Hydroxypropylmethylcellulose as a Free Water and Settling Control Agent in Oil Well Cement Slurry

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Abstract Free water and sedimentation of particles are considered as severe problems for cementing operation. The sedimentation of particles alters the density of designed cement slurry and reduces hydrostatic pressure that becomes the cause of gas migration. Different additives and polymers have been used for prevention of free water and sedimentation. However, the mineralogy, chemical reaction, and increasing temperature affect the properties of additives and polymers. At high temperature, polymers suffer high thermal thinning problem and loss of viscosity that become incapable of controlling free water. This study presents hydroxypropylmethylcellulose (HPMC) polymer that works as viscosifying agent at high temperature. The inclusion of HPMC polymer in cement slurry eliminates the free water separation and sedimentation of solid particles at high temperature. Laboratory experiments were performed to determine the viscosity of 2 wt% of HPMC solution at various temperatures 30–100 °C. Further API properties of HPMC-based cement slurries were determined in terms of rheology, free water, and fluid loss with other additives at 90 °C. It was observed that HPMC polymer was stable at high temperature. In cement slurry, HPMC polymer completely prevents the free water separation and sedimentation of solid particles and decreases the fluid loss through cement slurry at high temperature.

Keywords Cement slurry · Free water · Sedimentation · Additives · Hydroxy propylmethylcellulose

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1 Introduction

Separation of water and settling of particles are cause of primary cementing job failure. The excessive free water separation and sedimentation of solid particles through cement slurry leads to non-uniform density of cement slurry. As the water is separated from cement slurry, the viscosity of slurry increases and the solid particles settle down at bottom [1]. The sedimentation of particles builds the bridge inside the cement slurry and creates two phases of different densities. In this condition, high density at bottom creates fractures that become the cause of loss circulation. The low density at top of slurry decreases hydrostatic pressure that creates permanent channels and become the cause of gas migration through permeable zone [2].

Previously, the extender such as bentonite was used to control free water and sedimentation of solid particles. Bentonite prevents the breakthrough of formation and loss of circulation and has better yield to cement by remarkable amount of water. But the effectiveness of extender decreases tremendously in the presence of strong electrolytes such as $CaCl_2$ and NaCl [3]. Polysaccharides are extremely used as fluid loss control agent in oil well cement slurry. Allen states that the use of polysaccharides in cement slurry also controls the free water separation and shows more uniform density in cement slurry [4]. The polysaccharides such as hydroxyethylcellulose (HEC), hydroxypropylguar (HPG), and carboxymethylhydroxyethylcellulose (CMHEC) show limitation at high temperature. In oil well cementing operations, these polymers are unstable in cement slurry at high temperature. The viscosity of these polymers sharply reduces with respect to temperature, and polymers lose their desired properties in cement slurry [5]. Currently, polysaccharides were modified with some other chemicals to increase the stability of polymers at high temperature [6]. The utilization of chemicals to enhance the performance of polymers increased the operational cost and also affects the properties of cement. Therefore, it was necessary to use such type of polymer that could work effectively as a free water control agent and enhance the viscosity with increasing temperature without addition of any chemical.

Hydroxypropylmethylcellulose (HPMC) is a long chain cellulose water-soluble polymer that acts as thickener, film foamer, solid suspension agent and a surfactant. The rheology of HPMC polymer shows that it is stable at high temperature and will increase viscosity at gelation temperature. The application of HPMC in oil industry has been investigated as a permeability-reducing agent for profile modification and has long thermal stability through experimental analysis [7].

This paper presents the experimental study of HPMC polymer to control free water in the cement slurry. The objective of this study is to design HPMC-based cement slurry with other additives that control the free water, sedimentation, and fluid loss through cement slurry at high temperature. On the base of laboratory experiments, rheology of 2 wt% HPMC polymers in terms of viscosity was determined. Furthermore, the API properties of cement slurries in terms of rheology, free water, fluid loss, and settling of solid particles are determined by changing the concentration of HPMC solution at 90 °C temperature.

2 Experimental Procedure

2.1 Preparation of HPMC Polymer Solution

HPMC polymer was in the form of white fine powder. Commercial HPMC polymer was used for experiments. The concentration 2 wt% of HPMC polymer solution was prepared with distilled water to determine the properties of HPMC solution at different temperatures.

2.2 Viscosity of HPMC Polymer

High-pressure high-temperature viscometer (OFITE 1,100 model) was used to determine the viscosity of HPMC solution at different temperatures. The viscosity was determined at different shear rates from 1 to 1,000 s^{-1}. All viscosity measurements were performed at various temperatures from 30 to 100 °C to analyze the effect of temperature on HPMC polymer.

2.3 Preparation of Cement Slurry

The density of 16.5 pounds per gallon (ppg) was used to evaluate the effect of HPMC polymer on cement slurry at high temperature. Various cement slurries were prepared by changing the concentration of HPMC polymer from 0.20 to 0.65 gallon per sack (gps). The mixing process of cement, water, solution of HPMC polymer, and other additives was performed using constant high-speed mixture at 4,000 and 12,000 rpm according to API RP10B-2 procedure [8].

2.4 Conditioning of Cement Slurry

The preheating of cement slurry is very important for performing the rheology, fluid loss, and free fluid test. The rheology and free fluid test were performed at elevated temperature. Therefore, it was necessary to preheat the slurry at 90 °C. In order to determine the properties at 90 °C, the designed cement slurries were heated at 90 °C for 20 min using atmospheric consistometer.

2.5 Rheology Measurement

The rheology of designed cement slurry was determined using Fann rotational viscometer at different dial reading according the API standard. The preheated cement slurry poured in the slurry cup of rotational viscometer. The rheology of slurries was determined in terms of shear stress by giving shear rate in terms of rpm.

2.6 Fluid Loss Testing

The API fluid loss of slurries was determined by using HPHT filter press. According to API standard, the cement slurry was conditioned at 90 °C for 20 min using atmospheric consistometer. The preheated cement slurry was poured into the slurry cup of filter press. The fluid loss of slurries was determined for the time duration of 30 min according to API criteria.

2.7 Free Water and Slurry Sedimentation Test

The separation of fluid through cement slurry was determined by free water test using 250-ml graduated cylinder. The preheated cement slurry was poured into the cylinder for two hours. According to API standard, the graduated cylinder was placed at an inclination of 45° to observe the effect in deviated condition. The settling of solid particles was analyzed based on visual observations made after examining the slurry in viscometer cup and the graduated cylinder after the free water test.

3 Results and Discussion

3.1 Rheology of HPMC Polymer

The viscosity of 2 wt% HPMC solution was determined at various temperatures from 30 to 100 °C to examine the effect of temperature on viscosity. HPMC solution shows maximum viscosity at low shear rate 1 s^{-1} and minimum viscosity at high shear rate 1,000 s^{-1}. The viscosity of 2 wt% HPMC solution is shown in Fig. 1. HPMC polymer shows high viscosity at 30 °C. One the other hand, the viscosity of HPMC solution was decreasing with increasing temperature. Like other polymer, the HPMC polymer has thermal thinning behavior by increasing temperature. The thermal thinning at elevated temperature was imposed by thermal fluctuation on the body of ether molecules [9].

On the other hand, it was observed that when the temperature was increased from 80 to 90 °C, the viscosity of solution increased. First, at 80 °C, HPMC showed minimum viscosity 17 cP at 1 s^{-1} and 793 cP at 1,000 s^{-1}. After this, above 80 °C, it was observed that viscosity of solution increased at 90 °C.

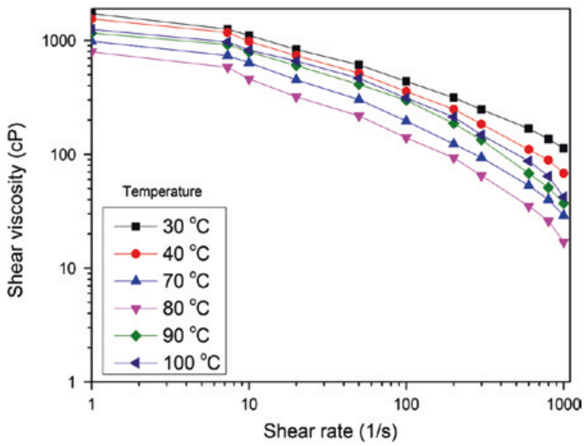

Fig. 1 Shear rate versus viscosity of HPMC solution at different temperatures

The viscosity of HPMC polymer was 37 cP at 1 s^{-1} and 1,160 cP at 1,000 s^{-1}. This was the property of HPMC polymer that above gelation temperature it will start to increase gel strength and viscosity. Increasing viscosity at 90 °C proves that HPMC polymer act as a viscosifying agent. The amplified viscosity at gelation temperature is a unique property of HPMC polymer and has not been observed in other cellulose-type polymers [10]. Further, it was also observed that at 100 °C the viscosity of both HPMC solutions was greater than the viscosity at 90 °C. The stability of HPMC polymer at high temperature made it possible to use in cement slurry for prevention of free water.

3.2 Formulation of HPMC-Based Cement Slurry

The formulation of HPMC-based cement slurries is given in Table 1. The free water, rheology, sedimentation, and fluid loss of different cement slurries were determined by changing the concentration of polymer and other additives.

3.3 Characteristics of HPMC-Based Cement Slurry

The API properties of HPMC-based cement slurries were determined at 90 °C. The density of all designed cement slurries was 16.5 ppg. The rheology, free water, visual sedimentation, and fluid loss of cement slurries at 90 °C are given below in Table 2.

It was clear that slurry 1 (without HPMC) showed high free water, fluid loss, and heavy sedimentation of particles. The solid particles settled down in the bottom of graduated cylinder. The remaining cement slurries 2–11 that contain

Table 1 Formulation of cement slurries

Slurry	Cement BWOC	FP9-LS gps	CD-33L gps	FL-66L gps	HPMC gps
1	100	0.02	–	–	–
2	100	0.02	–	–	0.65
3	100	0.02	–	–	0.50
4	100	0.02	–	–	0.30
5	100	0.02	–	–	0.20
6	100	0.02	0.03	0.40	0.30
7	100	0.02	0.04	0.30	0.50
8	100	0.02	0.05	0.40	0.30
9	100	–	0.05	0.40	–
10	100	0.02	0.05	0.40	0.40
11	100	0.02	0.05	0.40	0.50

Table 2 API properties of HPMC-based cement slurry

Slurry	Viscometer reading (rpm)						Free water ml	Fluid loss ml /30 min	Sedimentation comments
	600	300	200	100	6	3			
1	190	110	74	52	25	15	21	740	Heavy
2	+300	270	210	140	95	58	00	196	None
3	+300	257	198	127	81	47	04	288	None
4	281	233	164	107	57	37	11	484	Medium
5	257	206	147	97	42	32	15	548	Heavy
6	245	225	196	132	98	65	01	27	None
7	272	213	187	143	110	272	00	39	None
8	142	93	64	39	19	10	00	24	None
9	113	86	47	31	12	06	03	39	None
10	157	107	73	51	26	18	00	22	None
11	169	118	81	63	38	25	00	15	None

HPMC polymer shows low free water separation and very low settling of solid particles. Slurry 2 contains high-concentration 0.65 gps of HPMC showed zero free water separation within 2 h, and the fluid loss of this slurry was 196 ml in 30 min observed in slurry 2. It was also observed that as the concentration was decreasing from 0.65 to 0.20 in slurries 3–5, the free water and fluid loss was increasing. The sedimentation was analyzed by visual observation of cement slurry during free water test.

The high concentration of HPMC solution completely prevents the sedimentation of particles. HPMC polymer was viscosifying agent, and it increases the viscosity of slurry. HPMC-based cement slurries produce high viscosity and have better suspending properties. HPMC polymer has the property to act as particle suspension agent. In cement slurry, HPMC increases the cohesive force between particles that restrict the sedimentation of cement particles and control the separation of free water.

The high concentration of polymer was improving the properties of cement slurry in terms of fluid loss, free water, and sedimentation. On the other hand, high concentration of HPMC in cement slurry was increasing the rheology of cement slurry. The rheology of cement slurries is a very important property of oil well cementing operation during displacement of slurry. The high rheology of cement slurry requires high pump pressure at the time of displacement. High rheology of cement slurry will become the cause of fracture during displacement and loss of cement slurry. It was necessary to use dispersant in cement slurry that adjusts the rheology of cement slurry. Therefore, in order to maintain the rheology of cement slurries, 0.02–0.05 gps dispersant was used in slurry. On the basis of rheology of cement slurries, 0.30–0.50 gps HPMC was used for remaining cement slurries.

HPMC polymer had positive impact on cement slurry for controlling fluid loss. The increase in concentration of HPMC polymer decrease. It was also possible to decrease fluid loss further by increasing the concentration of HPMC polymer than 0.65 gps. But high concentration again becomes the cause of slurry viscosification and requires high pump pressure. Therefore, small quantity of fluid loss additive was used in cement slurry to maintain rheology and control fluid loss. The quantity 0.20–0.50 gps of fluid loss was used to obtain the fluid loss of less than 50 ml. The addition of dispersant in cement slurry has no effect on the properties of HPMC for controlling free water. For optimized cement slurries, the fluid loss and dispersant additives were used in cement slurries.

The addition of dispersant reduces the rheology in terms of viscometer dial reading, and fluid loss additive improves the properties of HMPC polymer for controlling fluid loss. The aim of dispersant is to reduce the rheology. The high concentration of HPMC increased the viscosity and rheology. Therefore, it was necessary to observe the effect of high concentration of HPMC for rheology. The concentration 0.05 gps of dispersant, 0.50 gps of fluid loss additive and 0.30–0.50 gps of HPMC solution was used to prepare cement slurry. The designed cement slurry improve the rheology, fluid loss control, free water seperation and sedimentation of solid particles through cement slurry. The visual observation of optimized cement slurries were without sedimentation of solid particles.

4 Conclusions

- The solution of HPMC polymer shows enhanced viscosity at 90 and 100 °C. It proves that HPMC polymer can be used in cement slurry at high temperature for improving the properties of cement slurry.
- Increasing viscosity of HPMC polymer at high temperature controls the sedimentation of particles as well as prevents the separation of free water at high temperature.
- HPMC polymer acknowledged as a multifunctional material that control the free water separation and improve the property of fluid loss additive at high temperature in cement slurry.

- HPMC polymer eliminates the free water completely, thus diminishing the formation of channels through cement column, and can minimize the fluid migration through permeable formation.

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