Experimental study to determine the rheological properties of oil well cement using HPMC Polymer

ISSN (e) 2520-7393
ISSN (p) 2521-5027
Received on 13st Dec, 2019
Revised on 28th Dec, 2019
www.estirj.com

Sohail A. Shiakh[1], A.Haque Tunio[2], A.Samad Shaikh[3], G.Abbas[4]

[1,3,4] *Department of Petroleum & Natural Gas Engineering, Mehran University of Engineering & Technology SZAB Campus Khairpur Mir's', Pakistan.*

[2] *Institute of Petroleum & Natural Gas Engineering, Mehran University of Engineering & Technology Jamshoro, Pakistan.*

Abstract: Cement rheology plays a significant role in the removal of mud from well and provide help in determining the flow consistency during cementing operation. These properties predict the flowing characteristics of cement under different well conditions. The flow properties of cement slurry such as yield point, gel strength, plastic viscosity, and frictional properties etc. can be calculated by rheological measurements. Rheological behavior of slurry is controlled by various factors including the mix water, cement grain size and shape, chemical structure, cement additives and testing procedures. Cement rheology does not retain its properties in high temperature environment and may lead to fluid loss and strength retrogression over the life of a well. Therefore, it is key challenge for petroleum industry to maintain the slurry properties. To address this issue, cellulose based polymer, i.e. hydroxypropyl methylcellulose (HPMC) is added to slurries to act as viscosifying agent. The purpose of this research is to examine the effect of HPMC polymer with other additives on rheology of cement slurry at temperature of 100°C. It is concluded that HPMC polymer works as multifunctional additive in cement slurry that overcome the effect of temperature on rheology and upgraded the rheological properties.

Keywords: *Class G cement, Cement Rheology, Plastic viscosity, Yield point, Gel strength*

1. Introduction

In oil well cementing, the cement slurry pumped down the hole and seal off the annular space between the casing and the wellbore to form a continuous and competent cement sheath, segregate the producing formation, prevent the undesirable fluid migration and produce oil /gas safely and economically. The main objective of the cementing is to provide structural support to the casing strings, protect casing strings from corrosion and sealing off thief zones. Oil well cementing operations may be commenced to set a plug in an existing well for abandonment or to push off with directional tools.

It is essential for an oil industry that Portland cements must often meet the wellbore requirements, that can only be accomplished by the admixing the different chemical compounds or additives. These additives can include accelerators, retarders, extenders, weighting agents, dispersants and fluid loss control agents. The number of additives in cement slurries increases the operational cost of cementing and incompatible with wellbore conditions. Therefore, it is necessary to use multifunctional additives that reduce the operational cost as well as quantities of additives in cement slurries.

During cementing job, several attempts are made to maintain the key characteristics of cement slurry. However, wide range of polymers is being used in the industry to mitigate the thermal degradation problem. Different classes of agents, including polymers, are used to boost the slurry properties, depending on the application of the well cement. Polymers are also served as fluid loss agents as well as gas migration control agent during cementing job. When cement slurry is pumped under pressure through permeable formation, water tends to leave the slurry in the permeable formation, particularly when the pumping has stopped and the slurry is static, but not yet set. If it is not controlled at the time of job, the rheology, thickening time and density of the cement slurry will change which in result to failure of cement job.

Polymers have been added in slurry to maintain and improve the API properties, including viscosity, thickening time, density, reduction in strength retrogression and cement rheology. Mostly of the polysaccharides and their additives are used as versatile additives in cement slurry and such polymers have a number of restrictions at high temperatures, because polysaccharides can not maintain adequate viscosity in slurry, resulting in fluid loss, gas migration and increased cement operation cost. It is therefore essential to use such types of cellulose polymers in cement slurry which can increase the viscosity of cement slurry at high temperatures and to avoid loss of fluid, gas migration via cement slurry, maintain cement slurry rheology and reduce the risk of cementing failures. Cellulose-based polymers such as Hydroxyethylcellulose, Carboxymethyl cellulose (CMC), Hydroxypropylmethyl

Corresponding author Email address: *sohailahmedpg@gmail.com*

cellulose (HPMC), Carboxymethyl hydroxyethyl cellulose (CMHEC) and Hydroxypropyl guar (HPG) are widely used as a multipurpose additive in the slurry, and thus it reduces the quantity of other materials/agents in cement slurry and eventually reduces cement operating cost. In this study, a cellulose based polymer Hydroxypropyl methylcellulose (HPMC) polymer is added in cement slurries. HPMC is water soluble polymer and acts as thickener, film former, water retention agent and surfactant at high temperature. HPMC is stable at high temperature due to thermal gel behavior and behaves as viscosifying agent in cement slurry. In order to evaluate the performance of HPMC polymer- based cement slurries, the rheological properties are determined at ambient and 100 ^{o}C temperature.

2. Methodology

In this study, HPMC based cement slurries with 3 wt% concentration of polymer solution are prepared according to API recommended procedure for experimental analysis.

2.1 Material selection

Cement slurries are prepared by mixing class G cement, distilled water, conventional additives and HPMC polymer solution. Cement slurry ingredients are given in table.1.

Table.1. Cement slurry materials

S.No	Additive name	Function
1	Class G cement	Base ingredients
2	Distilled Water	Used to form cement slurry
3	Dispersant	To reduce the slurry viscosity
4	HPMC	Thickener & viscofying agent.
5	Retarder	To increase the setting time of slurry.
6	Defoamer	To prevent the formation of foam during slurry preparation.

2.2 Preparation of cement slurry

Each material describes in section 2.1 weighted by electronic balance. Then, cement and additives were mixed uniformly before mixing the distilled water. Mixture of cement and additives are then blended by mixing distilled water and polymer solution in a speed blender for 50 -60 seconds at room temperature. The slurry density is reported as 15.8 ppg by mud balance.

2.3 Laboratory experiments

The various tests were conducted to evaluate the rheological properties of polymer-based cement slurries according to API recommended testing procedures. List of utilized equipment to achieve the objectives is given in table.2.

Table.2. List of Utilized Equipment

S.No	Equipment	Utilization
1	Mud Balance	To determine density of a slurry.
2	Speed Mixture	To prepare and mix the cement slurry.
3	Atmospheric Consistometer	To preheat the cement slurry.
4	Rotational Viscometer	To determine the rheology of cement slurries.

2.3.1 Conditioning of Cement Slurry

The conditioning of the slurry is very important for the determination of rheological properties. Therefore, it is mandatory to preheat the cement slurries at 100 ^{0}C using Atmospheric Consistometer as specified in API Specification 10B.

Figure.1. Atmospheric Consistometer

Test Procedure

- The cement slurry is prepared according to API Spec 10B.
- Fill sample cup with slurry up to prescribed line.
- Place the slurry cup into the temperature-controlled water bath.
- Turn the main switch ON and then turn the MOTOR and HEATER switches ON.
- Temperature must be setup at 100^{o}C.
- Turn the “Heat” and “Motor” switches off after conditioning of cement slurry.
- Remove the test cells after cooling and clean the unit.

2.3.2 Rheology of Cement Slurry

Determination of rheological properties of cement slurry is done with rotational viscometer. In this research Model 800 of OFITE manufacturer was used at various conditions.It is widely used in oil industry for measurement of rheological properties. There is speed controlling knob at top of the equipment which helps to control RPM without stopping the motor. In addition, there is also a magnified glass dial on other end of surface of equipment which displays shear stress values for reading. Testing speeds (shear-rates in RPM) are given as; 3 (Gel), 6, 30, 60, 100, 200, 300, and 600. A higher stirring speed is also provided.

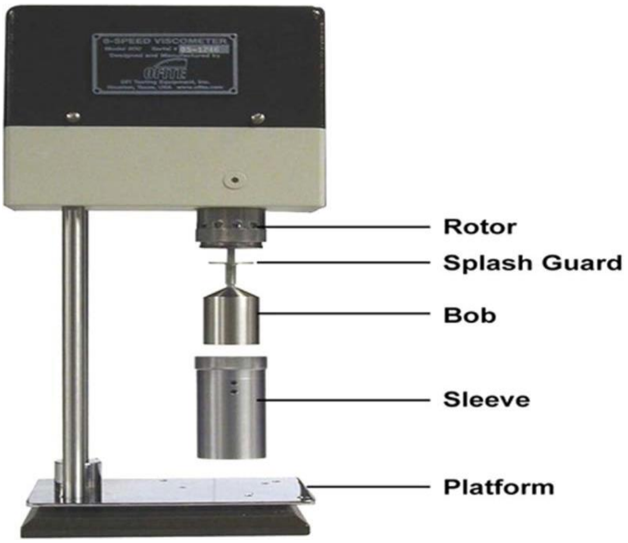

Figure.2. Rotational Viscometer

Test Procedure

a) Measuring Viscosity

- Place the sample cup filled with cement slurry.
- The slurry should be blend for 10 seconds on the “STIR “position and check the temperature.
- Switch the speed knob to 600 RPM. Note the reading when dial stabilizes.
- Switch the speed knob to 300 RPM. Record the reading when dial stabilizes.

b) Measuring Gel Strength

- Stir the cement slurry for 10 seconds.
- Adjust the speed knob to 3 RPM “GEL” and turn off the power.
- As rotation of sleeve stops/ends, after 10 seconds, power should be turn on. Maximum deflection is to be noted prior to breaking of gel. This would be the 10 seconds gel strength of sample.
- However, 10 minutes wait is required for 10 minutes gel strength. Same procedure must be followed for various times readings.

3. Results and Discussion

The rheological properties of cement slurries such as plastic viscosity, yield point and gel strength (initial and final) are determined at room temperature and 100ºC. The aim of conducting the test of rheology at ambient temperature is to observe the effect during pumping the slurry from surface. However, the scope of this research is to observe the effect of HPMC polymer on cement rheology at 100ºC temperature.

3.1 Formulation of HPMC Based Cement Slurry

The cement slurries were prepared according to API criteria. The designed cement slurries contain different additives and HPMC polymer solution. The formulation of HPMC based cement slurries is given below in Table.3.

Table.3. Formulation of HPMC Based Cement Slurries

Slurry	Cement BWOC	Foaming agent gps	Dispersant gps	Retarder gps	HPMC Gps
1	100	0.10	-	-	0.10
2	100	0.10	-	-	0.20
3	100	0.10	-	-	0.30
4	100	0.10	-	-	0.40
5	100	0.10	0.30	0.20	0.40
6	100	0.10	0.40	0.20	0.50
7	100	0.10	0.50	0.20	0.60
8	100	0.10	0.60	0.20	0.70
9	100	0.10		0.20	-

3.2 Rheology of HPMC Based Cement Slurries

The rheological properties of cement slurries such as plastic viscosity, yield point and gel strength (initial and final) were determined. The results of 3 wt % HPMC based cement slurries are shown in Table.4.

Table.4. Rheology of HPMC Based Cement Slurries

Slurry	HPMC Concentration (gps)	Temperature ^{0}C	Rheology			
			PV cP	YP 1b/100 ft^2	10 Sec Gel Strength lb/100 ft^2	10 min Gel Strength lb/100 ft^2
1	0.10	Room Temp:	127	21	42	57
		100 ^{0}C	86	09	29	42
2	0.20	Room Temp:	132	23	49	62
		100 ^{0}C	95	15	37	55
3	0.30	Room Temp:	139	27	56	69
		100 ^{0}C	103	20	44	58
4	0.40	Room Temp:	142	29	63	77
		100 ^{0}C	109	23	53	67
5	0.40	Room Temp:	128	24	51	69
		100 ^{0}C	90	15	45	59
6	0.50	Room Temp:	116	19	42	55
		100 ^{0}C	75	10	37	46
7	0.60	Room Temp:	107	14	35	49
		100 ^{0}C	59	08	32	43
8	0.70	Room Temp:	93	09	33	44
		100 ^{0}C	47	07	24	37
9	-	Room Temp:	120	16	30	62
		100 ^{0}C	79	05	14	30

3.2.1 Plastic Viscosity

In this study, the plastic viscosity of HPMC based cement slurries 1- 9 are measured at room temperature and 100^{o}C. Experimental results showed that plastic viscosity of HPMC based cement slurries increased with increase in concentration of HPMC solution at 100^{o}C as shown in figure 3. Cement slurry-4 with 0.40 gps concentration of HPMC showed maximum plastic viscosity of 109 cP at 100^{o}C. The high viscosity of HPMC polymer solution increases the pressure drop of cement slurry and it will require high pump pressure for displacement of cement slurry. Therefore, the small quantity of dispersant is added in cement slurries 5 to 9. The dispersant additive reduces the friction and improved the flow properties. Hence, plastic viscosity of slurry- 8 with 0.70 gps HPMC soluion is 47 cP at 100 ^{0}C whereas; plastic viscosity of slurry-9 is 79 cP without polymer solution.

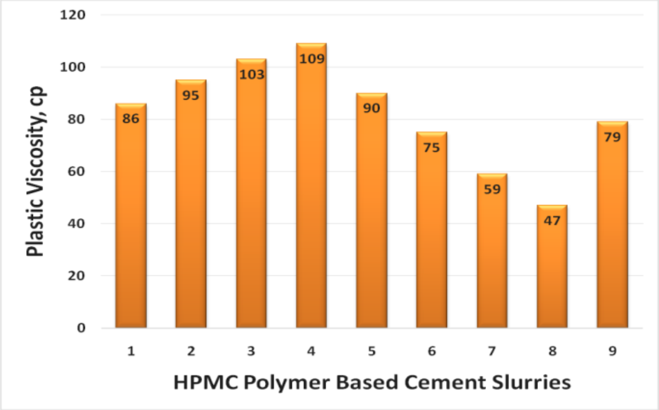

Figure.3. Plastic Viscosity v/s HPMC based cement slurries

3.2.2 Yeild Point

The investigation of yield point is essential in the overall study of slurry flow properties. Yield point affects the start-up pressure after a temporary shut-down. The yield point of cement slurries must be optimum to transport the cement slurry in the annulus because minimum energy is required to initiate flow. Experimental results of HPMC based cement slurries showed that the yield point is increasing with increase in concentration of HPMC solution at 100 ^{0}C as shown in Figure.4.

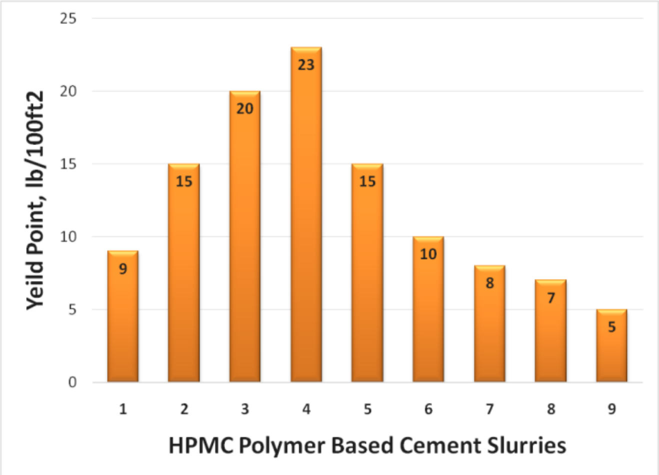

Figure.4. Yeild Point v/s HPMC based cement slurries

3.2.4 Gel Strength

The gel strength is measured at low shear rate after slurry has set quiescently for a period of time 10 seconds and 10 minutes according API procedure. Gel strength is an important parameter interrelated to annular fluid migration. It is the measure of attractive forces between the particles in a fluid under static conditions. The experiments results showed that as the concentration of HPMC solution (3 wt%) is changed from 0.10 to 0.40 gps, the gel strength increased from 29 lb/100 ft^2 to 53 lb/100 ft^2 for a time of 10 seconds at 100^0C temperature as shown in Figure.5.

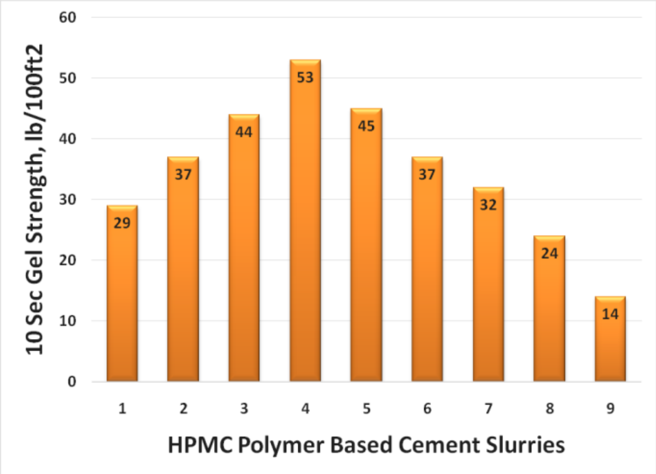

Figure.5. 10 sec: Gel Strength v/s HPMC based cement slurries

Similarly, gel strength of slurries is determined at 10 minutes. Experiments showed that as the concentration of HPMC solution (3 wt%) is changed from 0.10 to 0.40 gps, the gel strength increased from 42 lb/100 ft^2 to 67 lb/100 ft^2 at 100^0C temperature as shown in Figure.6. Afterthat the dispersant additive was added in slurries 5-8 to maintain the gel strength.

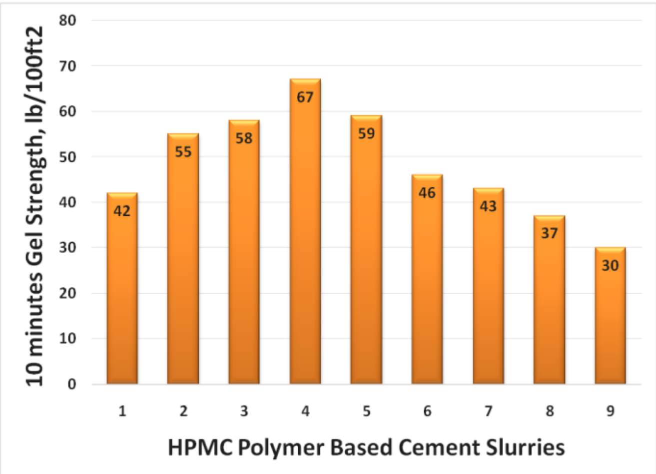

Figure.4. 10 min: Gel Strength v/s HPMC based cement slurries

4. Conclusion

Rheology has effect on the flow behavior of cement slurry. The rheology of cement slurries are determine at 100 °C temperature and found the rheological parameters such as plastic viscosity, yield point and gel strength increased with rise in HPMC concentration. HPMC polymer belongs to cellulose family that has long chain branch and high gel strength. The plastic viscosity and yeild point of cement slurries must be optimized to remove the mud and easily pumped in downhole. High value of plastic viscosity may create problem during pumping stage. Therefore, the dispersant was used in the slurries 5-8 for reducing the friction and enhances the slurry flow properties. HPMC based cement slurries showed that the HPMC polymer is good candidate for improving rheology of cement slurries at 100 ^{0}C. Hence, it is concluded from experimental study that HPMC polymer works as multifunctional additive in cement slurry that overcome the effect of temperature on rheology.

5. Nomenclatures

HPMC = Hydroxypropyl methylcellulose
P.V = Plastic Viscosity
Y.P = Yield Point
Ppg = Pounds per gallon
Gps = gallon per sack

References

[1] B.R.Reddy. *(2012)*, "Chemical Modification of Biopolymers To Design cement slurries with Temperature Activated Viscosification- A Laboratory Study".

[2] Abdullah S. Al Yami (2015), "An Overview of Different Chemicals Used in Designing Cement Slurries for Oil and Gas Wells".

[3] Lu Haischuan. "Cement Slurries with Rheological Properties Unaffected by Temperature" (2014).

[4] Ghulam Abbas , khalil ur Rehman, "Gas Migration Prevention using Hydroxypropyle methylcellulose as a Multifunctional Additive in Oil Well Cement Slurry, (2013)

[5] S. Abbas, J. Donovan, and A. Sanders, "Applicability of Hydroxyethylcellulose polymers for chemical EOR," *presented at the SPE Enhanced Oil Recovery Conference*, Kuala Lumpur, Malaysia, 2013, SPE 165311

[6] Roderick Pernities, "New Polymeric High Temperature Cement Retarder with Synergistic Suspending Aid Property in Fluid Loss Control Polymers". (2017)

[7] M.Murtaza, "Mechanical, Rheological and Microstructural Properties of Saudi Type G Cement Slurry with Silica Flour used in Saudi oil Field under HTHP conditions", SPE 168101presented at SPE Saudi Arabia section Annual Technical Symposium and Exhibition held in Saudi Arabia, 19–22, May 2013.

[8]H. Roshan, M.R. Asef, TarbiatMoallemUiversity and University of New South Wales, "Characteristics of oil Well Cement Slurry using CMC." SPE Paper no:114246, September: 2010.

[9] Standard API Recommended Practice 10B for Testing Well Cements, Petroleum and Natural gas industries, 22nd Edition (1997).

[10] Standard Handbook of Petroleum and Natural Gas Engineering By William C. Lyons, Ph.D., P.E., Gary J Plisga, BS.

[11] Structure and Performance of Cements, Second Edition By P. Barnes, J. Bensted

[12] H. Roshan and M. Asef, "Characteristics of oilwell cement slurry using CMC," *SPE Drilling & Completion*, vol. 25, no. 3, pp. 328–335, 2010

[13]Adam T. Bourgoyne Jr (1991), "Applied Drilling Engineering Handbook", SPE USA.

[14] H. Rabia, *Well Engineering and Construction*, p.186,. 2001.

[15] Fatima Daou et al. *(2016)*, "Cement-Slurry Performance and Set-Cement Properties vs Microsilica Densification".

[16] Shahriar, "Investigation on rheology of oil well cement slurries," The University of Western Ontario, 2011.

[17] A.Brandl, W. Bray, and C. Magelky, "Improving well cementing quality with an environmentally preferred multifunctional polymer," *presented at the SPE Europec/EAGE Annual Conference*, Denmark, 2012. SPE 154498.

[18] N. Sarkar and L. Walker, "Hydration—dehydration properties of methylcellulose and hydroxypropylmethylcellulose," *Carbohydrate Polymers*, vol. 8617, no. 95, pp. 177–185, 1995.

[19] N. K. Singh, P. C. Mishra, V. K. Singh, and K. K. Narang, "Effects of hydroxyethyl cellulose and oxalic acid on the properties of cement," *Cement and Concrete Research*, vol. 33, no. 9, pp. 1319–1329, 2003.

[20] H. Roshan and M. Asef, "Characteristics of oilwell cement slurry using CMC," *SPE Drilling & Completion*, vol. 25, no. 3, pp. 328–335, 2010.

About Authors

Sohail Ahmed persuing masters at Mehran University of Engineering and Technology Jamshoro. His field of intrest is drilling engineering and production engineering.

Abdul Haque Tunio has completed Ph.D from MUET Jamshoro. He is currently working as a Professor at Institute of Petroleum and Natural Gas Engineering, MUET Jamshoro.

Abdul Samad Shaikh has completed Master of Engineering in Pertoleum Engineering from MUET Jamshoro. He is currently working as a Lecturer at Department of Petroleum and Natural Gas Engineering, MUET SZAB Campus Khairpur Mirs.

Ghulam Abbas has completed Masters in Pertoleum Engineering from UTP Malyasia. He is currently working as a Assistant Professor at Department of Petroleum and Natural Gas Engineering, MUET SZAB Campus Khairpur Mirs.