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Weighting Material Sag

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ABSTRACT

This paper describes how applying different degrees of mixing-energy to an invert-emulsion drilling fluid affects rheological parameters and how this influences the sedimentation potential of weighting material from a drilling fluid. The paper presents results from a large scale factory application test and following laboratory measurements.

INTRODUCTION

In drilling operations, solid weighting materials are commonly added to the drilling fluid to give sufficient density to the fluid to hinder inflow of oil or gas into the wellbore from the down-hole formation. Weighting material sag, i.e. sedimentation of weighting material from the drilling fluid, has been and is currently one of the biggest challenges within the drilling fluid industry as it can lead to well control problems, lost circulation, hindered running of casing/liner, insufficient displacement etc.

Specific operations and procedures may either induce or minimize the sag potential[1,2,3,4] of the drilling fluid, with one of them described in the following.

It has previously been observed that sag is more pronounced in invert-emulsions than in water based drilling fluids. An invert emulsion drilling fluid is made up by a mixture of a brine phase together with a continuous oil phase. When drilling with invert-emulsion drilling fluids, one of the identified factors affecting sag is the stability and dispersion of the oil/water emulsion[5]. The emulsion stability can be adjusted by chemical modifications, as is shown in many publications[2,3]. The stability is a direct result of the mixing-energy applied to the drilling fluid. To obtain stability, the drilling fluid is sheared through the drill bit, or can be sheared at the surface by using high pressure pumps together with shear guns as shown in Fig. A.1 and A.2. The possibilities for using these expensive high pressure systems at the rig are often limited as they are often occupied by other operations. It is though possible to avoid the use of such heavy equipment by using specially designed shear devices.

In the following we describe a factory test performed at Ystral GmbH, a supplier of specially designed shear units. We shall further describe how rheological parameters can be affected when applying different degrees of shear, and how this will affect sag stability.

BACKGROUND

The sedimentation rate of the weighting material depends on several factors. The simplest description of sagging is based upon Stoke's law for the settling velocity, V_P , of a spherical particle of diameter D_P, settling in a fluid of viscosity η:

$$V_P = \frac{D_P{}^2 (r_P - r_o) g}{9h} \qquad (1)$$

where ρ_P and ρ_o is the density of the particle and the continuous phase respectively and g is the acceleration of gravity.

Many studies have been performed to determine rheological properties of ternary systems (solids, dispersed phase and continuous phase). Barnes et al.[6] showed that in general, the smaller and more monodisperse the droplet size is, the more viscous the emulsion becomes.

Theoretical work performed by Oldroyd[7] also showed that viscoelasticity results from the restoring force caused by the interfacial tension between the continuous and disperse phase. The unsheared emulsion droplets are spherical, but become ellipsoidal when subjected to shear. The ensuing increase of the surface area directly causes an increased viscosity. This is directly related to the viscoelastic properties: The smaller the droplets in an emulsion are, the shorter is the distance between them. According to Liu and Masliyah[8], this increases the storage modulus, G', and thus reduces the sag potential of the fluid. This assumes that the properties of the weighting agent are unchanged. G' is the part of the stress that is in phase with the strain divided by the strain under sinusoidal conditions when performing oscillatory measurements.

TEST FLUIDS

For evaluation of the efficiency of the different units, two different 200-liter samples of invert-emulsion drilling fluid were used. One was an unsheared premix of baseoil, brine, emulsifiers and clay. The other was a pre-sheared drilling fluid from the field that had been used for several drilling operations. By our experience, the selection of these two types of fluid should give indication of how the fluid's sag potential is influenced by different degrees of shear. Table 1 shows a typical composition of an invert-emulsion drilling fluid. The weighting agent used is commonly barite, hematite or ilmenite grinded to specified qualities.

Component	**Function**	**Concentration**
Base Oil	Cont. phase	580 l/m^3
Water	Disp. phase	150 l/m^3
Carboxylic Acid	Emulsifier	20-30 l/m^3
Salt	Formation salinity	30-50 kg/m^3
Organo. Clay	Viscosifier	5-15 kg/m^3
$CaCO_3$/ Polymer	Fluid Loss	10-100 kg/m^3
Weight agent.	Provide Density	880 kg/m^3

Table 1. Components in an invert-emulsion drilling fluid of density of 1520 kg/m^3

FACTORY TESTS

Two shear devices were used in the factory tests. One of these is designed as a pure shear unit, with the purpose of dispersing the emulsion water droplets in the continuous oil phase. The drilling fluids enter what is called the shear zone, where the fluid passes through specially designed openings (slots) in the stator before either being ejected out of the unit, or passed on to another similar shear zone. The machine can be designed with as many shear zones and slot openings as desired. The capacity is proportional to the energy consumption of the machine and the dispersion requirements.

The second unit tested was a combined shear and mixing unit, shown in Fig. 1. Lower pressure is created when the fluid enters the mixing zone, where the flow is highly accelerated. The created lower pressure zone makes the powder flow, bringing it well distributed into contact with the fluid, wetting it immediately. The fresh mixed fluid is then forced through the dispersing slots. This process eliminates particle agglomeration.

Empirically it has been found[9] that optimum dispersion is achieved when a volume, corresponding to at least 8 times the fluid volume, has passed through the shear unit. This means that statistically about 99.99999 % of the whole volume has actually passed the shearing zone at least once. In the factory tests this was controlled by measuring the time for one single pass and then extrapolating to get the time needed for a complete dispersion of the fluid.

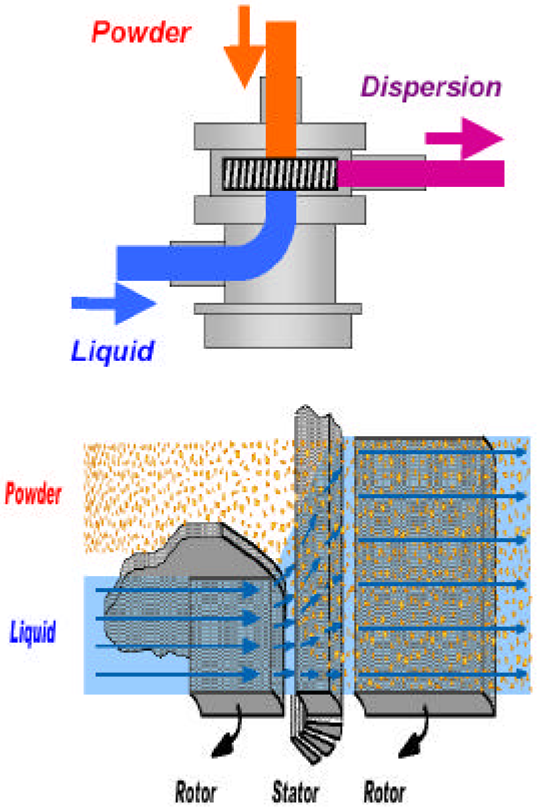

Figure 1. Illustration of the combined mixing and shearing unit tested.

LABORATORY MEASUREMENTS

To evaluate the shearing efficiency and how this affects the sag potential of the drilling fluid, several laboratory measurements were conducted.

Sag stability

The sag stability was measured by putting the samples in 30 cm steel cells for 64 hrs at 100ºC. Thereafter the amount of free fluid on top, and the density of 5 different layers from top to bottom of the cell is measured illustrated in Fig. 2. The density difference between the different layers relative to the initial weight of the fluid then gives a picture of the sedimentation potential of the fluid.

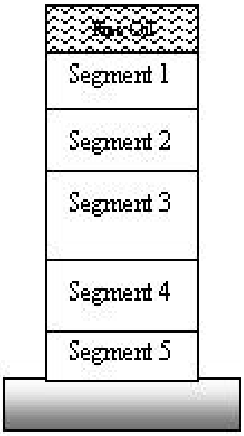

Figure 2. Cell for conductance of sag tests

The density difference between the different segments in the sag test cell can be used to calculate a sag factor. The sag factor provides a picture of the instantaneous density distribution in the cell at the moment of measurement. This is frequently used to indicate the sedimentation potential of the drilling fluid and is calculated by:

$$Sag\ \ factor = \frac{r_{bottom}}{r_{bottom} + r_{top}} \qquad (2)$$

where ρ_{bottom} and ρ_{top} are the density of the bottom and top layer respectively. A sag factor equal to 0.5 implies no sedimentation of the weighting material. Any degree of sag leaves a sag factor higher than 0.5. This does not give the complete picture since syneresis will take place as free liquid is found on top of the sample, and is not taken into account in the sag factor. A dynamic sedimentation index can be introduced to include this effect. It relates the instantaneous sedimentation of the initial drilling fluid, and is expressed by:

$$S_D(t) = \frac{r_{bottom}}{2r_{initial}} \qquad (3)$$

where $S_D(0) = ½$

Viscosity and viscoelastic properties

The standard viscosity measurements in the oil industry are performed using a 6 speed manually read rotational viscometer[10]. This was performed initially. In addition, linear viscoelastic properties of the samples were measured using a Physica MCR 100 rheometer, exposing the fluid to small amplitude oscillatory shear.

Electric stability

The electric stability, used as the oilfield standard[10], is a relative measurement of how stable the emulsion is. It is conducted by immersing a pair of accurate spaced electrode plates into the fluid. An AC-voltage is applied to the electrodes and the voltage that makes the emulsion conductive is read off. The reading is accepted when the difference between two following measurements is less than 5 %, and is recorded as the average of the two.

Particle size distribution

To evaluate if the shear-units degrade the powdered material, particle size distribution (PSD) measurements were conducted. The PSD was measured using laser diffraction and was performed prior to, and after shearing.

RESULTS

Sag stability measurements show that a clear relationship between shear energy, as here related to the number of circulations that the fluid has passed and the rotational speed, and sedimentation potential exists. The sag measurements show how the sedimentation potential varies with number of cycles that the fluid has passed through the shear zone. It also varies with slot size opening and circumferential speed of the rotor, as is seen from Table 2. The slot size openings are given in mm. In Table 2, two shear zones exist with slot openings in the stator of 4 mm (first and third number), and 4 and 2 mm in the rotor (second and fourth number).

The viscosity increases likewise as a function of number of cycles through the shear zone, the number of slot openings in the stator and rotor, and the circumferential speed, see Table A1 in the appendix.

No. Circ	Stator/rotor Config	Speed (rpm)	Sag Factor	S_D
0	4-4-4-2	6000	0.538	0.559
8	4-4-4-2	6000	0.527	0.543
8	4-4-4-2	12000	0.518	0.526
1	2-2-2-1	12000	0.530	0.546
3	2-2-2-1	12000	0.519	0.530
8	2-2-2-1	12000	0.516	0.520

Table 2. The sag factor and dynamic sedimentation index (S_D) for the premix as function of passes through the shearing zone, stator/rotor configuration and circumferential speed. Here 6000 and 12000 rpm equals 22 m/s and 42 m/s in tip speed respectively.

Regarding the linear viscoelastic properties measured, the storage modulus G' and the loss modulus, G'', are given in Fig. A.3 as functions of shear stress. The cross-over point between G' and G'' are at higher shear stresses for the sheared drilling fluid than for the unsheared pre-mix. For the premix, the cross-over is at 0.15 Pa compared to 0.9 Pa for the sheared fluid.

No. Circ	Stator/rotor Config	Speed (rpm)	E.S (V) at Amb./ 50 ºC
0	4-4-4-2	6000	80 / 160
8	4-4-4-2	6000	280 / 200
8	4-4-4-2	12000	440 / 400
1	2-2-2-1	12000	220 / 230
3	2-2-2-1	12000	315 / 320
8	2-2-2-1	12000	460 / 450

Table 3. Electric stability measurements at ambient temperature and 50 ºC as function of numbers of circulation for different stator/rotor configurations.

The electric stability measurements, given in Table 3, show increasing values for increased shear energy put into the system.

The increase in the measured electric stability is observed to be most pronounced when measured at ambient temperatures. The same measurements were conducted on the drilling fluid from the field, with the same trend of increasing stability measurements as a function of shear-energy.

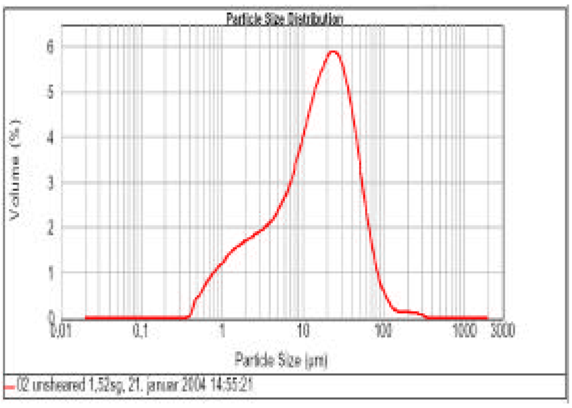

Figure 3. PSD of 1.52 SG unsheared premix. D_{10}= 1.84, D_{50}= 15.68, D_{90} = 49.71.

After shearing, the surface area of the weighting agent increases slightly. The portion of fine particles, when using barite as weighting agent, is increased as the D_{10}, D_{50} and D_{90} are all skewed to the left as shown when comparing Fig. 3 and 4. The D_{50} is reduced from 15.68 µm to 10.79 µm. The D_{10}, D_{50} and D_{90} describe at what particle size 10, 50 and 90 % volume percent of the particles are smaller.

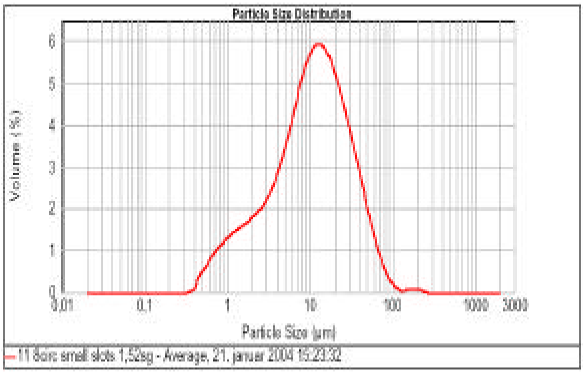

Figure 4. PSD after 8 passes at high speed D_{10}= 1.72, D_{50}= 10.79, D_{90} = 36.78

DISCUSSION

The tests show that the sag stability was improved significantly due to the shearing effect. This can result from many factors. It is well-known that emulsions can be stabilized by addition of fine solid particles[11]. The improved dispersion of the organophilic clay particles in the oil phase will thus aid the stability of the emulsion and lower the sedimentation potential. The organophilic clay also increases the viscosity of the fluid. According to Stokes's law (Eq.1) this gives a proportional reduction in sedimentation velocity.

The reduction in particle size of the weighting agent can also help stabilising the emulsion. In these experiments however, this degradation was seen to be of minor importance compared with the effect of the increased viscosity in addition to the stabilising effect when improving the dispersion of the clay particles in the emulsion.

Simple viscoelastic properties to give prediction of the sedimentation potential would be convenient to use. This could then be used to optimise the drilling fluid composition to provide the lowest sedimentation potential for that specific fluid mixture. This again assumes that the properties of the weighting agent are unchanged. The measurements conducted here give indications of such possibilities. The cross-over point between the storage modulus G' and loss modulus G'', is used as a measure for how stable the drilling fluid is. The results from the measurements correspond well to the experience one has with the different types of fluids. The unsheared premix, with the cross-over point at lowest shear stress, is found to be least stable. After each circulation, the cross-over point is skewed to higher shear stresses. This agrees well with the sedimentation measurements performed.

The viscoelastic properties can predict the sedimentation potential of a fluid, provided that the rest of the composition and the surrounding environment is constant. That is, according to Stoke's law, the major factor influencing the sedimentation rate is the size of the particles. This corresponds to our experience. Systems have now been designed with ultra fine weighting agents providing minimal or no sedimentation potential. The challenge with these weighting agents has been flocculation of the particles. This will depend on the choice of raw materials and the production process, resulting in different intermolecular actions.

CONCLUSIONS

The test -and laboratory measurements performed indicates the following:

- Increasing the shear-energy reduces the sedimentation potential of the weighting agent in the drilling fluid.
- The viscoelastic properties loss and storage modulus can be used to predict the sedimentation potential.
- The emulsion is stabilised by high degree of dispersion of organophilic clay into the continuous oil phase.
- The weighting agent barite is insignificantly degraded when passing through the shear unit.

REFERENCES

1. Bern, P.A., van Oort, E., Neusstadt, B., Ebeltoft, H., Zurdo, C., Zamora, M. and Slater, K.: “Barite Sag: Measurement, Modelling and Management,” SPE Drilling and Completion, vol. 15 (March 2000) 25.

2. Taugbøl, K., Sandberg, G.M., Grevstad, H.J., Cullum, D. and Dyrkolbotn, E.: “Reformulating Oil-Based Drilling Fluid by Using Especially Selected Chemicals Led to Development of a Low-Viscosity, High-Sag Stability Drilling Fluid,” paper IADC/SPE 87139 presented at the 2004 IADC/SPE Drilling Conference held in Dallas, 2–4 March.

3. Saasen, A.: “Sag of Weight Materials in Oil Based Drilling Fluids,” paper IADC/SPE 77190, presented at the 2002 IADC/SPE Asia Pacific Drilling Technology held in Jakarta, Indonesia, 9–11 September.

4. Hemphill, T.: ‘‘New Viscometer Allows for Improved Understanding of Drilling Fluid Behavior at Low-Shear Rates,’’ presented at the 1999 AADE Annual Technical Forum, Houston, 30–31 March.

5. Aldea.C, Growcock. F.B, Lee. J.E, Friedheim J.E and Oort E.van, “Prevention of Dynamic Sag in Deepwater Invert Emulsion Fluid”, AADE 01-NC-HO-51

6. Barnes, H.A., Hutton, J.F., and Walters, K. (1989), "An Introduction to Rheology", Elsevier, Amsterdam, pp. 135-139.

7. Oldroyd, J.G.: “The elastic and viscous properties of emulsions and suspensions”, Proc. Roy Soc. A218, 122-132.

8. Liu, S. and Masliyah, J.H.: “Rheology of Suspensions”, pp 149-160 in “Advances in Chemistry Series 251”

9. Jacob; H.J.: Ystral GmbH internal document.

10. API RP 13B-1, Recommended Practice – Standard Procedure for Field Testing Water-Based Drilling Fluids, American Petroleum Institute, Washington D.C. (1990).

11. Kitchener, J.A: Mussellwhite, P.R. In Emulsion Science; Sherman, P., Ed.; Academic: London, 1968; pp 77-130

SI Metric Conversion Factors

(°F –32) /1.8 = °C
bbl x 1.589 873 E-01 = m^3
cP x 1.0 * E+00 = mPa?s
in. x 2.54* E+00 = cm
lb x 4.535 924 E-01 = kg
lb/gal x 1.198 264 E+02 = kg/m3
lb/gal x 1.198 264 E-01 = sg
lbm/bbl x 2.853 E+00 = kg/m^3

* Conversion factor is exact.

APPENDIX A

No. Circ	Stator/rotor	Speed (rpm)	600 rpm	300 rpm	200 rpm	100 rpm	6 rpm	3 rpm
0	4-4-4-2	6000	114	68	50	32	12	9
8	4-4-4-2	6000	112	68	52	35	14	12
8	4-4-4-2	12000	135	90	73	54	26	24
1	2-2-2-1	12000	116	73	57	40	16	14
3	2-2-2-1	12000	125	81	64	47	21	19
8	2-2-2-1	12000	145	100	82	61	30	28

Table A.1. Viscosity measurements as function using a standard oilfield rotational viscometer. Especially the low end readings (3 rpm) are affected by the increased shearing.

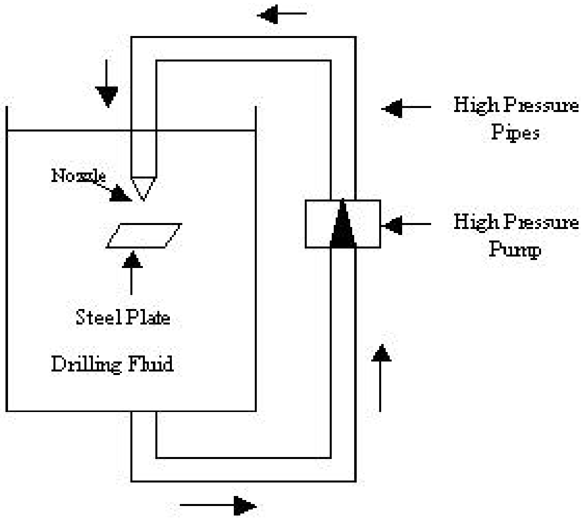

Figure A.1. High-pressure shearing unit. The fluid is pumped through nozzles towards a steel plate to improve emulsion stability.

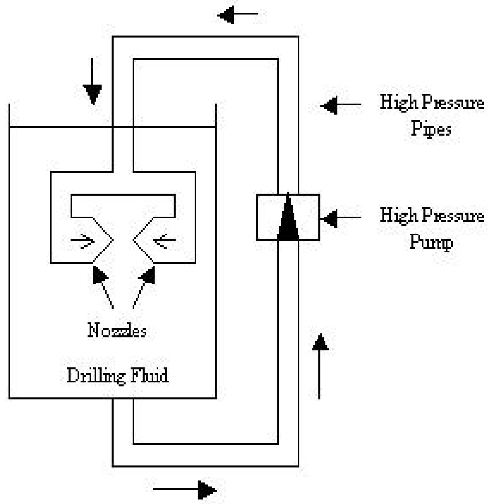

Figure A.2. High-pressure shearing unit. The fluid is sheared by directing two fluid streams towards each other through nozzles.

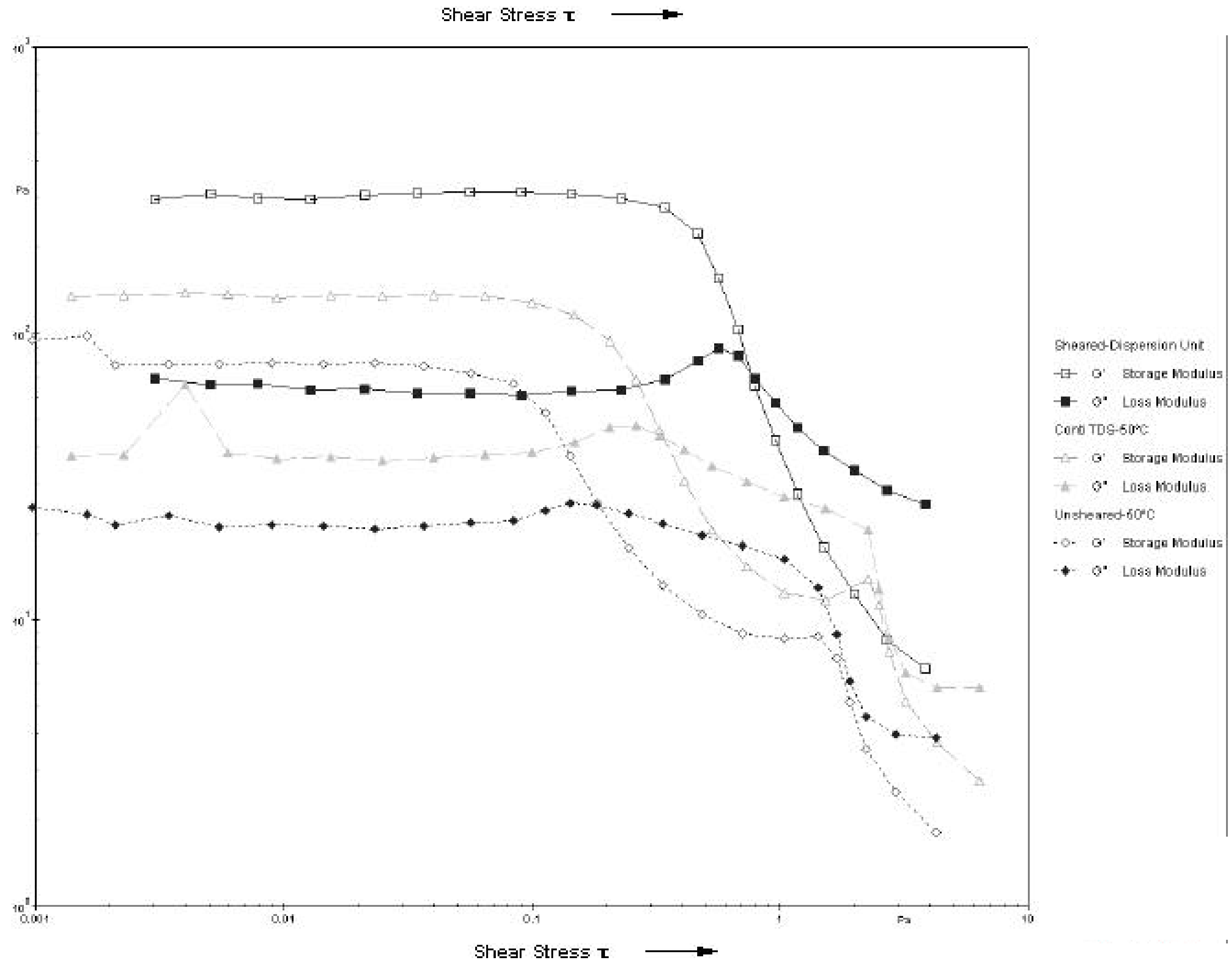

Figure A.3. Storage modulus G' and loss modulus G'' as function of shear stress for three different samples. Open and closed circles describe the values for G' and G'' for the unsheared pre-mix respectively. Triangles give the values after shearing the drilling fluid with the Conti TDS after 8 passes through the shearing zone. Squares represent values for the fluid passed 8 times through the shearing unit.