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Preparation Mechanism and Experimental Results on Deep Thermophilic and Halotolerant Solids-free Drilling Fluids

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A new deep thermophilic and halotolerant solids-free drilling fluid was prepared by adding the modified polysaccharide, xanthan gum and the common sulfonated phenolic resin. It was characterized by high temperature resistance, high shear force resistance and good stability in high salinity. It also had low fluid loss and low price. At the same time, the mechanism of action and coordination of polysaccharide and xanthan gum was also described in this paper.

Key Words: Solids-free, Drilling fluid, Fluid formulation.

INTRODUCTION

The solids-free drilling fluid is a water-soluble mixture and the stability and adaptability of this aqueous solution is much better than the solid drilling fluids. However, for most of the polymers, the viscosity decreases rapidly in high salinity and high temperature conditions. In general, the molecular weight of the polymer is higher, the temperature tolerance and salt endurance of the polymer are better.But, it may also lead to too thick in some high salinity conditions.

In general, the biological polymers, cellulose derivatives, synthetic polymers and weak gel are used as tackifier and the modified starch, polyanionic cellulose (PAC), sulfonated phenolic resin are used as fluid loss additives and the aggravating agents are used to adjust the density of the common solids-free drilling fluid[1,2]. The performance of the kinds of polymers is different during the process of drilling, just because of the adsorption of various substances is different when they are in stratum. This article only uses polysaccharide (A1) and xanthan gum (XC) as tackifier, with inorganic salts and organic salts as weighting agents and with the sulfonated phenolic resin and the sulfonated lignite resin (SPNH) as fluid loss additives to make an effective formula.

EXPERIMENTAL

The experimental apparatus include six-speed rotational viscometer, mud water loss tester, liquid density meter, high temperature and high pressure dynamic water loss tester, five-axis high-speed blender, portable roller furnace and brookfield viscometer. Experimental materials include NaOH, KCOOH, NaCOOH, NaCl, KCl, polysaccharide, xanthan gum, polyanionic cellulose, sulfonated phenolic resin, sulfonated lignite resin and the defoamer (JM401).

Temperature-tesistant and salt-tolerant studied on different tackifier polymers: The relationship between the variation of the viscosity and the temperature of the CAX (CAX was made up of 80 % of polysaccharide and 20 % of xanthan gum), polyanionic cellulose, polysaccharide and xanthan gum in water was shown in Figs. 1 and 2 shows the relationship of various polymers in the same concentration when they are in salt water.

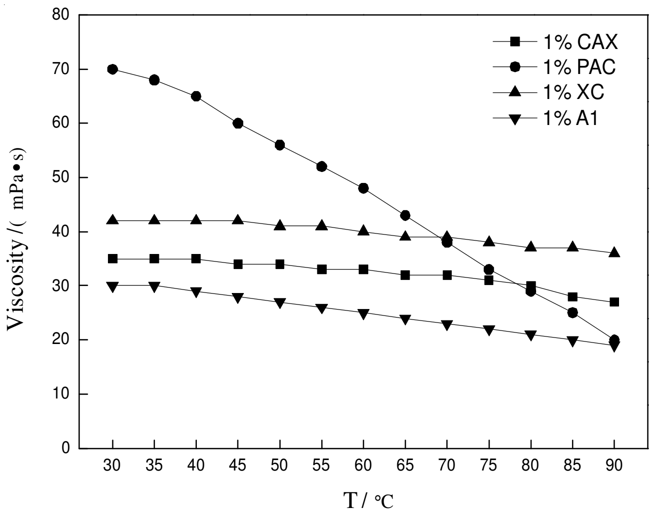

Fig. 1. Relationship between the temperature and the variation of the viscosity of various polymers in water

Annotation: CAX was prepared with 80 % of polysaccharide and 20 % of xanthan gum (the same below).

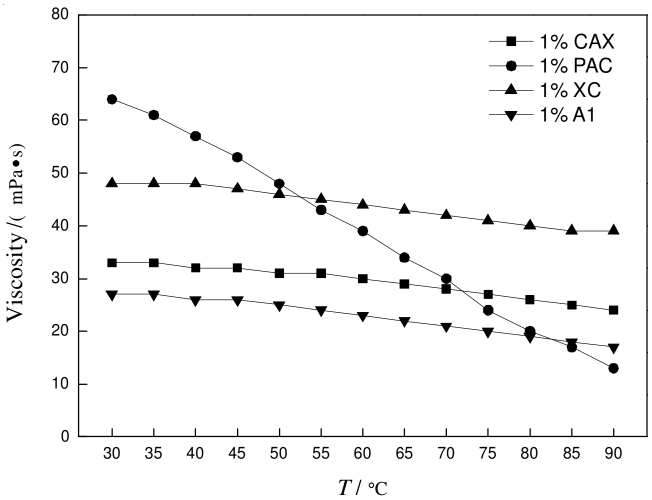

Fig. 2. Relationship between the temperature and the variation of the viscosity of various polymers in 10 % salt water

By comparison of Figs. 1 and 2, the performance of polyanionic cellulose is unstable; polysaccharide is stable in different temperatures, but the ability of tackify is not very good; the performance of CAX is very good and it is very stable in different conditions; the ability of tackify of xanthan gum is very good, but it is not stable in different salinity conditions and at certain concentrations its viscosity becomes too large when it is in high salinity condition.

Based on the performance of various polymers and take account of the market price of them, the most appropriate one can be chosen. The price of xanthan gum is 4,400 $/ton and the price of polysaccharide is 1,500 $/ton, so the price of CAX is 2,080 $/ton (CAX was made up of 80 % of polysaccharide and 20 % of xanthan gum). Fig. 3 shows that 1 % of CAX not only has better viscosity, but also much cheaper than 0.5 % of xanthan gum. Therefore, the CAX is more suitable for field applications from the comparation of the CAX and xanthan gum.

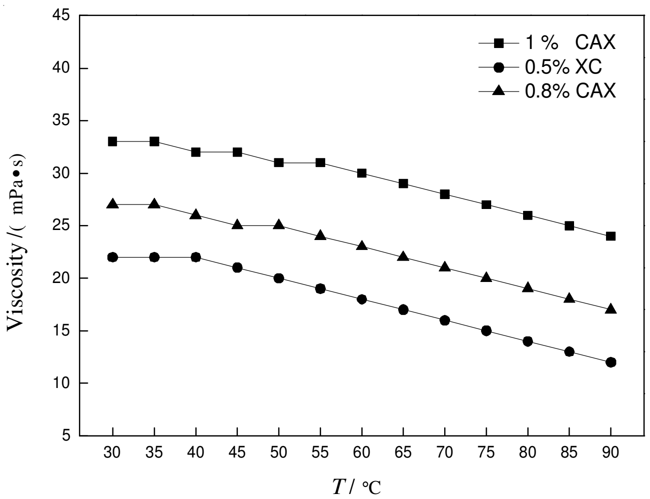

Fig. 3. Relationship between the temperature and the variation of the viscosity of 1 % CAX, 0.8 % CAX and 0.5 % xanthan gum in 10 % salt water

Choice of fluid loss additives: The sulfonated phenolic resin and sulfonated lignite resin are chosen as fluid loss additives in this paper and both of them have good properties of temperature-resistant and salt tolerance, so they can control fluid loss well in high temperature and high salinity conditions[3].

Choice of aggravating agents: The inorganic salts and organic salts are always chosen as weighting agents, however the ability of anti-calcium of many polymers is poor, meanwhile the inorganic salts solution is also too corrosive, therefore the organic salts are selected as weighting agents eventually. The common organic salts are potassium formate and sodium formate. Because of the formate has low activity and low impact in stratum, it is easy to adjust the density, viscosity and the fluid loss effectively to make a stable drilling condition. The compatibility of the formate with the common tackifier, fluid loss additives and other drilling fluid treatment agents is also very good. Considering these advantages, the formate is chosen as the weighting agent[4,5].

RESULTS AND DISCUSSION

Experimental formulae and results:

1#: 0.5 % XC + 1.0 % SMP + 1.0 % SPNH + 0.7 % JM401 + NaCOOH + NaCl + KCl + NaOH + H_2O

2#: 1 % CAX + 1.0 % SMP + 1.0 % SPNH + 0.7 % JM401 + NaCOOH + NaCl + KCl + NaOH + H_2O

3#: 0.8 % CAX + 1.0 % SMP + 1.0 % SPNH + 0.7 % JM401 + NaCOOH + NaCl + KCl + NaOH + H_2O

where, XC = xanthan gum; SMP = sulfonated phenolic resin; SPNH = sulfonated lignite resin.

The performance of solids-free drilling fluid at room temperature and after aging for 16 h at 120 ºC were shown in Tables 1 and 2.

TABLE-1
PERFORMANCE OF SOLIDS-FREE DRILLING FLUID AT ROOM TEMPERATURE

	AV (mPa·s)	PV (mPa·s)	YP (Pa)	FL_{API} (mL)	FL_{HTHP} (mL)
1#	25	16	9	4.4	22
2#	40	24	16	0	8.8
3#	33	20	13	1.6	13.2

TABLE-2
PERFORMANCE OF SOLIDS-FREE DRILLING FLUID AFTER AGING FOR 16 HOURS AT 120 ºC

	AV (mPa·s)	PV (mPa·s)	YP (Pa)	FL_{API} (mL)	FL_{HTHP} (mL)
1#	20	14	6	9.6	40.0
2#	36	19	17	1.2	14.4
3#	25	18	7	5.2	22.8

From Tables 1 and 2, it could be seen that after aging at 120 ºC, the properties of the system change slightly, with a decrease in viscosity and an increase in fluid loss. The experimental results show that the performance of formula 2 is much better than the others and it conforms to all kinds of requirements of the solids-free drilling fluid.

Rheological behaviour of the polymers: Fig. 4 shows the relationship between shear rate (D) and shear stress (t) and as is shown that the polymers have good rheological behaviour. When the shear rate belongs to 1-100 s^{-1}, the viscosity of the system decreases sharply, but it decreases slowly when the shear rate is higher than 100 s^{-1} and the rheological model of the system belongs to Herschel-Bulkley: $T = T_y + K\gamma^n$ (T_y is dynamic shear, K is consistency coefficient and n is flow index). Therefore K is proportional to the property of tackify of the system and n is related to the non-Newtonian behaviour of the system. And the smaller n is, the stronger of the non-Newtonian behaviour of the system will be[6-8]. By calculating, $T_{y1} = 17.885$, $n_1 = 0.484$, $K_1 = 1.395$ (1 % of xanthan gum); $T_{y2} = 5.12$, $n_2 = 0.335$, $K_2 = 0.806$ (1 % of polysaccharide) and $T_{y3} = 11.55$, $n_3 = 0.386$, $K_3 = 1.266$ (1 % of CAX). The viscosity of xanthan gum is too large in some conditions, but when it is compatible with polysaccharide, a new tackifier CAX is made, which exhibits favourable rheological behaviour.

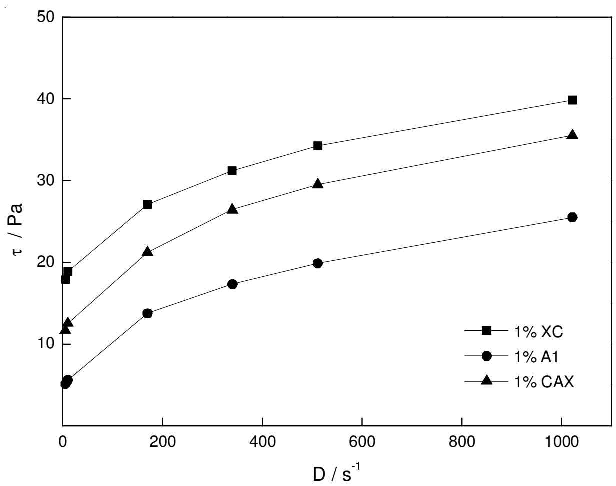

Fig. 4. Relationship between the shear rate (D) and the shear stress (t) of 1 % xanthan gum, 1 % CAX and 1 % polysaccharide

Structure mechanism of the compatibility of polysaccharide and xanthan gum: In this paper, polysaccharideand xanthan gum was chosen as tackifier by taking into account the properties of temperature-resistant, salt tolerance and the market price. Through experiments, we finally determined the complex ratio of polysaccharide: xanthan gum is about 4:1 and then the mechanism of the compatibility of polysaccharide and xanthan gum from both structure was analyzed.

From the primary structure of xanthan gum, the main chain connected with each other through 1,4-glycoside key and each of the two glucose residues connected to a side chain, which is connected alternately by two mannoses and one glucuronic acid. A double helix is formed through hydrogen bonds and most of them formed multiple helical polymers. Because of the unique structure, the xanthan gum has a good property of thickening.

Because of the side chains of the xanthan gum with negative charge, the cation usually reacts with side chains firstly, thus there is less impact on the main chain, so the aqueous solution of xanthan gum has a good property of salt tolerance. With the increased concentration of salt, the shielding effect of metal ions on the side chains makes the molecular conformation of xanthan gum more stable, so that the ability of temperature-resistant of xanthan gum is improved[9-11]. Based on these theories, the xanthan gum shows good performance of temperature-resistant and salt tolerance, but it may also become too thick when it is in high salinity condition.

Polysaccharide is a special polymer of polysaccharide. The structure of polysaccharide is similar to cellulose, but they also have some differences. It is different from the molecular of the cellulose, which has the ribbon spiral structure that is difficult to dissolve and degradation[12]. However the unique structure of polysaccharide makes it dissolve in water easily and has very good property of thickening. It also has good compatibility with xanthan gum and there is a very good function when polysaccharide and xanthan gum combined with each other.

Conclusion

The rheological behaviour and the mechanism of action and coordination of polysaccharide, xanthan gum and CAX were studied in this work. Based on the experiments, a new solids-free drilling fluid has been made and which is characterized by high temperature resistance,high shear force resistance, good stability in high salinity, good rheological properties and low fluid loss. It can be well used in the deep and high density wells.

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