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Environment Friendly Water-Based Drilling Fluid Using Natural Vegetable Gum

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This paper reported the formulation and the laboratory analysis of TLJ-1 vegetable gum drilling fluid with the temperature resistance capability up to 140 ºC. Based on the single-factor method, TLJ-1 is chosen as the main treatment agents for the fluid, LV-CMC and PEG taken as the filtrate reducer, QS-2 taken as the rigid filling particles, the three formulations, *i.e.*, the low-solids drilling fluid, the solids-free drilling fluid and the weighting natural vegetable gum drilling fluid have been presented. The laboratory analysis has demonstrated the good temperature resistance capability of the presented TLJ-1 vegetable gum drilling fluids for environmental safety.

Key Words: Water-based drilling fluid, Natural vegetable gum.

INTRODUCTION

In the oil and gas exploration, use of drilling and completion techniques for maximizing well productivity, accessing reserves and reducing impairment to the environment are increasing[1,2]. As environmental protection has become a prior issue in the oil and gas exploration, it needs a high-density, low-solids and non-damaging reservoir drilling fluids or "drilling-in fluid" in the age of deeper discovery and petroleum producing wells with hostile environment[3]. Several new types of drilling fluids are developed and analyzed for a mature oil field[4]. Advanced technologies such as water-based drilling fluid methodology, numerical simulation technique, oil-film method for developing drilling fluids[5] and taking polymers as drilling fluids[6], had also led to the development of new type of drilling fluid. A new bio-enzymatic drilling and completion fluid was developed and it could clean out the mud cakes[7]. Using non-traditional light weight completion fluid, a kind of completion fluid was developed to increase production by maximizing underbalance during performance[8]. The proper drilling fluid type and composition for drilling stable holes through the problems of the selected formations was also selected and experimental investigation had evaluated the drilling fluid performance[9].

However, the cost of the environmental safe drilling fluid is high and the synthesis of new type of environmental safe drilling fluid is complex[10]. In addition, lack of a new type of raw materials suitable for treatment agent, the weakness of the antihigh temperature resistance and the poor contamination resistance and the inhibition performance had also constrained the development of environmental safe drilling fluids.

This paper describes the effort to develop natural vegetable gum fluids with high temperature resistance for environment protection. The vegetable gum is chosen as raw material and TLJ-1 is optimized as the major treating agent. The LV-CMC, polyglycol and QS-2 are as the auxiliary treating chemicals in this system. Laboratory analysis shows that fluid is beneficial to the environment protection with low biological toxicity and good degradable performance. Its temperature resistance capability is up to 140 ºC.

Optimization of major vegetable gum treatment agent

Temperature resistance of vegetable gum: As natural organic polymer, vegetable gum is the water-soluble substance and chemical substances consisting of sugar, xylose, glucose sugars and other chemical substances. It is easy to degrade under high temperature and its physical prosperity will change. Therefore, it is necessary to investigate its temperature resistance for the formula of the vegetable gum drilling fluid. Five kinds of vegetable gum, including tara gum (TLJ-1), locust bean gum (HDJ-1), tamarind gum (LWZJ-1) and agar (QZ-1), are investigated from high temperature to low temperature. Before hot roll (BAR), the performances of TLJ-1, HDJ-1, LWZJ-1 and QZ-1 are good. TLJ-1, HDJ-1, LWZJ-1 and QZ-1 have been degraded for the solution viscosity of them sharply reduce with a sharp decline in ratio of dynamic shear force

(YP/PV) after hot roll (AHR) at 100 ºC. After hot roll at 90 ºC, MYJ-1 and QZ-1 has been degraded. The change tendency of solution viscosity for TLJ-1, HDJ-1, LWZJ-1 is also the same as QZ-1 in AV, YP and YP / PV except the PV increases slightly. It indicates that TLJ-1, HDJ-1, LWZJ-1 just begin to degrade. Therefore, the temperature resistance of TLJ-1, HDJ-1 and LWZJ-1 is better than that of QZ-1. After hot roll at 80 ºC, apparent viscosity(AV)and plastic viscosity (PV) of TLJ-1, HDJ-1, LWZJ-1 solution viscosity have increased slightly and yield value (YP),YP/PV decline a little. The reason is that vegetable gums have been fully hydrated or thickened by high-temperature. The rheological properties of TLJ-1, HDJ-1, LWZJ-1 have not been changed much after hot roll at 70 ºC. It is concluded that the temperature resistance of TLJ-1, HDJ-1 and LWZJ-1 at 70 ºC is stable.

From the analysis it can be concluded temperature resistance of TLJ-1, HDJ-1 and LWZJ-1 is *ca.* 80 ºC.

Effect of different density brines on the natural vegetable gums: The salt resistance of treatment agents is the precondition to that of drilling fluids. It depends on the type and proportion of hydration groups with molecular structure in the treatment agent. The more hydration groups and the stronger capacity of the hydration are, the stronger salt resistance of the treatment agent is. The resistance capacity of the general ion group to salt analysis is stronger than non-ionic group developing the salt resistance experimental for the vegetable gum fluids with 1.4 % TLJ-1, 1.4 % HDJ-1 and 1.4 % LWZJ-1, respectively. After adding 5 % NaCl to HDJ-1 and LWZJ-1, their rheological properties have only changed a little before hot roll. However, the parameters of their rheological properties fall sharply after hot roll. It indicates that NaCl can damage the polymer structures of HDJ-1 and LWZJ-1 under high temperature. Their rheological properties can not meet the requirements of drilling operation. So the resistance ability to salt of HDJ-1 and LWZJ- 1 is under 5 %. Adding 5 % NaCl to TLJ-1, the rheological properties have not changed much before hot roll. After hot roll, the AV, PV and YP/PV have decreased a little and the rheological properties can meet the basic requirements of drilling operation. Adding 10 % NaCl to TLJ-1, the AV, PV, YP and YP/PV have decreased. However, the properties can meet the basic requirements of drilling operation except YP/PV. So the resistance capacity to salt of TLJ -1 is above 5 % and within 10 %.

With comprehensive experiment to evaluate the rheological properties, the salt resistance capacities and temperature resistance of QZ-1, TLJ-1, LWZJ-1and HDJ-1, TLJ-1 is optimized as the primary treatment agent of natural plant drilling fluid for its good overall performances.

Optimum conditions of auxiliary additives

Choice of the rigid filling particles: To make the filter cake more resilient and denser in drilling fluid, it often need add to a certain amount of rigid filled particle based on the mechanism of the filtrate reducer. The most common rigid filled particles are ultra-fine calcium carbonate. The ultra-fine calcium carbonate is chosen in the study and used as the mud cake improved materials to reduce drilling fluid loss and to enhance the fluid performance of building walls, thereby reducing the complex things occurrence in wells. Calcium carbonate superfine powder (QS-2) is taken as rigid filled particle and the conventional dosage is 3 %.

Optimization of the filtrate reducer: Generally, there are four types filtrate reducer, *i.e*., natural and natural modified polymers, synthetic polymer, the drilling fluid loss additives from chemical by-products and industrial waste and synthetic resin. Low viscosity carboxy methl cellulose sodium (LV-CMC), polyglycol (PEG), sulfonated phendic resin (SMP-I) and FJ-03 polyol are taken as the research object for filtrate reducer. The dosage of LV-CMC is 0.3 % and the basic formula of the fluid is as follows.

Basic formula: 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. In the basic formula, PEG, SMP-I and FJ-03 as the filtrate reducer are added into the natural vegetable gum drilling fluid, respectively and the performance of the fluid is evaluated with the laboratory tests. In laboratory study scheme, 2 % PEG, 2 % SMP-I and 2 % FJ-03 polyol are added to the basic formula, respectively. FJ-03 polyol, SMP-I and PEG can reduce the filter loss (Fig. 1).

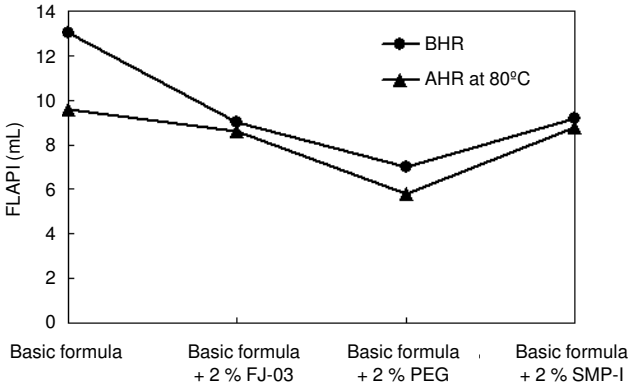

Fig. 1. Fluid loss effects of the different filtrate reducer

The addition of polyethylene glycol (PEG) to the basic formula can get the best effect for reducing the filter loss. In addition, PEG is a colourless liquid and it matches the colour of the natural vegetable gum drilling fluid. Therefore, PEG is taken as the filtrate reducer in natural vegetable gum drilling fluid.

Optimum conditions of the treatment agents

Optimum dosage of TLJ-1: As the primary treatment agent of the natural vegetable gum drilling fluid, the dosage of TLJ-1 decides the performance of the fluid. Therefore, the optimal dosage of TLJ-1 should be determined at first. Based on the experiment for optimizing the vegetable gum and the experiment for optimizing the filtrate reducer, we establish a low solid drilling fluid system experimental formula. The formula is as follows: Formula 1: 0.2 % TLJ-1 + 3 % bentonite + 0.3 % LV-CMC + 2 % PEG + 3 % QS-2. Formula 2: 0.4 % TLJ-1 + 3 % bentonite + 0.3 % LV-CMC + 2 % PEG + 3 % QS-2. Formula 3: 0.6 % TLJ-1 + 3 % bentonite + 0.3 % LV-CMC + 2 % PEG + 3 % QS-2. Formula 4: 0.8 % TLJ-1 + 3 % bentonite + 0.3 % LV-CMC + 2 % PEG + 3 % QS-2.

Experiment results show that parameters such as AV, YP, YP/PV and G10''/G10 ' have gone up and the filter loss has decreased with the increase of the dosage. If the dosage of TLJ-1 is small, its filtration loss is large. If the dosage of TLJ-1

is large, AV and YP are too high. Integrated with the rheological properties the dosage of TLJ-1 is taken as 0.4- 0.6 %.

Optimum dosage of PEG: In general, the more the dosage of the filtrate reducer is, the better the property of lowering filter loss is. But in practical use, its dosage should be in an appropriate range and the addition of the drilling fluid loss agent has a certain impact on the auto various properties of drilling fluids. In the study LV-CMC, QS-2 and PEG are chosen as filtrate reducers. The recommendation dosage of LV-CMC is 0.3 % and QS-2 is 3.0 %. Changing PEG dosage based on optimal dosage of TLJ- 1 as 0.6 %. Investigate the impact of the dosage of PEG of drilling fluid. The formulas are as follows: Formula A: 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. Formula B: 1% PEG + 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. Formula C: 2 % PEG + 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. Formula D: 3 % PEG + 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. Formula E: 4 % PEG + 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2. Formula F: 5 % PEG + 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2.

The effects of PEG dosage on the filter loss under pre-and post- heat aging are shown in Table-1.

While PEG dosage ranges from 1-4 %, the more PEG is, the less the filter loss is. When PEG dosage is more than 4 %, the effect of reducing the filter loss is getting worse. When PEG dosage ranges from 2-4 % in the fluid, the filter loss can be controlled within the industry standard provisions of CNPC. The reason that PEG can control the filter loss is PEG can be effectively adsorbed by the surface of clay particles, which brings enough hydration shell and increase the potential of clay particles. Hence, the proportion of clay colloidal particles in drilling fluid is ensured as well as the density and compressibility of mud cakes. Meanwhile, PEG is able to reduce the chemical activity of the drilling fluid filtrate and make walls stable, thereby reducing the filter loss. Formulas C, D and E can meet the requirement of drilling fluid. However, as the temperature increases, the feature of drilling fluid will change correspondingly. To meet the drill well engineering requirements with the increase of the temperature, the performance of temperature resistance of the fluid needs to be investigated. Based on system A (3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 3 % QS-2), PEG as the high-temperature stabilizer is added into the natural vegetable gum drilling fluid and the fluid performance is evaluated with the laboratory tests. The corresponding laboratory study scheme is that 2 % PEG, 3 % PEG and 4 % PEG are added to the basic formula, respectively. The effects of PEG added to the fluid are shown it can be concluded that the temperature resistance and filtration performance of system A at 100 ºC can not meet the need of the drilling well engineering. After adding PEG, the temperature resistance has been improved dramatically. With the different PEG dosage, the temperature resistance of the fluid changes correspondingly. When 4 % PEG is added to the basic formula, the fluid is resistant to high temperature at 120 ºC.

System of TLJ-1 vegetable gum drilling fluid: For TLJ-1 vegetable gum drilling fluid has a wide developing prospect, three kinds of natural vegetable gum drilling fluids, *i.e*., low-solids phase drilling fluid, the free-solids phase drilling fluid and weighing drilling fluid are studied.

Low-solids drilling fluid: By changing the physical and chemical environment of the fluid, the formula of the low solid fluid is taken as follows: 3 % bentonite + 0.3 % LV-CMC + 0.6 % TLJ-1 + 4 % PEG + 0.2 % Na_2SO_3 + 0.2 % Gemini quaternary ammonium salt + 3 % QS-2.

Experiment results show the low-solids drilling fluid can meet the drilling fluid performance requirements as YP of the fluid is large and YP/PV is relatively high. In addition, the filter loss and wall building capability of the fluid is also excellent. As for the temperature resistance capability, the high-temperature degradation of the vegetable gum can be alleviated and the fluid has been demonstrated to have good temperature resistance capability.

Solids-free drilling fluid: To improve the viscosity of fluid and reduce its filtration rate, the amount of the vegetable gum is increased and the other treatment agents are kept unchanged. The solids-free natural vegetable gum drilling fluid is formulated by evaluating the relation between the adding amount of the TLJ-1 and the fluid performance. The formulation of solid-free drilling fluid is as follows: 0.3 % LV-CMC + 1.2 % TLJ-1 + 4 % PEG + 0.2 % Na_2SO_3 + 0.2 % Gemini quaternary ammonium salt + 3 % QS-2 + water.

Experiment results show that the solid-free drilling fluid has good rheological properties and the filter loss and wall building capability are able to meet the drilling fluid requirements. Its stability under high temperature is strong up, as the

TABLE-1
EFFECTS OF PEG DOSAGE ON FILTER LOSS UNDER PRE- AND POST- HEAT AGING

Formula	80 ºC/16 h hot roll	AV (MPa s)	PV (MPa s)	YP (Pa)	YP/PV (Pa/MPa s)	G10''/ G10' (Pa/Pa)	FL_{API} (mL)
A	BHR	45	25	20.44	0.82	4.599/5.621	20
	AHR	49	26	23.51	0.90	8.690/12.260	25
B	BHR	45.5	24	21.97	0.92	5.110/8.176	8.6
	AHR	46	24	22.48	0.94	5.110/8.176	8.2
C	BHR	46	26	20.44	0.79	6.643/9.709	7.8
	AHR	49.5	31	18.91	0.61	6.643/9.709	7.5
D	BHR	47	27	20.44	0.76	8.687/12.264	7.2
	AHR	49	26	23.51	0.90	8.687/12.264	6.9
E	BHR	49	29	20.44	0.70	9.198/12.775	7.2
	AHR	49.5	29	20.95	0.72	9.198/12.775	6.9
F	BHR	53.5	31	23.00	0.74	10.220/13.286	8.0
	AHR	53	31	22.48	0.73	10.220/13.286	7.9

TABLE-2
EFFECTS OF THE WEIGHTING AGENTS TO THE NATURAL GUM DRILLING FLUID

Hot roll at 140 ºC	AV (mPa s)	PV (mPa s)	YP (Pa)	YP/PV Pa/mPa s)	G10''/G10' (Pa/Pa)	ρ (g/cm^3)	FL_{API} (mL)	FL_{HTHP} (mL)
BHR	53.5	28	26.06	0.93	9.20/13.29	1.04	6.7	11.2
AHR	49	27	22.48	0.83	7.15/10.73	1.04	5.6	10
BHR	81.5	42	40.37	0.96	14.31/18.40	1.20	–	–
AHR	45.5	34	11.75	0.35	8.69/14.82	1.20	5.8	10.4
BHR	87.5	51	37.30	0.73	17.37/27.59	1.40	–	–
AHR	69.5	47	23.00	0.49	10.22/16.86	1.40	6.6	11
BHR	95	55	40.88	0.74	19.42/29.64	1.60	–	–
AHR	75	50	25.55	0.51	14.82/19.93	1.60	6.9	11.5

anti-temperature could be up to 140 ºC. In addition, with the large dynamic shear strength and high dynamic plastic ratio, it is also suited for the drilling fluid in the extended reach well and horizontal well.

Weighting natural vegetable gum drilling fluid: The weighting natural vegetable gum drilling fluid is established by adding barite based on the low-solid phase fluid and the different density drilling fluid are formulated. The weighting agent has a certain impact on the rheological performance, lubrication, filter and wall building capability of the drilling fluid. The effects of the weighting agent can be shown in the results of Table-2.

Table-2 showed the fluid can suspend the barite stably without any other tackifying agent. There is nearly no viscous shearing change for the aging the fluid. The range of the vegetable gum drilling fluid density is large. It ranges from 1.04-1.60 g/cm^3. After the weighting agent is added into the fluid, the viscosity and shear strength of the fluid have increased dramatically. But after the aging action, they decrease and the rheological properties of the fluid become better and the dynamic plastic ratio of the fluid fully meets the requirements of drilling cuttings.

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