RHEOLOGICAL BEHAVIOR OF DRILLING FLUIDS UNDER LOW TEMPERATURES

Rosana F. T. Lomba – rlomba@cenpes.petrobras.com.br
Carlos H. M. de Sá – chsa@cenpes.petrobras.com.br
Edimir M. Brandão – edimir@cenpes.petrobras.com.br
PETROBRAS/CENPES. Quadra 7 – Cidade Universitária – Ilha do Fundão. Rio de Janeiro – RJ – 21949-900 – Brasil. Tel (55)(21)865-6930 Fax (55)(21)865-6795

ABSTRACT. *The so-called solid-free fluids represent a good alternative to drill through productive zones. These drill-in fluids are known to be non-damaging to the formation and their formulation comprise polymers, salts and acid soluble solids. Xanthan gum is widely used as viscosifier and modified starch as fluid loss control additive. The salts most commonly used are sodium chloride and potassium chloride, although the use of organic salt brines has been increasing lately. Sized calcium carbonate is used as bridging material, when the situation requires.*

The low temperatures encountered during deep water drilling demand the knowledge of fluid rheology at this temperature range. The rheological behavior of drill-in fluids at temperatures as low as 5 ^{o}C was experimentally evaluated. Special attention was given to the low shear rate behavior of the fluids. A methodology was developed to come up with correlations to calculate shear stress variations with temperature. The developed correlations do not depend on a previous choice of a rheological model. The results will be incorporated in a numerical simulator to account for temperature effects on wellbore cleaning later on.

INTRODUCTION

Sodium chloride is the most commonly used salt for inhibition when drilling through productive zones. Lately, the use of formates to enhance thermal stability of polymers in drill-in fluids has been widely presented in the literature (Downs, 1992, Downs, 1993, Hallman, 1996, Howard, 1995). Formate brines are known to be non damaging to the reservoir, to have high lubricity characteristics, to stabilize clays, to dissolve scales, and to allow for high densities in drilling and completion fluids (Downs, 1993, Ramsey et al., 1996, Svendsen et al., 1995). Besides, they pose little hazard either to personnel or the environment (Downs et al., 1994). Sodium formate (NaCOOH) can reach a density of about 1.33 SG. Potassium formate (KCOOH) is more soluble and can reach a maximum brine density of about 1.59 SG (Howard, 1995).

The paper presents data on the rheological behavior of sodium chloride and formate based drill-in fluids under temperatures from 5 to 30 ^{o}C. A new correlation was developed to evaluate fluid viscosities as a function of temperature. Special attention was given to low shear rate behavior. The thermal effects on the rheology of drilling fluids have been usually presented in the literature by means of temperature dependent rheological parameters obtained from best data fitting of test results (Alderman et al., 1988, Sinha, 1970). A different approach is presented herein which does not depend on a previous choice of a rheological model. The viscosity curves as a function of shear rate were obtained for the different fluids at different temperatures and the results led to an expression to represent their rheological behavior as a function of temperature. Surprisingly, all fluids showed similar behavior and a single expression was developed to account for temperature effects on rheology.

METHODOLOGY

The general composition of fluids used in the study is presented in Table 1. Sodium chloride and sodium and potassium formate brines were tested. The fluids were hot rolled at 50 °C for 16 hours before testing.

Table 1 – Composition of fluids

COMPONENT	FUNCTION	CONCENTRATION
Brine	Inhibition	1 L
Xanthan gum	Viscosifier	4.3 g/L
Modified starch	Fluid loss control	17.1 g/L
MgO	pH buffer	5.7 g/L
$CaCO_3$ fine	Bridging agent	57 g/L
$CaCO_3$ medium	Bridging agent	14.3 g/L

The rheological data were obtained in a Haake Rheostress RS-100 rheometer , with a cone/plate (C60/2) and shear rates in the range from 0.01 to 1500 s^{-1}. All tests were run at constant pressure. The test temperatures were in the range 5 - 30 °C.

TEST RESULTS AND DISCUSSION

The viscosity vs. shear rate curves for the different test fluids under different temperatures are presented in log-log plots (Fig. 1, 2 and 3).

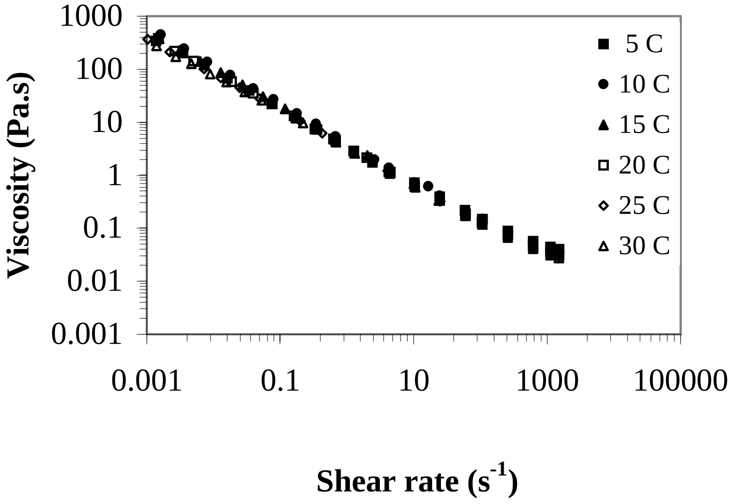

Figure 1 – Viscosity of sodium chloride fluid as function of temperature

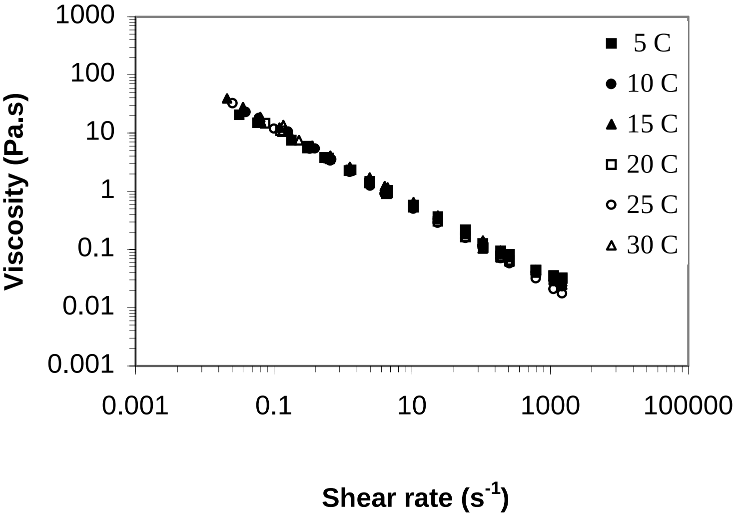

Figure 2 – Viscosity of sodium formate fluid as function of temperature

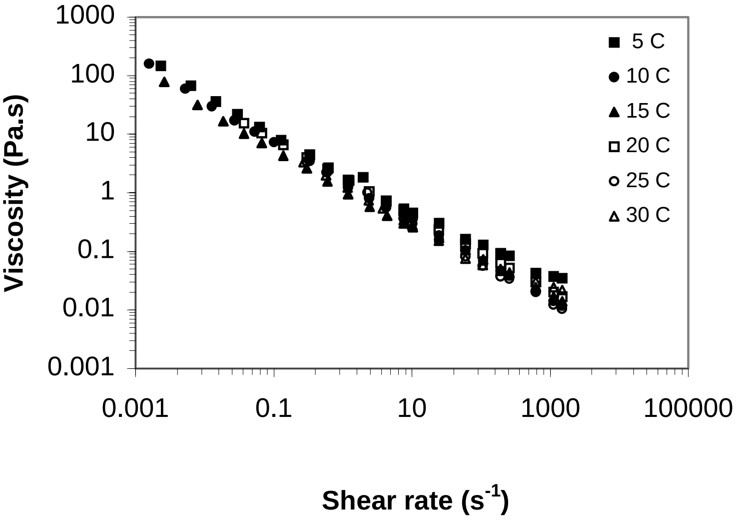

Figure 3 – Viscosity of potassium formate fluid as function of temperature

For comparison purpose the data were fitted using a two parameter power-law model (Tables 2, 3 and 4). The test results show that the flow index (n) does not change much with temperature.

The dimensionless shear stresses and temperatures were established relative to the rheological curve at a reference temperature of 10 ^{o}C. For comparison purposes, Fig. 4 shows the plot obtained for a high solids content water-based fluid under high temperatures (24 – 177^{o}C) and a pressure equal to 34,500 kPa. In this case, the reference temperature was set equal to 66 ^{o}C. The graph shows that the fluid viscosity increases as the temperature goes higher than the reference temperature, T_o. The effect is as more pronounced as the lower the shear rate is. The gel structures tend to be destroyed at high shear rates.

Table 2 – Power-law parameters as a function of temperature– Sodium chloride fluid

T (^{o}C)	**K (Pa.s^{n})**	**n**
5	3.830	0.330
10	4.391	0.304
15	3.993	0.305
20	3.604	0.311
25	3.355	0.315
30	3.204	0.318

Table 3 – Power-law parameters as a function of temperature– Sodium formate fluid

T (^{o}C)	**K (Pa.s^{n})**	**n**
5	1.902	0.401
10	2.544	0.358
15	3.100	0.340
20	2.531	0.363
25	2.561	0.314
30	2.581	0.358

Table 4 – Power-law parameters as a function of temperature– Potassium formate fluid

T (^{o}C)	**K (Pa.s^{n})**	**n**
5	2.634	0.375
10	1.611	0.322
15	1.283	0.368
20	1.846	0.358
25	1.542	0.306
30	1.454	0.364

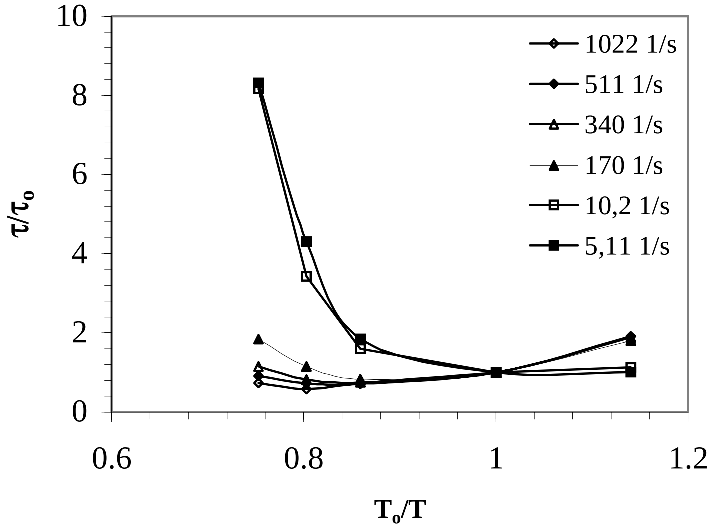

Figure 4 – Dimensionless shear stress vs. temperature plot for a high solids content water based fluid

The curves from Fig. 4 can be expressed by the superposition of two exponential using Churchill's technique. The resulting expression is presented as the following:

$$\frac{\tau}{\tau_o} = \left(\left(a.\exp\left(b.\frac{T_o}{T} \right) \right)^e + \left(c.\exp\left(d.\frac{T_o}{T} \right) \right)^e \right)^{1/e} \tag{1}$$

where

$a = 2.7712x10^7.\dot{\gamma}^{-2.0713}$

$b = -23.186.\dot{\gamma}^{-0.2288}$

$c = 0.0404$

$d = 3.3205$

$e = 10$

It is worth noticing that *a* and *b* are shear rate dependent parameters. We suggest that the first term of the right-hand side of the expression reflects the gelation of the fluid and the second term is related to Arrhenius equation.

Similar curves were obtained for the brines under high temperatures (Lomba et al., 2000) and under the low temperature range tested during this study. Due to the weak gel behavior of sodium and potassium brines, all curves collapsed into one, regardless of the shear rate (Figs. 5, 6 and 7). The resulting expression is as follows:

$$\frac{\tau}{\tau_o} = 0.0404.\exp\left(3.3205.\frac{T_o}{T} \right) \tag{2}$$

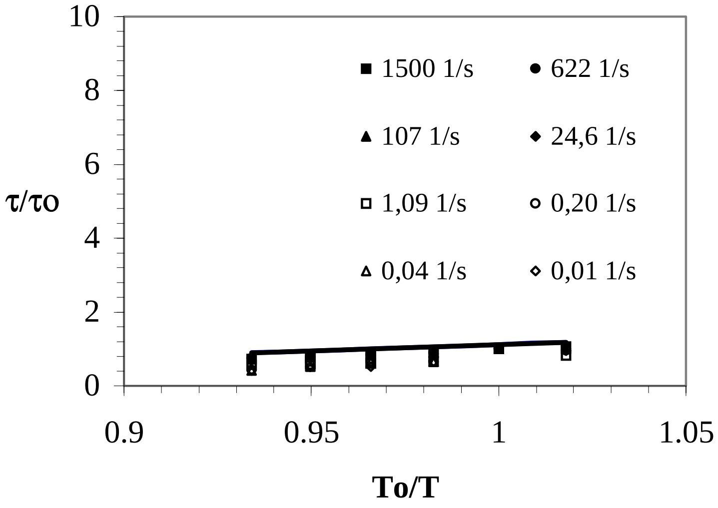

Figure 5 – Dimensionless shear stress vs. temperature plot for sodium chloride fluid

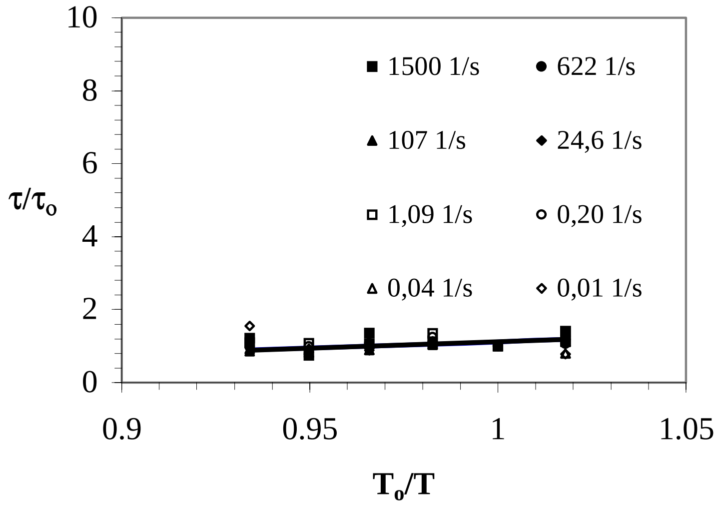

Figure 6 – Dimensionless shear stress vs. temperature plot for sodium formate fluid

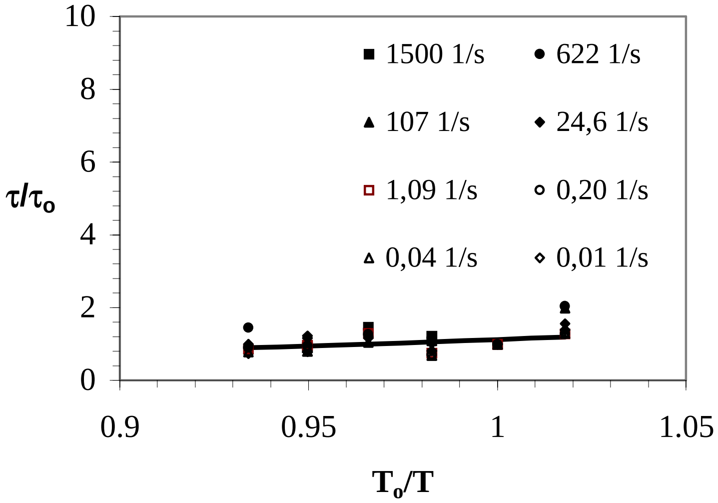

Figure 7 – Dimensionless shear stress vs. temperature plot for potassium formate fluid

It is very interesting to notice that we ended up with the same expression obtained for the high solids content water-based mud, except for the first term (gelation). This result is very important as it suggests a single expression to account for temperature effects on the rheology of drilling fluids at low temperatures. Also, once the shear stress vs. shear rate curve is known at a reference temperature, the rheological behavior can be determined at any temperature, regardless a previous choice of a rheological model.

CONCLUSIONS

Correlations were developed to evaluate the rheology of drilling fluids under low temperatures. The developed methodology does not depend on a previous choice of a rheological model. This new approach allows the best fitting of a fluid rheological behavior at any different temperature.

Formate based drill-in fluids showed improved thermal stability and weak gel characteristics.

The developed correlations will be incorporated in a wellbore cleaning numerical simulator to account for temperature effects on fluid rheology.

NOMENCLATURE

T : absolute temperature, K

a, b, c, d, e : model parameters

τ : shear stress, Pa

γ : shear rate, s^{-1}

T_o : reference absolute temperature, K

τ_o : shear stress at reference temperature, Pa

UNIT CONVERSION

g/L x 0,35 = lb/bbl

Pa x 1.450377×10^{-4} = psi

Pa x 2.0890 = lbf/100ft^2

Pa.s x 1000 = cP

^{o}C + 273.16 = K

^{o}C x 1.8 + 32 = ^{o}F

REFERENCES

Alderman, N. J., Gavignet, A., Guillot, O., and Maitland, G. C., 1988, "High-Temperature, High Pressure Rheology of Water-Based Muds," Proceedings, 63rd SPE Annual Technical Conference and Exhibition, pp. 187-195.

Downs, J., 1992, "High Temperature Stabilisation of Xanthan in Drilling Fluids by the Use of Formate Salts," Physical Chemistry of Colloids and Interfaces in Oil Production, pp. 197-202.

Downs, J. D., 1992, "Formate Brines: New Solutions to Deep Slim-Hole Drilling Fluid Design Problems," Proceedings, European Petroleum Conference, pp. 105-114.

Downs, J. D., 1993, "Formate Brines: Novel Drilling and Completion Fluids for Demanding Environments," Proceedings, SPE International Symposium on Oilfield Chemistry, pp. 267-279.

Downs, J. D., Killie, S., Whale, G. F., and Inglesfield, C., 1994, "Development of Environmentally Benign Formate-Based Drilling and Completion Fluids," Proceedings, Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, pp. 419-428.

Hallman, J. H., 1996, "Formates in Practice: Field Use and Reclamation," World Oil , October, pp. 81-90.

Howard, S. K., 1995, "Formate Brines for Drilling and Completion: State of the Art," Proceedings, SPE Annual Technical Conference and Exhibition, pp. 483-496.

Lomba, R. F. T., Sá, C. H. M., Brandão, E. M., 2000, "A New Approach to Evaluate Temperature Effects on Rheological Behavior Formate Based Fluids," Proceedings of ETCE/OMAE2000 Joint Conference Energy for the New Millennium, New Orleans, LA.

Ramsey, M. S., Shipp, J. A., Lang, B. J., Black, A., and Curry, D., 1996, "Cesium Formate: Results and Analysis of Drilling with a New High Density Unweighted Brine," Proceedings, SPE Annual Technical Conference and Exhibition, pp. 95-104.

Sinha, B. K., 1970, "A New Technique to Determine the Equivalent Viscosity of Drilling Fluids Under High Temperatures and Pressures," Proceedings, Fourth Conference on Drilling and Rock Mechanics, pp. 33-40.

Svendsen, O., Toften, J. K., Marshall, D. S., and Hermansson, C. L., 1995, "Use of a Novel Drill-In/Completion Fluid Based on Potassium Formate Brine on the First Open Hole Completion in the Gullfaks Field," Proceedings, SPE/IADC Drilling Conference, pp. 647-661.