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Improvement of CMC on the Performance of CGA Drilling Fluids for Geothermal Drilling

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ABSTRACT

Colloidal Gas Aphron (CGA) drilling fluids have been successfully used in petroleum industry to drill low depleted reservoirs. Recently, it has also been introduced to drill geothermal reservoirs of low-pressure and fractures. The rheological and filtration properties of drilling fluids are closely related to the cuttings carrying ability and the reservoirs invasion. Therefore, improving drilling fluid performance, especially at high temperature, will effectively increase the drilling efficiency and reduce the costs. In this paper, 0.2%-0.6% carboxymethyl cellulose (CMC) was added as viscosifier and fluid loss control agent to improve the performance of CGA drilling fluids at room temperature and 130℃ aged. Results show that:1) Power law model is the optimal model to describe the rheological behaviors of CGA drilling fluid containing CMC; 2) The addition of CMC significantly increased the LSRV and apparent viscosity of the CGA drilling fluid. CGA drilling fluid with or without CMC has significant shear thinning behaviors and the dosage of CMC has an influence on the strength of shear thinning behaviors; 3) The addition of CMC effectively reduces the fluid loss, whether at room temperature or 130℃. Compared with the control group without CMC, the filtration loss of CGA fluid containing 0.6% CMC was reduced by 62.5% and 46.7% at room temperature and 130℃, respectively.

1. INTRODUCTION

Colloidal Gas Aphron drilling fluids (CGA drilling fluids) have been successfully employed in drilling depleted oil and gas formations, Macphail et al (2008), Growcock F B et al (2007). Drilling is the only way to explore and develop geothermal resources. Recently CGA drilling fluid has also been proposed to be used in geothermal resources drilling, Tibor S (2012). CGA fluid has extremely high value of LSRV (low shear rate viscosity) which is beneficial for drilling operation, Ivan et al (2002). And the special bridging and plugging mechanism enables the CGA drilling fluid to reduce invasion to the formation and protect reservoir. Therefore, the use of CGA drilling fluid in geothermal drilling can effectively reduce costs.

The microbubbles in CGA drilling fluids size from10 to 100μm. According to Sebba, Aphrons is composed of two main parts: a gaseous core and a thin multi-layered aqueous surfactant shell that is composed of two surfactant layers, Molaei A and Waters K E (2015). The unique structure allows aphrons to withstand pressures above 2000psig and survive in severe conditions for a long time, Pasdar M (2018).

There have been many experimental studies on the properties of CGA fluids. Milad Arabloo et al (2014) studied the effects of different concentrations of SDS and XG on the stability and rheological properties of aphrons. Temperature parameters were also introduced in the rheological model. However, the temperature discussed in this paper is between 25-45℃, which is lower than the circulating temperature of the drilling fluid in actual drilling work. The rheological properties of CGA drilling fluids at 49℃, 71℃, 93℃ were studies by KHAMEHCHI Ehsan et al (2016), but the filtration properties at of were not discussed in this paper. Most of the experimental researches on CGA drilling fluid were carried out at room temperature or the temperature＜100℃. With the increase of drilling depth and reservoir temperature, it is necessary to improve the performance of CGA drilling fluid at higher temperature.

CGA drilling fluids are generally prepared by mixing surfactants and polymers and stirring at high speeds without the need for additional equipment such as air compressors. According to the reports, sodium dodecyl sulfate (SDS), cetyl trimethyl ammonium bromide (CTAB), hexadecyl trimethyl ammonium bromide (HTAB), Tweens, plant Saponin et al were used as to generate aphrons successfully, Molaei A (2015), Arabloo M et al (2013), Bjorndalen N (2008). Among them, SDS is the most widely used surfactants. Xanthan gum (XG) is the most commonly used polymer. Except for XG, starch, CMC and polyanionic cellulose (PAC) have been used as viscosifier to generate aphrons successfully, Arabloo M et al (2014), Ahmadi M A et al(2015), Jiansheng Luo et al (2001). In this paper, CMC was added as a viscosifier and fluid loss control agent to prepare CGA drilling fluids together with XG to improve the rheological and filtration properties of CGA drilling fluids. The performance of CGA fluid with or without CMC were studied at room temperature and 130℃.

2. MATERIALS AND METHOD

2.1 Materials and Preparation of CGA drilling fluid

In this paper, 0.571% biopolymer of xanthan gum (XG) and 0.286% sodium dodecyl sulfonate (SDS) were used as viscosifier and aphronizer to prepare CGA drilling fluids, respectively. 0.2%-0.6% carboxymethyl cellulose (CMC) was also added as viscosifier to study its impact on the performance of CGA fluid. 3%w/v bentonite fluid with 0.2% Na_2CO_3 was prepared as the based fluid. Details of the materials are given in Table 1. Mixing all the raw materials, i.e., based mud, XG and CMC together using a high-speed mixer at 8000 rpm for 20min. Then, SDS was added to the mixed fluid and mixing for 120s to generate aphrons. The detailed preparation process of CGA drilling fluid can be found in the literature, Nareh'ei M A et al (2012).

Table 1. Agents to prepare CGA drilling fluids.

No.	Reagent	Functions	Content	Provider company
1	SDS	Aphronizer	98.5%	Shandong Usolf Chemical Co., Ltd
2	XG	Viscosifier and fluid loss control	-	Tianjin Bailunsi Biotechnology, Inc.
3	CMC	Viscosifier and fluid loss control	CP	Sinopharm Chemical Reagent Co. Ltd
4	Na_2CO_3	hardness buffer	≥99.8%(AR)	Beijing Chemical Works
5	OCMA Bentonite	Viscosifier and fluid loss control	-	Chifeng Longze Bentonite Co., Ltd

2.2 Rheological model and rheological test

Two kinds of viscometer were used to study the rheological properties of CGA drilling fluids in this paper. The low shear rate viscosity (LSRV) was tested using Brookfield DV-2 viscometer under the rotational speed in range of 0.3 rpm to 100 rpm. The relationship between shear stress and shear rate was tested using six-speed viscometer (Model ZNN-D6). The measurements of fluids were recorded at the speed of 3r/min, 6r/min, 100r/min, 200r/min, 300r/min, 600r/min. Apparent viscosity (AV) were also tested and recorded using six-speed viscometer, see formula (1), Zoveidavianpoor M and Samsuri A (2016).

The experimental data of shear stress and shear rate is then fitted to two rheological models: Power Law model and Herschel-Bulkley model, see formula (2) and formula (3), respectively, Tabzar A et al (2015). Where τ is shear stress, γ is shear rate, τ_0 is yield point, K is consistency index and n is flow behavior index. Parameters constrains: 0<n<1; k>0; τ_0>0.

$$\mathrm{AV} = 0.5 * \theta_{600}(\mathrm{mP}a{\cdot}s) \tag{1}$$

$$\tau = \mathrm{K} \cdot \gamma^{\mathrm{n}} \tag{2}$$

$$\tau = \tau_0 + \mathrm{K} \cdot \gamma^{\mathrm{n}} \tag{3}$$

2.3 Filtration loss test

Fluid filtration tests were measured based on the American Petroleum Institute (API) specifications with a medium pressure filtration apparatus (Model SD-3). The mud was placed into a stainless-steel container with an opening at the bottom. Then the fluid was exposed to 100psi (0.69MPa) pressure at room temperature and the volume of fluid loss in 30 min was recorded.

3. RESULTS AND DISCUSSION

3.1 Rheology property

3.1.1 Rheological models

The Power Law model and the Herscchel-Bulkely as given in 2.2, are two common models for predicting the rheological behavior of non-Newtonian fluids and have good applicability in CGA fluids. The experimental data of shear rate and shear stress obtained by six speed viscometer was fitted to the above model and Figure 1 shows the fitting curves. Fitting parameters of the Power Law model and the Herscchel-Bulkely model are given in Table 2 and Table 3, respectively. R^2 (R-Squared) and RMSE (Root Mean Square Error) are the parameters for evaluating the goodness of fit. RMSE is obtained by Equation (4), where RSS is residual sum of squares and n is number of measurements. The closer the value of R^2 is to 1, the smaller the RMSE is, and the more precise the model is in predicting the rheological behaviors of tested fluids.

According to the results, the R^2 values of Power Law model are between 0.98953 and 0.9991, which are always lower than that of the Herscchel-Bulkely model, at room temperature or 130℃ aged. The RMSE values of Power Law model are between 0.6365 and 1.7564, which are higher than that of the Herscchel-Bulkely model. It is worth noting that the yield point of Herschel-Bulkley mode for the tested fluid containing 0.6% CMC at room temperature and the fluid containing 0.2%-0.6% CMC aging at 130℃ is less than zero, which is inconsistent with the applicable premise of this model. In other words, although Herschel-Bulkley model gives a lower value of RMSE and a closer values of R^2 to one, Power law is the more utilizable model to describe the rheological behaviors of CGA fluids since the negative parameter values of Herschel-Bulkley model.

$$\mathrm{RMSE} = \sqrt{\mathrm{RSS}/n} \tag{4}$$

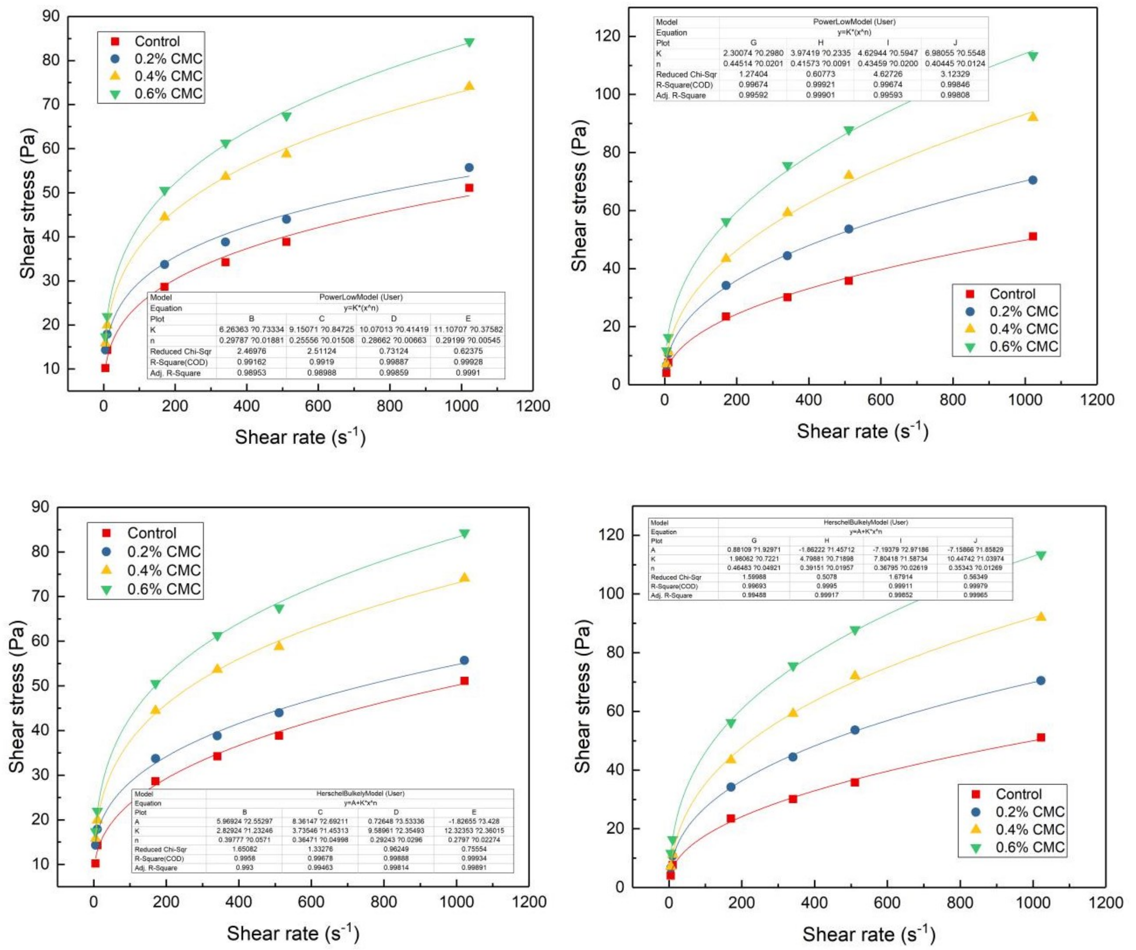

Figure 1. Rheological model fitting curves of different formulations: (a) Power law model-Room temperature; (b) Power law model-130℃ aged; (c) Herscchel-Bulkely model-Room temperature; (d) Herscchel-Bulkely model-130℃ aged.

Table 2. Fitting parameter of Power law model

	Formulation	n	K	R^2	RMSE
Room temperature	Control	0.29787	6.26363	0.98953	1.2832
	0.2%CMC	0.25556	9.15071	0.98988	1.2939
	0.4%CMC	0.28662	10.07013	0.99859	0.6982
	0.6%CMC	0.29199	11.10707	0.9991	0.6448
130℃	Control	0.44514	2.30074	0.99592	0.9216
	0.2%CMC	0.41573	3.97419	0.99901	0.6365
	0.4%CMC	0.43459	4.62944	0.99593	1.7564
	0.6%CMC	0.40445	6.98055	0.99808	1.4430

Table 3. Fitting parameter of Herscchel-Bulkely model

	Formulation	τ_0	n	K	R^2	RMSE
Room temperature	Control	5.96924	0.39777	2.82924	0.9958	0.9085
	0.2%CMC	8.36147	0.36471	3.73546	0.99678	0.8163
	0.4%CMC	0.72648	0.29243	9.58961	0.99888	0.6937
	0.6%CMC	-1.82655	0.2797	12.32353	0.99934	0.6146
130℃	Control	0.88109	0.46483	1.98062	0.99693	0.8944
	0.2%CMC	-1.86222	0.39151	4.79881	0.9995	0.5039
	0.4%CMC	-7.19379	0.36795	7.80418	0.99911	0.9163
	0.6%CMC	-7.15866	0.35343	10.44742	0.99979	0.5308

3.1.2 Low shear rate viscosity (LSRV), apparent viscosity (AV) and shear thinning behavior of CGA drilling fluids.

The drilling fluid process requires that the drilling fluid should have a good shear thinning behavior, that is, the viscosity of the drilling fluid decreases as the shear rate increases. The drilling fluid circulates in the annular space at a low shear rate, and the high viscosity is beneficial to the cuttings carrying. When the drilling fluid is ejected from the drill bit at a high shear rate, the low viscosity is conducive to the pumping. The relationship between the viscosity and rotational speed was obtained using the Brookfield viscometer, as shown in Figure 2. The low shear viscosity (LSRV) of the drilling fluid is characterized by the viscosity of 0.3 rpm. At room temperature or 130℃ aging, the LSRV values of the tested fluid with CMC were always higher than that of the control group, indicating that the addition of CMC significantly increased the LSRV value of the CGA drilling fluid. At room temperature, the LSRV values of CGA drilling fluids containing 0.2%, 0.4%, 0.6% CMC increased by 7.5%, 27.9%, 29.2% compared with the control group, respectively. After aged at 130℃for 16 hours, the LSRV values reduced rapidly. However the viscosity-increasing effect of CMC is still not negligible and CGA fluid with 0.6% CMC has the highest LSRV valus of 26794 mPa·s, which increases 164% comparing to the control group. Figure 2 also shows that CGA drilling fluid with or without CMC has significant shear thinning behaviors. As the rotational speed increases to 12 rpm, the viscosity declines rapidly. And the viscosity continues to decrease slowly with the rotational speed increase to 100 rpm. Figure 3 shows the apparent viscosity of different formulations at different temperature. As the CMC concentration increases, the apparent viscosity increases. Compared to the control group, the apparent viscosity of CGA fluid containing 0.2%, 0.4%, 0.6% CMC increased by 9%, 47%, 71%, respectively at room temperature. After 130℃ aged, it increased by 47.4%, 99%, 128.9%, respectively.

The values of flow behavior index (n) given in Table 2 is a parameter indicating the strength of fluid shear thinning behavior. The smaller the value of n, the stronger the shear thinning behavior of the fluid. At room temperature, as the dosage of CMC increased, the value of n increased. However the flow behavior index of CGA fluid containing CMC was always lower than that of the control group. At 130℃, 0.6% CMC has the lowest value of n, which is 0.40445. This indicates that the addition of CMC can reduce the value of n and increase the shear thinning behavior of CGA drilling fluid.

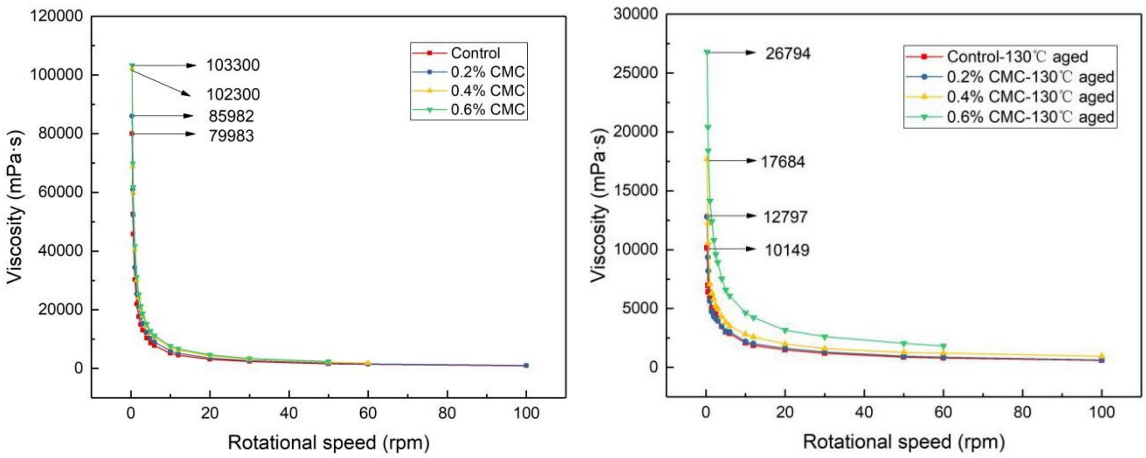

Figure 2. LSRV of CGA drilling fluids: (a) Room temperature; (b) 130℃ aged.

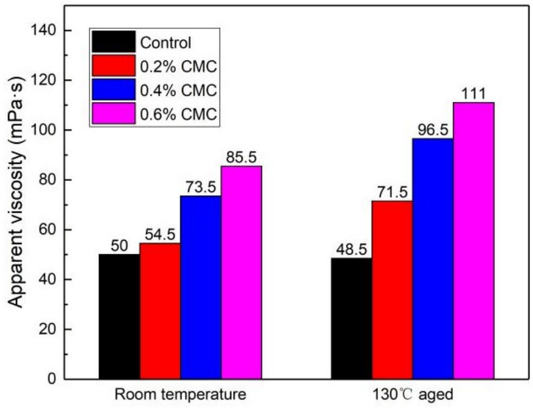

Figure 3. Apparent viscosity of different formulations.

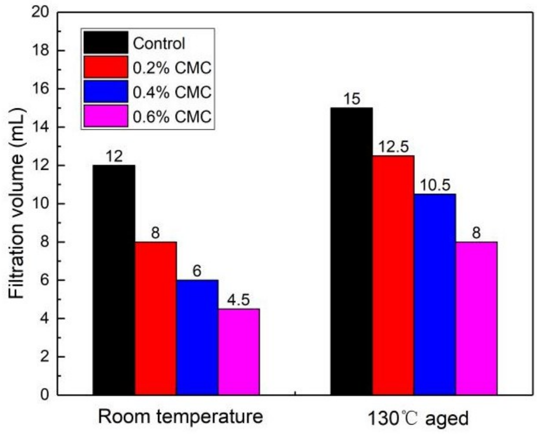

Figure 4: Filtration loss volume of different formulations at room temperature and 130℃ aged.

3.2 Filtration property

Under the pressure difference, the water in drilling fluid enters the formation, and the solid particles form a mud cake on the well wall. Low fluid loss and dense mud cakes help to reduce fluid invasion into the formation. API fluid loss for different formulations of CGA drilling fluid within 30 minutes was tested based on the method described in 2.3 and results are shown in Figure 4. The addition of CMC effectively reduces the fluid loss, whether at room temperature or 130℃. As the amount of CMC increases, the filtration volume decreases. CGA fluid with 0.6% CMC has the lowest fluid loss, which is 4.5mL and 8mL at room temperature or 130℃, respectively. Compared with the control group without CMC, the fluid loss of CGA fluid containing 0.6% CMC was reduced by 62.5% and 46.7% at room temperature and 130℃, respectively.

Based on the static filtration loss equation, the fluid loss is inversely proportional to the viscosity of the fluid: the greater the viscosity is, the lower the fluid loss is. According to the results shown in 3.1.2, the addition of CMC increases the LSRV and the apparent viscosity. Therefore, the reduction of fluid loss of the CGA fluid containing CMC can be attributed to the viscosity-increasing effect of CMC. As the CMC concentration increases, the viscosity of CGA fluid increases, and the fluid loss volume decreases.

4. CONCLUSION

In this paper, the effect of the addition of CMC on the rheological and filtration loss properties of CGA drilling fluid at room temperature or 130℃ aged was investigated. The results can be drawn as follows:

1) The R^2 values of the Herschel-Bulkley model and the Power law model are both greater than 0.98, indicating the good fitness in fitting the shear rate and shear stress data of CGA drilling fluids. Compared to the Power law model, the Herschel-Bulkley model gives lower RMSE values and closer R^2 values to one, indicating that this model has a better fitness. However, due to the negative parameter in the fitting results of the Herschel-Bulkley model, i.e., the yield point is less than zero, the Power law model is selected as a model to describe the rheological behaviors of CGA drilling fluid.

2) The addition of CMC significantly increased the LSRV and apparent viscosity of the CGA drilling fluid. CGA drilling fluid containing 0.6% CMC has the greatest increase in LSRV value, which is 29.2% and 164% higher than the control group at room temperature and 130 ℃, respectively. CGA drilling fluid with or without CMC has shear thinning behaviors which is beneficial for drilling operation. At room temperature, as the amount of CMC increases, the n value increases and the shear thinning strength

decreases. However, 0.6% CMC has the lowest n value at 130°C, indicating that the shear thinning behavior of CGA drilling fluid is enhanced.

3) The addition of CMC effectively reduces the fluid loss, whether at room temperature or 130°C. As the amount of CMC increases, the filtration volume decreases and CGA fluid with 0.6% CMC has the lowest fluid loss.

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