Improving Oil Well Cement Slurry Performance Using Hydroxypropylmethylcellulose Polymer

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Keywords: Additive, Cement slurry, Viscosity, Hydroxypropylmethylcellulose.

Abstract. At present, high temperature oil wells are known as the most problematic for cementing operation due to limitations of polymer. The polymers are significantly used as mutlifunctional additives for improving the properties of cement slurry. At high temperature, viscosity of polymer decreases and unable to obtained desired properties of cement slurry. It becomes then major cause of fluid loss and gas migration during cementing operations. Thus, it necessitates for polymers that can able to enhance viscosity of slurry at elevated temperatures. This paper is aiming to study Hydroxypropylmethylcellulose (HPMC) polymer at high temperature that is able to increase the viscosity at elevated temperature. In response, experiments were conducted to characterize rheological properties of HPMC at different temperatures (30 to 100 °C). Then it was incorporated as multifunctional additive in cement slurry for determining API properties (fluid loss, free water, thickening time and compressive strength). It was observed that HPMC polymer has remarkable rheological properties that can have higher viscosity with respect to high temperatures. The best concentration of HPMC was found from 0.30 to 0.50 gallon per sack. This concentration showed minimal fluid loss, zero free water, high compressive strength and wide range of thickening time in cement slurry. The results signified that HPMC polymer is becoming multifunctional additive in cement slurry to improve the API properties of cement slurry and unlock high temperature oil wells for cementing operations.

Introduction

Oil well cementing is considered as one of the important operation for wellbore completion. While doing this, to displace cement slurry between casing and formation leads the heavier particle sedimentation, bridging of particles, rapid dehydration and fluid loss. Further it becomes the main cause of gas migration and well abandonment [1]. Therefore, different additives and polymers are used to improve the properties of cement slurry that can reduce the risk of cementing failures. The polymers are capable to increase viscosity of cement slurry. It is also used as multifunctional additive to control fluid loss, free water and gas migration through cement slurry [2]. Such as, Hydroxyethylcellulose (HEC), Carboxymethylhydroxyethylcellulose (CMHEC), Vinylsulfonate and Hydroxypropylguar (HPG) are widely used in cement slurry [3, 4].

However, in oil well cementing operations these polymers are unstable in cement slurry at high temperature. The viscosity of these polymers sharply reduces with temperature and then polymer loss desired properties of cement slurry [5]. Excess concentration of polymer can be used to increase the viscosity at high temperature but it also increase the viscosity of slurry at surface condition [6]. Recently polysaccharides was modified with carbonates and other chemicals to increase the viscosity of polymer with increasing temperature [7]. Adding chemicals in polymers increase the operational cost and it may also affect the properties of cement and other additives. Therefore, it is necessary to use such polymer that increases viscosity with increasing temperature without addition of any chemicals.

Hydroxypropylmethylcellulose (HPMC) is natural polymer that was increasing viscosity at gelation temperature and is stable at high temperature. The increasing viscosity at gelation temperature is unique property of HPMC polymer in all types of cellulose polymers. HPMC is water soluble polymer that acts as thickener, film foamer, solid suspension agent and a surfactant.

Previously HPMC polymers have been used in civil industry for construction because of its multifunctional properties [8]. Recently in 2012, laboratory experiments prove that HPMC polymer have long thermal stability and will act as a permeability reducing agent for profile modification [9].

In this study HPMC polymer will use with other additives in cement slurry. The aim of this study is to find out the characteristics of HPMC polymer as an additive in cement slurry. Laboratory experiments will be perform to determine API properties of HPMC based cement slurry at 90 °C temperature.

Experimental

Materials. The materials were used in designing of cement slurries are listed below.

Cement. Class G Oil well cement provided by Baker Hughes, Kemaman (Malaysia).

Additives. Dispersant (CD-33L), Fluid Loss additive (FL-66L), Retarder (R-21LS), Defoamer (FP-9LS) supplied by Baker Hughes, Kemaman (Malaysia).

Polymer. Hydroxypropylmethylcellulose provided by Yillong Chemical Group Limited (China). **Measurements.** The properties of HPMC polymer in term of viscosity and HPMC based cement slurries were measured.

Rheology of HPMC Polymer. The viscosity of 2 wt% HPMC solution was determined using High Pressure High Temperature (HPHT) Viscometer. The viscosity of solution determined from 30 to 100 °C to examine the effect of temperature on viscosity of HPMC polymer.

Rheology of Cement Slurry. The density of all prepared cement slurries was 16.5 pounds per gallon (ppg). The rheological properties of prepared cement slurries were determined using HPHT Viscometer at 90 °C. The rheology of cement slurries was determined in term of plastic viscosity and yield point using ORCADA software of HPHT Viscometer.

Fluid Loss. According to API standard the cement slurry was conditioned at 90 °C for 20 minutes using Atmospheric Consistometer [10]. HPHT filter press was used to determine the static fluid loss of cement slurry at 90 °C for the time duration of 30 minutes.

Free Water. The free water test for cement slurry performed using 250 ml graduated cylinder. The cement slurry was conditioned in Atmospheric Consistometer at 90 °C for 20 minutes and poured in the cylinder. The cylinder kept at inclination of 45 degree according to API standard to measure the water separation through slurry. The total time duration for free water test was 2 hour.

Thickening Time. The pumpability of cement slurry in term of thickening time is important parameter for cementing operation [11]. HPHT Consistometer was used to determine the thickening time of cement slurry at 90 °C temperature and 5000 Psi pressure. The ramp time for heating the cement slurry was 49 minutes that was API standard for 16.5 ppg density of cement slurry.

Compressive Strength. The compressive strength of designed cement slurries was determined by using Static Gel Strength Analyser. According to API RP 10B-2 the compressive strength of cement slurry determined 20 to 24 hours.

Results and Discussion

Rheological Characteristic of HPMC Polymer. The viscosity of 2 wt % HPMC solution was determined from 30 to 100 °C. It was observed that viscosity of HPMC solution was decreasing with increasing shear rate from 1 to 1000 s⁻¹. HPMC solution shows maximum viscosity at low shear rate and minimum viscosity at 1000 s⁻¹ high shear rate. The trend of viscosity at all temperatures and various shear rates are shown in Fig.1 given below. The HPMC solution showed high viscosity at 30 °C that is maximum viscosity of HPMC solution. With increasing temperature from 30 to 80 °C, the viscosity of solution was decreasing continuously as shown in Fig. 1.



Fig. 1 Viscosity of 2 wt% HPMC solution at different temperature

But at 90 °C it was observed that viscosity of solution was going to increase. This is property of HPMC polymer that above gelation temperature it will start to increase gel strength and viscosity. Increasing viscosity at 90 °C proves that at high temperature greater than gelation temperature, HPMC polymer act as a viscosifying agent. The stability of HPMC polymer at high temperature makes it possible to use in cement slurry for improving properties at high temperature.

Formulation of HPMC Based Cement Slurry. The designed cement slurries contain different additives and HPMC polymer. The formulation of HPMC based cement slurries is given below in Table 1.

Slurry	Cement	FP-9LS	CD-33L	R-21LS	FL-66L	HPMC
	BWOC	gps	gps	gps	gps	gps
1	100	0.02	-	-	-	-
2	100	0.02	-	-	-	0.20
3	100	0.02	-	-	-	0.30
4	100	0.02	-	-	-	0.50
5	100	0.02	-	-	-	0.65
6	100	0.02	0.03	0.04	0.30	0.30
7	100	0.02	0.05	0.04	0.50	-
8	100	0.02	0.05	0.04	0.50	0.30

Table 1: Formulation of HPMC based cement slurry

Characteristics of HPMC Based Cement Slurry. The characteristics of HPMC polymer were analysed by performing the laboratory tests. The results of these tests are given below in Table 2 and the effect of HPMC polymer on cement slurry briefly described below.

Table 2: API properties of cement system

Slurry	Density	BHCT	PV/YP	Fluid Loss	Free	Thickening	Compressive Strength	
	(ppg)	(°C)	(cP /Ib/100ft ²)	(ml/30min)	water (ml)	Time (Hr:min)	Rate of Strength (psi/hr)	20 hour Compressive Strength (psi)
1	16.5	90	92/75	932	15	-	-	-
2	16.5	90	125/79	650	9	-	-	-
3	16.5	90	140/72	523	6	-	-	-
4	16.5	90	158/69	346	3	-	-	-
5	16.5	90	175/56	205	1	-	-	-
6	16.5	90	94/39	47	0	4:57	163	3260
7	16.5	90	52/30	36	0	3:23	139.7	2795
8	16.5	90	57/24	25	0	5:54	150.5	3010

Rheology of Cement Slurry. Rheology of cement slurry is important factor for simulating flow regimes and pump profile. The rheological properties of cement slurries were determined at 90 °C in term of plastic viscosity and yield point according to API RP 10B-2. By increasing concentration

of HPMC from 0.20 to 0.65 gps, the plastic viscosity was also increasing as shown in Table 2. Increasing concentration of polymer was increasing the viscosity and gel strength of cement slurry. The high value of plastic viscosity will create problem in pumpability of cement slurry. On other hand, HPMC polymer was decreasing the yield point that is important for flow regimes. It was necessary to decrease plastic viscosity and improves the rheology. For best cement slurry the plastic viscosity should be less than 100 cP. To improve rheology of cement slurries, the dispersant has been used in remaining cement slurries as shown in Table 1. The dispersant from 0.03 to 0.05 gps improved the rheology of HPMC based cement slurries in term of plastic viscosity and yield point at high temperature.

Fluid Loss and Free Water of Cement Slurry. Fluid loss control through cement slurry is important for cementing operations, especially to prevent fluid migration. The use of HPMC polymer in cement slurry decreases the fluid loss. The particle of HPMC polymer attaches to the surface of cement pores spaces. At the same time, reaction with water increasing the slurry viscosity that plugs interstitial pore spaces of cement filter cake. The effect of HPMC polymer on fluid loss of cement slurry can be analysed through slurries 1 to 5 as shown in Table 2. It was observed that slurry-1 without any polymer and additive showed high fluid loss 932 ml in 30 minutes. The fluid loss of remaining slurries 2 to 5 contain HPMC was decreasing from 932 to 205 ml. On the other side, the increasing concentration of HPMC has disadvantage in term of rheology of cement slurry. High concentration of HPMC solution was increasing the plastic viscosity that can create problem during displacement of cement slurry at surface condition. Further the effect of HPMC polymer for controlling fluid loss also noted in cement slurry-7 and slurry-8 that contain fluid loss additives. The presence of HPMC polymer in cement slurry-8 shows less fluid loss than the slurry-7 which was without HPMC polymer.

Separation of free water leads to change the density of slurry and sedimentation of heavier particles that becomes cause of channeling. HPMC polymer has the property to act as particle suspension agent. HPMC polymer increases the cohesive force between particles that restricts the sedimentation of cement particles and control free water separation. The increasing concentration of HPMC polymer controls the free water separation through cement slurry was observed in all cement slurries shown in Table 2.

Thickening Time. Thickening time is the duration where cement will remain liquid as a pumpable fluid. The thickening time of slurries were determined by using HTHP Consistometer. According to API RP 10B-2, the fluid will not be pumpable at consistency of 100 Bc (Bearden consistency). The time required for cement slurry to reach 100 Bc is the thickening time. HPMC polymer has positive impact on cement slurry for increasing thickening time as shown in Fig. 2, Fig.3 respectively. So the thinking time of cement slurry increase from 3:23 hour to 5:54 hour by using 0.30 gps of HPMC with other additives in slurry-8.





Fig. 3 Thickening time of slurry-8

HPMC polymer belongs to cellulose family that has long chain branch and high gel strength. This is property of long chain polymers that it slow down the setting reaction and the slurry remain in liquid state for long-time. It was observed that HPMC produced right angle thickening profile at

90 °C because the consistency of slurry increase rapidly from 30 to 70 Bc within 20 minutes. The right angle set property is important for designing cement slurry especially for reducing the transition state and prevention of fluid migration.

Compressive Strength. The compressive strength of cement slurry is one of the most important characteristic of cementing. High compressive strength of cement slurry also important to reduces the wait on cement time. The compressive strength of cement slurries determined using Static Gel Strength Analyser. The impact of HPMC polymer on compressive strength is clearly observed by the differentiation of two different slurries as shown in Fig. 4, Fig. 5.



Fig. 4 Compressive strength of slurry- 7

Fig. 5 Compressive strength of slurry- 8

It was analysed that after 20 hours the slurry without polymer has low compressive strength than HPMC contained cement slurry. The long chain of HPMC polymer creates strong chemical bond with particles and minerals of cement that increase the compressive strength. On the other hand, HPMC polymer also acts as permeability reducing agent and this property also contributes to increase the compressive strength of cement slurry.

Conclusions

• The viscosity of HPMC polymer was increasing continuously at 90° C and 100° C. It proved that HPMC polymer can be used as a viscosifying agent in cement slurry at high temperature.

• The addition of HPMC polymer in cement slurry improve the fluid loss property of cement slurry and less than 50 ml API fluid loss gained by adding fluid loss additive at 90 °C.

• Increasing viscosity of HPMC polymer at high temperature controls the sedimentation of particles as well as prevents free water at high temperature.

• The thickening time of optimized cement slurry increases with addition 0.30 gps of HPMC polymer. The result of thickening time shows that HPMC polymer acts as a retarding agent in cement slurry.

• From here, HPMC polymer recognized as a multifunctional material in cement slurry. Such as increase compressive strength and thickening time. On the other hand, it is reducing the free water separation at high temperature.

Acknowledgement

Authors wish to acknowledge Universiti Teknologi PETRONAS (Malaysia) for granting permission to present and publish this Paper. The authors also wish to Thanks Yillong Chemical Group Limited (China) and Baker Hughes Oil field Services (Kemaman, Malaysia) for the supply of materials for this research.

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10.4028/www.scientific.net/AMR.787

Improving Oil well Cement Slurry Performance Using Hydroxypropylmethylcellulose Polymer 10.4028/www.scientific.net/AMR.787.222