



Application of cellulose-based polymers in oil well cementing

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Abstract

Cellulose-based polymers have been successfully used in many areas of petroleum engineering especially in enhanced oil recovery drilling fluid, fracturing and cementing. This paper presents the application of cellulose-based polymer in oil well cementing. These polymers work as multifunctional additive in cement slurry that reduce the quantity of additives and lessen the operational cost of cementing operation. The viscosity of cellulose polymers such as hydroxyethyl cellulose (HEC), carboxymethylcellulose (CMC) and hydroxypropyl methylcellulose (HPMC) has been determined at various temperatures to evaluate the thermal degradation. Moreover, polymers are incorporated in cement slurry to evaluate the properties and affect in cement slurry at 90 °C. The API properties like rheology, free water separation, fluid loss and compressive strength of slurries with and without polymer have been determined at 90 °C. The experimental results showed that the viscosity of HPMC polymer was enhanced at 90 °C than other cellulose-based polymers. The comparative and experimental analyses showed that the implementation of cellulose-based polymers improves the API properties of cement slurry at 90 °C. The increased viscosity of these polymers showed high rheology that was adjusted by adding dispersant which optimizes the rheology of slurry. Further, improved API properties, i.e., zero free water separation, none sedimentation, less than 50 ml/30 min fluid loss and high compressive strength, were obtained through HEC, CMC and HPMC polymer. It is concluded that cellulose-based polymers are efficient and effective in cement slurry that work as multifunctional additive and improve API properties and cement durability. The cellulose-based polymers work as multifunctional additive that reduces the quantity of other additives in cement slurry and ultimately reduces the operational cost of cementing operation. The comparative analysis of this study opens the window for petroleum industry for proper selection of cellulose-based polymer in designing of cement slurry.

Keywords API properties · Cellulose · Cementing · Polymer

Abbreviations

API	American Petroleum Institute
BWOC	By weight of cement
CMC	Carboxy methylcellulose
cP	Centipoise
HEC	Hydroxyethyl cellulose
HPMC	Hydroxypropyl methylcellulose
PPG	Pound per gallon

Introduction

Polymers are dynamic research area in petroleum industry with respect to their applications. Variety of polymers has been used in different area of petroleum. The polymers are used in enhanced oil recovery, drilling fluid, fracturing application and oil well cementing. Cellulose are natural polymers that can be used as film former, thickener and viscosifying agent in different applications of petroleum industry (Abbas et al. 2013a, b). There are various types of cellulose such as xanthan, guar gum, hydroxypropyl guar, hydroxyethyl group, carboxyethyl and carboxymethyl group (Plank et al. 2009). These all cellulose-type polymers are used in different fields. Besides other applications, it has excellent usage in oil well cementing operations (Roshan and Asef 2010). Cement is the key material that has been used during drilling operation to provide zonal isolation, protect the casing string and provide the strength for installing wellhead (Pour and Moghadasi 2007). The oil well cement is mixed

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with water and other additives like dispersant, accelerator, deformer, retarder, fluid loss additive and loss circulation materials for their specific properties in cement slurry (Bayer and Knarr 2012). But in oil well cementing, the used additives have limitations related to temperature, pressure and admixture property with other additives and cement. The usages of multiple additives in cement slurry encourage the compatibility issue with cement material that reduces the efficiency of cement durability (Abbas et al. 2013a, b). This improper cement slurry creates the cracks and voids in cement. With the passage of time, it becomes permeable zone and the fluid lost from cement slurry. This fluid loss created permanent channel that becomes the cause of fluid migration to surface as shown in Fig. 1. On the other hand, the usages of multiple additives in designing of cement slurry increase the economical cost of cementing operation (Reddy and Patil 2012).

Oil industry moves to polymer that has more advantages on numerous additives. There are number of polymers that have been used in petroleum industry. From all of them, cellulose-based polymer has variety of applications in oil well cementing where it acts as multipurpose and functional additive in oil well cement slurry at wide range of density and temperature (Brandl et al. 2012). The single derivative of cellulose polymer has advantage on other polymers as being film former and viscosifying agent that could be used in cement slurry for gas migration and fluid loss control (Reddy and Patil 2012). Therefore, this paper presents the applications of cellulose type polymers in cement slurry to evaluate their effect on cement slurry. The polymers like guar gum, xanthan and hydroxypropyl guar were studied by various authors to evaluate their effect in cement slurry at different temperature ranges. There was gap in the literature for comparative analysis of natural cellulose polymer and their applications in cementing operations. Therefore, the

comparative study on the base of experiments for cement slurry design has been studied for the first time in this paper using different derivatives of cellulose. The comparative analysis through viscosity and API properties of cement slurries of this study assists the petroleum industry for proper selection of cellulose polymer for cementing operation. The present study is limited to viscosity determination of cellulose polymers at 90 °C and API properties measurement in term of rheology, fluid loss, sedimentation, free water separation and compressive strength of cement slurries.

The derivatives of cellulose ethyl, methyl and propyl methyl group like HEC, CMC and HPMC have been investigated. As cellulose polymers have been considered as viscosifier, the comparative analysis of viscosity using HEC, CMC and HPMC, respectively, has been performed at 90 °C with respect to shear rates through experiment using HPHT viscometer. In next, this study explores the prospective of cellulose-based polymer in oil well cementing at elevated temperature of 90 °C. The slurry of 15.8 lb per gallon (ppg) density having class G cement system was prepared and used to study the effect of cellulose-based polymer on API properties of cement slurries. The different experiments have been performed using various cement slurries in order to determine API properties such as free water, sedimentation of particles, fluid loss, rheology as well as compressive strength with and without addition of HEC, CMC and HPMC.

Materials and methods

The experimental plan for this study was accomplished by using API-recommended practice. The API RP 10B-2 provides the recommended practice for designing of cement slurries, preparation and testing the specified API properties of cement slurries (API Practice 2009). The class G cement having specific gravity of 3.14 was used for preparation of slurries with other additives such as deformer, fluid loss additive, dispersant and cellulose-based polymer. The class G cement contains different concentrations of various components such as SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , K_2O , P_2O_5 , CaO , MgO , SO_3 (Ou et al. 2012).

Preparation of polymer solution and viscosity measurement method

It was necessary for viscosity measurement that the polymers should be in liquid form. Therefore, the liquid solution of polymers was prepared using distilled water by performing the experiment through hot magnetic plate at room temperature (Abbas et al. 2015). The 02 wt% concentration of each polymer solution was prepared for investigation.

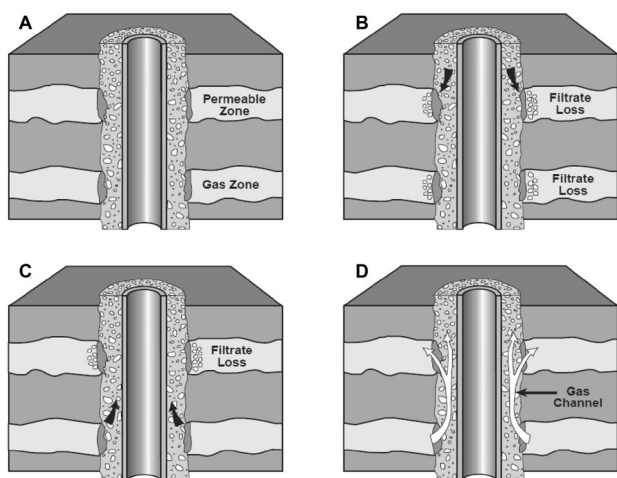


Fig. 1 Gas migration problem due to improper cement selection

The viscosity of HEC, CMC and HPMC polymer solutions was determined through HPHT viscometer at 90 °C and 1–1000 S⁻¹ shear rates.

Preparation of cement slurries method

The series of slurries were prepared using polymer and additives with class G cement for API properties of cement slurry measurement. The cement slurries were prepared through speed mixture equipment where fluctuating dosage of additives mixed with class G cement having concentration of 100 BWOC (by weight of cement) and water in all cement slurries. Different concentrations of additives such as naphthalene sulfonate (dispersant), silicone (defoamer), borates (retarder), sodium polyacrylate (fluid loss) have been mixed with cellulose to prepare cement slurries. The cement slurry formulation is given in Table 1.

API properties of cement slurries measurement methods

The API properties of prepared cement slurries will be determined at elevated temperature of 90 °C. Therefore, it was necessary to increase the temperature of cement slurry manually. In order to enhance the temperature, the formulated cement slurries were preheated and conditioned in atmospheric consistometer at 90 °C for 20 min to elevate the temperature of slurries in order to perform API properties measurement experiments.

In next for determination of rheology in term of plastic viscosity and yield point of cement slurries, the rotation viscometer has been used. The preheated cement slurry was transferred in rotational viscometer to determine rheology of slurries.

In next, the preheated cement slurries were poured in graduated cylinder and kept at 45° angle to observe the effect of cement particles sedimentation and separation of free water (Ganguli 1993).

The loss of fluid through cement slurries of preheated slurries was determined using HPHT filter press having

175 ml cell with 45 µm (325) mesh screen of OFIT company at 90 °C temperature and 1500 psi pressure (Baig et al. 2017).

To simulate the effect of cellulose-based cement slurries on compressive strength for bottom hole condition, the compressive strength of cement slurries was determined through ultra sonic cement analyzer for the time period of 18 h (Xuli and Chung 1996). The temperature for complete experiment was 90 °C, and the pressure was 3000 psi.

Results and discussion

Viscosity of cellulose-based polymer

The viscosity of 02 weight percent solution of HEC, CMC and HPMC polymer was determined at 90 °C at different shear rates as shown in Fig. 2. Initially at 1 S⁻¹ shear rate, the viscosity of these polymers was high, but the viscosity was reduced as shear rate was increased. The measured viscosity of HEC solution was 7 centipoise (cP), the viscosity of CMC solution was 25 cP, and the viscosity of

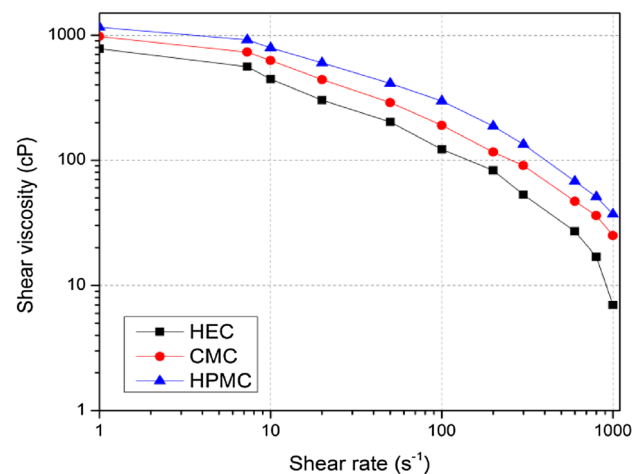


Fig. 2 Viscosity of cellulose-based solutions at 90 °C

Table 1 Designing of cement slurries

Slurry no.	Dispersant gps	Fluid loss additive gps	Defoamer gps	Retarder gps	HEC gps	CMC gps	HPMC gps
01	0.20	0.30	0.02	0.04	–	–	–
02	–	–	0.02	0.04	0.30	–	–
03	0.20	0.30	0.02	0.04	0.30	–	–
04	–	–	0.02	0.04	–	0.30	–
05	0.20	0.30	0.02	0.04	–	0.30	–
06	–	–	0.02	0.04	–	–	0.30
07	0.20	0.30	0.02	0.04	–	–	0.30

HPMC solution was 36 cP at 1000 S⁻¹. The HEC polymer solution showed very low viscosity than other solutions. It shows that at 90 °C with high shear rate, the HEC polymer degrades and showed minimum viscosity. On the other hand, HPMC polymer shows high viscosity and could act as viscosifying agent at 90 °C with respect to other polymers.

Properties of cellulose-based cement slurries

The cement slurries of 15.8 ppg density were prepared to observe the effect of cellulose-based polymers at 90 °C. A series of cement slurries of altered dosage of additives and polymers were prepared as formulation is shown in Table 1. The properties of all slurries are shown in Table 2 and discussed separately.

Rheology of cement slurries

The plastic viscosity and yield point are considered important rheological properties of cement slurries to control pressure drop and creating turbulent flow for mud cake removal (Sarkar and Walker 1995). It was observed that cellulose-based slurries-2 to 7 show increased plastic viscosity and yield point as shown in Table 2. As the cellulose is a long-chain polymer, it increases the viscosity in cement slurries that absorbs water on cellulose group. As HPMC and CMC showed less temperature and shear rate degradation than HEC solution, in cement slurries the plastic viscosity and yield point of these both solutions were higher than that of HEC-based slurries. On the other hand, the enhanced viscosity affects the pressure drop. Therefore, it will increase the pressure drop and create problems during displacement of slurry. The friction reducing agent like lignosulfonate called dispersant was added in slurries to adjust the viscosity and enhance the rheology of slurries. The addition of 0.20 gps of dispersant

adjusts the plastic viscosity and yield point of cellulose-based cement slurries.

Sedimentation and free water

The sedimentation of designed cement slurries was analyzed through visual observation in graduated cylinder through API slandered (Ganguli 1993). As discussed in materials and methods section, the cement slurry was poured in the graduate cylinder that was kept at 45° angle according to API slandered to observe the effect of sedimentation (API API Practice 2009). The determination of sedimentation is based on only visual observation of sediment particles in cement slurry. The slurry-01 that was without cellulose polymer showed heavy sediments and 12 ml free water was collected from the top of slurry that was poured in graduated cylinder. The slurry that has heavy sediments creates non-homogeneity in cement which directly affects the compressive strength of slurry. The sediment and free water separation can be reduced by adding any viscosifying agent. Therefore, the free water separation and sedimentation was reduced by adding cellulose polymer in cement slurries as observed in slurries 02–07 and shown in Table 2. It was observed that slurries-06 and 07 have no sedimentation and the free water separation was less than 05 ml. It was due to the viscosity of cement slurry as these both slurries contain HPMC that have high viscosity than that of other both polymer solutions. Therefore, HPMC polymer is considered as better viscosifying agent than other cellulose polymer for controlling free water separation and particle sedimentation.

Fluid loss of cement slurries

Under the pressurized condition of wellbore, the loss of fluid creates channel in the cement sheath. During settling time of cement, it becomes permanent and gas starts to migrate through these channels that ultimately disturb the complete phenomena of drilling operation. According to API standard, the fluid loss through cement slurries should be less than 50 ml in 30 min and it could be achieved by adding

Table 2 API properties of cement slurries at 90 °C

Slurry no.	Plastic viscosity (PV) cP	Yield point (YP) lb/100 ft ²	Free water ml	Sedimentation	Fluid loss (ml/30 min)	Compressive strength (Psi)
01	48	30	12	Heavy	65	2430
02	72	47	10	Medium	42	–
03	59	35	08	Medium	29	2700
04	78	51	07	Medium	33	–
05	64	42	04	None	18	3700
06	85	58	03	None	25	–
07	71	49	01	None	15	3600

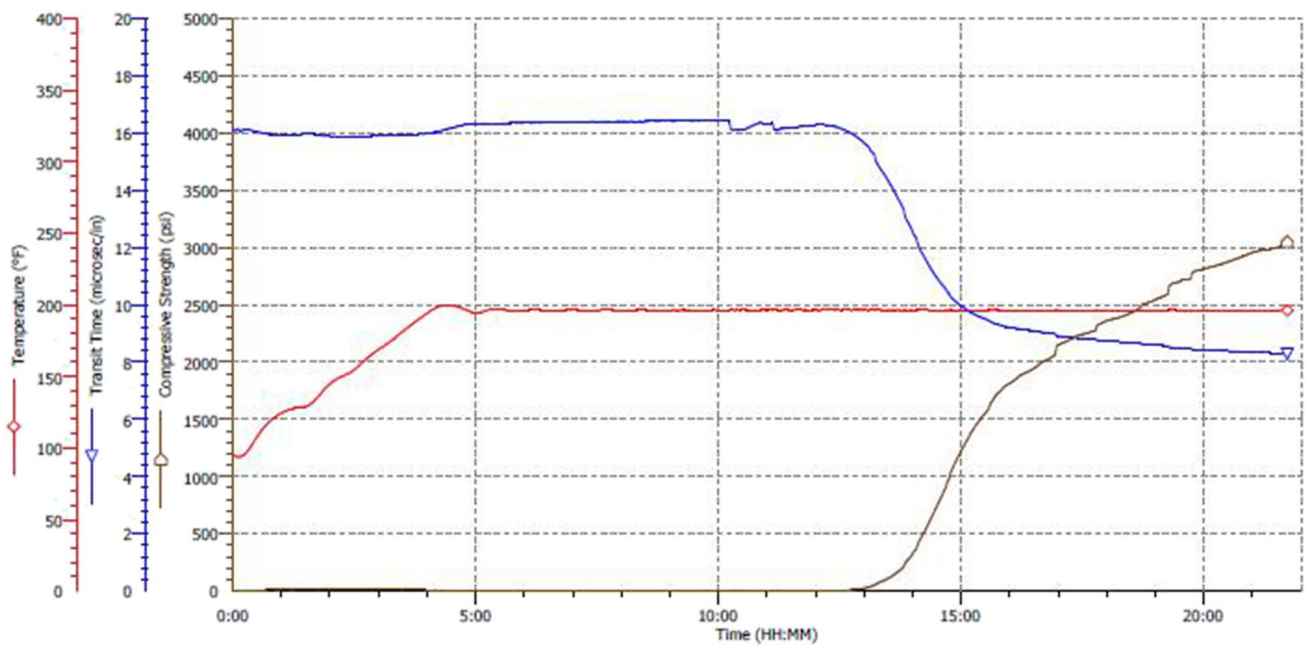


Fig. 3 Compressive strength of slurry-01 (without polymer)

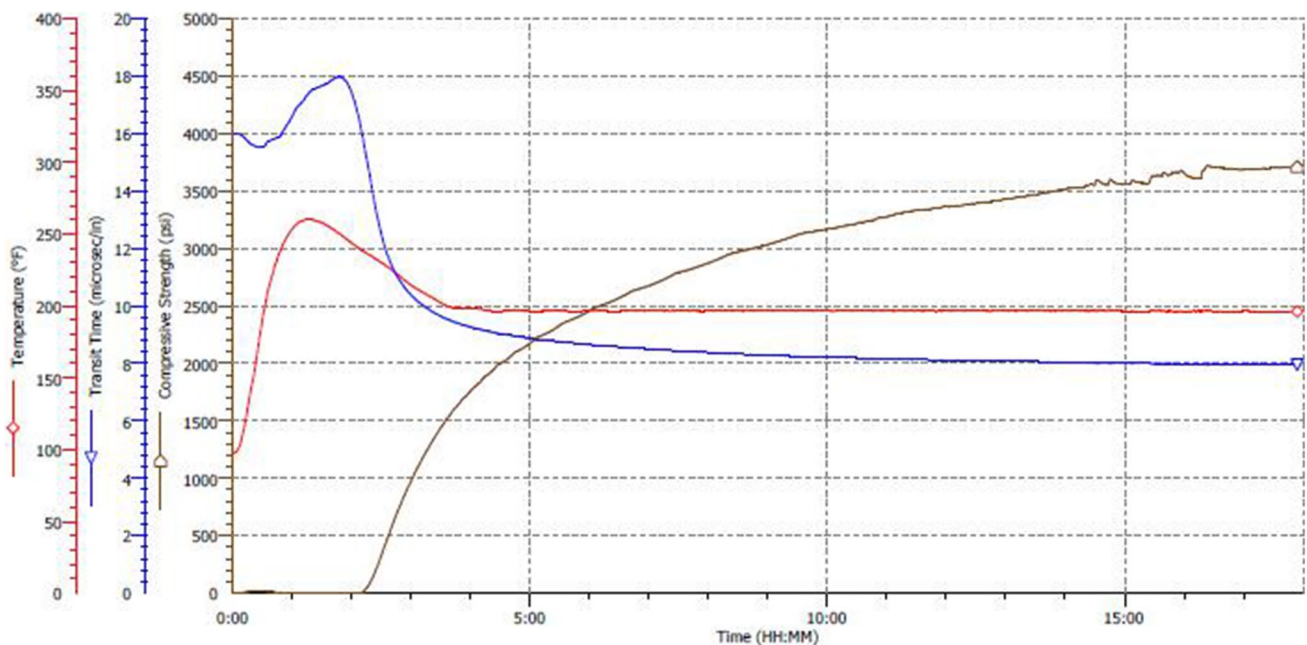


Fig. 4 Compressive strength of slurry-05 (CMC polymer)

viscosifying agent (Ganguli 1991). Through the laboratory experiment of HPHT filter press it was observed that the addition of cellulose polymer like HEC, CMC and HPMC in cement slurry reduces the fluid loss. Secondly, it depends upon the viscosity of polymer solution at elevated temperature. It was observed that the fluid loss of slurry-01 without polymer solution was higher than that of other slurries-02

to 07 which comprise cellulose polymer. The reduced fluid loss was due to the impact of addition of these polymers in cement slurry, as these polymers act as film former and thicker at specified temperature that enhances the viscosity and reduce the removal of water at high temperature.

Compressive strength of slurries

The compressive strength of slurries is considered an important characteristic of drilling cement as it is related to tensile strength and elastic property of slurry. The high compressive strength increases the service life of well, provides the zonal isolation and supports the wellhead at surface (Sabins and Sutton 1986). Therefore, the compressive strength of improved cement slurries with other additives is determined and discussed in this paper. It was observed that the polymer-based cement slurries 03, 05 and 07 showed improved compressive strength than slurry-01 as shown in Figs. 3 and 4. The addition of cellulose polymer in cement increases the compressive strength and gains the early compressive strength as shown in Figs. 3 and 4. In compressive strength analysis, the 3D structure chain of cellulose creates the strong chemical bond with other components and it increases the compressive strength between the cement particles.

Conclusions

The API properties of 15.8 ppg density cement slurries were determined to observe the effect of cellulose polymers on cementing operation. Through the experimental study, it was concluded that:

- The viscosity of HPMC polymer was greater than CMC and HEC polymer solutions at 90 °C. This showed that at high temperature the HPMC will be more stable and will behave as viscosifying agent in cement slurry than other cellulose polymers.
- It is necessary to use friction reducing agents like dispersant in polymer-based cement slurries in order to improve the rheology such as plastic viscosity and yield point for reducing pump pressure during displacement.
- The cellulose-based polymer has been used as multipurpose and multifunctional additive in cement slurry, as single integer of cellulose reduces the loss of fluid, sedimentation of particles and free water separation through cement slurries at high temperature.
- The cellulose-based polymers also enhance the early compressive strength of cement slurries. The HPMC solution showed high compressive strength than that of other cellulose-based polymer.

Recommendations

The present study is limited to performance evaluation of cellulose derivatives in cement slurries. Further studies should be carried out for determination of transient time

period as well gas migration through cement slurries. It is also recommended to evaluate the performance of these derivatives in other field of petroleum related to enhanced oil recovery, fracturing and drilling fluid through comparative analysis.

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