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Characteristics of Oil Well Cement Slurry using Hydroxypropylmethylcellulose

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Abstract: Polymers have been used in oil well cementing for improving the properties of cement slurry. Polysaccharides and their derivatives are mostly used as multifunctional additive in cement slurry. But these polymers present number of limitations at high temperature. Polysaccharides do not reveal an appropriate thickening of viscosity in cement slurry at high temperature which turn gives the fluid loss, gas migration and loss of economics. It is necessary to use such type of polymer in cement slurry that increases viscosity at high temperature. Therefore, this study present Hydroxypropylmethylcellulose (HPMC) polymer that is able to increase viscosity at high temperature and improve the properties of cement slurry. Laboratory experiments were performed to determine the characteristics of HPMC based cement slurry. The viscosity of 2 wt.% solution of HPMC polymer was determined at various temperatures. Further 0.20-0.50 gallon sack^{-1} concentration of HPMC polymer was used in cement slurry to evaluate the API properties of HPMC based cement slurry in term of rheology, free water, fluid loss, thickening time and compressive strength. It was observed that HPMC polymer was stable at high temperature and increases viscosity at elevated temperature. In cement slurries HPMC polymer resulted less than 50 mL of fluid loss; zero free water and predictable thickening time as well as enhanced final compressive strength with some other additives. The experimental result showed that HPMC has significantly improved the properties of cement slurry at high temperature.

Key words: Polymers, polysaccharides, oil well cementing, cement slurry, hydroxypropylmethylcellulose

INTRODUCTION

Oil well cementing is most important operation for wellbore completion. The cement slurry is placed in wellbore to isolate permeable zone, support axial load of casing string, protect casing from corrosion and prevent fluid migration. The designing of optimum cement slurries for desired properties requires several chemicals to adjust the slurry properties (Brandl *et al*., 2012). Therefore, various types of additives and polymers have been used to improve API properties of cement slurry. Currently, different types of polymers are used in petroleum industry as viscosifying agent. Those polymers used as multifunctional additive in cement slurry. The polymers such as, Carboxymethylcellulose (CMC), Hydroxyethylcellulose (HEC), Carboxymethylhydroxyethylcellulose (CMHEC) and Hydroxypropylguar (HPG) are widely used in cement slurry (Brandl *et al*., 2011; Reddy *et al*., 2012). These polymers act as free water, fluid loss and gas migration control agent in cement slurry. But most of the polymers suffer thermal thinning problem and loss the viscosity at high temperature. Such type of multifunctional additives did not show any effect on fluid loss and thickening time at 94°C. However, polysaccharides showed some retardation effect and control fluid loss below 60°C (Ganguli, 1993). The polymers were modified with other chemicals to improve slurry performance and stability of polymer at high temperature. HEC used as fluid loss control agent in cement slurry. Recently, polysaccharides were synthesized with carbonates to increase the viscosity at high temperature (Reddy, 2011). The modification of polymers with other additives is increasing the cost and it can also affect the properties of cement. Therefore, it becomes essential to use such viscosifying polymer that increases viscosity with temperature.

Hydroxypropylmethylcellulose (HPMC) is self active viscosifier polymer. HPMC is stable at high temperature and increase viscosity at gelation temperature without addition of any other chemical (Abbas *et al*., 2013). HPMC has property to act as thickener, film foamer, suspension aid, water retention agent and surfactant at high temperature (Sarkar and Walker, 1995). The increasing viscosity of HPMC polymer with increasing temperature is unique property that was not found in other cellulose

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type polymers. HPMC polymer has wide range of applications in food, pharmaceutical and civil industry. Previously, HPMC polymer was used in cement for construction to increase the strength and mechanical properties of cement (Fu and Chung, 1996). Recently in 2012, HPMC polymer was used in EOR application for profile modification. It was observed that HPMC polymer was stable at high temperature and worked as permeability reducing agent at high temperature (He *et al*., 2012).

This study presents the use of HPMC polymer in cement slurry. HPMC polymer is used for the first time ever as an additive in oil well cementing for improving the properties of cement slurry. The aim of this study is to find out the characteristics of HPMC polymer as an additive in cement slurry. The viscosity of HPMC polymer was determined in term of shear rate at different temperature. Further, series of experiments were conducted to determine the API properties of HPMC based cement slurry. The properties such as, rheology, fluid loss, free water, compressive strength and thickening time was determined by changing the concentration of HPMC and other additives at 90°C.

MATERIALS AND METHODS

Materials: The commercial sample of HPMC polymer used for performing experiments. The HPMC polymer was provided by Yillong Chemical Group Limited (China). The oil well cement class "G" was used to prepare cement slurry. Additionally, some other additives such as Dispersant (CD-33L), Fluid Loss additive (FL-66L), Retarder (R-21LS), Defoamer (FP-9LS) were also used with HPMC polymer for designing optimum cement slurry. The class G cement and other additives supplied by Baker Hughes Oil Tool Services, Kemaman (Malaysia).

Viscosity measurement: To observe the effect of temperature on HPMC polymer, the viscosity was determined at various temperatures 30-90°C. The viscosity of solution was determined using Rotational Viscosmeter (OFITE) model 1100.

Rheology measurement: The rheology of cement slurries was determined in terms of plastic viscosity and yield point using Rotational viscometer. The density of cement slurries was 16.5 pounds per gallon (ppg). The cement slurries were conditioned at 90°C using Atmospheric Consistometer. Then, the rheology of cement slurries determined at elevated temperature of 90°C.

Fluid loss measurement: The fluid loss test was performed using HTHP Filter Press. It determines static fluid loss through cement slurry. In order to determine fluid loss at 90°C, the cement slurry was preheated in atmospheric consistometer for 20 min and poured into filter press cup. According to API standard, the fluid loss of cement slurry determined for 30 min at differential pressure of 1000 psi (API RP 10B-2, 2009).

Free water determination: The 250 mL graduated cylinder was used to determine the free water through cement slurry. As the free water was determined at 90°C, therefore the cement slurry was preheated at 90°C using Atmospheric Consistometer. According to API standard, the graduated cylinder was kept at 45° inclination to obtain the free water at the surface. The total time duration for free water determination was 2 h. Further, the sedimentation effect was also observed in graduate cylinder through visual observation.

Thickening time determination: The determination of thickening time of cement slurry is very important parameter of cementing operation. The thickening time of cement slurry determine the length of time of cement slurry remains in pumpable fluid state for wellbore temperature and pressure (He *et al*., 2012). The thickening time was determined using HPHT Consistomer. The thickening time was determined in term of consistency unit Bc (Bearden consistency). The thickening time of designed cement slurries was determined at 90°C at differential pressure of 5000 psi. The ramp time was 49 min for increasing the temperature of 16.5 ppg density of cement slurry.

Compressive strength measurement: There are two methods to determine compressive strength. The compressive strength of cement slurry is non destructive method. It determines compressive strength ultrasonically and measures the time interval of ultrasonic energy through cement slurry under simulated temperature and pressure. Ultra sonic cement analyzer (UCA) and Static Gel Strength Analyzer (SGSA) have been used to determine non destructive compressive strength. In this study SGSA was used to determine compressive strength. The compressive strength of cement slurries determined at 90°C and 5000 psi for 18-24 h according to API standard.

RESULTS AND DISCUSSION

Rheological characteristic of HPMC solution: The viscosity was determined to insure the stability of HPMC at elevated temperature. The viscosity was determined at different temperature ranging from 30-90°C with respect to shear rate. HPMC polymer showed maximum viscosity at ambient temperature (30°C). It was observed that viscosity of HPMC decreased with increase of shear rate. Polymer showed maximum viscosity of 1723 cP at 1 sec^{-1} sear rate and minimum viscosity of 134 cP at 1000 sec^{-1} at 30°C as given in Fig. 1.

To investigate the impact of temperature on HPMC polymer, the viscosity was also determined at 30, 40, 70, 80 and 90°C. Like other polymers, the viscosity of HPMC decreased with increasing temperature. The viscosity of HPMC polymer was continuously decreased until 80°C. HPMC polymer showed minimal viscosity of 793 cP at 1 sec^{-1} and 11 cP at 1000 s^{-1} at 80°C. However, the viscosity of HPMC polymer was increased at 90°C. The viscosity of HPMC polymer at 90°C was greater than the viscosity of solution at 70 and 80°C as showed in Fig. 1. With increasing temperature 80-90°C, viscosity of solution increased from 793-1190 cP at 1 sec^{-1} shear rate and 11-31.5 cP at 1000 sec^{-1} shear rate. This is attributed to property of HPMC polymer that the viscosity and gel strength of solution is enhanced as the temperature is increased above gelation temperature. The increase in viscosity of HPMC solution at gelation temperature is due to hydrophobic interaction between the molecules of methoxyl group. With increase in temperature HPMC solution hydrates which causes decrease in viscosity. However, at gelation temperature, sufficient dehydration of polymer occurs.

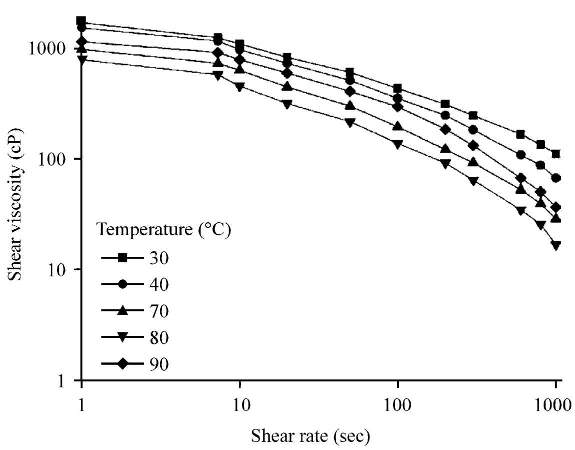

Fig. 1: Shear rate vs shear viscosity of HPMC solution at different temperatures

As a result, polymer to polymer association happens and the solution begins to increase the viscosity. The amplified viscosity at gelation temperature is unique property of HPMC polymer and was not observed in other cellulose type polymers. The increased viscosity of HPMC polymer at 90°C showed that HPMC is self active viscosifying agent. The enhanced viscosities of HPMC polymer at elevated temperature confirmed that HPMC polymer can be used in cement slurry at high temperature.

Formulation of cement slurry: The cement slurries were prepared using cement, HPMC polymer and other additive. The formulation at various concentration of HPMC based cement slurries are given below in Table 1. The additive defoamer (FP-9LS) was used in cement slurry to remove the bubbles from slurry. The minor quantity of retarder (R-21LS) was also used for the safety of equipment during thickening time test.

Characteristics of cement slurry: Various laboratory tests were performed to investigate the characteristics of HPMC polymer. The results of these tests are given below in Table 2 and the effect of HPMC polymer on cement slurry briefly described below.

Rheology of cement slurry: Rheology of cement slurry is one of the most important parameters to simulate the flow regimes and pump profile. All the characteristics of

Table 1: Formulation of HPMC based cement slurry

Slurry	Cement BWOC	FP-9LS (gps)	CD-33L (gps)	R-21LS (gps)	FL-66L (gps)	HPMC (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	0.40	0.30
7	100	0.02	0.05	0.04	0.40	-
8	100	0.02	0.05	0.04	0.50	0.40

Table 2: Characteristics of cement slurries

Slurry	Density (ppg)	Temperature (°C)	PV/YP (cP /Ib/100ft^2)	Fluid loss (mL 30 min^{-1})	Free water (mL)	Thickening time (h: min)	Compressive strength (psi)
1	16.5	90	92/75	740	21	-	-
2	16.5	90	125/79	548	15	-	-
3	16.5	90	140/85	484	11	-	-
4	16.5	90	158/91	288	04	-	-
5	16.5	90	175/94	196	00	-	-
6	16.5	90	94/39	36	00	4:57	3010
7	16.5	90	52/30	47	00	3:23	2795
8	16.5	90	57/24	25	00	5:54	3260

cement slurry are given in Table 2. It can be observed from the Table 2 that as the concentration of HPMC is increased from 0.20-0.65 gps, the plastic viscosity and yield point are increased. This increment is due in the viscosity and gel strength of cement slurry. In general, the problem of pumping the cement slurry through wellbore occurs when plastic viscosity becomes high. Therefore, it was required to maintain the plastic viscosity to a value less than 100 cP. Hence, dispersant was added to cement slurry for improving rheology of cement slurries and results of rheology are presented in Table 2. The dispersant from 0.03-0.05 gps improved the rheology of HPMC based cement slurries in terms of plastic viscosity and yield point at high temperature. The plastic viscosity and yield point were reduced to 57 cp and 24 Ib/100ft^2 using 0.05 gps of dispersant in cement slurry-8.

Effect of HPMC on fluid loss and free water separation: The loss of fluid through cement slurry under borehole condition decreases the hydrostatic pressure and causes gas migration. The use of HPMC polymer in cement slurry decreases the fluid loss. The effect of HPMC polymer on fluid loss of cement slurry is presented in Table 2. As can be seen in the Table 2, slurry-1 is prepared without HPMC polymer and additive shows high fluid loss 740 mL in 30 min. On the other hand, the fluid loss decreased from 740-196 mL for the slurries-2 to 5 due to addition of HPMC. In the mean time, the use of HPMC polymer increases the plastic viscosity of cement slurry. The high plastic viscosity of cement slurry requires high pump pressure during cementing operation. Thus, the fluid loss additive was used in cement slurries. It was observed that addition of fluid loss additive improved the properties of HPMC by reducing fluid loss. The fluid loss was reduced to 36 mL in 30 min using 0.40 gps of fluid loss additve and 0.30 gps of HPMC solution in slurry-6. Further, it was observed that slurry-7 without HPMC polymer showed high fluid loss of 47 mL than slurry-6. The fluid loss was further decreased to 25 mL for slurry-8 by increasing concentration of HPMC polymer.

The free water through cement slurry was determiend at 90°C using graduated cylinder. The free water through cement slurries decreased from 21-04 mL using 0.50 gps concentration of HPMC solution in cement slurry-04 as presented in Table 2. Further, the free water was reduced to 0.0 mL of slurry-5 when the concentrationof HPMC solution was inceased to 0.65 gps. The slurries 6-8 also showed the 0.0 mL of free water.

Thickening time of cement slurries: The thickening time is very important constraint for designing cement slurry. The thickening time is the duration where slurry behaves as pumpable fluid during placement of cement slurry. In laboratory, the thickening time was determined using HPHT consistometer and measured in Bc (Bearden consistency). According to API criteria, the cement slurry becomes solid at 100 Bc consistency and cannot be pumpable. The thickening time of cement slurry is highly effected by temperature. Through the laboratory experiments it was observed that HPMC was increasing the thickening time of cement slurry. Figure 2 and 3 illustrates the thickening time of slurry 7 and 8, respectively. The thickening time of cement slurry-7 was 3:23 h. The addition of 0.40 gps HPMC polymer further increased the thickening time to 5:54 h.

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

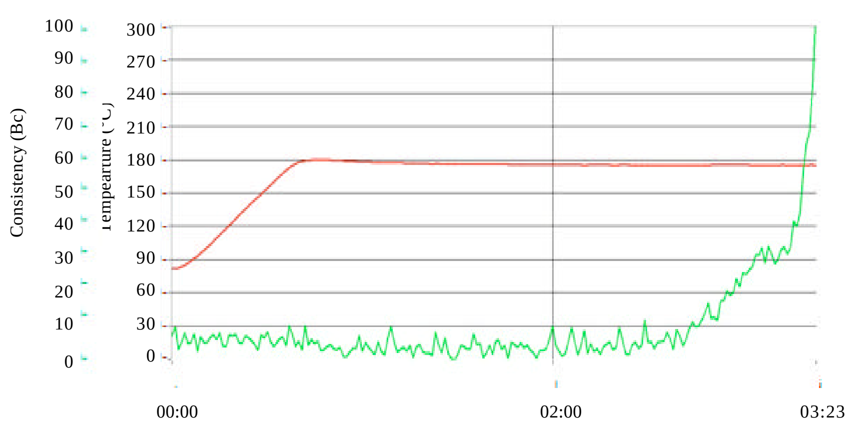

Fig. 2: Thickening time of slurry-7

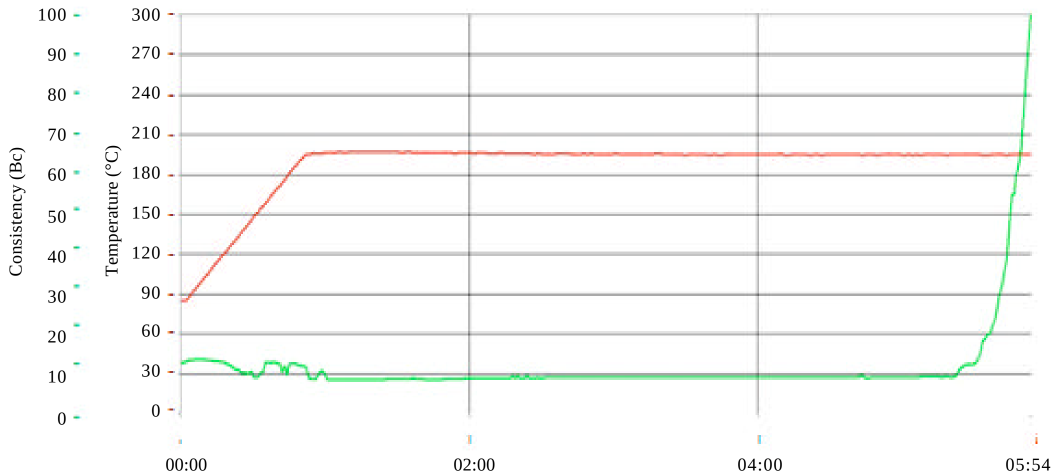

Fig. 3: Thickening time of slurry-8

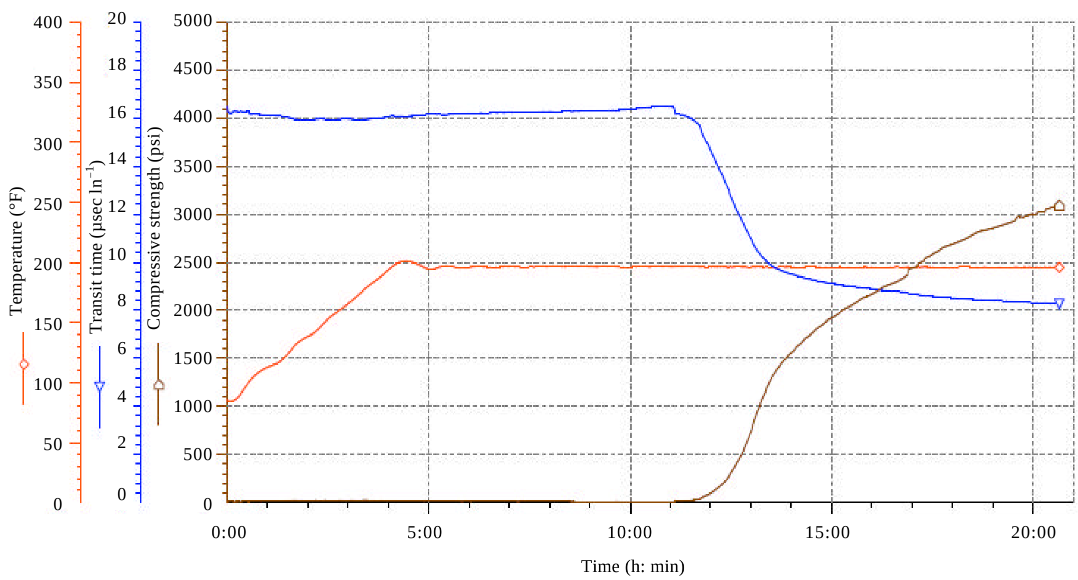

Fig. 4: Compressive strength of slurry-6

cement slurry for increasing thickening time as shown in Fig. 2 and 3, respectively. The thinking time of cement slurry increase from 3:23-5:54 h by using 0.30 gps of HPMC with other additives in slurry-8.

HPMC polymer effect on compressive strength: The compressive strength of cement slurry is important characteristic for reducing Wait On Cement (WOC) and gas channelling through cement sheath. The impact of HPMC polymer on compressive strength was analyzed through the experimental results of cement slurries. Same like thickening time, HPMC polymer also increase the compressive strength at elevated temperature. It was observed that HPMC contained slurry showed high compressive strength than the slurry without polymer as showed in Fig. 4 and 5.

It was observed that after 20 h the slurry without polymer showed low compressive strength than HPMC contained cement slurry-6 and slurry 8. The compressive strength of slurry-7 was 2800 psi in 20 h where the compressive strength of slurry-6 was 3050 psi as showed in Fig. 4 and 5. The increase in compressive strength was

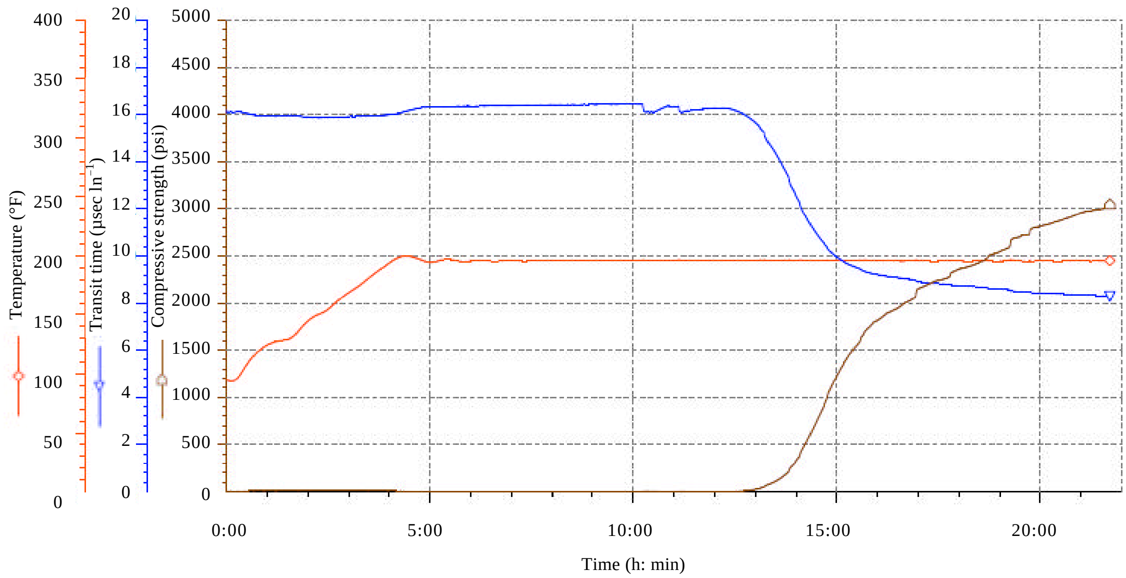

Fig. 5: Compressive strength of slurry-7

due to the long chain of HPMC polymer that created strong chemical bond with particles and minerals of cement and increased the compressive strength. It is concluded that HPMC polymer also acts as permeability reducing agent and contributes to increase the compressive strength of cement slurry.

CONCLUSION

The solution of HPMC polymer showed higher viscosity at 90°C, it proves that HPMC polymer act as viscosifying agent at high temperature. The plastic viscosity of cement slurry was increased due HPMC polymer. However, plastic viscosity was maintained when dispersant was added to the slurry. The addition of HPMC polymer in cement slurry decreased the fluid loss. Fluid loss of slurry minimized to 50 mL API fluid loss at 90°C using 0.30-0.40 gps of HPMC. The combination of HPMC polymer with cement slurry also improved thickening time, free water and compressive strength. HPMC polymer is recognized as a multifunctional additive for oil well cementing and can be beneficial for high temperature cementing applications.

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