V.C. Kelessidis*, V. Chatzistamou*, E. Repouskou*, M. Zografou*, M. Karimi**

USE OF PHPA POLYMER FOR MODIFICATION OF RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER BASED DRILLING FLUIDS USED FOR CONVENTIONAL AND CASING DRILLING***

1. INTRODUCTION

Drilling fluids are the blood of the well and perform a multitude of functions like, carrying the solids to the surface, providing lubrication to the drill pipe and the bit, supporting the cuttings when circulation is stopped and aiding the cutting process by imparting high impact energy to the bit in order to cut more easily the formation. Drilling fluids may be water or oil based (diesel or synthetic oils) although the latter are more expensive and there is more and more search for environmentally friendly water-based fluids which should contain several additives which could give the required properties and the properties of oil-based fluids while protecting more the environment.

Polymers have become very popular for their use in drilling muds due to their ability to modify rheological properties of bentonite suspensions and their low impact on environment [Dolz *et al*., 2007]. Several types of polymers have been used like Carboxyl-methyl-cellulose (CMC), polyanionic cellulose (PAC), Xanthan gum (Benchabane and Bekkour, 2006; Iscan and Kok, 2007) while quantification of the effects of CMC on rheological properties has been given recently by Kelessidis *et al*. (2011).

A series of such polymers are the PHPA polymers, or else, partially hydrolyzed polyacrylamide polymers. PHPA polymers are drilling fluid additives that help stabilize shales in the wellbore, they are used as clay extenders, flocculants and for encapsulating colloids

* Technical University of Crete, GREECE, kelesidi@mred.tuc.gr
** TESCO USA
*** This work has been partially supported by an e-internship program of TESCO Corporation

(Caenn and Chillingar, 1996). The polymer molecules act as shale stabilizers, cuttings stabilizers, and wellbore stabilizers. By bonding on site these polymers "inhibit" dispersion of formation solids into the drilling fluid system and also bond on the wellbore formation thus providing gauge hole and achieving borehole stability (Liao *et al.*, 1990).

Partially Hydrolyzed Poly Acrylamide is a polymer made from acrylonitrile after polymerization to form polyacrylonitrile which afterwards is partially hydrolyzed to for acrylamide and acrylic acid groups along the polymer chain (Fig. 1). It is normally used in field applications with concentrations ranging between 0.2 to 1.5%.

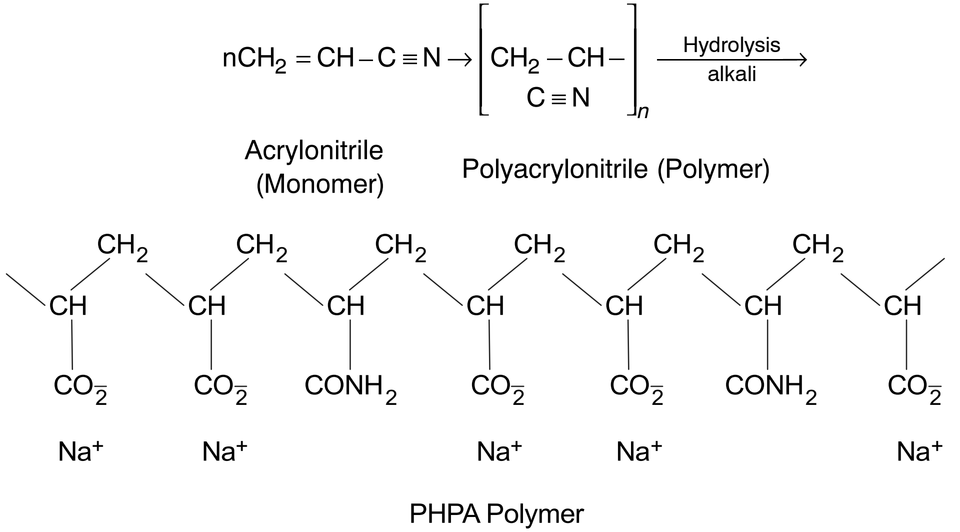

Fig. 1. PHPA structure

Despite their extended use by drilling fluid industry, quantitative assessment of the alteration of rheological and filtration properties of water-based bentonite dispersions is not readily available, while also information regarding their optimum concentration is not available to be used in field applications. This is the objective of this study.

2. MATERIALS AND METHODS

Dilute water-bentonite suspensions were used in which various quantities of PHPA were added. The bentonite used for the present work was Wyoming bentonite (Halliburton-Cebo Holland) while PHPA was from Baker Hughes (Newdrill Plus). The preparation of the suspensions was carried out following American Petroleum Institute standard (API 13D). Firstly bentonite was added to deionized water and was mixed for 5 minutes using Hamilton Beach high speed mixer. The PHPA was added slowly and mixing continued for 20 more minutes. The suspensions were then sealed and left for 16 hours at room temperature to hydrate. After hydration, the suspensions were mixed for 5 minutes and the rheological measurements were performed followed by the fluid loss measurements, all done at room temperature. The viscometric data was acquired using a Fann type Couette viscometer }(Grace Instruments, USA) at fixed speeds of 600, 300, 200, 100, 6, 3 rpm. The rheological model used for data fitting was the Herschel-Bulkley model (Kelessidis *et al*. 2006)

$$\tau = \tau_y + K\dot{\gamma}^n \tag{1}$$

where $\tau, \tau_y, K, \dot{\gamma}, n$ are the shear stress, yield stress, flow consistency, shear rate and flow behavior index respectively.

The filtration properties of the suspensions were measured using a low pressure-low temperature (LPLT) API filter press. For some of the tests cuttings (shales) were added to study the effect of cuttings on the rheological and filtration properties (which is part of another publication) and in some of these tests pictures of filter cakes were taken and analyzed visually as well as in a Scanning Electron Microscope (SEM) in order to get better insight into the ways the polymer attaches to the shale cuttings.

Concentrations of PHPA tested were 0.3%, 0.5% and 0.7% w/w in water-bentonite concentrations of 2 and 3% w/w.

3. RESULTS AND DISCUSSION

3.1. Rheological measurements

The rheograms for these bentonite suspensions with and without PHPA are shown in Figures 2 and 3.

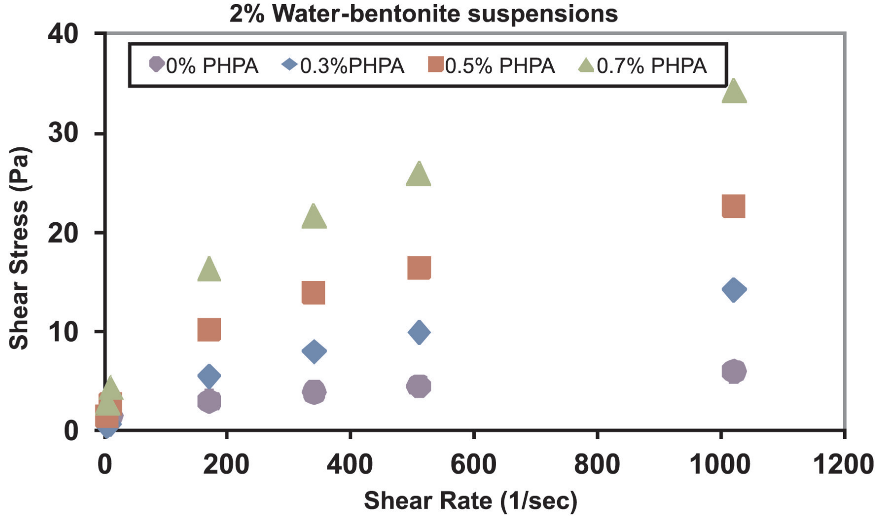

Fig. 2. Rheograms of various concentrations (0.3%, 0.5% and 0.7%) PHPA in the 2% water-bentonite suspension

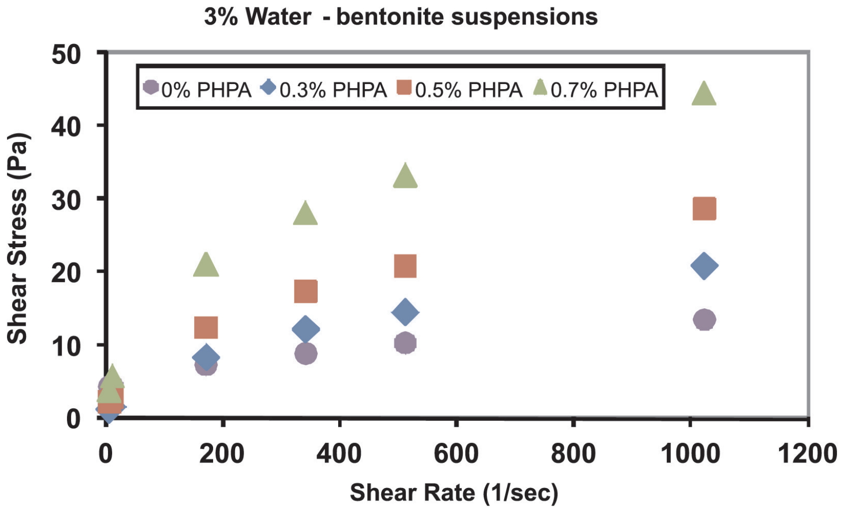

Fig. 3. Rheograms of various concentrations (0.3%, 0.5% and 0.7%) PHPA in the 3% water-bentonite suspension

The Herschel-Bulkley rheological parameters are shown in Table 1 for all samples that were analyzed, together with the correlation coefficient and the sum of square errors (SUMQ). The variation of the HB parameters with the PHPA concentrations for the two bentonite concentrations is depicted in Figures 4 and 5 for the 2% and 3% water-bentonite suspensions. The PHPA free suspensions exhibit very good Herschel-Bulkley rheological behaviour with good correlation coefficients and small sum of square errors, having yield stresses of 0.34 Pa and 2.94 PA for the 2% and 3% bentonite respectively.

Table 1

Rheological parameters for the base fluids

Sample		$\tau_y [=] Pas^n$	$K [=] Pas^n$	$n [=] -$	R_c^2	SUMQ (Pa^2)
2% bentonite	0,0% PHPA	0.3398	0.4806	0.3501	0.985	0.231
	0,3% PHPA	0	0.3115	0.5533	0.997	0.1595
	0,5% PHPA	0	0.9473	0.4592	0.9988	0.3856
	0,7% PHPA	0	1.7255	0.43296	0.9987	1.0057
3% bentonite	0,0% PHPA	3.9424	0.1794	0.5762	0.9993	0.0471
	0,3% PHPA	0	0.6188	0.5091	0.9993	0.1896
	0,5% PHPA	0	1.3460	0.4675	0.9996	0.1923
	0,7% PHPA	0	2.2896	0.4297	0.9994	0.7649

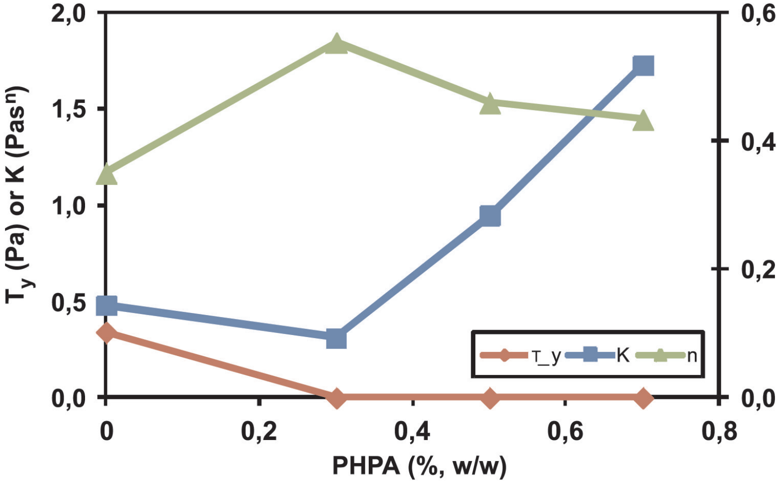

Fig. 4. Variation of HB rheological parameters with PHPA concentration for 2% (m/V) water – bentonite suspensions

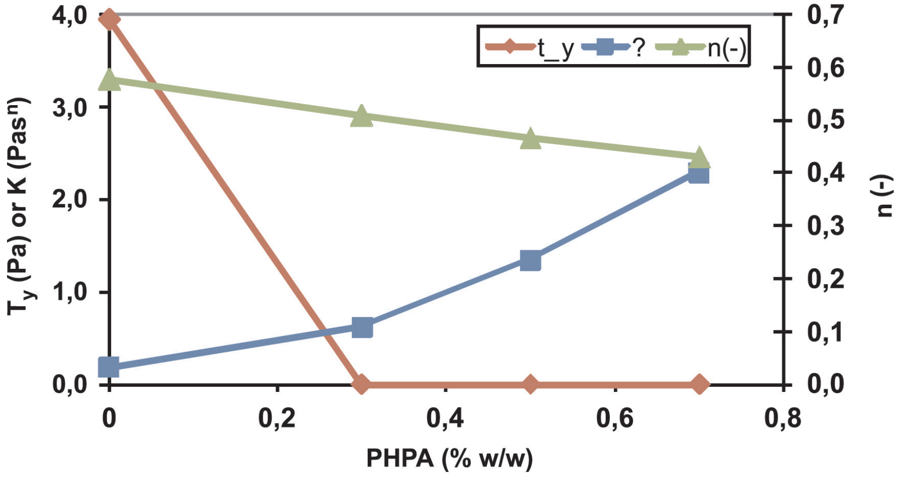

Fig. 5. Variation of HB rheological parameters with PHPA concentration for 3% (m/V) water – bentonite suspensions

Addition of PHPA at all concentrations changes the rheological behavior of the fluids from Herschel-Bulkley to power law, possibly because of the coating that PHPA molecules offer to bentonite particles, as it will be demonstrated below, which prevents bentonite particles to form gel structures which are responsible for the yield stress. It would be interesting to investigate up to what concentration of bentonite we see the diminution of the yield stress with the addition of even the smallest amounts of PHPA, and this is part of another study. The flow consistency index K presents also a minimum, as did with the CMC addition for the 2% bentonite, while there is a smooth increase in K with PHPA concentration for the 2% bentonite suspension. The values of the flow behavior ndex n change a little for the 3% bentonite suspension while there is gradual decrease for n for the 3% bentonite concentration.

It is interesting to compare the performance of PHPA with respect to the addition of CMC, which is one of the most common additives used for modifying rheological and filtration properties of water-bentonite dispersions. The variation of the HB parameters for water-bentonite-CMC solutions is shown in Figure 6. Comparing the results of Figures 5 and 6, which have the samples with the same bentonite concentration of 3%, one can see that addition of CMC reduces the yield stress of the bentonite suspension but does not diminish it, as did the PHPA additive, at almost similar concentrations. It only presents a minimum in yield stress with respect to the CMC concentration. The trends in the K and n values is very similar for CMC and PHPA suspensions, with the difference that K values in the PHPA fluids increased by a factor of 4 for both 2% and 3% bentonite concentrations, while CMC addition just doubled the K values for the maximum concentration studied.

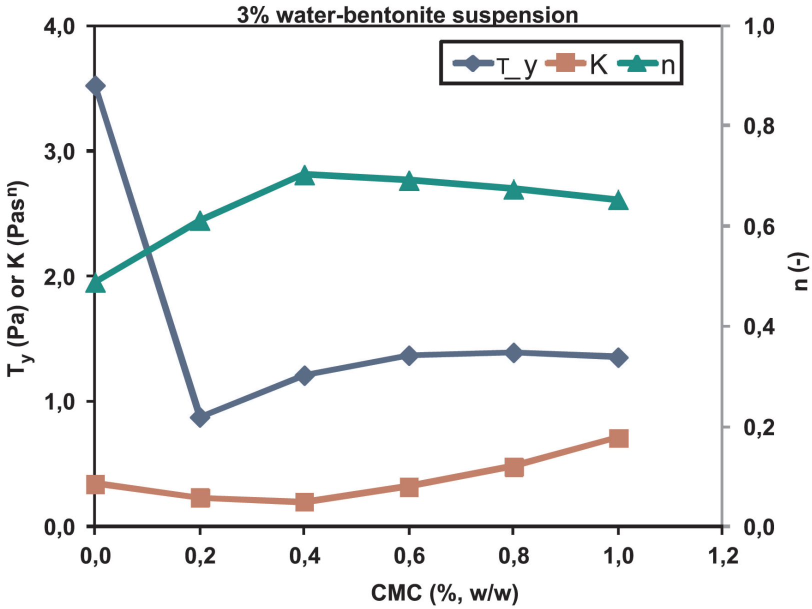

Fig. 6. Variation of Herschel-Bulkley rheological parameters with the CMC concentration (data from Kelessidis *et al.*, 2011).

3.2. Fluid loss measurements

The API 30 min fluid loss values for all samples tested are given in Table 2. The 30 min fluid loss values for the PHPA free suspensions were much higher than the API suggested maximum of 15 ml, with the 2% bentonite showing 33.6 ml and the 3% bentonite showing 22.6 ml fluid loss in 30 min. The fluid loss for the suspensions with the PHPA at all concentrations studied were very good, with a very small decrease in the values both with the increase in PHPA concentration and with the increase in bentonite concentration. Analyzing the values of the fluid loss for the 2% bentonite concentration and observing that it is approximately constant for all PHPA concentrations one can say that apparently there is saturation of the bentonite particles with PHPA at about 0.5% PHPA and no further decrease in the fluid loss is observed with the 0.7% PHPA. For the 3% bentonite suspension, even at 0.7% there is not full saturation of bentonite particles and there is room for further reduction in the fluid loss values, even though the values are very small. The time evolution of the 30 min fluid loss values for all samples is depicted in Figure 7 where it is evident that for all samples, the curve obeys the square root law.

Table 2
Fluid loss for base muds

Sample	+PHPA	Fluid Loss (ml)
2% bentonite	0.0%	33.6
	0.3%	8.8
	0.5%	8.2
	0.7%	8.1
3% bentonite	0.0%	22.6
	0.3%	7.4
	0.5%	7.2
	0.7%	5.6

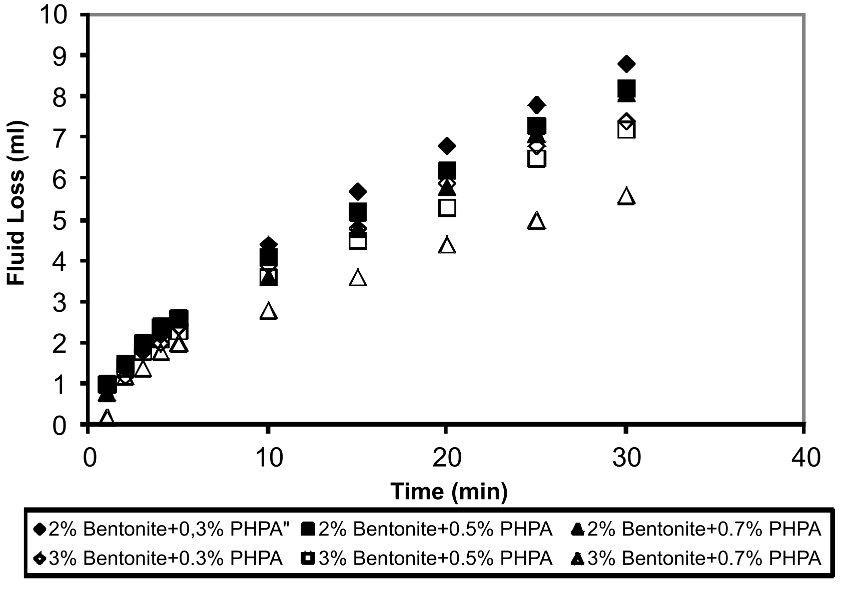

Fig. 7. Development of fluid loss versus time

In addition to the fluid loss values, we have studied the surface morphology of the filter cake of the water bentonite suspension with PHPA but also with the shale cuttings added to the base fluid. The morphology of the filter cake with bentonite only is shown in Figure 8 while Figure 9 shows the morphology of the sample of bentonite with the addition of PHPA. PHPA has a typical arachnoid (spider-net like) structure, indicated in Figure 9 with the circle, and this structure probably contributes to the compaction of the filter cake and the closing of any fluid channels resulting in the strong reduction of the fluid loss compared to bentonite only samples (compare value of 22.6 ml for 3% bentonite with 7.2 ml for 3% bentonite with 0.5% PHPA).

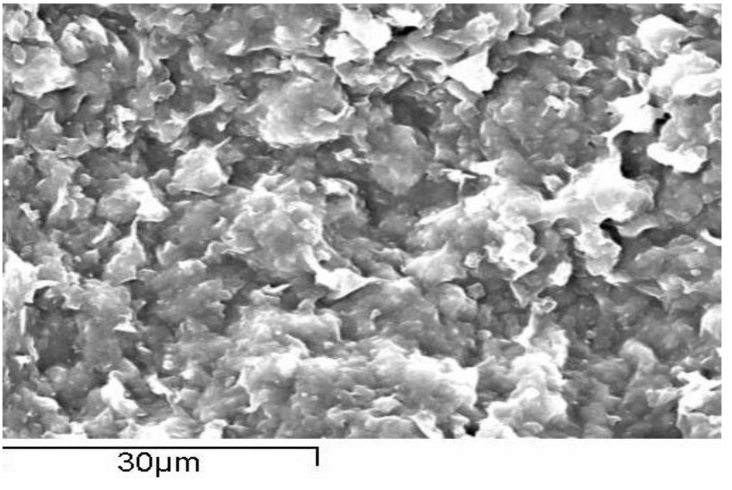

Fig. 8. Scanning Electron Microscope picture of filter cake with 3% bentonite only

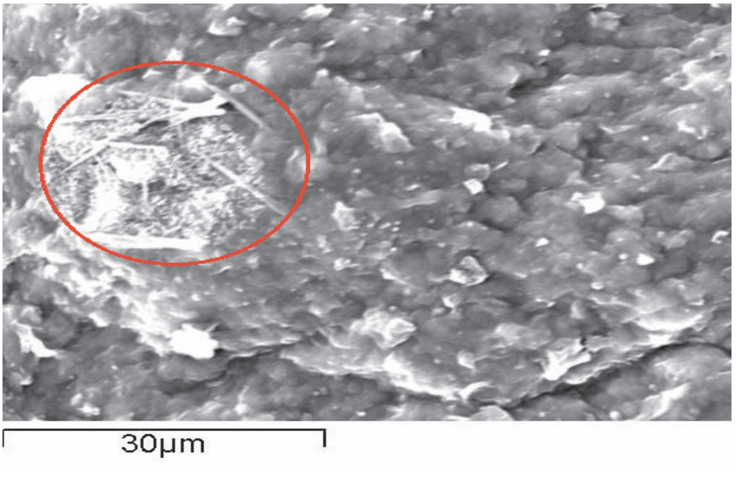

Fig. 9. Scanning Electron Microscope picture of filter cake with 3% bentonite and 0.5% PHPA

We have performed some experiments on fluid loss of bentonite with PHPA additive with the addition of shale cuttings and took SEM pictures of the filter cake, which is shown in Figure 10. It is very interesting to see the attachment of PHPA on the shale cuttings which would then result in the inhibition of shale swelling and thus shows the reasons why PHPA is considered a very good inhibitor.

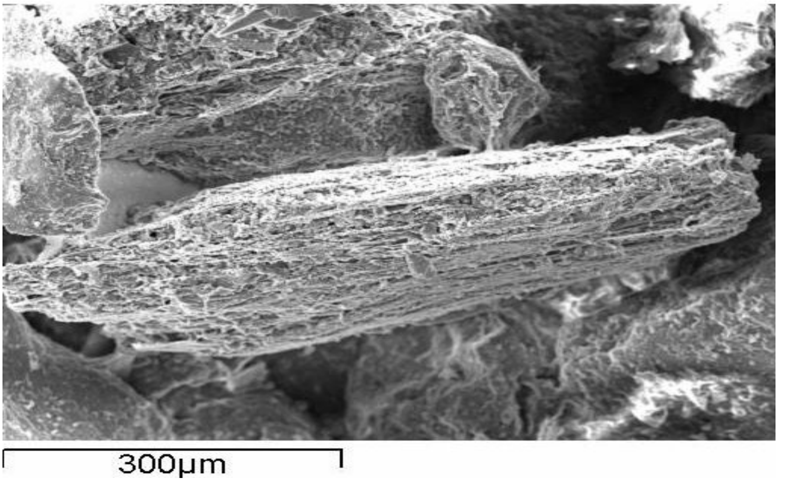

Fig. 10. Scanning Electron Microscope picture of filter cake with 3% bentonite and 0.5% PHPA and shale cuttings of size 200–500 μm

Liao *et al*. (1990) concluded after an extensive study that PHPA molecules inhibit shale degradation by coating the cuttings and wellbore formation through ionic attraction and hydrogen bonding. The SEM pictures derived in this work show clearly the bonding of the polymer on the shale surface which has immediate result in the very good performance of the additive in terms of fluid loss control.

4. CONCLUSIONS

Addition of different amounts of PHPA to of 2% and 3% bentonite suspensions has proven very effective in reducing fluid loss. For the 2% bentonite the reduction was from 33.6 ml to 8.8 ml for 0.3%, 8.2 ml for 0.5% and 8.1 ml for the 0.7% PHPA. For the fluid loss of 3% bentonite the reduction was from 22.6 ml at 0% PHPA to 7.4 ml at 0.3%, 7.2 ml at 0.5% PHPA and 5.6ml for 0.7% PHPA.

PHPA modified the rheological properties by increasing considerably the flow consistency index while keeping the flow behaviour index essentially the same. The yield stress of the bentonite only suspensions was modified and the bentonite suspensions from a yield-pseudoplastic fluids became power law fluids for all PHPA concentrations.

SEM pictures revealed very clearly that PHPA spreads onto bentonite particles but also the added shale cuttings as an arachnoid-structure which then prevents any further swelling of the particles thus providing the inhibitive behaviour.

PHPA is very easy to mix with the bentonite suspension, especially compared to many other polymers like CMC.

REFERENCES

Benchabane A., Bekkour K.: *Effects of anionic additives on the rheological behavior of aqueous calcium montmorillonite suspensions*. J. Rheological Acta, 45, 2006, 425–434.

Caenn R., Chillingar GV.: *Drilling fluids: State of the art*. Journal of Petroleum Science and Engineering, I4, 1996, 22, l–230.

Dolz M., Jiménez J., Hernández M.J., Delegido J., Casanovas A.: *Flow and thixotropy of non-contaminating oil drilling fluids formulated with bentonite and sodium carboxymethyl cellulose*. Journal of Petreleum Science and Engineering, 57, 2007, 294–302.

Iscan A.G., Kok M.V.: *Effects of Polymers and CMC Concentration on Rheological and Fluid Loss Parameters of Water-Based Drilling Fluids*. J. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 29, 2007, 939–949.

Kelessidis V.C., Poulakakis M., Chatzistamou V.: *Use of Carbopol 980 and Carboxymethyl-Cellulose polymers as rheology modifiers of sodium-bentonite water dispersions*. Applied Clay Science, 54, 2011, 63–69.

Liao WA, Siems D.R.: *Adsorption characteristics of PHPA on formation solids, paper IADC/SPE 19945 presented at the Drilling Conference*. Houston, TX, Feb.27-March 2 1990.