21,5	466	M-
3	1 400	13	9,3	21,5	462	M-
4	1 400	12,6	9,03	21,5	449	M-
5	1 400	13,5	9,63	21,5	478	M-
6	1 400	12,8	9,15	21,5	454	M-
7	1 400	13	9,27	21,5	460	M-
8	1 400	11,9	8,47	21,5	420	M-
9	1 400	12,6	9,03	21,5	448	M-
10	1 400	13	9,26	21,5	460	M-
11	1 400	13	9,26	21,5	460	M-
12	1 400	13,3	9,5	21,5	472	M-
13	1 400	14,4	10,3	21,5	509	M-
14	1 400	13,3	9,53	21,5	473	M-
15	1 400	14,3	10,2	21,5	508	M-

Table A. 26: Physica. 60 °C, 15 days to the left, 20 days to the right.

Name: HEC+water. 60 degrees, aging 15 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	5,15	6,43	22	0,183	M-M+
2	800	6,01	7,51	22	0,213	M-
3	800	5,51	6,89	22	0,196	M-
4	800	3,64	4,55	22	0,129	M-
5	800	5,06	6,33	22	0,179	M-
6	800	3,17	3,96	22	0,112	M-
7	800	3,79	4,74	22	0,134	M-
8	800	3,58	4,48	22	0,127	M-
9	800	4,39	5,49	22	0,156	M-
10	800	3,23	4,04	22	0,115	M-
11	800	1,47	1,84	22	0,0522	M-
12	800	3,84	4,79	22	0,136	M-
13	800	2,38	2,98	22	0,0845	M-
14	800	5,43	6,79	22	0,193	M-
15	800	2,23	2,78	22	0,079	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	2,45	2,73	22	0,087	M-
2	900	0	0	22	0	M-
3	900	3,99	4,43	22	0,141	M-
4	900	4,73	5,26	22	0,168	M-
5	900	5,87	6,53	22	0,208	M-
6	900	5,13	5,7	22,1	0,182	M-
7	900	7,01	7,79	22	0,249	M-
8	900	2,62	2,91	22,1	0,093	M-
9	900	5,58	6,2	22,1	0,198	M-
10	900	2,74	3,05	22,1	0,0972	M-
11	900	4,12	4,57	22	0,146	M-
12	900	5,71	6,35	22,1	0,203	M-
13	900	6,09	6,76	22,1	0,216	M-
14	900	5,49	6,1	22	0,195	M-

Name: HEC+water, 60 degrees, aging 20 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	21,4	0	M-M+
2	800	5,22	6,52	21,3	0,185	M-
3	800	2,15	2,69	21,3	0,0762	M-
4	800	3,47	4,34	21,3	0,123	M-
5	800	2,55	3,18	21,3	0,0903	M-
6	800	4,42	5,53	21,3	0,157	M-
7	800	2,58	3,23	21,3	0,0915	M-
8	800	1,82	2,27	21,3	0,0645	M-
9	800	1,46	1,83	21,3	0,0518	M-
10	800	0	0	21,3	0	M-
11	800	3,89	4,86	21,3	0,138	M-
12	800	3,54	4,42	21,3	0,126	M-
13	800	3,36	4,19	21,3	0,119	M-
14	800	0	0	21,3	0	M-
15	800	3,8	4,75	21,2	0,135	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	7,03	7,81	21,2	0,249	M-
2	900	5,45	6,05	21,2	0,193	M-
3	900	3,43	3,81	21,2	0,122	M-
4	900	5,22	5,8	21,2	0,185	M-
5	900	5,33	5,93	21,2	0,189	M-
6	900	6,03	6,7	21,2	0,214	M-
7	900	5,7	6,34	21,2	0,202	M-
8	900	6,99	7,77	21,2	0,248	M-
9	900	6,56	7,29	21,2	0,233	M-
10	900	5,14	5,71	21,2	0,182	M-
11	900	2,04	2,27	21,2	0,0723	M-
12	900	3,02	3,35	21,2	0,107	M-
13	900	6,19	6,88	21,2	0,22	M-
14	900	5,57	6,19	21,2	0,198	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
15	900	3,69	4,1	22,1	0,131	M-	15	900	7,35	8,16	21,2	0,261	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	7,79	7,79	22,1	0,276	M-	1	1 000	6,8	6,8	21,2	0,241	M-
2	1 000	7,42	7,42	22,1	0,263	M-	2	1 000	6,25	6,25	21,2	0,222	M-
3	1 000	6,54	6,54	22,1	0,232	M-	3	1 000	8,46	8,46	21,2	0,3	M-
4	1 000	7,39	7,39	22	0,262	M-	4	1 000	6,89	6,89	21,2	0,244	M-
5	1 000	7,5	7,5	22,1	0,266	M-	5	1 000	7,41	7,41	21,2	0,263	M-
6	1 000	6,34	6,34	22,1	0,225	M-	6	1 000	6,12	6,12	21,2	0,217	M-
7	1 000	7,47	7,47	22,1	0,265	M-	7	1 000	8,02	8,02	21,2	0,284	M-
8	1 000	5,83	5,83	22,1	0,207	M-	8	1 000	6,32	6,32	21,2	0,224	M-
9	1 000	7,3	7,3	22,1	0,259	M-	9	1 000	6,46	6,46	21,2	0,229	M-
10	1 000	7,16	7,16	22	0,254	M-	10	1 000	5,79	5,79	21,2	0,205	M-
11	1 000	6,87	6,87	22	0,244	M-	11	1 000	4,43	4,43	21,2	0,157	M-
12	1 000	5,72	5,72	22,1	0,203	M-	12	1 000	6,31	6,31	21,2	0,224	M-
13	1 000	6,31	6,31	22,1	0,224	M-	13	1 000	4,8	4,8	21,2	0,17	M-
14	1 000	4,94	4,94	22	0,175	M-	14	1 000	5,98	5,98	21,1	0,212	M-
15	1 000	6,87	6,87	22,1	0,244	M-	15	1 000	6,5	6,5	21,2	0,231	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	8,41	7,65	22,1	0,298	M-	1	1 100	7,95	7,23	21,2	0,282	M-
2	1 100	7,68	6,99	22,1	0,273	M-	2	1 100	8,84	8,04	21,2	0,314	M-
3	1 100	7,71	7,01	22,1	0,273	M-	3	1 100	8,93	8,12	21,2	0,317	M-
4	1 100	7,7	7	22,1	0,273	M-	4	1 100	8,04	7,31	21,2	0,285	M-
5	1 100	7,41	6,74	22,1	0,263	M-	5	1 100	7,73	7,02	21,2	0,274	M-
6	1 100	8,51	7,74	22,1	0,302	M-	6	1 100	7,16	6,5	21,2	0,254	M-
7	1 100	7,49	6,81	22,1	0,266	M-	7	1 100	5,87	5,33	21,2	0,208	M-
8	1 100	6,33	5,75	22,1	0,225	M-	8	1 100	7,76	7,06	21,1	0,275	M-
9	1 100	7,36	6,69	22,1	0,261	M-	9	1 100	7,81	7,1	21,1	0,277	M-
10	1 100	7,77	7,07	22,1	0,276	M-	10	1 100	7,89	7,17	21,2	0,28	M-
11	1 100	7,89	7,17	22,1	0,28	M-	11	1 100	8,42	7,65	21,2	0,299	M-
12	1 100	7,94	7,22	22,1	0,282	M-	12	1 100	7,94	7,22	21,1	0,282	M-
13	1 100	8,4	7,64	22,1	0,298	M-	13	1 100	7,63	6,94	21,1	0,271	M-
14	1 100	9,26	8,42	22,1	0,329	M-	14	1 100	7,66	6,97	21,1	0,272	M-
15	1 100	7,82	7,11	22,1	0,277	M-	15	1 100	6,8	6,18	21,1	0,241	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	10,6	8,86	22,1	0,377	M-	1	1 200	8,44	7,03	21,2	0,299	M-
2	1 200	10	8,34	22,1	0,355	M-	2	1 200	10,5	8,72	21,1	0,371	M-
3	1 200	9,53	7,94	22,1	0,338	M-	3	1 200	9,06	7,55	21,2	0,321	M-
4	1 200	9,36	7,8	22,1	0,332	M-	4	1 200	8,5	7,08	21,1	0,301	M-
5	1 200	10,1	8,39	22,1	0,357	M-	5	1 200	9,42	7,85	21,1	0,334	M-
6	1 200	9,38	7,82	22,1	0,333	M-	6	1 200	10,1	8,41	21,2	0,358	M-
7	1 200	9,32	7,77	22,1	0,331	M-	7	1 200	10	8,36	21,2	0,356	M-
8	1 200	8,83	7,36	22,1	0,313	M-	8	1 200	8,46	7,05	21,2	0,3	M-
9	1 200	10,1	8,41	22,1	0,358	M-	9	1 200	9,61	8,01	21,2	0,341	M-
10	1 200	9,59	8	22,1	0,34	M-	10	1 200	8,6	7,17	21,2	0,305	M-
11	1 200	10,2	8,54	22,1	0,363	M-	11	1 200	9,11	7,59	21,2	0,323	M-
12	1 200	8,95	7,46	22,1	0,318	M-	12	1 200	8,18	6,81	21,1	0,29	M-
13	1 200	9,78	8,15	22,1	0,347	M-	13	1 200	9,7	8,08	21,1	0,344	M-
14	1 200	9,33	7,77	22,1	0,331	M-	14	1 200	9,26	7,72	21,1	0,329	M-
15	1 200	9,12	7,6	22,1	0,324	M-	15	1 200	9,58	7,99	21,1	0,34	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	9,81	7,54	22,1	0,348	M-	1	1 300	11,2	8,62	21,1	0,397	M-
2	1 300	11,5	8,85	22,1	0,408	M-	2	1 300	10,9	8,35	21,2	0,385	M-
3	1 300	10,9	8,4	22,1	0,387	M-	3	1 300	11	8,44	21,1	0,389	M-
4	1 300	11	8,44	22,1	0,389	M-	4	1 300	11,9	9,13	21,1	0,421	M-
5	1 300	11,7	8,98	22,1	0,414	M-	5	1 300	10,2	7,83	21,1	0,361	M-
6	1 300	10,7	8,24	22,1	0,38	M-	6	1 300	10,5	8,04	21,1	0,371	M-
7	1 300	10,6	8,16	22,1	0,376	M-	7	1 300	11,2	8,59	21,1	0,396	M-
8	1 300	11,1	8,55	22,1	0,394	M-	8	1 300	10,4	7,99	21,2	0,368	M-
9	1 300	11,1	8,54	22,1	0,394	M-	9	1 300	10,4	7,98	21,1	0,368	M-
10	1 300	10,9	8,42	22,1	0,388	M-	10	1 300	9,64	7,42	21,1	0,342	M-
11	1 300	10,8	8,3	22,1	0,383	M-	11	1 300	11,6	8,95	21,1	0,413	M-
12	1 300	11,4	8,76	22,1	0,404	M-	12	1 300	11,4	8,79	21,1	0,405	M-
13	1 300	11,4	8,75	22,1	0,403	M-	13	1 300	10,3	7,88	21,1	0,363	M-
14	1 300	10,6	8,16	22,1	0,376	M-	14	1 300	10,4	8,01	21,2	0,37	M-
15	1 300	10,8	8,28	22,1	0,382	M-	15	1 300	11,2	8,6	21,1	0,396	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	13,5	9,63	22,1	0,478	M-	1	1 400	13	9,31	21,1	0,462	M-
2	1 400	12,7	9,08	22,1	0,451	M-	2	1 400	12,8	9,13	21,1	0,454	M-
3	1 400	12,6	9,02	22,1	0,448	M-	3	1 400	12,9	9,21	21,1	0,457	M-
4	1 400	13,2	9,45	22,1	0,469	M-	4	1 400	12,7	9,04	21,2	0,449	M-
5	1 400	9,79	6,99	22,1	0,347	M-	5	1 400	13,1	9,37	21,1	0,465	M-
6	1 400	12,3	8,75	22,1	0,435	M-	6	1 400	11,6	8,27	21,1	0,41	M-
7	1 400	12,9	9,18	22,1	0,456	M-	7	1 400	12,2	8,72	21,1	0,433	M-
8	1 400	12,4	8,82	22,1	0,438	M-	8	1 400	13,1	9,33	21,1	0,463	M-
9	1 400	13	9,31	22,1	0,462	M-	9	1 400	12	8,58	21,1	0,426	M-
10	1 400	13,2	9,42	22,1	0,467	M-	10	1 400	13	9,3	21,2	0,462	M-
11	1 400	12,1	8,64	22,1	0,429	M-	11	1 400	12,1	8,66	21,1	0,43	M-
12	1 400	12,2	8,74	22,1	0,434	M-	12	1 400	13,4	9,59	21,1	0,476	M-
13	1 400	11,2	7,99	22,1	0,397	M-	13	1 400	13,3	9,48	21,1	0,47	M-
14	1 400	12,8	9,12	22,1	0,453	M-	14	1 400	11,9	8,48	21,1	0,421	M-
15	1 400	12,3	8,76	22,1	0,435	M-	15	1 400	13	9,29	21,1	0,461	M-

90 °C aging temperature

Table A. 27: Physica. 90 °C, 1 day to the left, 3 days to the right.

Name:	HEC+water. 90 degrees, aging 1 day						Name:	HEC+water. 90 degrees, aging 3 days					
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	22,5	0	M-M+	1	800	6,11	7,63	23,6	0,217	M-M+
2	800	2,78	3,48	22,5	0,0988	M-	2	800	5,97	7,46	23,6	0,212	M-
3	800	2,58	3,23	22,5	0,0915	M-	3	800	3,86	4,82	23,6	0,137	M-
4	800	2,76	3,45	22,5	0,098	M-	4	800	5,36	6,71	23,6	0,19	M-
5	800	3,69	4,61	22,5	0,131	M-	5	800	5,01	6,27	23,5	0,178	M-
6	800	2,45	3,07	22,5	0,087	M-	6	800	3,05	3,81	23,6	0,108	M-
7	800	2,11	2,63	22,5	0,0747	M-	7	800	3,46	4,33	23,5	0,123	M-
8	800	4,2	5,25	22,5	0,149	M-	8	800	3,97	4,96	23,5	0,141	M-
9	800	2,21	2,77	22,5	0,0785	M-	9	800	3,5	4,38	23,5	0,124	M-
10	800	3,51	4,38	22,4	0,124	M-	10	800	4,21	5,26	23,5	0,149	M-
11	800	2,09	2,61	22,4	0,0742	M-	11	800	3,67	4,58	23,5	0,13	M-
12	800	3,31	4,14	22,5	0,117	M-	12	800	2,7	3,38	23,5	0,0958	M-
13	800	2,83	3,53	22,4	0,1	M-	13	800	3,32	4,15	23,5	0,118	M-
14	800	3,54	4,42	22,5	0,126	M-	14	800	5,13	6,42	23,4	0,182	M-
15	800	5,07	6,34	22,4	0,18	M-	15	800	4,17	5,22	23,4	0,148	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	4,07	4,53	22,4	0,145	M-
2	900	7,73	8,59	22,4	0,274	M-
3	900	6,23	6,92	22,4	0,221	M-
4	900	4,9	5,44	22,4	0,174	M-
5	900	2,64	2,93	22,4	0,0935	M-
6	900	5,8	6,44	22,4	0,206	M-
7	900	4,5	5	22,4	0,16	M-
8	900	3,75	4,17	22,4	0,133	M-
9	900	2,79	3,1	22,4	0,099	M-
10	900	3,48	3,87	22,4	0,124	M-
11	900	4,54	5,05	22,4	0,161	M-
12	900	4,3	4,78	22,4	0,153	M-
13	900	4,47	4,97	22,4	0,159	M-
14	900	5,02	5,58	22,4	0,178	M-
15	900	0	0	22,4	0	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	7,78	7,78	22,4	0,276	M-
2	1 000	6,27	6,27	22,4	0,222	M-
3	1 000	6,81	6,81	22,4	0,242	M-
4	1 000	6,83	6,83	22,4	0,242	M-
5	1 000	6,73	6,73	22,4	0,239	M-
6	1 000	4,64	4,64	22,4	0,165	M-
7	1 000	6,61	6,61	22,4	0,235	M-
8	1 000	6,65	6,65	22,4	0,236	M-
9	1 000	7,49	7,49	22,4	0,266	M-
10	1 000	6,24	6,24	22,4	0,221	M-
11	1 000	6,12	6,12	22,4	0,217	M-
12	1 000	7,05	7,05	22,4	0,25	M-
13	1 000	6,5	6,5	22,4	0,231	M-
14	1 000	6,35	6,35	22,4	0,225	M-
15	1 000	4,59	4,59	22,4	0,163	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	8,53	7,75	22,4	0,303	M-
2	1 100	8,67	7,88	22,4	0,307	M-
3	1 100	8,29	7,54	22,4	0,294	M-
4	1 100	8,07	7,34	22,4	0,286	M-
5	1 100	9,63	8,76	22,4	0,342	M-
6	1 100	8,81	8,01	22,4	0,313	M-
7	1 100	7,95	7,23	22,4	0,282	M-
8	1 100	8,59	7,81	22,4	0,305	M-
9	1 100	7,97	7,25	22,4	0,283	M-
10	1 100	8,23	7,48	22,4	0,292	M-
11	1 100	7,69	6,99	22,4	0,273	M-
12	1 100	7,05	6,4	22,4	0,25	M-
13	1 100	8,11	7,38	22,4	0,288	M-
14	1 100	9,44	8,58	22,4	0,335	M-
15	1 100	7,6	6,91	22,4	0,269	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	10,2	8,52	22,4	0,362	M-
2	1 200	10,4	8,69	22,4	0,37	M-
3	1 200	9,73	8,11	22,4	0,345	M-
4	1 200	10,2	8,49	22,3	0,361	M-
5	1 200	9,56	7,97	22,4	0,339	M-
6	1 200	8,93	7,44	22,4	0,317	M-
7	1 200	7,95	6,62	22,4	0,282	M-
8	1 200	11,2	9,35	22,4	0,398	M-
9	1 200	10,2	8,5	22,4	0,362	M-
10	1 200	10,3	8,55	22,4	0,364	M-
11	1 200	9,12	7,6	22,4	0,323	M-
12	1 200	11	9,14	22,4	0,389	M-
13	1 200	9,12	7,6	22,3	0,324	M-
14	1 200	9,09	7,57	22,4	0,322	M-
15	1 200	9,77	8,14	22,4	0,346	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	11	8,47	22,4	0,391	M-
2	1 300	11,5	8,86	22,4	0,408	M-
3	1 300	11,6	8,96	22,4	0,413	M-
4	1 300	11,3	8,67	22,3	0,4	M-
5	1 300	11,5	8,81	22,4	0,406	M-
6	1 300	12,4	9,53	22,4	0,439	M-
7	1 300	10,9	8,38	22,3	0,386	M-
8	1 300	11,2	8,61	22,4	0,397	M-
9	1 300	11,8	9,05	22,4	0,417	M-
10	1 300	11,7	9,03	22,4	0,417	M-
11	1 300	11,9	9,12	22,4	0,42	M-
12	1 300	11,4	8,79	22,3	0,405	M-
13	1 300	11,4	8,8	22,4	0,406	M-
14	1 300	11,3	8,72	22,4	0,402	M-
15	1 300	11,3	8,66	22,4	0,399	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	13,7	9,76	22,4	0,484	M-
2	1 400	12,8	9,14	22,4	0,454	M-
3	1 400	13,3	9,5	22,4	0,472	M-
4	1 400	13,2	9,4	22,4	0,467	M-
5	1 400	12,7	9,07	22,4	0,45	M-
6	1 400	13,6	9,7	22,4	0,482	M-
7	1 400	13,1	9,34	22,4	0,463	M-
8	1 400	13,6	9,75	22,4	0,484	M-
9	1 400	12,9	9,18	22,4	0,456	M-
10	1 400	13,3	9,48	22,4	0,471	M-
11	1 400	13,2	9,42	22,3	0,468	M-
12	1 400	13	9,29	22,3	0,461	M-
13	1 400	11,9	8,46	22,4	0,42	M-
14	1 400	13	9,28	22,4	0,461	M-
15	1 400	13,3	9,49	22,3	0,471	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	5,68	6,31	23,5	0,201	M-
2	900	5,3	5,89	23,4	0,188	M-
3	900	6,95	7,72	23,4	0,246	M-
4	900	6,43	7,15	23,4	0,228	M-
5	900	6,11	6,79	23,4	0,217	M-
6	900	6,62	7,36	23,4	0,235	M-
7	900	6,01	6,68	23,4	0,213	M-
8	900	5,95	6,61	23,4	0,211	M-
9	900	3	3,33	23,4	0,106	M-
10	900	5,84	6,49	23,4	0,207	M-
11	900	6,72	7,47	23,4	0,238	M-
12	900	6,94	7,72	23,4	0,246	M-
13	900	5,08	5,64	23,4	0,18	M-
14	900	6,21	6,9	23,4	0,22	M-
15	900	3,24	3,6	23,3	0,115	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	7,39	7,39	23,3	0,262	M-
2	1 000	6,08	6,08	23,3	0,216	M-
3	1 000	8,39	8,39	23,3	0,298	M-
4	1 000	6,47	6,47	23,3	0,229	M-
5	1 000	7,99	7,99	23,3	0,283	M-
6	1 000	6,64	6,64	23,3	0,236	M-
7	1 000	6,87	6,87	23,3	0,244	M-
8	1 000	6,52	6,52	23,3	0,231	M-
9	1 000	7,09	7,09	23,3	0,252	M-
10	1 000	6,98	6,98	23,3	0,248	M-
11	1 000	5,68	5,67	23,3	0,201	M-
12	1 000	6,81	6,81	23,3	0,242	M-
13	1 000	7,03	7,03	23,3	0,249	M-
14	1 000	7,36	7,36	23,3	0,261	M-
15	1 000	6,74	6,74	23,3	0,239	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	8,68	7,89	23,2	0,308	M-
2	1 100	8,29	7,53	23,3	0,294	M-
3	1 100	7,68	6,98	23,3	0,272	M-
4	1 100	9,13	8,3	23,2	0,324	M-
5	1 100	8,98	8,16	23,2	0,319	M-
6	1 100	9,33	8,48	23,3	0,331	M-
7	1 100	7,96	7,24	23,3	0,282	M-
8	1 100	8,28	7,52	23,2	0,293	M-
9	1 100	7,44	6,77	23,2	0,264	M-
10	1 100	7,04	6,4	23,2	0,25	M-
11	1 100	8,09	7,36	23,3	0,287	M-
12	1 100	8,82	8,02	23,2	0,313	M-
13	1 100	9,54	8,67	23,2	0,338	M-
14	1 100	9,88	8,99	23,2	0,351	M-
15	1 100	10,1	9,2	23,2	0,359	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	11,9	9,93	23,2	0,423	M-
2	1 200	10,9	9,07	23,2	0,386	M-
3	1 200	9,64	8,03	23,2	0,342	M-
4	1 200	10,3	8,59	23,2	0,366	M-
5	1 200	10,5	8,73	23,2	0,371	M-
6	1 200	10,9	9,09	23,2	0,387	M-
7	1 200	10,4	8,67	23,2	0,369	M-
8	1 200	9,21	7,67	23,2	0,327	M-
9	1 200	9,89	8,24	23,2	0,351	M-
10	1 200	10,2	8,53	23,2	0,363	M-
11	1 200	11,8	9,85	23,2	0,419	M-
12	1 200	12,1	10,1	23,2	0,429	M-
13	1 200	11,5	9,6	23,2	0,409	M-
14	1 200	10,8	9,02	23,2	0,384	M-
15	1 200	9,62	8,01	23,2	0,341	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	13,3	10,2	23,2	0,471	M-
2	1 300	12,1	9,29	23,2	0,428	M-
3	1 300	11,2	8,59	23,2	0,396	M-
4	1 300	11,5	8,84	23,2	0,407	M-
5	1 300	12,5	9,61	23,2	0,443	M-
6	1 300	12,1	9,28	23,2	0,428	M-
7	1 300	12,2	9,42	23,2	0,434	M-
8	1 300	11,5	8,84	23,2	0,407	M-
9	1 300	11,9	9,14	23,2	0,422	M-
10	1 300	11	8,45	23,2	0,39	M-
11	1 300	11,7	9,02	23,2	0,416	M-
12	1 300	11,6	8,89	23,2	0,41	M-
13	1 300	11,3	8,68	23,2	0,4	M-
14	1 300	11,3	8,67	23,2	0,4	M-
15	1 300	11,4	8,77	23,2	0,404	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	15,4	11	23,2	0,546	M-
2	1 400	16,7	11,9	23,2	0,592	M-
3	1 400	13,2	9,46	23,1	0,47	M-
4	1 400	12,1	8,62	23,2	0,428	M-
5	1 400	11	7,89	23,2	0,392	M-
6	1 400	13,2	9,41	23,2	0,467	M-
7	1 400	12,7	9,04	23,2	0,449	M-
8	1 400	12,7	9,07	23,2	0,451	M-
9	1 400	13,6	9,69	23,2	0,481	M-
10	1 400	13,1	9,32	23,2	0,463	M-
11	1 400	13,6	9,75	23,2	0,484	M-
12	1 400	13,2	9,45	23,2	0,469	M-
13	1 400	12	8,56	23,1	0,425	M-
14	1 400	14	9,99	23,2	0,496	M-
15	1 400	12,1	8,64	23,2	0,429	M-

Table A. 28: Physica. 90 °C, 8 days to the left, 11 days to the right.

Name: HEC+water. 90 degrees, aging 8 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	21,2	0	M-M+
2	800	2,19	2,73	21,2	0,0775	M-

Name: HEC+water. 90 degrees, aging 11 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	800	0	0	22	0	M-M+
2	800	0	0	22	0	M-

3	800	4,22	5,28	21,2	0,15	M-
4	800	0	0	21,2	0	M-
5	800	1,88	2,35	21,2	0,0667	M-
6	800	2,19	2,73	21,2	0,0775	M-
7	800	1,97	2,46	21,2	0,0698	M-
8	800	1,7	2,13	21,2	0,0603	M-
9	800	0	0	21,2	0	M-
10	800	1,91	2,39	21,2	0,0677	M-
11	800	1,78	2,23	21,2	0,0632	M-
12	800	0	0	21,2	0	M-
13	800	0	0	21,2	0	M-
14	800	0	0	21,2	0	M-
15	800	0	0	21,2	0	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	0	0	21,2	0	M-
2	900	2,93	3,26	21,2	0,104	M-
3	900	1,66	1,84	21,2	0,0588	M-
4	900	3,21	3,57	21,2	0,114	M-
5	900	3,24	3,6	21,2	0,115	M-
6	900	0	0	21,2	0	M-
7	900	2,33	2,59	21,2	0,0827	M-
8	900	0	0	21,2	0	M-
9	900	0	0	21,2	0	M-
10	900	2,54	2,83	21,2	0,0902	M-
11	900	1,51	1,68	21,2	0,0535	M-
12	900	2,35	2,61	21,2	0,0832	M-
13	900	1,65	1,84	21,2	0,0587	M-
14	900	0	0	21,2	0	M-
15	900	2,37	2,63	21,2	0,084	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	2,76	2,76	21,2	0,098	M-
2	1 000	2,94	2,94	21,2	0,104	M-
3	1 000	2,34	2,34	21,2	0,083	M-
4	1 000	3,53	3,53	21,2	0,125	M-
5	1 000	2,63	2,63	21,2	0,0933	M-
6	1 000	3,2	3,2	21,2	0,114	M-
7	1 000	2,26	2,26	21,2	0,0803	M-
8	1 000	3,32	3,32	21,2	0,118	M-
9	1 000	2,25	2,25	21,2	0,0798	M-
10	1 000	4,39	4,39	21,2	0,156	M-
11	1 000	3,34	3,34	21,2	0,118	M-
12	1 000	3,88	3,88	21,2	0,138	M-
13	1 000	1,53	1,53	21,2	0,0542	M-
14	1 000	3,92	3,92	21,2	0,139	M-
15	1 000	4,16	4,16	21,2	0,148	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	6,43	5,85	21,2	0,228	M-
2	1 100	6,08	5,52	21,2	0,216	M-
3	1 100	5,76	5,23	21,2	0,204	M-
4	1 100	3,64	3,31	21,2	0,129	M-
5	1 100	5,78	5,26	21,2	0,205	M-
6	1 100	5,34	4,86	21,2	0,19	M-
7	1 100	3,81	3,46	21,2	0,135	M-
8	1 100	6,42	5,83	21,2	0,228	M-
9	1 100	3,81	3,46	21,2	0,135	M-
10	1 100	6,18	5,62	21,2	0,219	M-
11	1 100	5,63	5,11	21,2	0,2	M-
12	1 100	5,73	5,21	21,2	0,203	M-
13	1 100	2,77	2,52	21,2	0,0983	M-
14	1 100	7,59	6,9	21,2	0,269	M-
15	1 100	5,56	5,06	21,2	0,197	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	7,42	6,18	21,2	0,263	M-
2	1 200	7,26	6,05	21,2	0,257	M-
3	1 200	7,36	6,13	21,2	0,261	M-
4	1 200	6,66	5,55	21,2	0,236	M-
5	1 200	6,9	5,75	21,2	0,245	M-
6	1 200	7,09	5,91	21,2	0,252	M-
7	1 200	7,9	6,58	21,2	0,28	M-
8	1 200	6,93	5,77	21,2	0,246	M-
9	1 200	6,87	5,73	21,2	0,244	M-
10	1 200	6,56	5,46	21,2	0,232	M-
11	1 200	6,93	5,78	21,2	0,246	M-
12	1 200	5,88	4,9	21,2	0,208	M-
13	1 200	7,05	5,87	21,2	0,25	M-
14	1 200	7,23	6,03	21,2	0,257	M-
15	1 200	7,29	6,07	21,2	0,259	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	8,75	6,73	21,2	0,31	M-
2	1 300	6,98	5,37	21,2	0,248	M-
3	1 300	9,16	7,05	21,2	0,325	M-
4	1 300	7,98	6,14	21,2	0,283	M-
5	1 300	8,49	6,53	21,2	0,301	M-
6	1 300	9,3	7,15	21,2	0,33	M-
7	1 300	7,21	5,55	21,2	0,256	M-
8	1 300	8,23	6,33	21,2	0,292	M-
9	1 300	7,67	5,9	21,2	0,272	M-
10	1 300	7,36	5,66	21,2	0,261	M-
11	1 300	8,95	6,88	21,2	0,317	M-
12	1 300	6,27	4,82	21,2	0,222	M-
13	1 300	7,53	5,79	21,2	0,267	M-
14	1 300	8,3	6,39	21,2	0,294	M-
15	1 300	7,32	5,63	21,2	0,26	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	8,97	6,41	21,2	0,318	M-
2	1 400	9,32	6,65	21,2	0,33	M-
3	1 400	9,29	6,63	21,2	0,329	M-
4	1 400	9,62	6,87	21,2	0,341	M-
5	1 400	9,73	6,95	21,2	0,345	M-
6	1 400	8,97	6,41	21,2	0,318	M-
7	1 400	9,69	6,92	21,2	0,344	M-
8	1 400	9,27	6,62	21,2	0,329	M-
9	1 400	9,22	6,59	21,2	0,327	M-
10	1 400	9,67	6,91	21,2	0,343	M-
11	1 400	8,68	6,2	21,2	0,308	M-
12	1 400	9,23	6,59	21,2	0,327	M-
13	1 400	8,48	6,06	21,2	0,301	M-
14	1 400	8,77	6,26	21,2	0,311	M-
15	1 400	8,47	6,05	21,2	0,3	M-

3	800	0	0	22	0	M-
4	800	0	0	22	0	M-
5	800	0	0	22	0	M-
6	800	2,64	3,3	22	93,8	M-
7	800	0	0	22	0	M-
8	800	3,47	4,34	21,9	123	M-
9	800	3,19	3,99	21,9	113	M-
10	800	1,46	1,82	21,9	51,7	M-
11	800	1,8	2,25	21,9	63,8	M-
12	800	1,47	1,84	21,9	52,2	M-
13	800	4,42	5,53	21,9	157	M-
14	800	5,63	7,03	21,9	200	M-
15	800	2,13	2,66	21,9	75,5	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	900	2,69	2,99	21,9	95,5	M-
2	900	2,33	2,59	21,9	82,5	M-
3	900	0	0	21,9	0	M-
4	900	1,64	1,82	21,9	58	M-
5	900	0	0	21,8	0	M-
6	900	1,67	1,85	21,8	59,2	M-
7	900	2,39	2,66	21,8	84,8	M-
8	900	3,06	3,4	21,8	109	M-
9	900	2,26	2,51	21,8	80	M-
10	900	0	0	21,8	0	M-
11	900	1,65	1,83	21,8	58,5	M-
12	900	0	0	21,8	0	M-
13	900	0	0	21,8	0	M-
14	900	0	0	21,8	0	M-
15	900	0	0	21,8	0	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 000	5,43	5,43	21,8	193	M-
2	1 000	6,16	6,16	21,8	219	M-
3	1 000	2,82	2,82	21,8	100	M-
4	1 000	1,96	1,96	21,8	69,7	M-
5	1 000	2,26	2,26	21,8	80	M-
6	1 000	3,35	3,35	21,8	119	M-
7	1 000	4,05	4,05	21,8	144	M-
8	1 000	2,16	2,16	21,8	76,7	M-
9	1 000	0	0	21,8	0	M-
10	1 000	3,93	3,93	21,8	140	M-
11	1 000	5,49	5,49	21,8	195	M-
12	1 000	3,03	3,03	21,8	108	M-
13	1 000	3,01	3,01	21,8	107	M-
14	1 000	2,27	2,27	21,7	80,5	M-
15	1 000	1,52	1,52	21,7	54	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 100	4,44	4,03	21,7	157	M-
2	1 100	4,28	3,89	21,8	152	M-
3	1 100	3,81	3,46	21,7	135	M-
4	1 100	4,85	4,41	21,7	172	M-
5	1 100	6,29	5,72	21,7	223	M-
6	1 100	2,81	2,55	21,7	99,5	M-
7	1 100	2,59	2,35	21,7	91,8	M-
8	1 100	6,34	5,77	21,7	225	M-
9	1 100	4,42	4,02	21,7	157	M-
10	1 100	5,69	5,17	21,7	202	M-
11	1 100	3,84	3,49	21,7	136	M-
12	1 100	4,14	3,76	21,7	147	M-
13	1 100	2,2	2	21,7	78	M-
14	1 100	2,62	2,38	21,7	92,8	M-
15	1 100	5,76	5,24	21,7	204	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 200	4,06	3,38	21,7	144	M-
2	1 200	6,15	5,13	21,7	218	M-
3	1 200	5,22	4,35	21,7	185	M-
4	1 200	5,68	4,73	21,7	201	M-
5	1 200	6,13	5,11	21,7	218	M-
6	1 200	6,8	5,66	21,7	241	M-
7	1 200	7,11	5,93	21,7	252	M-
8	1 200	3,19	2,66	21,7	113	M-
9	1 200	6,33	5,28	21,7	225	M-
10	1 200	7,42	6,19	21,7	263	M-
11	1 200	5,69	4,74	21,7	202	M-
12	1 200	6,71	5,59	21,7	238	M-
13	1 200	6,03	5,02	21,7	214	M-
14	1 200	7,27	6,06	21,7	258	M-
15	1 200	4,62	3,85	21,7	164	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 300	8,4	6,46	21,7	298	M-
2	1 300	7,18	5,52	21,7	255	M-
3	1 300	7,63	5,87	21,7	271	M-
4	1 300	8,04	6,19	21,7	285	M-
5	1 300	7,1	5,46	21,7	252	M-
6	1 300	8,01	6,16	21,7	284	M-
7	1 300	7,86	6,05	21,7	279	M-
8	1 300	6,52	5,01	21,7	231	M-
9	1 300	7,08	5,44	21,7	251	M-
10	1 300	5,79	4,46	21,7	205	M-
11	1 300	6,55	5,04	21,7	232	M-
12	1 300	6,88	5,29	21,7	244	M-
13	1 300	6,58	5,06	21,7	233	M-
14	1 300	7,05	5,42	21,7	250	M-
15	1 300	8,28	6,37	21,7	294	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [µNm]	Status []
1	1 400	8,56	6,11	21,7	303	M-
2	1 400	9,49	6,78	21,7	337	M-
3	1 400	9,18	6,56	21,7	326	M-
4	1 400	8,18	5,84	21,7	290	M-
5	1 400	9,55	6,82	21,7	339	M-
6	1 400	7,38	5,27	21,7	262	M-
7	1 400	9,97	7,12	21,7	354	M-
8	1 400	9,63	6,88	21,7	342	M-
9	1 400	8,35	5,97	21,7	296	M-
10	1 400	6,37	4,55	21,7	226	M-
11	1 400	8,61	6,15	21,7	305	M-
12	1 400	8,28	5,92	21,7	294	M-
13	1 400	9,53	6,81	21,7	338	M-
14	1 400	7,99	5,71	21,7	284	M-
15	1 400	8,47	6,05	21,7	300	M-

Table A. 29: Physica. 90 °C, 8 days to the left, 11 days to the right.

Name: HEC+water. 90 degrees, aging 15 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	22	0	M-M+
2	800	0	0	21,9	0	M-
3	800	3,04	3,8	22	0,108	M-
4	800	3,46	4,33	22	0,123	M-
5	800	3,02	3,78	21,9	0,107	M-
6	800	0	0	22	0	M-
7	800	3,75	4,68	21,9	0,133	M-
8	800	0	0	22	0	M-
9	800	1,75	2,19	22	0,062	M-
10	800	0	0	22	0	M-
11	800	1,65	2,06	22	0,0585	M-
12	800	1,74	2,17	22	0,0617	M-
13	800	2,71	3,39	22	0,0962	M-
14	800	3,09	3,87	22	0,11	M-
15	800	3,79	4,74	22	0,135	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	3,03	3,37	22	0,108	M-
2	900	2,19	2,43	22	0,0775	M-
3	900	1,87	2,07	22	0,0662	M-
4	900	2,28	2,53	22	0,0808	M-
5	900	1,59	1,77	22	0,0565	M-
6	900	3,12	3,46	22	0,111	M-
7	900	2,79	3,1	22	0,099	M-
8	900	2,81	3,12	22	0,0995	M-
9	900	0	0	22	0	M-
10	900	2,77	3,08	22	0,0983	M-
11	900	1,63	1,81	22	0,0577	M-
12	900	0	0	22	0	M-
13	900	0	0	22	0	M-
14	900	2,98	3,31	22	0,106	M-
15	900	2,28	2,53	22,1	0,0808	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	2,43	2,43	22	0,086	M-
2	1 000	4,5	4,5	22,1	0,16	M-
3	1 000	2,21	2,21	22	0,0785	M-
4	1 000	3,76	3,76	22	0,133	M-
5	1 000	2,28	2,28	22	0,081	M-
6	1 000	3,15	3,15	22,1	0,112	M-
7	1 000	3,88	3,88	22	0,138	M-
8	1 000	2,4	2,4	22	0,085	M-
9	1 000	0	0	22,1	0	M-
10	1 000	1,68	1,68	22	0,0597	M-
11	1 000	2,23	2,23	22	0,079	M-
12	1 000	1,93	1,93	22	0,0685	M-
13	1 000	1,98	1,98	22,1	0,0703	M-
14	1 000	3,35	3,35	22	0,119	M-
15	1 000	3,12	3,12	22,1	0,111	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	5,02	4,56	22,1	0,178	M-
2	1 100	5,45	4,96	22,1	0,193	M-
3	1 100	5,5	5	22,1	0,195	M-
4	1 100	3,8	3,46	22,1	0,135	M-
5	1 100	2,59	2,35	22,1	0,0918	M-
6	1 100	2,32	2,11	22,1	0,0823	M-
7	1 100	5,09	4,63	22	0,18	M-
8	1 100	5,75	5,22	22,1	0,204	M-
9	1 100	5,09	4,63	22,1	0,181	M-
10	1 100	3,92	3,57	22,1	0,139	M-
11	1 100	5,02	4,57	22,1	0,178	M-
12	1 100	3,65	3,32	22,1	0,129	M-
13	1 100	0	0	22,1	0	M-
14	1 100	2,47	2,25	22,1	0,0878	M-
15	1 100	2,64	2,4	22,1	0,0938	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	5,97	4,98	22,1	0,212	M-
2	1 200	5,82	4,85	22,1	0,206	M-
3	1 200	6,11	5,09	22,1	0,217	M-
4	1 200	3,36	2,8	22,1	0,119	M-
5	1 200	5,22	4,35	22,1	0,185	M-
6	1 200	7,25	6,04	22,1	0,257	M-
7	1 200	7,27	6,06	22,1	0,258	M-
8	1 200	3,77	3,14	22,1	0,134	M-
9	1 200	6,45	5,37	22	0,229	M-
10	1 200	6,42	5,35	22	0,228	M-
11	1 200	6,66	5,55	22,1	0,236	M-
12	1 200	4,5	3,75	22,1	0,16	M-
13	1 200	6,63	5,53	22,1	0,235	M-
14	1 200	6,8	5,67	22,1	0,241	M-
15	1 200	4,21	3,51	22,1	0,149	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	7,59	5,83	22,1	0,269	M-
2	1 300	7,02	5,4	22,1	0,249	M-
3	1 300	6,81	5,24	22,1	0,242	M-
4	1 300	7,17	5,51	22,1	0,254	M-
5	1 300	2,72	2,09	22,1	0,0965	M-
6	1 300	6,74	5,18	22,1	0,239	M-
7	1 300	7,23	5,56	22,1	0,256	M-
8	1 300	6,68	5,14	22,1	0,237	M-
9	1 300	6,83	5,26	22,1	0,242	M-
10	1 300	4,77	3,67	22,1	0,169	M-
11	1 300	7,16	5,51	22,1	0,254	M-
12	1 300	8,67	6,67	22,1	0,308	M-
13	1 300	6,77	5,21	22,1	0,24	M-
14	1 300	6,46	4,97	22,1	0,229	M-
15	1 300	7,4	5,69	22,1	0,263	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	7,89	5,64	22,1	0,28	M-
2	1 400	8,5	6,07	22,1	0,301	M-

Name: HEC+water. 90 degrees, aging 20 days

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	0	0	21,3	0	M-M+
2	800	0	0	21,2	0	M-
3	800	0	0	21,2	0	M-
4	800	2,35	2,94	21,2	0,0835	M-
5	800	2,1	2,63	21,2	0,0745	M-
6	800	2,43	3,04	21,2	0,0862	M-
7	800	3,83	4,79	21,2	0,136	M-
8	800	0	0	21,2	0	M-
9	800	2,13	2,66	21,2	0,0755	M-
10	800	0	0	21,2	0	M-
11	800	1,84	2,3	21,2	0,0653	M-
12	800	1,44	1,8	21,2	0,0512	M-
13	800	2,86	3,57	21,2	0,101	M-
14	800	0	0	21,2	0	M-
15	800	0	0	21,2	0	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	0	0	21,2	0	M-
2	900	0	0	21,2	0	M-
3	900	0	0	21,2	0	M-
4	900	3,12	3,46	21,2	0,111	M-
5	900	3,29	3,66	21,2	0,117	M-
6	900	0	0	21,2	0	M-
7	900	2,52	2,8	21,2	0,0892	M-
8	900	0	0	21,2	0	M-
9	900	2,14	2,37	21,2	0,0757	M-
10	900	0	0	21,2	0	M-
11	900	1,89	2,1	21,2	0,067	M-
12	900	0	0	21,2	0	M-
13	900	0	0	21,2	0	M-
14	900	0	0	21,2	0	M-
15	900	0	0	21,2	0	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	2,42	2,42	21,2	0,0857	M-
2	1 000	0	0	21,2	0	M-
3	1 000	2,35	2,35	21,2	0,0832	M-
4	1 000	2,46	2,46	21,2	0,0873	M-
5	1 000	5,37	5,37	21,2	0,191	M-
6	1 000	1,45	1,45	21,2	0,0513	M-
7	1 000	0	0	21,2	0	M-
8	1 000	1,76	1,76	21,2	0,0625	M-
9	1 000	0	0	21,2	0	M-
10	1 000	1,44	1,44	21,2	0,051	M-
11	1 000	2,61	2,61	21,2	0,0925	M-
12	1 000	1,51	1,51	21,2	0,0535	M-
13	1 000	0	0	21,2	0	M-
14	1 000	1,65	1,65	21,2	0,0587	M-
15	1 000	1,46	1,46	21,2	0,0518	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	3,43	3,11	21,2	0,122	M-
2	1 100	5,53	5,03	21,2	0,196	M-
3	1 100	4,13	3,76	21,2	0,147	M-
4	1 100	3,02	2,75	21,2	0,107	M-
5	1 100	5,66	5,15	21,2	0,201	M-
6	1 100	4,48	4,08	21,2	0,159	M-
7	1 100	2,49	2,26	21,2	0,0883	M-
8	1 100	4,84	4,4	21,2	0,171	M-
9	1 100	5,21	4,74	21,2	0,185	M-
10	1 100	3,59	3,26	21,2	0,127	M-
11	1 100	4,12	3,75	21,2	0,146	M-
12	1 100	3,25	2,95	21,2	0,115	M-
13	1 100	0	0	21,2	0	M-
14	1 100	0	0	21,2	0	M-
15	1 100	2,15	1,95	21,2	0,0762	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	5,37	4,48	21,2	0,191	M-
2	1 200	3,92	3,27	21,2	0,139	M-
3	1 200	6,52	5,43	21,2	0,231	M-
4	1 200	5,67	4,72	21,2	0,201	M-
5	1 200	4,02	3,35	21,2	0,143	M-
6	1 200	4,74	3,95	21,2	0,168	M-
7	1 200	6,06	5,05	21,2	0,215	M-
8	1 200	6,34	5,29	21,2	0,225	M-
9	1 200	5,1	4,25	21,2	0,181	M-
10	1 200	4,03	3,36	21,2	0,143	M-
11	1 200	4,62	3,85	21,2	0,164	M-
12	1 200	4,75	3,96	21,2	0,169	M-
13	1 200	5,61	4,68	21,2	0,199	M-
14	1 200	6,51	5,42	21,2	0,231	M-
15	1 200	6,09	5,07	21,2	0,216	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	6,42	4,94	21,2	0,228	M-
2	1 300	6,81	5,24	21,2	0,242	M-
3	1 300	5,58	4,29	21,2	0,198	M-
4	1 300	7,46	5,74	21,2	0,265	M-
5	1 300	5,18	3,98	21,2	0,184	M-
6	1 300	6,58	5,06	21,2	0,233	M-
7	1 300	7,2	5,54	21,2	0,255	M-
8	1 300	6,43	4,95	21,2	0,228	M-
9	1 300	5,62	4,32	21,2	0,199	M-
10	1 300	7,49	5,76	21,2	0,266	M-
11	1 300	5,86	4,51	21,2	0,208	M-
12	1 300	6,29	4,84	21,2	0,223	M-
13	1 300	3,88	2,98	21,2	0,138	M-
14	1 300	6,85	5,27	21,2	0,243	M-
15	1 300	7,41	5,7	21,2	0,263	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	7,37	5,27	21,2	0,262	M-
2	1 400	7,83	5,59	21,2	0,278	M-

3	1 400	8,37	5,98	22,1	0,297	M-
4	1 400	8,14	5,82	22,1	0,289	M-
5	1 400	8,92	6,37	22,1	0,316	M-
6	1 400	7,79	5,56	22,1	0,276	M-
7	1 400	7,9	5,64	22,1	0,28	M-
8	1 400	7,63	5,45	22,1	0,271	M-
9	1 400	7,5	5,36	22,1	0,266	M-
10	1 400	8,31	5,94	22,1	0,295	M-
11	1 400	8,71	6,22	22,1	0,309	M-
12	1 400	7,79	5,57	22,1	0,276	M-
13	1 400	8,01	5,72	22,1	0,284	M-
14	1 400	7,61	5,44	22,1	0,27	M-
15	1 400	8,64	6,17	22,1	0,307	M-

3	1 400	7,67	5,48	21,2	0,272	M-
4	1 400	6,82	4,87	21,2	0,242	M-
5	1 400	8,81	6,29	21,2	0,312	M-
6	1 400	7,07	5,05	21,2	0,251	M-
7	1 400	7,09	5,06	21,2	0,251	M-
8	1 400	7,54	5,38	21,2	0,267	M-
9	1 400	7,43	5,31	21,2	0,264	M-
10	1 400	8,09	5,78	21,2	0,287	M-
11	1 400	6,54	4,67	21,2	0,232	M-
12	1 400	7,82	5,59	21,2	0,277	M-
13	1 400	8,28	5,91	21,2	0,293	M-
14	1 400	8,02	5,73	21,2	0,285	M-
15	1 400	7,26	5,19	21,2	0,258	M-

A.2.3 Calibration of Physica viscometer

In the tables and figures below (Table A. 30, Table A. 31, Table A. 32, Table A. 33 and Figure A. 1, Figure A. 2, Figure A. 3, Figure A. 4, Figure A. 5) are some of the data from the calibration experiment included.

Table A. 30: Avr. shear stress and viscosity from Physica, 8 vol-% Exxsol D-60.

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
0	0,00	
800	29,68	34,64
900	31,26	34,74
1000	35,07	35,07
1100	38,66	35,15
1200	42,75	35,61

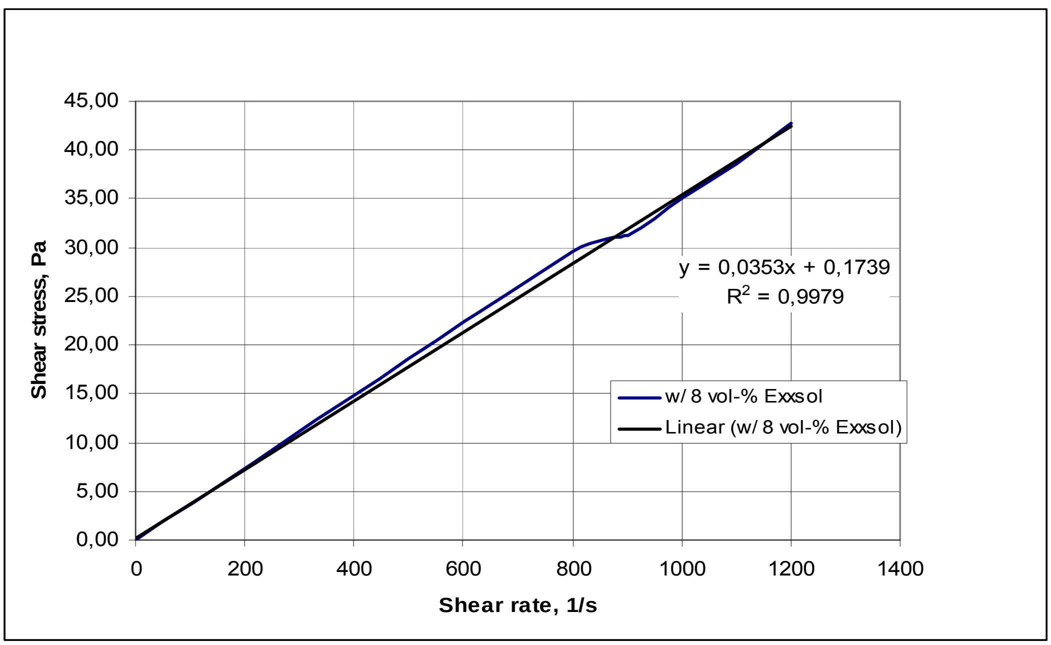


Figure A. 1: Physica, shear rate vs shear stress 8 vol-% Exxsol D-60 added.

Table A. 31: Avr. shear stress and viscosity Physica, 10 vol-% Exxsol D-60.

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
0	0	0
800	24,56	30,69
900	27,59	30,65
1000	30,98	30,98
1100	34,14	31,04
1200	37,89	31,58

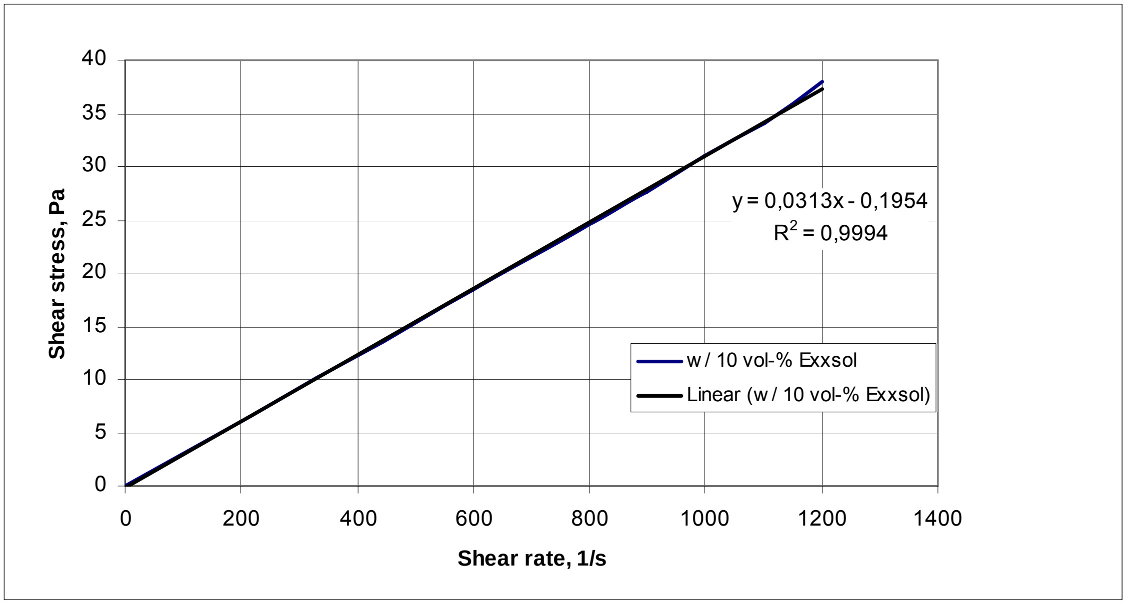


Figure A. 2: Physica viscometer, shear rate vs shear stress 10 vol-% Exxsol D-60.

Table A. 32: Avr. shear stress and viscosity Physica viscometer, 20 vol-% Exxsol D-60.

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
0	0	0
800	13,69	15,85
900	15,13	16,81
1000	17,06	17,06
1100	19,20	17,44
1200	21,46	17,89

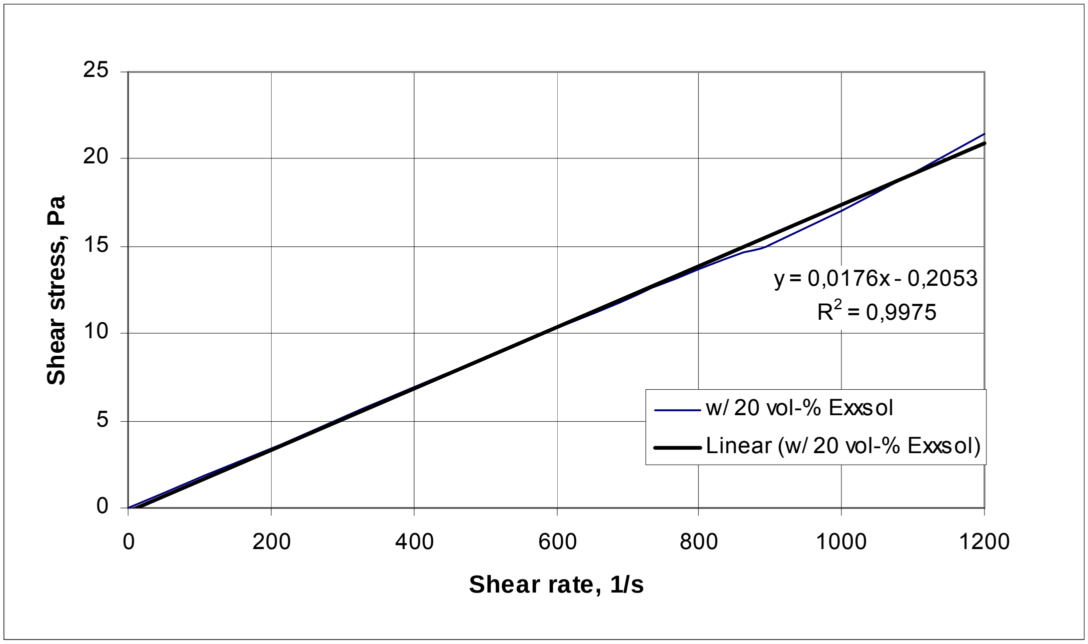


Figure A. 3: Physica viscometer, shear rate vs shear stress 20 vol-% Exxsol D-60 added.

Table A. 33: Avr. shear stress and viscosity Physica, 30 vol-% Exxsol D-60.

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
0	0	0
800	8,30	10,36
900	9,06	10,06
1000	10,26	10,26
1100	11,75	10,68
1200	13,01	10,84

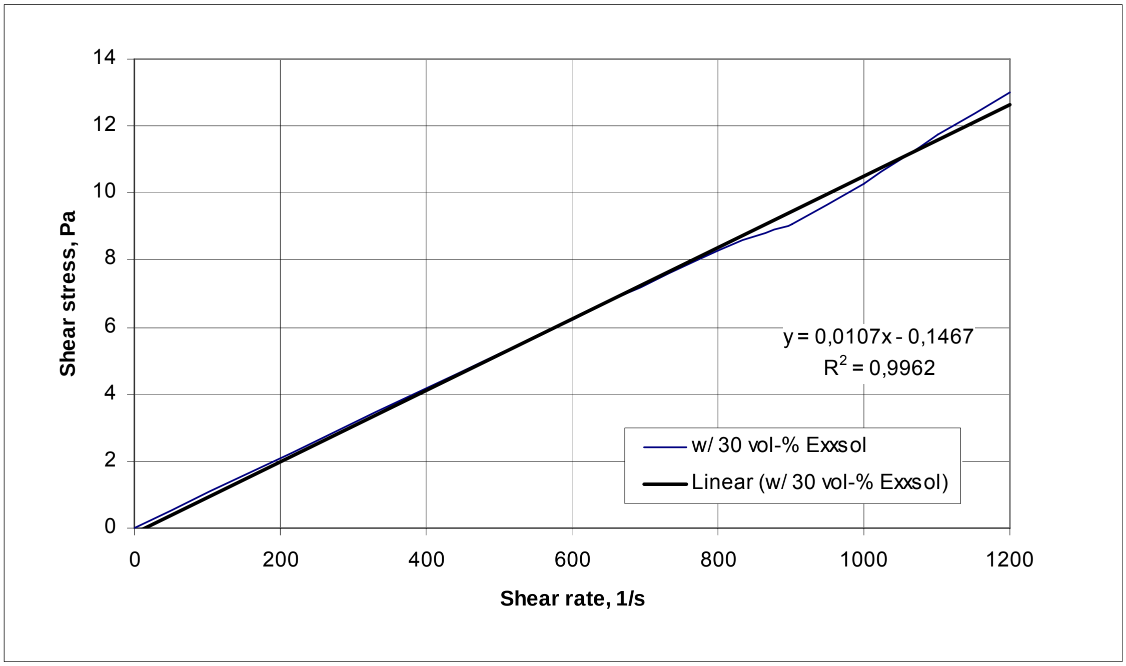


Figure A. 4: Physica viscometer, shear rate vs shear stress 30 vol-% Exxsol D-60.

$$y = 1{,}0619x - 3{,}6627 \qquad (A.1)$$

$$R^2 = 0{,}9956 \qquad (A.2)$$

or in other words,

$$\mu_{ubelohde} = 1{,}0619 * \mu_{Physica} - 3{,}6627 \qquad (A.3)$$

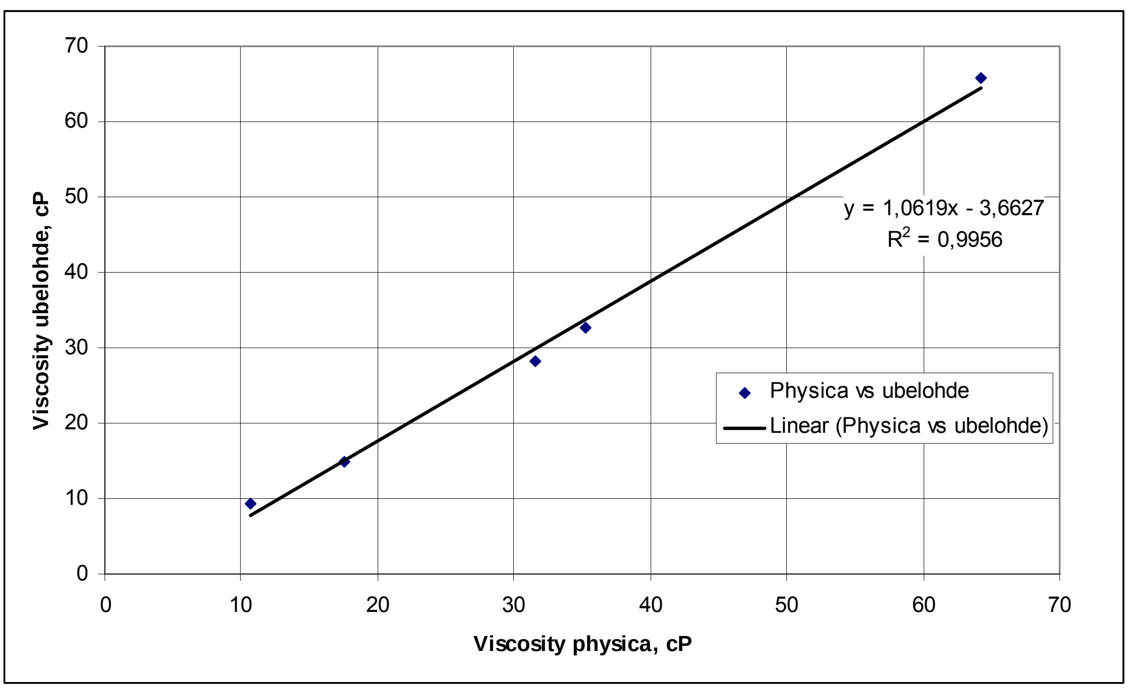


Figure A. 5: Physica viscometer vs ubelohde. Calibration oil + exxsol D-60.

A.2.4 Rheological testing experiment- Results Physica

The plot of shear rate vs shear stress for T = 20 °C and P = 1 bar is shown in Figure A. 6.

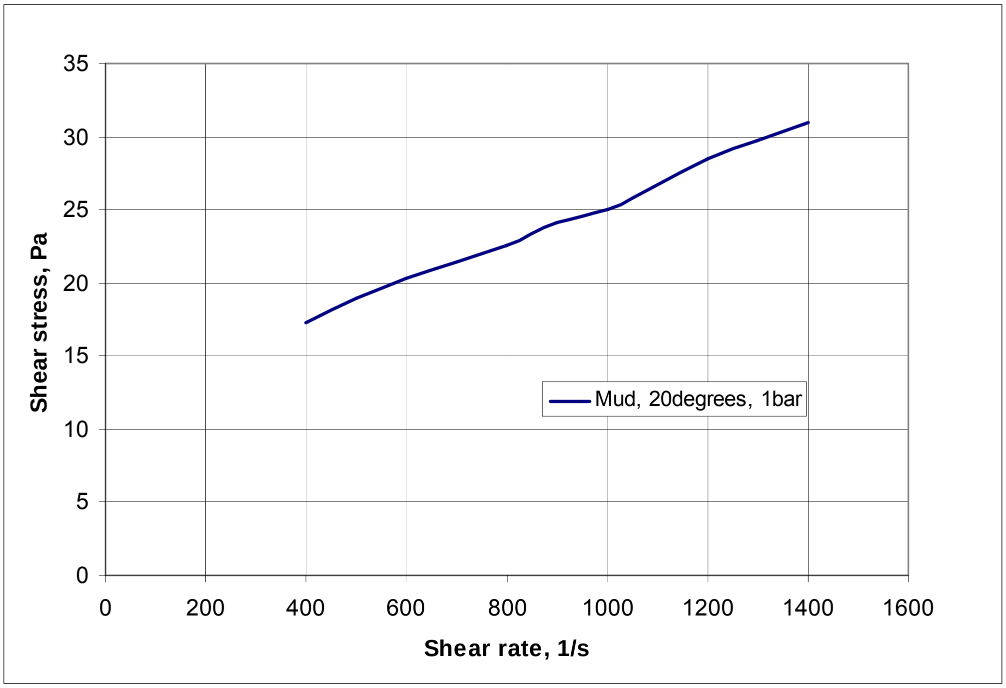


Figure A. 6: Drill-in mud, T=20 °C, P=1 bar.

The results from the measurements at 20 °C at 40 bar and 80 bar are shown in Figure A. 7 and Figure A. 8 respectively.

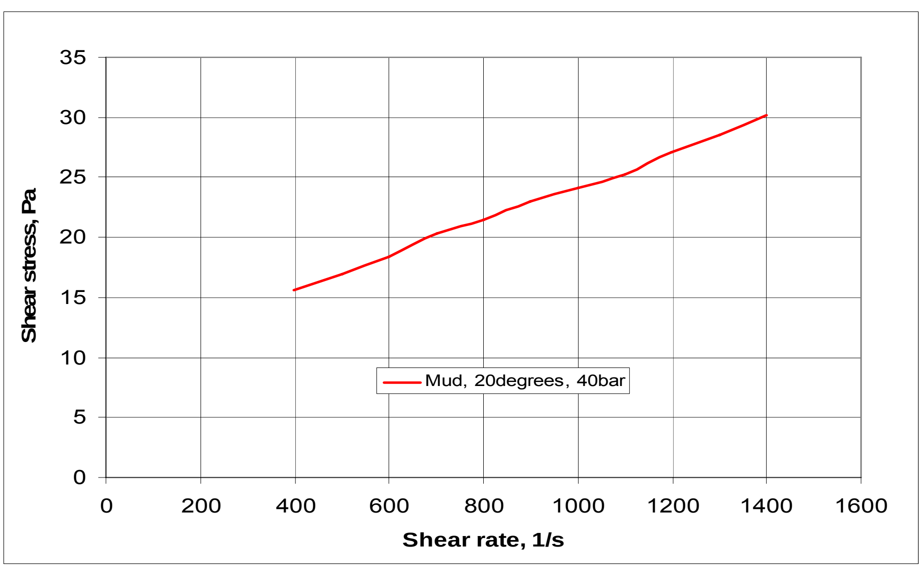


Figure A. 7: Drill- in mud, T=20 °C, P=40 bar.

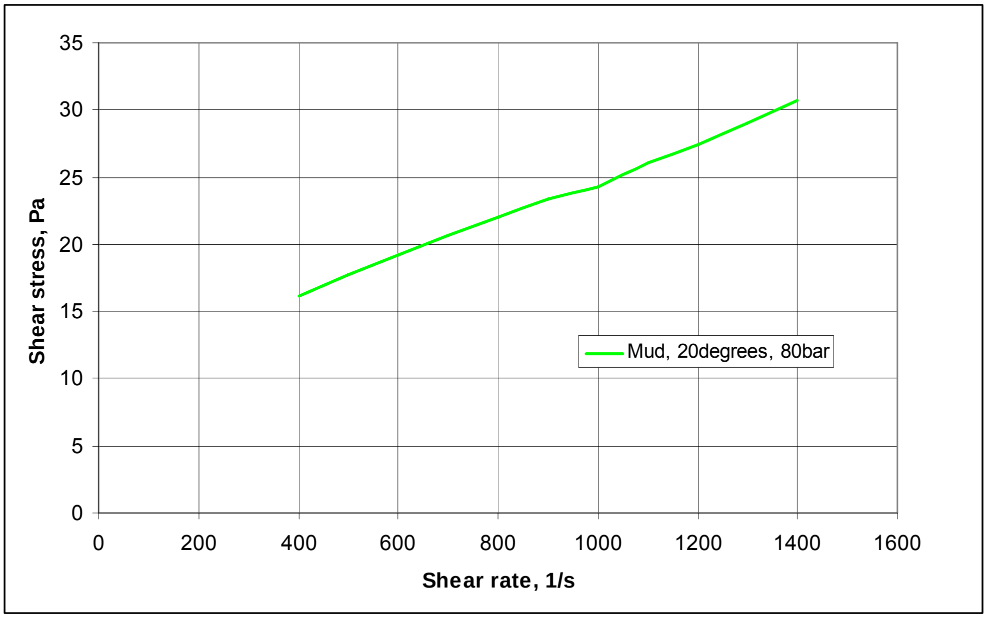


Figure A. 8: Drill- in mud, T=20 °C, P=80 bar.

A.2.5 Physica viscometer 60

The plotted shear rate is for 1000 s^{-1}. The results from the 60 °C aging experiments are shown in Figure A. 9.

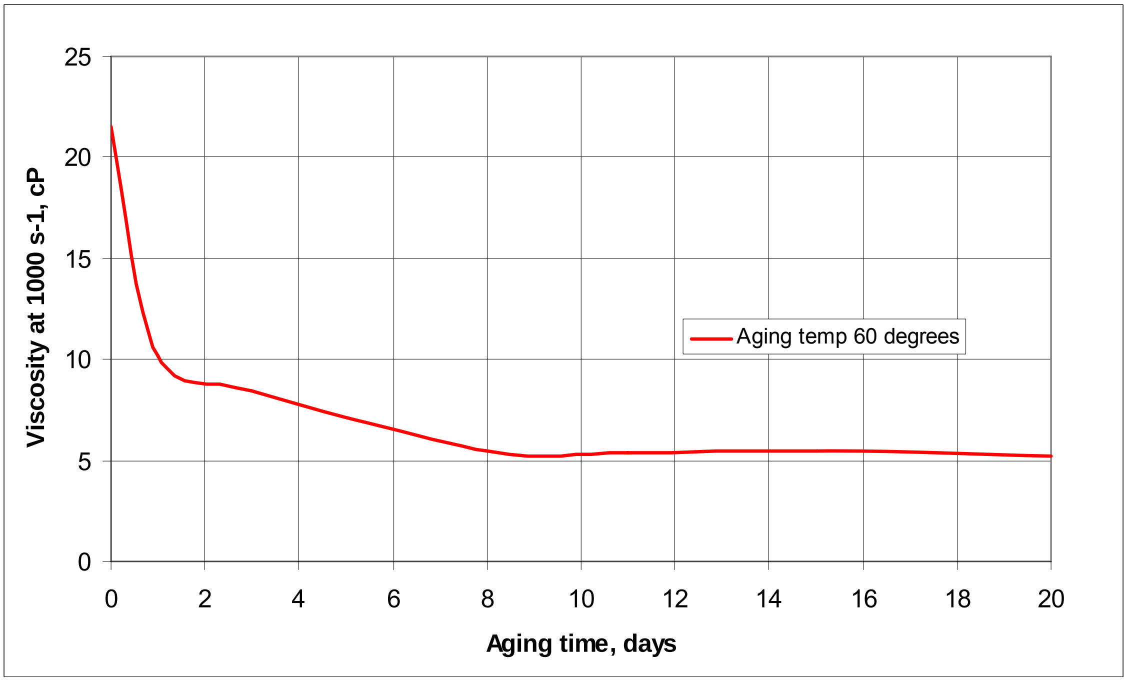


Figure A. 9: Physica, aging effects at 60 °C.

A.2.6 Fann viscometer- 60 °C

The plot of aging time vs. viscosity at 511 s^{-1} in Fann viscometer at 60 °C is shown in Figure A. 10.

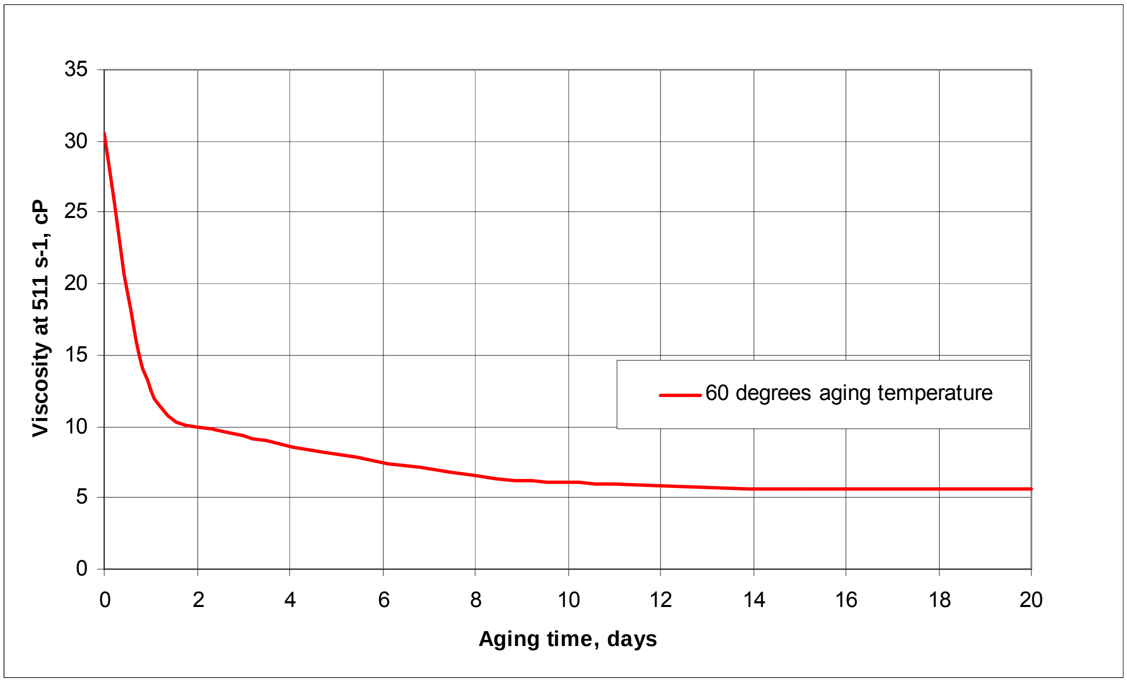


Figure A. 10: Fann viscometer, aging effects at 60 °C.

From the plot is it seen that the viscosity is decreasing quite rapidly between 0 and 1 days of aging. In the range from 1 day to approximately 11 days is the decrease rather constant until the viscosity is constant at approximately 5 – 6 cP for the rest of the measurements.

A.2.7 Physica viscometer- 90 °C

The results from the 90 °C measurements in the Physica viscometer is plotted in Figure A. 11.

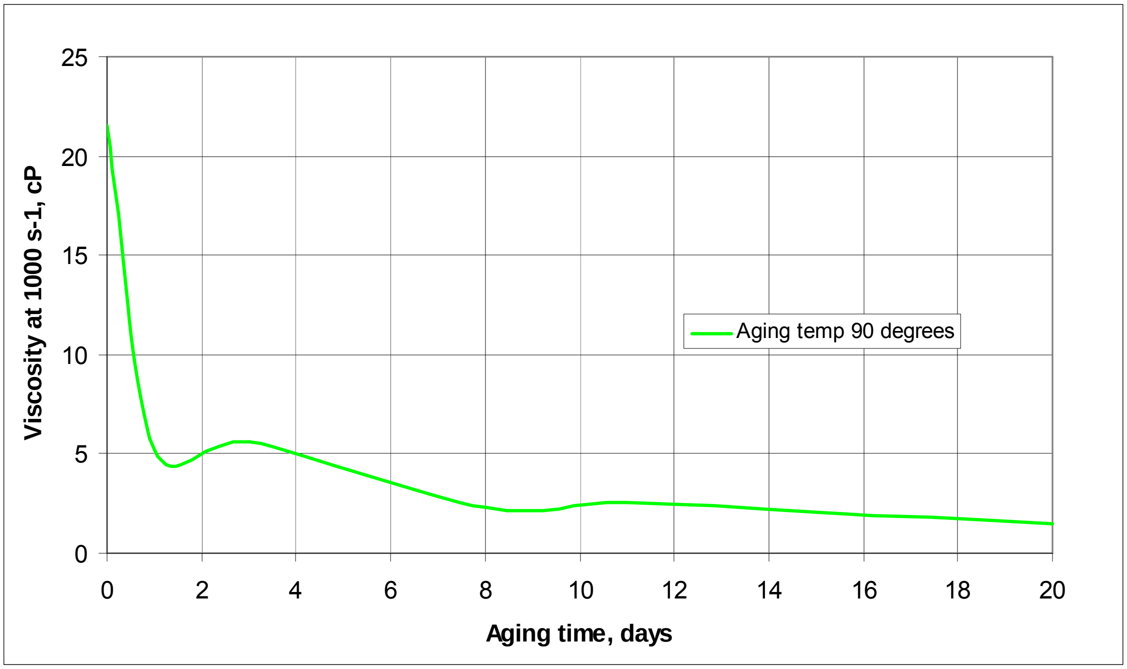


Figure A. 11: Physica, aging effects at 90 °C.

A.2.8 Fann viscometer- 90 °C

The results from the Fann viscometer at 90 °C aging temperature are shown in Figure A. 12.

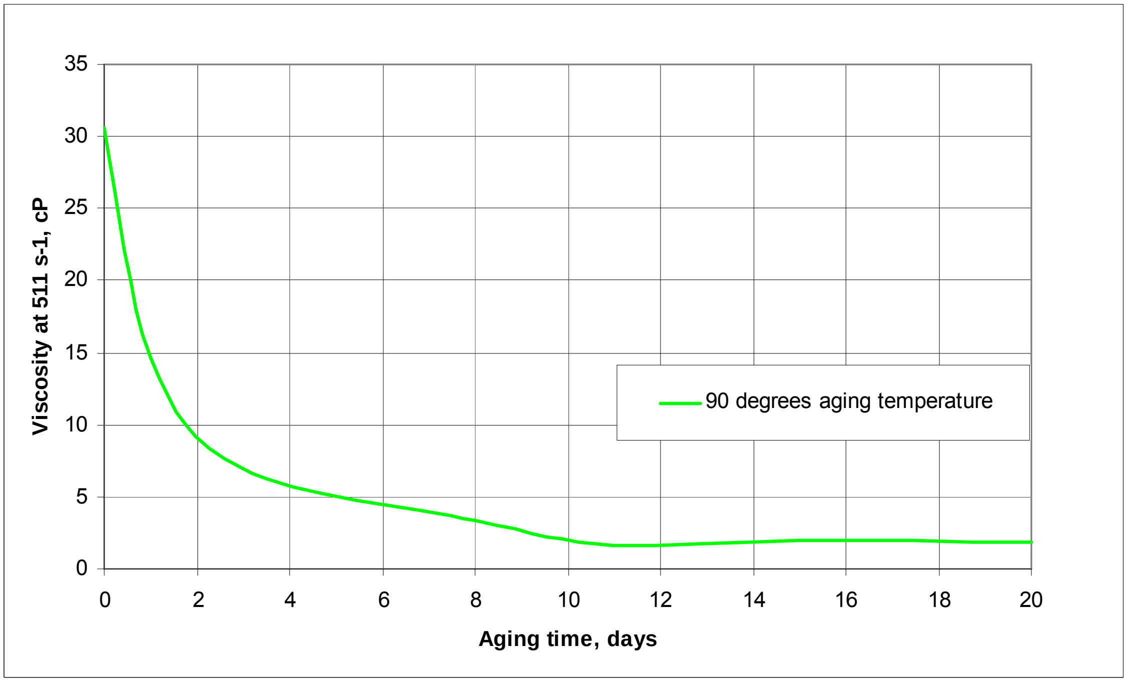


Figure A. 12: Fann, aging effects at 90 °C.

A.3 HPHT experiment on drill- in mud

A.3.1 Recorded data Physica

These measurements were only conducted in the Physica viscometer. The tables show the recorded values in the PC program at different temperatures and pressures for the drill-in mud.

The tables show the following parameters:

- Number of measuring points
- Shear rate [1/s]
- Shear stress at the given shear rate [Pa]
- Calculated viscosity [cP] from the measured shear rate and shear stress
- Temperature of the measuring cell [°C]
- Measured torque in the apparatus [mNm]
- Status

Table A. 34: Mud rheology. 20°C at 1bar in left column, 20°C at 40bar in right column.

Name: Mud. rampLin 100-1400. T=20degrees. P=1 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	100	15,3	153	21,5	0,541	M-
2	100	12,5	125	21,5	0,444	M-
3	99,9	13,7	138	21,5	0,488	M-
4	100	12,6	126	21,5	0,447	M-
5	100	12,5	125	21,5	0,443	M-
6	99,9	13,7	137	21,5	0,487	M-
7	100	12,4	124	21,5	0,44	M-
8	100	12,1	121	21,6	0,428	M-
9	100	11,7	117	21,6	0,415	M-
10	100	12,1	121	21,5	0,43	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	15,4	76,8	21,5	0,544	M-
2	200	15,2	75,9	21,5	0,538	M-
3	200	14,7	73,6	21,5	0,522	M-
4	200	14,4	71,9	21,6	0,51	M-
5	200	14,4	72,2	21,5	0,512	M-
6	200	15,4	77	21,6	0,546	M-
7	200	14,1	70,7	21,5	0,501	M-
8	200	13,8	69,2	21,6	0,491	M-
9	200	15,2	76	21,5	0,539	M-
10	200	13,2	66	21,6	0,468	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	17,8	59,3	21,6	0,631	M-
2	300	16,4	54,8	21,6	0,583	M-
3	300	16,5	55,1	21,6	0,586	
4	300	16,3	54,4	21,6	0,579	
5	300	16,4	54,7	21,6	0,582	M-
6	300	15,9	52,9	21,6	0,563	M-
7	300	16,6	55,3	21,6	0,589	M-
8	300	15,3	50,9	21,6	0,542	M-
9	300	15,1	50,2	21,6	0,534	M-
10	300	16,2	53,9	21,6	0,573	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	19,1	47,7	21,6	0,677	M-
2	400	16,4	40,9	21,6	0,58	
3	400	16,5	41,1	21,6	0,584	M-
4	400	17,9	44,7	21,6	0,634	
5	400	16,2	40,5	21,6	0,574	
6	400	17,1	42,7	21,6	0,606	
7	400	18,2	45,5	21,5	0,645	
8	400	17,3	43,3	21,6	0,614	
9	400	18,7	46,7	21,6	0,662	M-
10	400	15,9	39,7	21,6	0,564	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	18,7	37,4	21,6	0,664	M-
2	500	19	38	21,6	0,675	
3	500	19,8	39,6	21,6	0,701	
4	500	18,8	37,5	21,6	0,665	
5	500	19,5	39	21,6	0,692	
6	500	18,7	37,4	21,6	0,663	
7	500	18,4	36,7	21,6	0,652	
8	500	18,8	37,5	21,6	0,665	
9	500	19	38	21,6	0,673	
10	500	18,6	37,1	21,6	0,658	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	20,1	33,5	21,6	0,713	M-
2	600	20,6	34,3	21,6	0,729	
3	600	21,1	35,1	21,6	0,747	
4	600	20,7	34,5	21,6	0,735	
5	600	20,4	34,1	21,6	0,725	
6	600	20,7	34,5	21,6	0,735	

Name: Mud. rampLin 100-1400. T=20degrees. P=40 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	100	9,98	99,8	21,7	0,354	M-
2	100	10,7	107	21,7	0,38	M-
3	100	10,9	109	21,7	0,386	M-
4	100	11	110	21,7	0,39	M-
5	100	10,3	103	21,7	0,365	M-
6	100	11,5	115	21,7	0,409	M-
7	100	10,7	107	21,7	0,381	M-
8	100	10,4	104	21,7	0,368	M-
9	100	10,3	103	21,7	0,367	M-
10	100	10,8	108	21,7	0,383	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	13,2	66,1	21,7	0,469	M-
2	200	14,3	71,7	21,7	0,508	M-
3	200	13,2	66,2	21,8	0,469	M-
4	200	11,9	59,6	21,7	0,423	M-
5	200	13,2	66	21,7	0,468	M-
6	200	12,1	60,4	21,8	0,428	M-
7	200	12,6	62,8	21,7	0,446	M-
8	200	12,2	61	21,7	0,433	M-
9	200	12,1	60,4	21,7	0,429	M-
10	200	13	64,9	21,7	0,46	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	14,4	48,1	21,7	0,512	M-
2	300	13,6	45,5	21,7	0,484	M-
3	300	14,1	46,9	21,7	0,499	M-
4	300	14,7	49,2	21,7	0,523	M-
5	300	14	46,8	21,7	0,498	M-
6	300	14,6	48,7	21,7	0,518	M-
7	300	13,4	44,5	21,7	0,474	M-
8	300	13,8	46	21,7	0,489	M-
9	300	13,2	44	21,7	0,468	M-
10	300	13,6	45,4	21,8	0,483	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	16	40	21,7	0,568	M-
2	400	16,1	40,3	21,7	0,572	M-
3	400	15,4	38,4	21,7	0,545	M-
4	400	16,2	40,5	21,7	0,574	M-
5	400	15,9	39,7	21,7	0,564	M-
6	400	15,4	38,4	21,7	0,545	M-
7	400	14,2	35,6	21,7	0,505	M-
8	400	15,5	38,8	21,7	0,55	M-
9	400	16,1	40,1	21,7	0,569	M-
10	400	15,4	38,5	21,7	0,547	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	17,7	35,4	21,7	0,628	M-
2	500	16,4	32,8	21,7	0,582	
3	500	17	34	21,7	0,603	M-
4	500	17,3	34,6	21,7	0,614	M-
5	500	17,3	34,7	21,7	0,615	M-
6	500	17,3	34,6	21,7	0,614	M-
7	500	16,6	33,2	21,7	0,588	
8	500	16,7	33,4	21,7	0,592	
9	500	16,5	33	21,7	0,586	
10	500	16,9	33,8	21,8	0,599	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	19,2	32	21,8	0,681	M-
2	600	18,9	31,4	21,7	0,669	
3	600	18,3	30,5	21,7	0,648	
4	600	18,8	31,3	21,7	0,667	
5	600	18,5	30,8	21,7	0,655	
6	600	17,9	29,8	21,7	0,633	

7	600	20,2	33,7	21,6	0,716	
8	600	19,8	33	21,6	0,703	
9	600	19,9	33,2	21,6	0,706	
10	600	19,4	32,4	21,6	0,689	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	22,2	31,7	21,6	0,788	M-
2	700	21,3	30,4	21,6	0,755	
3	700	22,6	32,2	21,6	0,8	
4	700	21,8	31,2	21,6	0,774	
5	700	20,1	28,8	21,6	0,714	
6	700	20,6	29,4	21,6	0,73	
7	700	22,4	32	21,6	0,793	
8	700	21,6	30,8	21,6	0,765	
9	700	21,5	30,7	21,6	0,761	
10	700	20,6	29,4	21,6	0,731	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	23,7	29,6	21,6	0,84	M-
2	800	21,9	27,4	21,6	0,777	
3	800	22,5	28,1	21,6	0,798	
4	800	22,9	28,7	21,6	0,813	
5	800	23,2	28,9	21,6	0,821	
6	800	20,4	25,5	21,6	0,724	
7	800	22,6	28,3	21,6	0,803	
8	800	22,4	28	21,6	0,795	
9	800	23	28,7	21,6	0,815	
10	800	22,9	28,7	21,6	0,814	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	24,4	27,1	21,6	0,867	M-
2	900	24,1	26,8	21,6	0,855	
3	900	23,3	25,9	21,6	0,828	
4	900	24,3	27	21,6	0,86	
5	900	23,5	26,1	21,6	0,834	
6	900	24,1	26,8	21,5	0,856	
7	900	24,5	27,3	21,6	0,87	
8	900	24,4	27,1	21,6	0,864	
9	900	23,9	26,6	21,6	0,847	
10	900	24,4	27,1	21,6	0,865	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	24,6	24,6	21,6	0,873	M-
2	1 000	25	25	21,6	0,886	
3	1 000	25,2	25,2	21,6	0,894	
4	1 000	25,6	25,6	21,6	0,906	
5	1 000	25,8	25,8	21,6	0,915	
6	1 000	25,7	25,7	21,6	0,913	
7	1 000	24,2	24,2	21,6	0,857	
8	1 000	25,8	25,8	21,6	0,917	
9	1 000	24,3	24,3	21,6	0,863	
10	1 000	24,5	24,5	21,6	0,868	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	27,4	24,9	21,6	0,972	M-
2	1 100	27,1	24,6	21,5	0,96	
3	1 100	26	23,7	21,6	0,923	
4	1 100	26,2	23,8	21,6	0,93	
5	1 100	27,3	24,8	21,6	0,968	
6	1 100	28	25,5	21,6	0,994	
7	1 100	25,6	23,2	21,6	0,907	
8	1 100	26,4	24	21,6	0,936	
9	1 100	26,5	24,1	21,6	0,939	
10	1 100	26,2	23,9	21,6	0,931	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	27,8	23,2	21,6	0,986	M-
2	1 200	28,4	23,7	21,6	1,01	
3	1 200	27,6	23	21,6	0,978	
4	1 200	28,8	24	21,6	1,02	
5	1 200	28,3	23,6	21,6	1	
6	1 200	28,3	23,6	21,6	1	
7	1 200	27,8	23,2	21,6	0,987	
8	1 200	28,2	23,5	21,6	1	
9	1 200	31	25,8	21,6	1,1	
10	1 200	28,2	23,5	21,6	1	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	29,7	22,9	21,6	1,05	M-
2	1 300	29,7	22,9	21,6	1,05	
3	1 300	30,4	23,4	21,6	1,08	
4	1 300	29,4	22,6	21,6	1,04	
5	1 300	30,6	23,6	21,6	1,09	
6	1 300	28,4	21,9	21,6	1,01	
7	1 300	30	23,1	21,6	1,07	
8	1 300	30,7	23,6	21,6	1,09	
9	1 300	29,7	22,9	21,6	1,05	
10	1 300	29,2	22,4	21,6	1,03	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	30,9	22,1	21,6	1,1	M-
2	1 400	31,4	22,4	21,6	1,11	
3	1 400	30,3	21,6	21,6	1,07	
4	1 400	31,8	22,7	21,6	1,13	
5	1 400	30,7	21,9	21,6	1,09	
6	1 400	31,3	22,4	21,6	1,11	
7	1 400	31,5	22,5	21,6	1,12	
8	1 400	30,4	21,7	21,6	1,08	
9	1 400	30,7	21,9	21,6	1,09	
10	1 400	30,2	21,6	21,6	1,07	

7	600	18,1	30,1	21,7	0,642	
8	600	18,3	30,5	21,7	0,649	
9	600	17,9	29,8	21,7	0,634	
10	600	17,8	29,6	21,7	0,63	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	20,7	29,6	21,7	0,735	M-
2	700	20,2	28,9	21,7	0,718	
3	700	19,9	28,4	21,7	0,704	
4	700	20,5	29,3	21,7	0,726	
5	700	20	28,6	21,7	0,71	
6	700	19,5	27,9	21,7	0,693	
7	700	20,4	29,2	21,8	0,724	
8	700	22,4	32	21,7	0,793	
9	700	20,4	29,2	21,7	0,724	
10	700	18,8	26,9	21,7	0,668	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	21,6	27	21,7	0,766	M-
2	800	22,3	27,9	21,7	0,791	
3	800	21,2	26,6	21,7	0,753	
4	800	20	25,1	21,7	0,711	
5	800	22,1	27,6	21,7	0,782	
6	800	20,7	25,8	21,7	0,733	
7	800	21,3	26,6	21,7	0,754	
8	800	22,3	27,9	21,8	0,791	
9	800	21,6	27	21,7	0,767	
10	800	21,3	26,6	21,7	0,755	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	23,2	25,8	21,8	0,824	M-
2	900	24	26,7	21,7	0,851	
3	900	22,5	25	21,7	0,796	
4	900	23,9	26,5	21,7	0,846	
5	900	23,3	25,8	21,7	0,825	
6	900	22,9	25,5	21,7	0,814	
7	900	22,5	25	21,7	0,798	
8	900	21,8	24,2	21,8	0,773	
9	900	22,8	25,3	21,7	0,807	
10	900	23,1	25,7	21,7	0,82	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	24,9	24,9	21,7	0,883	M-
2	1 000	23,7	23,7	21,7	0,842	
3	1 000	24,5	24,5	21,7	0,87	
4	1 000	23,6	23,6	21,7	0,838	
5	1 000	23	23	21,7	0,817	
6	1 000	25,4	25,4	21,8	0,9	
7	1 000	23,6	23,6	21,7	0,838	
8	1 000	24,4	24,4	21,7	0,866	
9	1 000	23,8	23,8	21,7	0,844	
10	1 000	23,9	23,9	21,8	0,846	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	25,7	23,4	21,7	0,911	M-
2	1 100	25,2	22,9	21,7	0,895	
3	1 100	25,5	23,2	21,7	0,905	
4	1 100	25,7	23,3	21,7	0,911	
5	1 100	26,5	24,1	21,8	0,94	
6	1 100	24,8	22,6	21,7	0,88	
7	1 100	24,7	22,4	21,7	0,875	
8	1 100	25	22,7	21,7	0,885	
9	1 100	25	22,8	21,8	0,888	
10	1 100	24,6	22,4	21,8	0,873	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	27,3	22,7	21,7	0,967	M-
2	1 200	27,1	22,6	21,7	0,961	
3	1 200	27,2	22,6	21,7	0,963	
4	1 200	26,3	21,9	21,7	0,934	
5	1 200	26,1	21,8	21,8	0,927	
6	1 200	27,1	22,6	21,7	0,961	
7	1 200	28,3	23,6	21,7	1	
8	1 200	26,9	22,5	21,8	0,956	
9	1 200	27,2	22,7	21,8	0,966	
10	1 200	27,6	23	21,8	0,98	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	28,5	21,9	21,8	1,01	M-
2	1 300	28,6	22	21,8	1,01	
3	1 300	29,4	22,6	21,8	1,04	
4	1 300	27,7	21,3	21,7	0,983	
5	1 300	28,7	22	21,8	1,02	
6	1 300	28,3	21,8	21,8	1	
7	1 300	27,8	21,4	21,8	0,988	
8	1 300	28,9	22,2	21,8	1,02	
9	1 300	28	21,6	21,8	0,994	
10	1 300	29,3	22,6	21,8	1,04	
Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	30,7	21,9	21,7	1,09	M-
2	1 400	30	21,4	21,7	1,06	
3	1 400	31	22,2	21,8	1,1	
4	1 400	30,5	21,8	21,8	1,08	
5	1 400	29,7	21,2	21,8	1,05	
6	1 400	30,9	22,1	21,8	1,1	
7	1 400	29	20,7	21,8	1,03	
8	1 400	30,5	21,8	21,8	1,08	
9	1 400	29,7	21,2	21,8	1,05	
10	1 400	29,5	21,1	21,8	1,05	

Table A. 35: Mud rheology. 20°C at 80bar in left column, 60°C at 1bar in right column.

Name: Mud. rampLin 100-1400. T=20degrees. P=80 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	99,9	13,2	132	22,7	0,467	M-
2	100	12,2	122	22,7	0,432	M-

Name: Mud. rampLin 100-1400. T=60degrees. P=1 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	100	9,81	98,1	58,9	0,348	M-
2	100	9,06	90,6	58,9	0,321	M-

3	100	11,3	113	22,7	0,4	M-
4	100	11,5	115	22,7	0,407	M-
5	100	11	110	22,7	0,39	M-
6	100	10,1	101	22,7	0,36	M-
7	100	10,4	104	22,7	0,37	M-
8	100	10,8	108	22,7	0,382	M-
9	100	10,7	107	22,7	0,378	M-
10	100	10,8	108	22,7	0,382	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	13,7	68,7	22,7	0,487	M-
2	200	12,9	64,4	22,7	0,457	M-
3	200	12,6	63	22,7	0,446	M-
4	200	13,2	65,8	22,7	0,467	M-
5	200	13,8	69	22,7	0,489	M-
6	200	12,6	63,2	22,7	0,448	M-
7	200	12,6	62,8	22,7	0,445	M-
8	200	11,9	59,7	22,7	0,424	M-
9	200	12,9	64,7	22,7	0,459	M-
10	200	12,7	63,3	22,7	0,449	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	14,6	48,8	22,7	0,519	M-
2	300	14,2	47,5	22,7	0,505	M-
3	300	15,2	50,8	22,7	0,54	M-
4	300	15,2	50,8	22,7	0,54	M-
5	300	15,3	50,9	22,7	0,542	M-
6	300	15	50	22,7	0,532	M-
7	300	14,7	49	22,7	0,521	M-
8	300	12,9	43,1	22,7	0,459	M-
9	300	13,6	45,4	22,7	0,483	M-
10	300	14,7	49	22,7	0,521	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	16	40	22,7	0,568	M-
2	400	15,4	38,6	22,7	0,548	M-
3	400	16,6	41,4	22,7	0,588	M-
4	400	16,4	40,9	22,7	0,581	M-
5	400	15,4	38,4	22,7	0,545	M-
6	400	16	40	22,7	0,568	M-
7	400	16,5	41,2	22,7	0,584	M-
8	400	16,1	40,3	22,7	0,572	M-
9	400	15,7	39,2	22,6	0,556	
10	400	16,8	41,9	22,7	0,594	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	18,8	37,6	22,7	0,667	M-
2	500	18,4	36,8	22,7	0,653	
3	500	18,5	37,1	22,7	0,657	
4	500	18,8	37,6	22,7	0,666	
5	500	16,5	33	22,6	0,586	
6	500	17,4	34,8	22,6	0,618	
7	500	17,9	35,9	22,7	0,636	
8	500	16,7	33,4	22,7	0,592	
9	500	17,1	34,3	22,6	0,608	
10	500	17,7	35,4	22,7	0,627	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	19	31,7	22,6	0,675	M-
2	600	19,7	32,8	22,6	0,698	
3	600	20	33,4	22,6	0,711	
4	600	18,7	31,2	22,6	0,664	
5	600	18,2	30,3	22,7	0,644	
6	600	19,9	33,1	22,6	0,704	
7	600	19,3	32,1	22,6	0,684	
8	600	19,2	32	22,6	0,68	
9	600	18,7	31,2	22,6	0,663	
10	600	19	31,7	22,6	0,674	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	20	28,5	22,6	0,708	M-
2	700	21,2	30,3	22,6	0,751	
3	700	22,9	32,7	22,6	0,811	
4	700	20,2	28,9	22,6	0,718	
5	700	21,2	30,3	22,6	0,751	
6	700	20,3	29	22,6	0,721	
7	700	20,9	29,9	22,6	0,741	
8	700	20,5	29,3	22,6	0,729	
9	700	20,6	29,4	22,6	0,731	
10	700	18,8	26,9	22,6	0,667	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	22,5	28,1	22,6	0,798	M-
2	800	22,4	28	22,6	0,795	
3	800	22,2	27,7	22,6	0,787	
4	800	21	26,3	22,6	0,746	
5	800	21,3	26,6	22,6	0,754	
6	800	21,8	27,2	22,6	0,772	
7	800	22,6	28,2	22,6	0,801	
8	800	22,9	28,7	22,6	0,814	
9	800	22,2	27,7	22,6	0,787	
10	800	21,2	26,6	22,6	0,754	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	24,1	26,8	22,6	0,854	M-
2	900	24,6	27,3	22,6	0,872	
3	900	23,3	25,9	22,6	0,828	
4	900	23,5	26,1	22,6	0,833	
5	900	23,4	26	22,6	0,83	
6	900	23,1	25,6	22,6	0,818	
7	900	23,8	26,4	22,6	0,843	
8	900	22	24,4	22,6	0,78	
9	900	23,2	25,8	22,6	0,823	
10	900	23,2	25,8	22,6	0,823	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	25	25	22,6	0,887	M-
2	1 000	24,1	24,1	22,6	0,854	
3	1 000	23,8	23,8	22,6	0,845	
4	1 000	24	24	22,6	0,851	
5	1 000	23,9	23,9	22,6	0,849	
6	1 000	24,6	24,6	22,6	0,874	

3	100	7,85	78,4	58,9	0,278	M-
4	100	7,81	78,1	58,9	0,277	M-
5	100	8,13	81,3	58,9	0,288	M-
6	100	6,52	65,2	58,9	0,231	M-
7	100	7,84	78,4	59	0,278	M-
8	100	7,6	76,1	59	0,27	M-
9	100	7,15	71,5	59	0,254	M-
10	100	7,81	78,1	59	0,277	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	9,35	46,7	59	0,331	M-
2	200	9,19	46	59	0,326	M-
3	200	9,3	46,5	59	0,33	M-
4	200	9,83	49,2	59	0,349	M-
5	200	9,96	49,8	59	0,353	M-
6	200	8,7	43,5	59	0,308	M-
7	200	9,79	49	59	0,347	M-
8	200	9,52	47,6	59	0,338	M-
9	200	9,42	47,1	59	0,334	M-
10	200	9,81	49	59	0,348	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	10,8	36,1	59	0,384	M-
2	300	10,3	34,3	59	0,365	M-
3	300	11,2	37,3	59	0,396	M-
4	300	10,7	35,5	59	0,378	M-
5	300	11	36,8	59	0,391	M-
6	300	10,4	34,7	59,1	0,369	M-
7	300	9,24	30,8	59,1	0,328	M-
8	300	11,5	38,5	59	0,409	M-
9	300	10,5	35	59,1	0,373	M-
10	300	11	36,6	59,1	0,39	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	11,9	29,8	59,1	0,423	M-
2	400	12,2	30,5	59,1	0,432	M-
3	400	12,5	31,3	59,1	0,444	M-
4	400	12,5	31,3	59,1	0,444	M-
5	400	10,5	26,3	59,1	0,373	M-
6	400	11	27,5	59,1	0,39	M-
7	400	11,4	28,5	59,1	0,405	M-
8	400	11,7	29,2	59,1	0,414	M-
9	400	12,6	31,6	59,1	0,448	M-
10	400	11,2	27,9	59,1	0,396	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	10,9	21,7	59,1	0,385	M-
2	500	12,7	25,4	59,1	0,45	M-
3	500	12,6	25,2	59,1	0,447	M-
4	500	11,8	23,6	59,1	0,418	M-
5	500	12,5	25	59,1	0,442	M-
6	500	13,2	26,3	59,1	0,467	M-
7	500	13,4	26,7	59,1	0,474	M-
8	500	12,9	25,8	59,2	0,457	M-
9	500	12,3	24,6	59,2	0,436	M-
10	500	12,1	24,1	59,2	0,428	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	14,4	24	59,2	0,511	M-
2	600	12,9	21,5	59,2	0,458	M-
3	600	13	21,7	59,2	0,462	M-
4	600	14,4	24	59,2	0,511	M-
5	600	14,8	24,6	59,2	0,524	M-
6	600	14,9	24,8	59,2	0,528	M-
7	600	12,5	20,9	59,2	0,444	M-
8	600	13,7	22,8	59,2	0,486	M-
9	600	13,8	23	59,2	0,49	M-
10	600	13	21,6	59,3	0,46	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	13,8	19,7	59,3	0,489	M-
2	700	15,7	22,4	59,3	0,555	M-
3	700	13,9	19,8	59,3	0,493	M-
4	700	14,5	20,6	59,3	0,513	M-
5	700	14	20	59,3	0,497	M-
6	700	15,2	21,7	59,3	0,539	M-
7	700	13,8	19,7	59,3	0,49	M-
8	700	15,4	22	59,3	0,545	M-
9	700	14,3	20,5	59,3	0,508	M-
10	700	14,2	20,3	59,4	0,504	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	16,8	21,1	59,4	0,597	M-
2	800	15,8	19,8	59,4	0,562	M-
3	800	15,9	19,9	59,4	0,565	
4	800	16	19,9	59,4	0,566	M-
5	800	16	20	59,4	0,568	M-
6	800	15,2	19	59,4	0,54	M-
7	800	15,6	19,5	59,4	0,552	M-
8	800	15	18,8	59,4	0,533	M-
9	800	15,2	19	59,5	0,54	M-
10	800	15,3	19,2	59,5	0,544	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	17	18,9	59,5	0,603	M-
2	900	17,8	19,8	59,5	0,633	
3	900	16,6	18,4	59,6	0,588	
4	900	17,5	19,4	59,5	0,619	
5	900	16,6	18,5	59,5	0,59	M-
6	900	16,5	18,4	59,6	0,587	
7	900	16,5	18,4	59,6	0,586	M-
8	900	16,6	18,4	59,6	0,588	M-
9	900	16,2	18	59,6	0,575	M-
10	900	15,5	17,3	59,6	0,551	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	18	18	59,6	0,639	M-
2	1 000	17,4	17,4	59,6	0,616	
3	1 000	16,2	16,2	59,6	0,575	M-
4	1 000	16,9	16,9	59,6	0,599	
5	1 000	15	15	59,6	0,532	M-
6	1 000	16,6	16,6	59,6	0,589	

7	1 000	23,5	23,5	22,6	0,833	
8	1 000	24,9	24,9	22,6	0,884	
9	1 000	24,6	24,6	22,6	0,872	
10	1 000	23,8	23,8	22,6	0,845	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	26,6	24,2	22,6	0,945	M-
2	1 100	25,7	23,3	22,6	0,91	
3	1 100	25,2	22,9	22,6	0,894	
4	1 100	26,3	23,9	22,6	0,933	
5	1 100	27,1	24,6	22,6	0,96	
6	1 100	26,9	24,4	22,6	0,953	
7	1 100	26,8	24,4	22,6	0,95	
8	1 100	26,5	24,1	22,6	0,941	
9	1 100	25,5	23,2	22,5	0,904	
10	1 100	24,7	22,5	22,6	0,878	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	27,7	23,1	22,6	0,983	M-
2	1 200	27,1	22,6	22,6	0,96	
3	1 200	28	23,3	22,6	0,992	
4	1 200	27,6	23	22,6	0,978	
5	1 200	26,8	22,4	22,6	0,952	
6	1 200	27,5	22,9	22,6	0,976	
7	1 200	26,5	22,1	22,6	0,94	
8	1 200	27,4	22,8	22,6	0,971	
9	1 200	28	23,3	22,5	0,991	
10	1 200	28,2	23,5	22,6	0,999	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	28,6	22	22,6	1,01	M-
2	1 300	29,7	22,9	22,6	1,05	
3	1 300	29,5	22,7	22,6	1,05	
4	1 300	29,6	22,7	22,6	1,05	
5	1 300	29,1	22,4	22,6	1,03	
6	1 300	28,1	21,6	22,6	0,997	
7	1 300	28,6	22	22,6	1,01	
8	1 300	29,3	22,5	22,5	1,04	
9	1 300	28,4	21,9	22,6	1,01	
10	1 300	29,1	22,4	22,6	1,03	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	30,6	21,8	22,6	1,08	M-
2	1 400	30,5	21,8	22,6	1,08	
3	1 400	30,6	21,8	22,6	1,08	
4	1 400	31,2	22,3	22,6	1,1	
5	1 400	31	22,1	22,6	1,1	
6	1 400	31,1	22,2	22,6	1,1	
7	1 400	31,1	22,2	22,6	1,1	
8	1 400	30,7	21,9	22,6	1,09	
9	1 400	30,2	21,6	22,5	1,07	
10	1 400	30,2	21,6	22,6	1,07	

7	1 000	18,6	18,6	59,7	0,66	M-
8	1 000	16,2	16,2	59,7	0,575	M-
9	1 000	17,5	17,5	59,7	0,621	
10	1 000	17,3	17,3	59,7	0,614	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	18	16,4	59,7	0,638	M-
2	1 100	19,3	17,5	59,7	0,684	
3	1 100	18,4	16,7	59,7	0,653	
4	1 100	18,6	16,9	59,7	0,659	
5	1 100	18,2	16,6	59,7	0,646	
6	1 100	18,4	16,7	59,8	0,652	
7	1 100	17,1	15,6	59,8	0,607	
8	1 100	18	16,3	59,8	0,637	
9	1 100	18,7	17	59,8	0,664	
10	1 100	18,3	16,6	59,8	0,647	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	20,8	17,4	59,8	0,739	M-
2	1 200	19,6	16,4	59,8	0,696	
3	1 200	20,7	17,3	59,8	0,734	
4	1 200	19,1	15,9	59,8	0,678	
5	1 200	18	15	59,8	0,637	
6	1 200	19,7	16,4	59,8	0,697	
7	1 200	19,6	16,3	59,8	0,695	
8	1 200	18,7	15,5	59,8	0,662	
9	1 200	19,2	16	59,9	0,68	
10	1 200	20	16,7	59,9	0,711	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	20,6	15,8	59,9	0,73	M-
2	1 300	20,2	15,6	59,9	0,717	
3	1 300	19,9	15,3	59,9	0,707	
4	1 300	20	15,4	59,9	0,709	
5	1 300	19,7	15,1	59,9	0,697	
6	1 300	19,4	14,9	59,9	0,689	
7	1 300	20,9	16,1	59,9	0,742	
8	1 300	20,5	15,8	59,9	0,727	
9	1 300	20,1	15,5	59,9	0,713	
10	1 300	20,7	15,9	59,9	0,733	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	21,6	15,4	59,9	0,765	M-
2	1 400	21,5	15,4	60	0,763	
3	1 400	21,4	15,3	60	0,759	
4	1 400	21,9	15,7	60	0,778	
5	1 400	21,1	15,1	60	0,749	
6	1 400	21,4	15,3	60	0,758	
7	1 400	21,2	15,1	60	0,751	
8	1 400	21,1	15	60	0,747	
9	1 400	20,6	14,7	60	0,73	
10	1 400	21,8	15,6	60	0,774	

Table A. 36: Mud rheology. 60°C at 40bar in left column, 60°C at 80bar in right column.

Name: Mud. rampLin 100-1400. T=60degrees. P=40 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	100	7,85	78,5	60	0,279	M-
2	100	7,38	73,8	60	0,262	M-
3	100	8,69	86,9	60	0,308	M-
4	100	6,93	69,3	60	0,246	M-
5	100	7,87	78,7	60	0,279	M-
6	100	7,61	76,1	60	0,27	M-
7	100	7,06	70,6	60	0,25	M-
8	99,9	7,87	78,8	60	0,279	M-
9	100	7,31	73,1	60	0,259	M-
10	100	7,78	77,8	60	0,276	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	9,35	46,8	60	0,332	M-
2	200	8,89	44,5	60	0,315	M-
3	200	9,09	45,4	60	0,322	M-
4	200	10,3	51,8	60	0,367	M-
5	200	8,08	40,4	60	0,287	M-
6	200	9,69	48,4	60	0,344	M-
7	200	10	50,2	60	0,356	M-
8	200	8,82	44,1	60	0,313	M-
9	200	9,38	46,9	60	0,333	M-
10	200	9,08	45,4	60	0,322	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	11	36,6	60	0,389	M-
2	300	10,8	35,9	60	0,382	M-
3	300	9,41	31,4	60	0,334	M-
4	300	11,5	38,3	60	0,407	M-
5	300	10,4	34,6	60	0,368	M-
6	300	10,7	35,7	60	0,379	M-
7	300	11,2	37,5	60	0,399	M-
8	300	10,6	35,4	60	0,377	M-
9	300	11,4	37,9	60	0,403	M-
10	300	10,9	36,3	60	0,386	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	12,1	30,3	60	0,43	M-
2	400	11,5	28,7	60	0,408	M-
3	400	12,6	31,6	60	0,448	M-
4	400	11,4	28,6	60	0,405	M-
5	400	12,1	30,2	60	0,429	M-
6	400	11,3	28,2	60	0,4	M-
7	400	10,3	25,6	60	0,364	M-
8	400	10,2	25,4	60	0,361	M-
9	400	11,2	27,9	60	0,396	M-
10	400	11,3	28,2	60	0,399	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	13,7	27,4	60	0,486	M-
2	500	13,5	27	60	0,48	M-

Name: Mud. rampLin 100-1400. T=60degrees. P=80 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	99,9	9,53	95,4	60	0,338	M-
2	100	8,76	87,6	60	0,311	M-
3	100	8,2	82	60	0,291	M-
4	100	6,95	69,5	60	0,247	M-
5	99,9	8,76	87,6	60	0,311	M-
6	100	7,77	77,7	60	0,276	M-
7	100	7,33	73,2	60	0,26	M-
8	100	7,52	75,2	60	0,267	M-
9	100	7,15	71,5	60	0,254	M-
10	100	7,65	76,5	59,9	0,271	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	9,49	47,5	60	0,337	M-
2	200	9,73	48,6	59,9	0,345	M-
3	200	9,41	47,1	60	0,334	M-
4	200	8,68	43,4	59,9	0,308	M-
5	200	8,64	43,2	60	0,306	M-
6	200	9,36	46,8	60	0,332	M-
7	200	10	50	60	0,355	M-
8	200	8,85	44,3	60	0,314	M-
9	200	8,39	42	60	0,298	M-
10	200	9,01	45	60	0,32	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	11,5	38,3	60	0,407	M-
2	300	9,94	33,1	59,9	0,353	M-
3	300	9,39	31,3	60	0,333	M-
4	300	11,2	37,2	60	0,396	M-
5	300	9,9	33	60	0,351	M-
6	300	10,5	35	60	0,372	M-
7	300	10,1	33,5	60	0,357	M-
8	300	10,5	35,1	60	0,374	M-
9	300	10,7	35,6	59,9	0,379	M-
10	300	10,2	34,1	60	0,363	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	12,4	31	60	0,44	M-
2	400	11,9	29,8	60	0,422	M-
3	400	11	27,6	60	0,392	M-
4	400	13,4	33,5	60	0,476	M-
5	400	11,7	29,3	59,9	0,416	M-
6	400	11,2	28,1	59,9	0,398	M-
7	400	12,5	31,2	60	0,443	M-
8	400	10,8	27	60	0,383	M-
9	400	11,3	28,2	60	0,4	M-
10	400	12,2	30,5	59,9	0,432	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	12,9	25,8	60	0,457	M-
2	500	13	26	60	0,46	M-

3	500	12,8	25,7	60	0,455	M-
4	500	12,3	24,7	60	0,437	M-
5	500	11,9	23,9	60	0,423	M-
6	500	13,4	26,9	60	0,476	M-
7	500	12,8	25,5	60	0,453	M-
8	500	13,1	26,3	60	0,466	M-
9	500	13,3	26,7	60	0,473	M-
10	500	12,6	25,3	60,1	0,449	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	13,1	21,9	60,1	0,466	M-
2	600	14,8	24,7	60	0,526	M-
3	600	14,8	24,7	60	0,525	M-
4	600	12,6	21	60,1	0,446	M-
5	600	14,1	23,6	60	0,502	M-
6	600	14,3	23,9	60	0,508	M-
7	600	13,1	21,8	60	0,463	M-
8	600	13,5	22,4	60,1	0,478	M-
9	600	13,5	22,5	60,1	0,478	M-
10	600	14	23,3	60,1	0,497	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	14,8	21,1	60	0,524	M-
2	700	14,2	20,3	60,1	0,503	M-
3	700	13,8	19,6	60	0,488	M-
4	700	13,5	19,3	60,1	0,479	M-
5	700	14,1	20,2	60,1	0,501	M-
6	700	14,9	21,2	60,1	0,527	M-
7	700	14,5	20,7	60,1	0,515	M-
8	700	14,1	20,1	60,1	0,499	M-
9	700	15,4	22	60,1	0,547	M-
10	700	14,8	21,1	60,1	0,524	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	15,5	19,4	60,1	0,549	M-
2	800	16,7	20,9	60,1	0,592	M-
3	800	15,4	19,2	60,1	0,545	M-
4	800	15,3	19,2	60,1	0,544	M-
5	800	14,8	18,5	60,1	0,524	M-
6	800	15,7	19,6	60,1	0,556	M-
7	800	16,5	20,6	60,1	0,585	M-
8	800	15,1	18,8	60,1	0,535	M-
9	800	15,9	19,9	60,1	0,565	M-
10	800	15,5	19,4	60,1	0,551	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	17,3	19,2	60,1	0,612	M-
2	900	16,8	18,6	60,1	0,595	
3	900	16,9	18,8	60,1	0,599	M-
4	900	15,9	17,6	60,1	0,562	
5	900	17,8	19,8	60,1	0,633	M-
6	900	16,6	18,4	60,1	0,589	M-
7	900	16,6	18,4	60,1	0,587	
8	900	16,5	18,4	60,1	0,586	M-
9	900	16	17,8	60,1	0,568	M-
10	900	16,8	18,7	60,1	0,597	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	17,7	17,7	60,1	0,629	M-
2	1 000	18,1	18,1	60,1	0,641	
3	1 000	17,6	17,6	60,1	0,624	M-
4	1 000	17,6	17,6	60,1	0,626	
5	1 000	17,2	17,2	60,1	0,61	
6	1 000	17,2	17,2	60,1	0,608	
7	1 000	17,9	17,9	60,1	0,637	
8	1 000	16,8	16,8	60,1	0,597	
9	1 000	16,7	16,7	60,1	0,594	M-
10	1 000	17,1	17,1	60,1	0,606	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	18,2	16,6	60,1	0,647	M-
2	1 100	18,6	16,9	60,1	0,66	
3	1 100	18,3	16,7	60,1	0,65	
4	1 100	18,6	16,9	60,1	0,658	
5	1 100	18,5	16,8	60,1	0,655	
6	1 100	18,4	16,7	60,1	0,651	
7	1 100	19,2	17,5	60,1	0,681	
8	1 100	18,1	16,4	60,1	0,641	
9	1 100	18,2	16,5	60,1	0,644	
10	1 100	18,4	16,7	60,1	0,653	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	18,7	15,6	60,1	0,662	M-
2	1 200	20,1	16,8	60,1	0,714	
3	1 200	19,7	16,4	60,1	0,7	
4	1 200	19,6	16,4	60,1	0,696	
5	1 200	19,4	16,1	60,1	0,687	
6	1 200	18	15	60,1	0,637	
7	1 200	19	15,9	60,1	0,675	
8	1 200	19,1	15,9	60,1	0,679	M-
9	1 200	18,6	15,5	60,1	0,66	
10	1 200	19,9	16,6	60,1	0,705	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	20,5	15,8	60,1	0,728	M-
2	1 300	21,2	16,3	60,1	0,753	
3	1 300	20,5	15,8	60,1	0,727	
4	1 300	19,6	15,1	60,1	0,694	
5	1 300	20,1	15,5	60,1	0,713	
6	1 300	20,4	15,7	60,1	0,723	
7	1 300	20,5	15,8	60,1	0,728	
8	1 300	20,6	15,8	60,1	0,729	
9	1 300	20,5	15,8	60,1	0,727	
10	1 300	20	15,4	60,1	0,711	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	21,5	15,3	60,1	0,761	M-
2	1 400	21,7	15,5	60,1	0,77	
3	1 400	22,2	15,9	60,1	0,789	
4	1 400	21,6	15,4	60,1	0,766	
5	1 400	22,7	16,2	60,1	0,804	
6	1 400	21,7	15,5	60,1	0,768	

3	500	12,6	25,2	59,9	0,447	M-
4	500	11,9	23,7	60	0,421	M-
5	500	13,2	26,4	60	0,468	M-
6	500	12,8	25,6	60	0,453	M-
7	500	12,3	24,5	60	0,434	M-
8	500	13	26	59,9	0,461	M-
9	500	11,8	23,6	60	0,418	M-
10	500	12,9	25,8	60	0,458	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	13,4	22,4	60	0,477	M-
2	600	14,5	24,1	60	0,513	M-
3	600	14,8	24,6	60	0,523	M-
4	600	12,7	21,2	59,9	0,452	M-
5	600	14,4	24,1	59,9	0,512	M-
6	600	13,8	23	60	0,49	M-
7	600	13	21,7	59,9	0,463	M-
8	600	14	23,3	60	0,495	M-
9	600	13,7	22,8	60	0,485	M-
10	600	13,9	23,1	59,9	0,492	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	15,1	21,6	60	0,537	M-
2	700	13,9	19,8	60	0,492	M-
3	700	14,8	21,1	59,9	0,524	M-
4	700	14	20	60	0,496	M-
5	700	13,2	18,9	60	0,468	M-
6	700	14,2	20,2	60	0,502	M-
7	700	14,2	20,2	60	0,502	M-
8	700	14,7	21	60	0,521	M-
9	700	13,8	19,7	60	0,488	M-
10	700	15,2	21,7	60	0,539	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	16,6	20,7	60	0,588	M-
2	800	16,4	20,6	60	0,583	M-
3	800	16,9	21,1	60	0,599	M-
4	800	16,3	20,4	60	0,579	M-
5	800	15	18,8	60	0,532	M-
6	800	16,4	20,5	60	0,581	M-
7	800	15,1	18,9	60	0,536	M-
8	800	14,7	18,4	60	0,521	M-
9	800	16,2	20,2	60	0,573	M-
10	800	17	21,2	60	0,602	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	17,3	19,2	60	0,612	M-
2	900	14,7	16,3	60	0,521	M-
3	900	15,7	17,5	60	0,558	
4	900	17,1	19	60	0,605	
5	900	17,4	19,4	59,9	0,619	
6	900	17,3	19,3	60	0,615	M-
7	900	17	18,9	60	0,602	M-
8	900	15,7	17,5	60	0,558	M-
9	900	16,3	18,1	60	0,577	M-
10	900	15,8	17,5	60	0,559	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	17,9	17,9	60	0,635	M-
2	1 000	18,5	18,5	59,9	0,655	
3	1 000	17,5	17,5	60	0,619	
4	1 000	17,9	17,9	59,9	0,636	M-
5	1 000	17,4	17,4	59,9	0,617	
6	1 000	18,3	18,3	60	0,649	
7	1 000	18	18	60	0,638	
8	1 000	18	18	60	0,638	
9	1 000	17,4	17,4	60	0,618	
10	1 000	17,4	17,4	60	0,617	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	18,3	16,7	60	0,65	M-
2	1 100	18	16,4	60	0,64	
3	1 100	18	16,4	59,9	0,638	
4	1 100	17,8	16,2	59,9	0,63	
5	1 100	17,9	16,3	60	0,635	
6	1 100	17,9	16,3	59,9	0,636	
7	1 100	18,4	16,8	59,9	0,654	
8	1 100	18,7	17	60	0,663	
9	1 100	17,4	15,8	60	0,617	
10	1 100	18,7	17	60	0,664	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	19,1	15,9	59,9	0,678	M-
2	1 200	19,3	16,1	60	0,685	
3	1 200	19,7	16,4	60	0,7	
4	1 200	19,4	16,1	60	0,687	
5	1 200	19,7	16,4	59,9	0,699	
6	1 200	18,6	15,5	59,9	0,66	
7	1 200	19,3	16,1	59,9	0,683	
8	1 200	19,3	16	59,9	0,683	
9	1 200	18,7	15,6	60	0,664	
10	1 200	19	15,8	59,9	0,674	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	21,2	16,3	59,9	0,752	M-
2	1 300	20,6	15,8	59,9	0,731	
3	1 300	20,8	16	59,9	0,739	
4	1 300	20	15,4	59,9	0,71	
5	1 300	20,4	15,7	59,9	0,722	
6	1 300	20,8	16	59,9	0,739	
7	1 300	20	15,4	59,9	0,708	
8	1 300	20,5	15,8	59,9	0,727	
9	1 300	21,2	16,3	59,9	0,752	
10	1 300	20,4	15,7	59,9	0,725	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	21,8	15,6	59,9	0,775	M-
2	1 400	21,7	15,5	59,9	0,771	
3	1 400	21,8	15,5	59,9	0,772	
4	1 400	20,3	14,5	59,9	0,721	
5	1 400	21,9	15,6	59,9	0,775	
6	1 400	21,4	15,3	59,9	0,76	

7	1 400	22	15,7	60,1	0,78	7	1 400	22,5	16,1	59,9	0,797
8	1 400	21,1	15,1	60,1	0,749	8	1 400	22,9	16,3	59,9	0,811
9	1 400	21,4	15,3	60,1	0,76	9	1 400	21,6	15,5	59,9	0,767
10	1 400	21,5	15,4	60,1	0,764	10	1 400	21,7	15,5	59,9	0,771

Table A. 37: Mud rheology. 90°C at 1bar in left column, 90°C at 40bar in right column.

Name: Mud. rampLin 100-1400. T=90degrees. P=1 bar | Name: Mud. rampLin 100-1400. T=90degrees. P=40 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	100	7,75	77,5	86,4	0,275	M-	1	100	6,36	63,5	86,6	0,226	M-
2	100	7,83	78,3	86,4	0,278	M-	2	100	8,09	80,9	86,6	0,287	M-
3	99,9	7,15	71,5	86,4	0,254	M-	3	100	7,48	74,8	86,6	0,265	M-
4	100	6,71	67,1	86,4	0,238	M-	4	100	6,98	69,8	86,6	0,247	M-
5	100	5,18	51,8	86,4	0,184	M-	5	100	6,89	69	86,6	0,245	M-
6	100	5,94	59,4	86,4	0,211	M-	6	100	6,14	61,4	86,6	0,218	M-
7	100	5,79	57,8	86,4	0,205	M-	7	100	6,02	60,2	86,6	0,213	M-
8	100	6,96	69,6	86,4	0,247	M-	8	100	6,18	61,8	86,6	0,219	M-
9	99,9	7,89	78,9	86,4	0,28	M-	9	100	5,86	58,5	86,6	0,208	M-
10	100	7,11	71,1	86,4	0,252	M-	10	100	6,82	68,2	86,6	0,242	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	7,77	38,8	86,4	0,276	M-	1	200	7,25	36,3	86,6	0,257	M-
2	200	8,95	44,8	86,5	0,318	M-	2	200	7,79	38,9	86,6	0,276	M-
3	200	8,17	40,8	86,5	0,29	M-	3	200	7,84	39,2	86,6	0,278	M-
4	200	7,78	38,9	86,5	0,276	M-	4	200	8,32	41,6	86,6	0,295	M-
5	200	8,68	43,4	86,4	0,308	M-	5	200	8,15	40,7	86,6	0,289	M-
6	200	9,25	46,3	86,5	0,328	M-	6	200	9	45	86,6	0,319	M-
7	200	7,98	39,9	86,5	0,283	M-	7	200	8,49	42,5	86,6	0,301	M-
8	200	7,74	38,7	86,4	0,274	M-	8	200	9,53	47,7	86,6	0,338	M-
9	200	8,75	43,7	86,5	0,31	M-	9	200	8,19	41	86,6	0,291	M-
10	200	7,8	39	86,5	0,277	M-	10	200	7	35	86,6	0,248	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	10,5	35,1	86,5	0,373	M-	1	300	10,7	35,5	86,6	0,378	M-
2	300	9,24	30,8	86,5	0,328	M-	2	300	10,9	36,2	86,6	0,385	M-
3	300	9,07	30,2	86,5	0,322	M-	3	300	9,59	32	86,6	0,34	M-
4	300	10,5	35,2	86,5	0,374	M-	4	300	10,3	34,5	86,6	0,367	M-
5	300	8,34	27,8	86,5	0,296	M-	5	300	8,03	26,8	86,6	0,285	M-
6	300	9,61	32	86,5	0,341	M-	6	300	9,63	32,1	86,6	0,342	M-
7	300	9,98	33,3	86,5	0,354	M-	7	300	10,2	34	86,6	0,362	M-
8	300	9,02	30,1	86,5	0,32	M-	8	300	9,29	31	86,7	0,329	M-
9	300	9,05	30,2	86,5	0,321	M-	9	300	9,08	30,3	86,6	0,322	M-
10	300	9,27	30,9	86,5	0,329	M-	10	300	8,85	29,5	86,7	0,314	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	400	11,2	27,9	86,5	0,396	M-	1	400	12,4	31,1	86,6	0,441	M-
2	400	11	27,5	86,5	0,39	M-	2	400	9,44	23,6	86,6	0,335	M-
3	400	11,5	28,8	86,5	0,408	M-	3	400	10,2	25,4	86,6	0,361	M-
4	400	9,73	24,3	86,6	0,345	M-	4	400	10,6	26,5	86,6	0,376	M-
5	400	10,8	27,1	86,5	0,384	M-	5	400	10,8	26,9	86,6	0,381	M-
6	400	11,6	28,9	86,5	0,41	M-	6	400	11,1	27,7	86,6	0,393	M-
7	400	11,8	29,5	86,5	0,419	M-	7	400	10,1	25,2	86,6	0,358	M-
8	400	11,5	28,8	86,5	0,409	M-	8	400	9,65	24,1	86,6	0,342	M-
9	400	9,14	22,8	86,5	0,324	M-	9	400	11,9	29,7	86,6	0,422	M-
10	400	9,76	24,4	86,5	0,346	M-	10	400	10,5	26,2	86,6	0,372	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	500	11,4	22,9	86,5	0,406	M-	1	500	12	23,9	86,6	0,425	M-
2	500	11,9	23,9	86,5	0,423	M-	2	500	12,1	24,2	86,6	0,429	M-
3	500	9,68	19,4	86,5	0,343	M-	3	500	11,6	23,1	86,6	0,41	M-
4	500	11,4	22,8	86,5	0,405	M-	4	500	10,9	21,8	86,6	0,386	M-
5	500	10,7	21,3	86,5	0,378	M-	5	500	11,6	23,2	86,6	0,411	M-
6	500	11,1	22,2	86,5	0,394	M-	6	500	11,2	22,3	86,6	0,396	M-
7	500	11,5	22,9	86,5	0,406	M-	7	500	12	24	86,6	0,426	M-
8	500	11,9	23,8	86,5	0,421	M-	8	500	9,93	19,9	86,6	0,352	M-
9	500	10,3	20,5	86,5	0,364	M-	9	500	11,1	22,3	86,6	0,395	M-
10	500	12,1	24,1	86,5	0,428	M-	10	500	11,6	23,2	86,6	0,411	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	600	12,1	20,2	86,5	0,43	M-	1	600	13,6	22,6	86,6	0,481	M-
2	600	13	21,6	86,5	0,46	M-	2	600	12,5	20,9	86,6	0,444	M-
3	600	11,5	19,2	86,5	0,409	M-	3	600	12,4	20,7	86,6	0,44	M-
4	600	12,7	21,1	86,5	0,45	M-	4	600	13,1	21,8	86,6	0,463	M-
5	600	14	23,4	86,5	0,498	M-	5	600	11,4	19	86,6	0,404	M-
6	600	13,2	22	86,5	0,468	M-	6	600	13,2	22,1	86,6	0,469	M-
7	600	12,3	20,5	86,5	0,437	M-	7	600	14,2	23,7	86,6	0,504	M-
8	600	13	21,6	86,5	0,46	M-	8	600	12,1	20,2	86,6	0,429	M-
9	600	12,4	20,7	86,5	0,44	M-	9	600	12,4	20,6	86,6	0,438	M-
10	600	14,6	24,4	86,5	0,518	M-	10	600	13	21,6	86,6	0,459	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	700	16,3	23,3	86,5	0,579	M-	1	700	14,3	20,4	86,6	0,506	M-
2	700	16,1	23,1	86,5	0,573	M-	2	700	12,9	18,5	86,6	0,459	M-
3	700	12,2	17,4	86,5	0,433	M-	3	700	13,7	19,6	86,6	0,485	M-
4	700	14,5	20,8	86,5	0,516	M-	4	700	13,3	19	86,6	0,473	M-
5	700	14	19,9	86,5	0,495	M-	5	700	12,9	18,4	86,6	0,457	M-
6	700	14,2	20,3	86,5	0,505	M-	6	700	14,9	21,2	86,6	0,527	M-
7	700	14,1	20,1	86,5	0,499	M-	7	700	13,6	19,4	86,6	0,482	M-
8	700	13,3	19	86,5	0,471	M-	8	700	13,8	19,8	86,6	0,491	M-
9	700	14,4	20,5	86,5	0,509	M-	9	700	13,5	19,3	86,6	0,479	M-
10	700	14,2	20,3	86,5	0,505	M-	10	700	12,1	17,3	86,6	0,43	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	800	16,2	20,2	86,5	0,573	M-	1	800	15,8	19,8	86,6	0,561	M-
2	800	14,5	18,2	86,5	0,516	M-	2	800	15,7	19,6	86,7	0,555	M-
3	800	14,2	17,8	86,4	0,504	M-	3	800	15,8	19,8	86,6	0,562	M-
4	800	14,2	17,8	86,4	0,505	M-	4	800	15	18,8	86,7	0,533	M-
5	800	14,2	17,7	86,4	0,502	M-	5	800	14,8	18,5	86,6	0,525	M-
6	800	14,1	17,7	86,4	0,501	M-	6	800	14	17,5	86,6	0,497	M-
7	800	14,5	18,1	86,4	0,513	M-	7	800	14,3	17,9	86,6	0,509	M-
8	800	15,2	19	86,4	0,54	M-	8	800	13,5	16,8	86,6	0,478	M-
9	800	14,7	18,3	86,4	0,52	M-	9	800	14,8	18,5	86,6	0,526	M-
10	800	14,1	17,6	86,4	0,499	M-	10	800	13	16,2	86,6	0,46	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []	Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	900	13,8	15,3	86,4	0,489	M-	1	900	15,3	16,9	86,6	0,541	M-
2	900	16,2	18	86,4	0,574	M-	2	900	15,7	17,4	86,6	0,556	M-

3	900	14,9	16,6	86,4	0,53	M-
4	900	15,7	17,4	86,4	0,557	M-
5	900	16,1	17,9	86,4	0,572	M-
6	900	15,8	17,5	86,4	0,559	M-
7	900	16,1	17,9	86,3	0,572	M-
8	900	16,7	18,6	86,4	0,592	M-
9	900	13,6	15,1	86,4	0,481	M-
10	900	13	14,4	86,4	0,461	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	16,8	16,8	86,4	0,595	M-
2	1 000	16,5	16,5	86,4	0,586	M-
3	1 000	17,8	17,8	86,4	0,632	M-
4	1 000	16,4	16,4	86,4	0,583	M-
5	1 000	16,9	16,9	86,4	0,6	
6	1 000	16,4	16,4	86,4	0,581	M-
7	1 000	15,8	15,8	86,4	0,559	M-
8	1 000	16,4	16,4	86,4	0,583	M-
9	1 000	16,8	16,8	86,4	0,595	M-
10	1 000	16,2	16,2	86,4	0,573	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	17,1	15,5	86,4	0,606	M-
2	1 100	16,9	15,4	86,4	0,6	
3	1 100	15,9	14,4	86,4	0,564	M-
4	1 100	15,5	14,1	86,4	0,55	M-
5	1 100	17,1	15,5	86,4	0,605	M-
6	1 100	17,9	16,2	86,4	0,634	
7	1 100	17,1	15,5	86,4	0,605	
8	1 100	17,7	16,1	86,4	0,629	
9	1 100	17,4	15,8	86,4	0,617	
10	1 100	17,5	15,9	86,4	0,62	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	18,2	15,2	86,4	0,647	M-
2	1 200	17,1	14,2	86,4	0,606	
3	1 200	17,4	14,5	86,4	0,618	
4	1 200	17,6	14,7	86,4	0,625	
5	1 200	18	15	86,4	0,639	
6	1 200	18,5	15,4	86,4	0,657	
7	1 200	18,2	15,2	86,4	0,645	
8	1 200	18,4	15,3	86,4	0,653	
9	1 200	17,1	14,3	86,4	0,607	
10	1 200	18,4	15,3	86,4	0,652	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	19,4	14,9	86,4	0,688	M-
2	1 300	19,9	15,3	86,4	0,706	
3	1 300	18	13,9	86,5	0,639	
4	1 300	18,3	14,1	86,5	0,649	
5	1 300	19,5	15	86,4	0,693	
6	1 300	18,6	14,3	86,5	0,658	
7	1 300	18,4	14,1	86,5	0,651	
8	1 300	18,4	14,2	86,5	0,653	
9	1 300	19,5	15	86,5	0,69	
10	1 300	19,8	15,2	86,5	0,703	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	20,1	14,4	86,5	0,714	M-
2	1 400	20,6	14,7	86,5	0,73	
3	1 400	18,4	13,1	86,5	0,651	
4	1 400	20,8	14,9	86,5	0,737	
5	1 400	20,4	14,6	86,5	0,724	
6	1 400	18,8	13,5	86,5	0,668	
7	1 400	20,4	14,6	86,5	0,724	
8	1 400	18,7	13,4	86,5	0,664	
9	1 400	20,5	14,7	86,5	0,728	M-
10	1 400	19,6	14	86,5	0,695	

3	900	16,3	18,2	86,6	0,579	M-
4	900	16,4	18,2	86,6	0,58	M-
5	900	16,3	18,1	86,6	0,577	M-
6	900	15,6	17,4	86,6	0,554	M-
7	900	16,2	18	86,6	0,576	M-
8	900	15,2	16,9	86,6	0,54	M-
9	900	15,3	17	86,6	0,543	M-
10	900	13,2	14,7	86,6	0,468	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 000	17,1	17,1	86,6	0,608	M-
2	1 000	17,4	17,4	86,6	0,616	M-
3	1 000	16,3	16,3	86,6	0,577	M-
4	1 000	16,4	16,4	86,6	0,58	M-
5	1 000	16	16	86,5	0,568	M-
6	1 000	16,5	16,5	86,6	0,587	M-
7	1 000	15,8	15,8	86,6	0,559	M-
8	1 000	17,6	17,6	86,6	0,624	M-
9	1 000	16	16	86,6	0,569	
10	1 000	15,5	15,5	86,6	0,548	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 100	17,8	16,1	86,6	0,63	M-
2	1 100	16,6	15,1	86,6	0,589	M-
3	1 100	17,1	15,5	86,6	0,605	
4	1 100	16,1	14,6	86,6	0,571	
5	1 100	16,6	15,1	86,6	0,589	
6	1 100	17,6	16	86,6	0,625	
7	1 100	18,3	16,7	86,6	0,65	
8	1 100	17,2	15,6	86,6	0,61	
9	1 100	16,3	14,8	86,6	0,578	
10	1 100	16,5	15	86,6	0,586	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 200	18,9	15,8	86,6	0,671	M-
2	1 200	19,7	16,4	86,6	0,697	
3	1 200	19,2	16	86,6	0,681	
4	1 200	18,5	15,4	86,6	0,655	
5	1 200	18	15	86,6	0,639	
6	1 200	17,5	14,6	86,6	0,62	
7	1 200	18,5	15,4	86,6	0,657	
8	1 200	18,3	15,2	86,6	0,648	
9	1 200	18,9	15,8	86,6	0,671	
10	1 200	17,7	14,8	86,6	0,629	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 300	19,5	15	86,6	0,692	M-
2	1 300	20	15,4	86,6	0,71	
3	1 300	19,3	14,9	86,6	0,685	
4	1 300	19,4	14,9	86,5	0,687	
5	1 300	19,1	14,7	86,6	0,676	
6	1 300	18,2	14	86,6	0,646	
7	1 300	19,4	14,9	86,6	0,688	
8	1 300	19,2	14,8	86,6	0,683	M-
9	1 300	18,8	14,4	86,6	0,666	
10	1 300	20,3	15,6	86,6	0,718	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	21,1	15,1	86,6	0,75	M-
2	1 400	20,4	14,6	86,6	0,724	
3	1 400	20,7	14,8	86,6	0,733	
4	1 400	19,9	14,2	86,6	0,707	
5	1 400	20,9	14,9	86,6	0,74	
6	1 400	21,5	15,4	86,6	0,762	
7	1 400	21	15	86,6	0,744	
8	1 400	21,8	15,6	86,6	0,774	
9	1 400	19,3	13,8	86,6	0,686	
10	1 400	21,9	15,6	86,6	0,775	

Table A. 38: Mud rheology test. 90 °C at 80 bar.

Name: Mud. rampLin 100-1400. T=90degrees. P=80 bar

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	99,9	8,74	87,5	87	0,31	M-
2	100	7,13	71,3	86,9	0,253	M-
3	100	7,56	75,6	87	0,268	M-
4	100	7,38	73,8	87	0,262	M-
5	100	6,96	69,5	87	0,247	M-
6	100	7,46	74,6	87	0,265	M-
7	100	6,94	69,4	87	0,246	M-
8	100	7,14	71,5	87	0,253	M-
9	100	6,09	60,9	87	0,216	M-
10	100	5,36	53,6	87	0,19	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	200	7,52	37,6	87	0,267	M-
2	200	8,95	44,7	87	0,317	M-
3	200	9,07	45,3	87	0,322	M-
4	200	6,6	33	87	0,234	M-
5	200	8,43	42,2	87	0,299	M-
6	200	8	40	87	0,284	M-
7	200	8,77	43,9	87	0,311	M-
8	200	7,66	38,3	87	0,272	M-
9	200	8,77	43,9	87	0,311	M-
10	200	8,86	44,3	87	0,314	M-

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	300	9,4	31,3	87	0,333	M-
2	300	10,3	34,4	87	0,366	M-
3	300	9,31	31	87	0,33	M-
4	300	10,2	34	87	0,361	M-
5	300	9,79	32,6	87	0,347	M-
6	300	9,25	30,8	87	0,328	M-
7	300	9,58	31,9	87	0,34	M-
8	300	9,33	31,1	87	0,331	M-
9	300	8,87	29,6	87	0,314	M-
10	300	9,79	32,6	87	0,347	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status

	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	400	11,5	28,8	87	0,409	M-
2	400	10,5	26,2	87	0,372	M-
3	400	10,4	26	87	0,368	M-
4	400	10,8	27	87	0,383	M-
5	400	10,2	25,6	87	0,363	M-
6	400	11,1	27,7	87	0,393	M-
7	400	10,5	26,2	87	0,372	M-
8	400	10,3	25,8	87	0,366	M-
9	400	11,1	27,8	87	0,394	M-
10	400	10,1	25,3	87	0,358	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	500	11,3	22,5	87	0,4	M-
2	500	12,3	24,6	87	0,437	M-
3	500	11,4	22,8	87	0,405	M-
4	500	12,4	24,8	87	0,439	M-
5	500	11,8	23,6	87	0,418	M-
6	500	11,3	22,7	87	0,402	M-
7	500	12,4	24,8	87	0,44	M-
8	500	11,5	23	87	0,409	M-
9	500	11,7	23,4	87	0,415	M-
10	500	12,4	24,7	87	0,438	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	600	13,6	22,7	87	0,483	M-
2	600	12,4	20,7	87	0,44	M-
3	600	13,9	23,1	87	0,492	M-
4	600	11	18,3	87	0,389	M-
5	600	12,7	21,1	87	0,449	M-
6	600	13,9	23,2	87	0,493	M-
7	600	12,1	20,2	87	0,429	M-
8	600	13,3	22,2	87	0,473	M-
9	600	14,1	23,6	87	0,501	M-
10	600	12	19,9	87	0,424	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	700	14,8	21,1	87	0,524	M-
2	700	15,1	21,6	87	0,536	M-
3	700	14,6	20,8	87	0,517	M-
4	700	14,9	21,3	87	0,53	M-
5	700	14,7	21	87	0,522	M-
6	700	14	19,9	87	0,495	M-
7	700	13,7	19,6	86,9	0,486	M-
8	700	13,6	19,4	87	0,483	M-
9	700	15,1	21,5	87	0,535	M-
10	700	13	18,5	87	0,459	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	800	15,2	19	87	0,54	M-
2	800	15,1	18,9	87	0,535	M-
3	800	15,1	18,8	87	0,534	M-
4	800	14,2	17,7	87	0,502	M-
5	800	15,4	19,3	87	0,547	M-
6	800	13,8	17,2	87	0,488	M-
7	800	15,8	19,7	87	0,559	M-
8	800	15,2	19	87	0,539	M-
9	800	15,3	19,1	87	0,543	M-
10	800	15,4	19,3	87	0,548	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	900	16,2	18	87	0,574	M-
2	900	18,1	20,2	87	0,643	M-
3	900	15,7	17,5	87	0,558	M-
4	900	17,1	19	87	0,605	M-
5	900	16,1	17,9	87	0,57	M-
6	900	16	17,7	87	0,566	M-
7	900	16,7	18,5	87	0,592	M-
8	900	15,3	17	87	0,542	M-
9	900	14,6	16,3	87	0,519	M-
10	900	15,7	17,4	87	0,555	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	1 000	17,9	17,9	87	0,636	M-
2	1 000	17,4	17,4	87	0,619	
3	1 000	16,7	16,7	87	0,592	M-
4	1 000	16,5	16,5	87	0,584	M-
5	1 000	17,7	17,7	87	0,626	M-
6	1 000	17,6	17,6	87	0,624	
7	1 000	16	16	87	0,567	M-
8	1 000	16,2	16,2	87	0,575	M-
9	1 000	17,1	17,1	87	0,606	M-
10	1 000	15,4	15,4	87	0,546	M-

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	1 100	18,8	17,1	87	0,666	M-
2	1 100	18,1	16,4	87	0,641	
3	1 100	18,2	16,5	87	0,644	M-
4	1 100	17,7	16,1	87	0,627	
5	1 100	16,9	15,4	87	0,599	
6	1 100	16,4	14,9	87	0,582	
7	1 100	16,2	14,8	87	0,576	
8	1 100	16,9	15,4	87	0,599	
9	1 100	18,2	16,5	87	0,644	
10	1 100	18,7	17	87	0,662	

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	1 200	18,8	15,7	87	0,666	M-
2	1 200	19	15,8	87	0,674	
3	1 200	18,5	15,4	87	0,657	
4	1 200	18,2	15,2	87	0,646	
5	1 200	19,1	15,9	87	0,677	
6	1 200	18,7	15,6	87	0,664	
7	1 200	16,7	13,9	87	0,591	M-
8	1 200	18,1	15,1	87	0,643	
9	1 200	18,4	15,4	87,1	0,654	
10	1 200	18,3	15,3	87	0,651	

Meas. Pts.	Shear Rate	Shear Stress	Viscosity	Temperature	Torque	Status
	[1/s]	[Pa]	[cP]	[°C]	[mNm]	[]
1	1 300	19,4	14,9	87	0,689	M-
2	1 300	19,3	14,8	87	0,683	
3	1 300	20,1	15,5	87,1	0,714	

4	1 300	19,6	15,1	87	0,696	
5	1 300	19,7	15,2	87	0,7	
6	1 300	20,2	15,5	87	0,716	
7	1 300	18,4	14,1	87	0,651	
8	1 300	19,1	14,7	87	0,679	
9	1 300	19,1	14,7	87	0,677	
10	1 300	19,4	14,9	87	0,686	

Meas. Pts.	Shear Rate [1/s]	Shear Stress [Pa]	Viscosity [cP]	Temperature [°C]	Torque [mNm]	Status []
1	1 400	21,6	15,4	87	0,765	M-
2	1 400	20,2	14,5	87	0,718	
3	1 400	21,7	15,5	87	0,77	
4	1 400	20,2	14,4	87,1	0,717	
5	1 400	21,4	15,3	87	0,76	
6	1 400	22,4	16	87	0,793	
7	1 400	19,5	13,9	87	0,691	
8	1 400	21,3	15,2	87	0,756	
9	1 400	20,3	14,5	87	0,72	
10	1 400	19,9	14,2	87	0,707	

A.4 Landmark

A.4.1 Results for the different cases in the evaluations of pressure loss

Results case 1:

In Figure A. 13 is the plot of annular pressure vs. measured depth for case 1 plotted. The pressure at 3000 m MD is approximately 36000 kPa (360 bar).

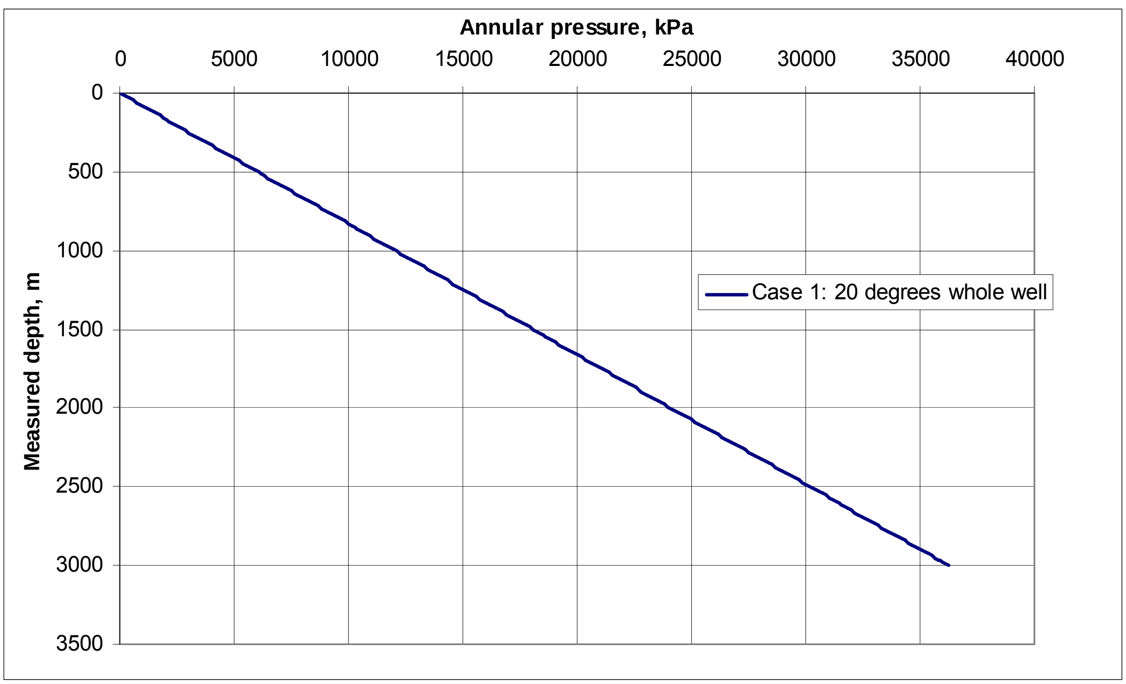


Figure A. 13: Case 1, annular pressure vs. measured depth, temperature 60 °C.

Results Case 2

The results from case 2 is plotted in Figure A. 14 at 60 °C. The annular pressure varies from 0 – 35000 kPa from 0 – 3000 m measured depth.

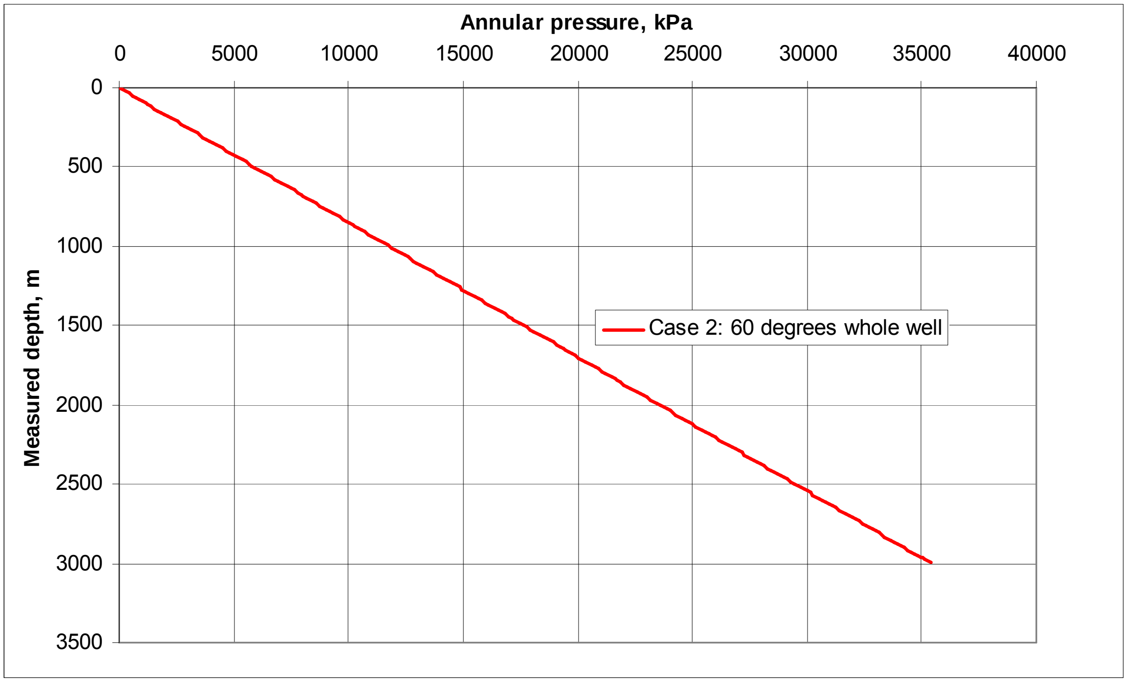


Figure A. 14: Case 2, annular pressure vs. measured depth, temperature 60 °C.

Results case 3

In Figure A. 15 is the results from case 3 plotted. The annular pressure varies from 0 – 35000 kPa from 0 – 3000 m measured depth.

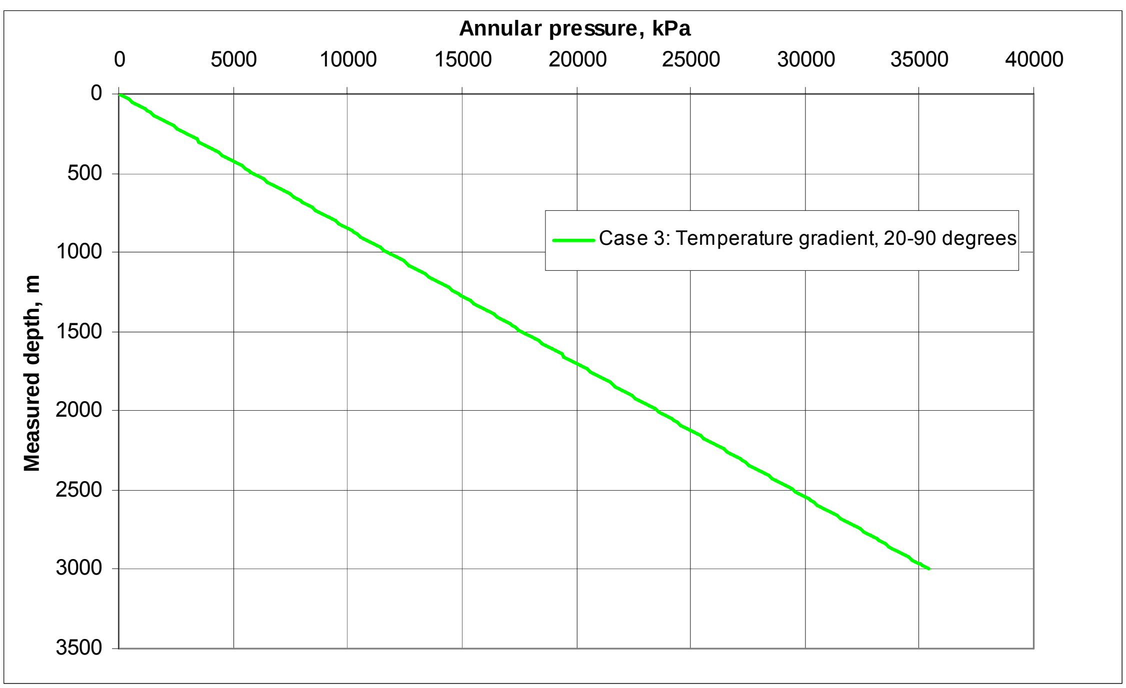


Figure A. 15: Case 3, annular pressure vs. measured depth, temperature gradient.

A.4.2 Results Landmark Wellplan calculations

The tables presented below are he calculated values from Landmark Wellplan software. These values are at selected depths as it would be too much data to present if the whole table from Landmark should be presented. The values for the different cases in chapter 6 are shown.

Table A. 39: Case 1. String and annular pressures at selected depths. T=20 °C.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
5096	0	0	0
6252,1	107,96	1300,3	107,96
7279,7	203,93	2456,2	203,93
8307,4	299,9	3612	299,9
9463,4	407,86	4912,4	407,86
10491,1	503,83	6068,2	503,83
11518,7	599,8	7224,1	599,8
12674,8	707,76	8524,4	707,76
13702,5	803,73	9680,3	803,73
14730,1	899,7	10836,1	899,7
15886,2	1007,66	12136,5	1007,66
16913,8	1103,63	13292,3	1103,63
17941,5	1199,6	14448,2	1199,6
19097,6	1307,56	15748,5	1307,56
20125,2	1403,53	16904,4	1403,53
21152,9	1499,5	18060,2	1499,5
22309	1607,46	19360,6	1607,46
23336,6	1703,43	20516,4	1703,43
24364,2	1799,4	21672,3	1799,4
25520,3	1907,36	22972,6	1907,36
26548	2003,33	24128,9	2003,33
27575,6	2099,3	25297,8	2099,3
28731,7	2207,26	26612,9	2207,26
29759,4	2303,23	27781,8	2303,23
30787	2399,2	28950,7	2399,2
31943,1	2507,16	30265,8	2507,16
32970,8	2603,13	31434,7	2603,13
33998,4	2699,1	32603,6	2699,1
35154,5	2807,07	33918,7	2807,07
36182,2	2903,04	35087,6	2903,04
36562,8	2999	36256,5	2999

Table A. 40: Case 2. String and annular pressures at selected depths. T=60 °C.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
3593	0	0	0
4770,8	107,96	1271	107,96
5817,7	203,93	2400,8	203,93
6864,7	299,9	3530,6	299,9
8042,5	407,86	4801,6	407,86
9089,4	503,83	5931,4	503,83
10136,4	599,8	7061,2	599,8
11314,2	707,76	8332,3	707,76
12361,1	803,73	9462	803,73
13408	899,7	10591,8	899,7
14585,9	1007,66	11862,9	1007,66
15632,8	1103,63	12992,7	1103,63
16679,7	1199,6	14122,5	1199,6
17857,5	1307,56	15393,5	1307,56
18904,5	1403,53	16523,3	1403,53
19951,4	1499,5	17653,1	1499,5
21129,2	1607,46	18924,1	1607,46
22176,2	1703,43	20053,9	1703,43
23223,1	1799,4	21183,7	1799,4
24400,9	1907,36	22454,7	1907,36
25447,8	2003,33	23584,8	2003,33
26494,8	2099,3	24723,1	2099,3
27672,6	2207,26	26003,7	2207,26
28719,5	2303,23	27142	2303,23
29766,5	2399,2	28280,3	2399,2
30944,3	2507,16	29560,9	2507,16
31991,2	2603,13	30699,2	2603,13
33038,2	2699,1	31837,5	2699,1
34216	2807,07	33118,1	2807,07
35262,9	2903,04	34256,4	2903,04
35701	2999	35394,7	2999

Table A. 41: Case 3. String and annular pressures at selected depths. T=20-90°C.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
3593	0	0	0
4770,8	107,96	1271	107,96
5817,7	203,93	2400,8	203,93
6864,7	299,9	3530,6	299,9
8042,5	407,86	4801,6	407,86
9089,4	503,83	5931,4	503,83
10136,4	599,8	7061,2	599,8
11314,2	707,76	8332,3	707,76
12361,1	803,73	9462	803,73
13408	899,7	10591,8	899,7
14585,9	1007,66	11862,9	1007,66
15632,8	1103,63	12992,7	1103,63
16679,7	1199,6	14122,5	1199,6
17857,5	1307,56	15393,5	1307,56
18904,5	1403,53	16523,3	1403,53
19951,4	1499,5	17653,1	1499,5
21129,2	1607,46	18924,1	1607,46
22176,2	1703,43	20053,9	1703,43
23223,1	1799,4	21183,7	1799,4
24400,9	1907,36	22454,7	1907,36
25447,8	2003,33	23584,8	2003,33
26494,8	2099,3	24723,1	2099,3
27672,6	2207,26	26003,7	2207,26
28719,5	2303,23	27142	2303,23
29766,5	2399,2	28280,3	2399,2
30944,3	2507,16	29560,9	2507,16
31991,2	2603,13	30699,2	2603,13
33038,2	2699,1	31837,5	2699,1
34216	2807,07	33118,1	2807,07
35262,9	2903,04	34256,4	2903,04
35701	2999	35394,7	2999

Table A. 42:Case 4. Cumulative annular pressure at every 250 m depth in the well.

Measured depth [m]	Annular pressure [kPa]	Cum ann pressure [kPa]
0	0	0
250	2950	2950
499	2942	5892
749	2937	8829
999	2930	11759
1249	2928	14687
1499	2926	17613
1749	2924	20537
1999	2925	23462
2249	2930	26392
2499	2948	29340
2749	2952	32292
2999	2959	35251

A.5 API Recommended practices

A.5.1 Mud weight (density)- water based drilling fluids

Description:

The test procedure is a method for determining the weight of a given volume of fluid. Mud weight may be expressed in different ways, but we will use kilograms per cubic meter [kg/m^3] or kilograms per litre [kg/l].

Equipment:

Any instrument of sufficient accuracy to perform measurement within ±10 kg/m^3 may be used. The mud balance is the instrument generally used for mud weight determinations. The mud balance is designed such that the mud cup, at one end of the beam, is balanced by a fixed counterweight at the other end, with a sliding-weight rider free to move along a graduated scale. A level-bubble is mounted on the beam to allow for accurate balancing.
In addition a thermometer.
In our laboratory experiment we used a pycnometer instead of the mud balance instrument.

Procedure:

a. The instrument base should be set on a flat, level surface.
b. Measure the temperature of the mud.
c. Fill the clean, dry cup with the mud to be tested; put the cap on the filled mud cup and rotate the cap until it is firmly seated. Ensure that some of the mud is expelled through the hole in the cap in order to free any trapped air or gas.
d. Holding cap firmly on mud cup (with cap hole covered), wash or wipe the outside of the cup clean and dry.
e. Place the beam on the base support and balance it by moving the rider along the graduated scale. Balance is achieved when the bubble is under the center line.
f. Read the mud weight at the edge of the rider toward the mud cup.

Procedure-Calibration:

The instrument should be calibrated frequently with fresh water. Fresh water should give a reading of 1000 kg/m^3 at 21°C. If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm as required.

Calculation:

Report the mud weight to the nearest 10 kg/m^3.

A.5.2 Viscosity- water based drilling fluids

MARSH FUNNEL

Equipment:

A Marsh funnel is calibrated to outflow one-quart (946 cm^3) of fresh water at a temperature of 21°C ±3 in 26 seconds ±0.5. A graduated cup is used as a receiver.

a. Marsh funnel

b. Graduated cup: one-quart

c. Stopwatch

d. Thermometer

Procedure:

a. Cover the funnel orifice with a finger and pour freshly sampled drilling fluid through the screen into the clean, upright funnel. Fill until fluid reaches the bottom of the screen.

b. Remove finger and start stopwatch. Measure the time for mud to fill to one-quart (946 cm^3) mark of the cup.

c. Measure temperature of fluid in degrees.

d. Report the time to nearest second as marsh funnel viscosity. Report the temperature of fluid to nearest degree Celsius.

A.6 Student exercise on the HPHT viscometer and Landmark calculations

Student exercise on the HPHT viscometer and Landmark calculations

Goals:

- Learn the use of advanced laboratory equipment

- Learn about rheology under HPHT conditions
- Se how results from laboratory measurements and calculations can be used in an advanced PC-program, Landmark Wellplan

Exercise:

1. Measure the viscosity differences as a result of changes in the pressure and temperature by the use of PHYSICA HPHT viscometer.

2. Estimate annular pressure vs. measured depth by the use of Landmark Wellplan software and Microsoft Excel by using the results obtained from the laboratory experiment.

Procedure

The procedures are divided in two parts. One parts that describes the laboratory experiment while the other part describes the Landmark Wellplan calculations.

Equipment

- Thermometer
- A mixer
- Physica viscometer
- Pressure bottle with Nitrogen
- Water bath

Lab experiment

1 litre of drill-in mud consists of the following:

I. 1 litre of water
II. 2 weight-% starch
III. 5 weight-% $CaCO_3$- Calciumcarbonate
IV. 0,6 weight-% Xanthan gum
V. 250 gram salt (NaCl)

The mud is aged for approximately one day to settle and get its rheological properties.

- Turn on the PHYSICA viscometer at D = 1000 s^{-1} manually on the instrument. Let it rotate for 15-30 minutes in order for the instrument to get desired working temperature. Instructions on how the measurements are conducted are described in the manuals for the apparatus.

- Mount all parts according to instructions and measure on an empty measuring- cup, meaning that you measure the viscosity of air. It is optional to measure by the use of the PC or manually on the apparatus. The viscosity is supposed to be 0 cP. If the apparatus indicates a higher viscosity one has to check for potential sources of error (cleaning and adjustment procedures are described in the manuals).

- If the viscosity is zero, dismount the parts and pour the required amount of mud in the measuring cup and mount the parts together.

The measurements are from now on done from the US200- software on the computer. Turn on the computer and open the program US200. A more detailed procedure of how to measure is described in the manual.
When conducting measurements from software:

- Make sure that the desired measurement system is installed and active. Turn the apparatus in REMOTE-mode, meaning that it is ready to connect to the computer.
- Open a new workbook or an existing workbook.

    If existing workbook:
    STUDENT EXERCISE- RAMP LOG
    Logaritmic distribution (many points at low rates, fewer at higher rates)
    50 measuring points, one point each 5 second

    STUDENT EXERCISE- RAMP LIN
    Linear distribution (Constant distance between each shear rate)
    50 measuring points, one point each 5 second

  It is also possible to make a new measuring method. How this is done is shown in the manual.

- Connect the pressure hose to the pressure cell and turn on the water bath.
- Measurement pressures and temperatures:

Tasks Physica viscometer:

Below are the two test matrixes for the laboratory experiments (Physica viscometer) shown.

Test matrix 1: Effect of pressure at a given temperature.

Liquid	Temperature [°C]	Pressure [bar]	# experiments
Drill- in mud	20	1	1
	20	40	1
	20	60	1
	20	80	1
	20	100	1

Test matrix 2: Effect of temperature at a given pressure.

Liquid	Temperature [°C]	Pressure [bar]	# experiments
Drill- in mud	20	1	1
	60	1	1
	90	1	1

- The pressure and temperatures adjustments have to be done on the respective instruments as it is not possible to change the pressure and temperature in the computer program.
- The visualization and plots from the different measurements can be seen if choosing the desired run. To do this click Window and choose either 2 Table 1: Flow Curve or 3 Diagram 1: Flow curve/ log. The recorded data may also be copied to Microsoft Excel were one might plot other types of diagrams than the program do.

1. Use the method saved in STUDENT EXERCISE RAMP LIN to measure the effect of pressure on a mud at 20 °C:
   - T = 20 °C, P = 1 bar
   - T = 20 °C, P = 40 bar
   - T = 20 °C, P = 60 bar
   - T = 20 °C, P = 80 bar
   - T = 20 °C, P = 100 bar

2. Use the method saved in STUDENT EXERCISE RAMP LIN to measure the effect of temperature at constant pressure:
   - T = 20 °C, P = 1 bar (already measured but compare the results)
   - T = 60 °C, P = 1 bar
   - T = 90 °C, P = 1 bar

3. Copy all of the data to Microsoft Excel and make two plots (shear rate vs. shear stress) of the data in the same plot for task 1. and task 2. respectively. Use the mean value for the shear stress at each shear rate. Check if any of the results are zero or invalid, these points should not be used. Discuss the results.

Solution laboratory measurement (Physica viscometer)

1. and 3. Only the average values for the shear stress are shown here for the measurements at:

- T = 20 °C, P = 1 bar
- T = 20 °C, P = 40 bar
- T = 20 °C, P = 80 bar

T = 20 °C, P = 1 bar

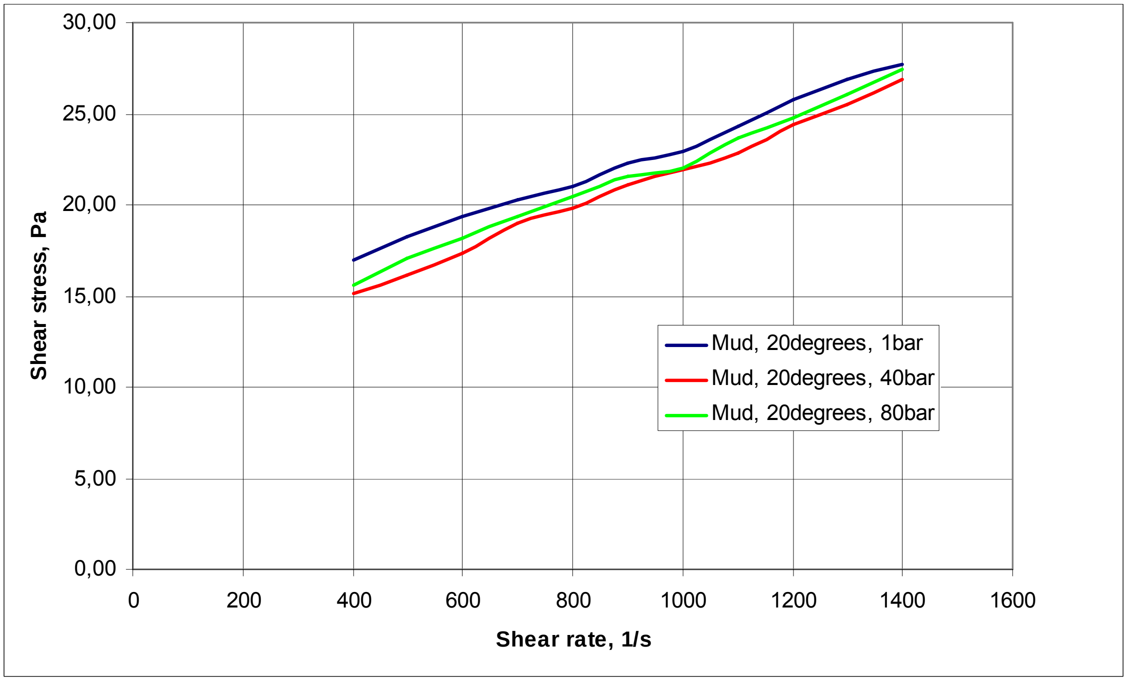
Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	17,33	43,28
500	18,93	37,82
600	20,29	33,83
700	21,47	30,66
800	22,55	28,19
900	24,09	26,78
1000	25,07	25,07
1100	26,67	24,25
1200	28,44	23,71
1300	29,78	22,93
1400	30,92	22,08

T = 20 °C, P = 40 bar

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	15,62	39,03
500	16,97	33,95
600	18,37	30,58
700	20,28	29
800	21,44	26,81
900	23	25,55
1000	24,08	24,08
1100	25,27	22,98
1200	27,11	22,6
1300	28,52	21,94
1400	30,15	21,54

T = 20 °C, P = 80 bar

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	16,09	40,19
500	17,78	35,59
600	19,17	31,95
700	20,66	29,52
800	22,01	27,51
900	23,42	26,01
1000	24,22	24,22
1100	26,13	23,75
1200	27,48	22,9
1300	29	22,31
1400	30,72	21,93



It is seen that the results from the measurements at different pressures at 20 °C give almost the same values for all pressures. The slope of the lines appears to be, at least visually, the same. The differences in the calculated viscosity seem to be in the range of 2 cP at any given shear rate. The results from the measurements at 1 bar give somewhat higher values than for the other pressures for all shear rates. An explanation might be that the pressure does have an impact. Another explanation might be that as the same mud was used at all measurements and that the first experiment was done at 1 bar, might the mud have shear thinning properties which makes the viscosity less as the mud is rotated in the bob and cup.

2. and 3.

Only the average values for shear stress and viscosity are shown here for the measurements at:

- T = 20 °C, P = 1 bar
- T = 60 °C, P = 1 bar
- T = 90 °C, P = 1 bar

T = 20 °C, P = 1 bar

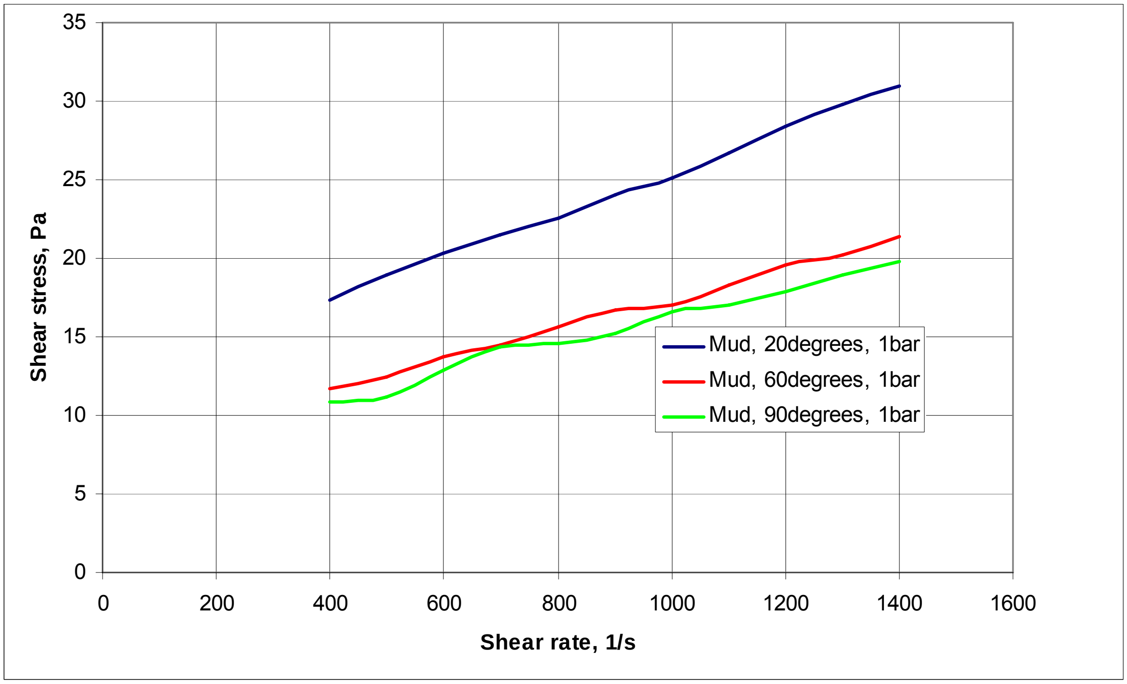
Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	17,33	43,28
500	18,93	37,82
600	20,29	33,83
700	21,47	30,66
800	22,55	28,19
900	24,09	26,78
1000	25,07	25,07
1100	26,67	24,25
1200	28,44	23,71
1300	29,78	22,93
1400	30,92	22,08

T = 60 °C, P = 1 bar

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	11,75	29,39
500	12,44	24,84
600	13,74	22,89
700	14,48	20,67
800	15,68	19,62
900	16,68	18,55
1000	16,97	16,97
1100	18,3	16,63
1200	19,54	16,29
1300	20,2	15,54
1400	21,36	15,26

T = 90 °C, P = 1 bar

Shear rate [1/s]	Shear stress [Pa]	Viscosity [cP]
400	10,803	27
500	11,198	22,38
600	12,88	21,47
700	14,33	20,47
800	14,59	18,24
900	15,19	16,87
1000	16,6	16,6
1100	17,01	15,44
1200	17,89	14,91
1300	18,98	14,6
1400	19,83	14,19



Discussion: The shear stress (and viscosity) is higher for the measurements conducted at 20 °C than for the other two temperatures. The results at 60 and 90 are more or less the same, but the values at 60 are somewhat larger than for 90.
If one compare the results for the viscosity in the tables one can see that the viscosity is decreasing as the temperature is increasing. The same trend is seen for the other pressures and shear rates as well but it seems that the effect of temperature is decreasing as the temperature is increasing (at least for temperatures above 60 °C) because the difference in viscosity is less between 60 °C and 90 °C than between 20 °C and 60 °C. It is though clear that it is larger difference between 20 and 60 °C (ΔT = 40 °C) and 60 and 90 °C (ΔT = 30 °C) but the difference in viscosity is more significant at lower temperatures.

Landmark Wellplan

Three different temperatures are to be used in the Landmark wellplan software:

1. By using the readings at 20 °C in the Physica viscometer
2. By using the readings at 60 °C in Physica viscometer
3. Geothermal gradient: 20 °C at surface, 90 °C at bottom of the hole.

The density is supposed to be equal at 20 and 60 °C. This is calculated in the laboratory (if not, use ρmud = 1150 kg/m3)

The well used in Landmark is as follows:

Depth of well: 3000m MD/TVD
Inclination: 0
Azimuth: 0

No riser is used.
9 5/8" casing shoe at 2000m TVD

Type of casing: API connection catalog-> 9 5/8" -> Nominal weight 40-> Grade C75

Drill string: Nominal diameter 5 -> Nominal weight 19,5 -> Grade E -> Connection 5 ½ FH -> Class 1

Drill collar:
Drill collar: Nominal OD 5 -> Nominal ID 1 ¾ -> Connection 3 ½ H90

Bit
Bit: Bit size 8 ½ -> (Manufacturer security DBS -> IADC Code 427X -> Type tri-Cone Bit -> Model XS06)

In the modules mode choose HYDRAULICS and then Pump Rate Fixed.

Fluid editor:
Convert the readings from the Physica viscometer into Fann readings. Use a mud density of 1150 kg/m3 if not measured by the students in the laboratory.

Geothermal gradient, 3 different cases:
1. 20 °C at surface and at 3000 m TVD
2. 60 °C at surface and at 3000 m TVD
3. 20 °C at surface, 90 °C at 3000 m TVD

Circulation:
Choose enough pumps to deliver a minimum pump rate of 1,5 m3/min.

Rate:
Pump rate fixed = 0,5 m3/min

<u>Tasks Landmark Wellplan:</u>
The same well- properties, casing depths, drill string etc are used in all of the tasks. The graph is shown by view-> plot -> Pressure vs. measured depth.
1. Calculate the annular pressure vs. measured depth for the following:
    a. 20 °C at surface and at 3000 m TVD, readings at 20 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.
    b. 60 °C at surface and at 3000 m TVD, readings at 60 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.
    c. Geothermal gradient: 20 °C at surface, 90 °C at 3000 m TVD, readings at 20 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.

2. Copy the date from Task 1 a, b and c to Microsoft excel. Switch between graph/grid by right-click on the graph and then Graph/ Grid..
    a. Make a plot of the annular pressure vs. measured depth for the 3 different measurements (a, b and c) in the same plot using Microsoft Excel. Discuss the results.

<u>Solution Landmark</u>

1a) Annular pressure. 20 °C at surface and at 3000 m TVD, readings at 20 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
5096	0	0	0
6252,1	107,96	1300,3	107,96
7279,7	203,93	2456,2	203,93
8307,4	299,9	3612	299,9
9463,4	407,86	4912,4	407,86
10491,1	503,83	6068,2	503,83
11518,7	599,8	7224,1	599,8
12674,8	707,76	8524,4	707,76
13702,5	803,73	9680,3	803,73
14730,1	899,7	10836,1	899,7
15886,2	1007,66	12136,5	1007,66
16913,8	1103,63	13292,3	1103,63
17941,5	1199,6	14448,2	1199,6
19097,6	1307,56	15748,5	1307,56
20125,2	1403,53	16904,4	1403,53
21152,9	1499,5	18060,2	1499,5
22309	1607,46	19360,6	1607,46
23336,6	1703,43	20516,4	1703,43
24364,2	1799,4	21672,3	1799,4
25520,3	1907,36	22972,6	1907,36
26548	2003,33	24128,9	2003,33
27575,6	2099,3	25297,8	2099,3
28731,7	2207,26	26612,9	2207,26
29759,4	2303,23	27781,8	2303,23
30787	2399,2	28950,7	2399,2
31943,1	2507,16	30265,8	2507,16
32970,8	2603,13	31434,7	2603,13
33998,4	2699,1	32603,6	2699,1
35154,5	2807,07	33918,7	2807,07
36182,2	2903,04	35087,6	2903,04
36562,8	2999	36256,5	2999

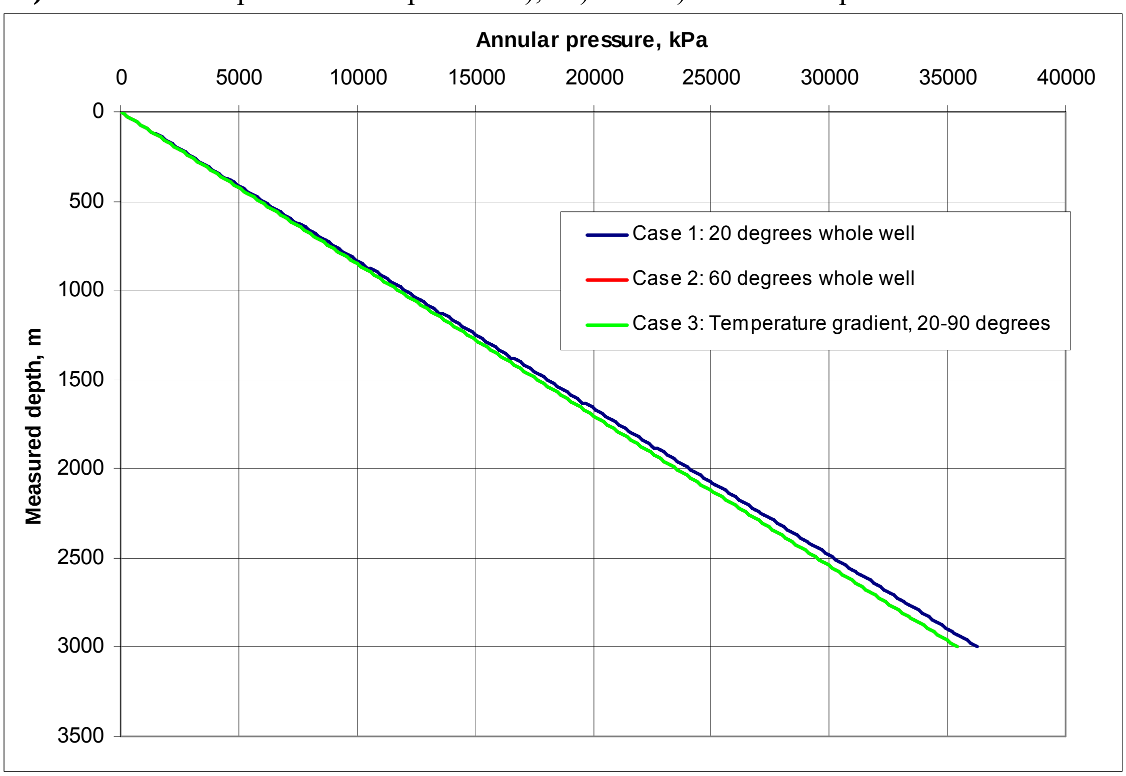
1 b) Annular pressure. 60 °C at surface and at 3000 m TVD, readings at 60 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
3593	0	0	0
4770,8	107,96	1271	107,96
5817,7	203,93	2400,8	203,93
6864,7	299,9	3530,6	299,9
8042,5	407,86	4801,6	407,86
9089,4	503,83	5931,4	503,83
10136,4	599,8	7061,2	599,8
11314,2	707,76	8332,3	707,76
12361,1	803,73	9462	803,73
13408	899,7	10591,8	899,7
14585,9	1007,66	11862,9	1007,66
15632,8	1103,63	12992,7	1103,63
16679,7	1199,6	14122,5	1199,6
17857,5	1307,56	15393,5	1307,56
18904,5	1403,53	16523,3	1403,53
19951,4	1499,5	17653,1	1499,5
21129,2	1607,46	18924,1	1607,46
22176,2	1703,43	20053,9	1703,43
23223,1	1799,4	21183,7	1799,4
24400,9	1907,36	22454,7	1907,36
25447,8	2003,33	23584,8	2003,33
26494,8	2099,3	24723,1	2099,3
27672,6	2207,26	26003,7	2207,26
28719,5	2303,23	27142	2303,23
29766,5	2399,2	28280,3	2399,2
30944,3	2507,16	29560,9	2507,16
31991,2	2603,13	30699,2	2603,13
33038,2	2699,1	31837,5	2699,1
34216	2807,07	33118,1	2807,07
35262,9	2903,04	34256,4	2903,04
35701	2999	35394,7	2999

1 c) Annular pressure. Geothermal gradient: 20 °C at surface, 90 °C at 3000 m TVD, readings at 20 °C, ρ = 1150 kg/m3, pump rate = 1 m3/min.

String Pressure(kPa)	String Measured Depth(m)	Annulus Pressure(kPa)	Annulus Measured Depth(m)
3593	0	0	0
4770,8	107,96	1271	107,96
5817,7	203,93	2400,8	203,93
6864,7	299,9	3530,6	299,9
8042,5	407,86	4801,6	407,86
9089,4	503,83	5931,4	503,83
10136,4	599,8	7061,2	599,8
11314,2	707,76	8332,3	707,76
12361,1	803,73	9462	803,73
13408	899,7	10591,8	899,7
14585,9	1007,66	11862,9	1007,66
15632,8	1103,63	12992,7	1103,63
16679,7	1199,6	14122,5	1199,6
17857,5	1307,56	15393,5	1307,56
18904,5	1403,53	16523,3	1403,53
19951,4	1499,5	17653,1	1499,5
21129,2	1607,46	18924,1	1607,46
22176,2	1703,43	20053,9	1703,43
23223,1	1799,4	21183,7	1799,4
24400,9	1907,36	22454,7	1907,36
25447,8	2003,33	23584,8	2003,33
26494,8	2099,3	24723,1	2099,3
27672,6	2207,26	26003,7	2207,26
28719,5	2303,23	27142	2303,23
29766,5	2399,2	28280,3	2399,2
30944,3	2507,16	29560,9	2507,16
31991,2	2603,13	30699,2	2603,13
33038,2	2699,1	31837,5	2699,1
34216	2807,07	33118,1	2807,07
35262,9	2903,04	34256,4	2903,04
35701	2999	35394,7	2999

2 a) Plot of annular pressure vs depth for 1a), 1b) and 1c) in the same plot.



Discussion: Temperature- effects are almost not showing. The different calculations give almost the same lines. Temperature gradient give somewhat higher pressure than the other measurements, but it is difficult to draw any other conclusions than that the temperature effect is more or less negligible. Some of the data plot on the same line and is therefore not visible. the results from 1b) (case 2) and 1c) (case 3) give identical values for the annular pressure.