

Development of partially hydrolyzed polyacrylamide based gel system for its application in profile modification jobs

Rahim Seikh and Vikas Mahto¹

*Department of Petroleum Engineering, Indian School of Mines,
Dhanbad - 826004, India*

Abstract

The gelation time and gel quality are the important considerations of any gel system for its suitable placement in the high permeable or fractured formations during profile modification jobs in the oilfields. Keeping these in view, an attempt has been made to study the effect of chromium acetate and thiourea crosslinkers on the gelation time of the polyacrylamide based gel. The crosslinkers are mixed with base partially hydrolyzed polyacrylamide suspension and gelation time for the formation of stiff /rigid gel was determined. The experimental studies show that with increase in concentration of crosslinkers the gelation decreases. These studies help us for the optimization of the concentration of the organic polymer and chromium acetate and thiourea crosslinkers for successful profile modification jobs.

Keywords: *Polymer gel system, profile modification, gelation time, in-situ gelation*

1. Introduction

Inadequate sweep efficiency due to reservoir heterogeneity often causes poor oil recovery during water flooding in matured reservoir. The presence of fractures and high permeability streaks in heterogeneous five spot pattern reservoirs are responsible for undesirable influx of water into well bore and early breakthrough of injection water. This excessive water production from the producer leads to raise handling and disposal cost and reduces economic life of the well (Marty et al., 1991; El-Hadidi et al, 2000; Nguyen et al., 2004; Ma et al., 2007; Mahto et al. 2010).

¹ Corresponding author Email: vikas.ismpe@gmail.com

Profile modification is a means of enhancing oil recovery by diverting flood water into previous upswept zones. The method comprises emplacements of a gelant slug into the highly permeable flooded out layers of the formation close to well bore. The gel is designed to reduce the permeability of the target zone to the flooding fluid, there by modifying the flow profile and diverting injected fluid into zones of greater residual oil content (Mahto, 2008; Mahto and Seikh, 2009;Mahto et al. 2009;Nguyen et al., 2012).

Polymer gel system can effectively improve the sweep efficiency in reservoirs. A gel treatment reduces the water production and increases oil production from upswept zones. Gel is normally formed by adding a cross-linker to polymer solutions. The base polymers like polyacrylamide or xanthan gum are cross linked with eithers inorganic or organic crosslinkers. Inorganic crosslinkers include Cr (III), Al (III) and Zr^{+4} and have been mostly utilized to crosslink partially hydrolyzed polyacrylamide. Inorganically crosslinked gels result from the ionic bonding between the negatively charged carboxylate groups and the multivalent cation. The organic cross linkers used in acrylamide based polymers include phenol, formaldehyde and its derivatives. The gelation mechanism of organic cross linkers is done by covalent bonding, which is much more stable than the ionic bonds (Huang et al., 1986; Syndask, 1988; Marty et al., 1991; Stokke et al., 1995;Brayant, 1997; Jain et al, 2004; Nguyen et al., 2004; Al-Muntasheri, 2006; Al-Assi et al., 2006; Ma et al., 2007; Mahto et al. 2009;).

In this study, the partially hydrolyzed polyacrylamide polymer is cross linked with chromium acetate and thiourea crosslinkers to form the polymer gel and the effect of cross linkers on gelation behavior of the partially hydrolyzed polyacrylamide are thoroughly analyzed. The plugging ability of this polymer gel system in the barea sand stone core was thoroughly investigated at 80°C for the study of the effectiveness of gel system in the profile modification jobs.

2. Experimental procedure

Initially, the stock solutions of partially hydrolyzed polyacrylamide polymer and chromium acetate cross linkers were prepared, and from these stock solutions further polymer solutions and cross linker solutions of appropriate concentrations required to form the gel were prepared. The polymer stock solution was prepared by dissolving the polymer in NaCl solution containing 200 ppm of sodium sulphite and kept for hydration for 24 hours. Proper salinity of the solution was

maintained so that it should be compatible with the formation water. The appropriate amount of cross linkers was mixed with this polymer solution and pH of resulting mixture was maintained using NaOH and HCl solutions. The resulting mixture was kept in small bottle in hot air oven at 80°C for gelation and inspected the quality of gel visually at regular intervals.

After Bottle testing, core flow studies were carried out using Core Flow Apparatus manufactured by Vinci Technologies, France. Using this experimental set up, the permeability of the core sample before injection of gelant solution and after injection and setting of gel in the core sample at reservoir conditions was determined using Darcy's Law. The Berea sandstone core sample was kept inside the core holder which was further housed in a constant temperature oven at the simulated reservoir temperature under confining pressure. The required concentration of brine solution was initially filled in a cell and connections were made and pressure gauges were set in place. A proportionating pump was used to generate the pressure required at desired flow rate of brine solution through the core sample. The diesel was used as the displacing medium for the brine or gelant solution. The pressure drop across the core plug was measured by a pressure transducer. After brine flooding, absolute permeability of core sample was measured. Once the base permeability was established, a gelling solution was injected at slow rate, and then core treated with optimized gel solution shut in and aged for five days at $80 \pm 2^\circ\text{C}$ to give ample time for the gelling solution to set. Following the shut-in, brine was again re-injected and return permeability was measured at reservoir simulated conditions for calculating reduction in permeability.

3. Results and discussions

The chromium acetate and thiourea crosslinkers can build a complex network with carboxylate groups of partially hydrolyzed polyacrylamide and form a three dimensional gel network. The crosslinker concentration has a significant effect on gel strength. Several samples were prepared to investigate the effect of cross linker concentration on network gel strength. Bottling Test result shown in Table 1 indicates that when the concentration of both cross linker was decreased, the gelation rate and gel quality were also decreased. In other words, when cross linking agent concentration was increased, the stage of polymer gel changed from a state of flowing gel to stiff/rigid gel in lesser time due to increase in cross linking sites.

Polymer (ppm)	Cross linker (ppm)			Gelation time
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A	K ₂ Cr ₂ O ₇	Thiourea	Brine Concentration (ppm)	pH	(hrs)
6000	3000	3000	10000	6.9	7
6000	2500	2500	10000	7.1	10
6000	2000	2000	10000	7.1	13
6000	1500	1500	10000	7.2	13
6000	1000	1000	10000	7.4	No gel

Table 1. Effect of cross linkers on the gelation time of 6000 ppm PHPA polymer solution at 80 °C

The cross linked partially hydrolyzed polyacrylamide polymer gel system give better physical properties (viscosity and gel strength) than the polymer solution that facilitates physical plugging of porous media. The experimental investigation under insitu gelation and core flooding are shown in Table 2-5. It was found that porosity of the Berea sandstone core was 20% and initial permeability was 115.34 mD (Table 3-4). For the determination of permeability of the core sample, Darcy's law was used which was as follows:

$$K = \frac{Q \cdot \mu \cdot L}{\Delta P \cdot A}$$

K = Absolute permeability to brine (Darcy)

Q = Flow rate of brine (ml/sec)

μ = Viscosity of brine (cP)

L = Length of core holder (cm)

ΔP = Pressure drop (atm)

A = Area of core holder (cm²)

Components	Units	Composition
PHPA Concentration	ppm	6000
Brine Concentration	ppm	10000
K ₂ Cr ₂ O ₇	ppm	1500
Thiourea	ppm	1500

Table 2. Composition of Polymer Cross linker solution for insitu gelation studies in cores

Parameters	Units	Value
Core Length	mm	60.85
Core Diameter	mm	37.66
Pore Volume	cc	13.5
Porosity	%	20

Table 3. Core Parameters

Brine flow (cc/min)	Differential pressure (psi)	Permeability of core(K_i) (mD)
1.0	1.20	111.50
1.5	1.70	118.06
2.0	2.30	116.35
2.5	2.90	115.34
3.0	3.50	114.69

Table 4. Absolute permeability of core before polymer treatment with respect to brine

After passing the gelant solution through the Berea sandstone core, the core was kept inside the oven for 5 days. After insitu gelation, the brine was injected into the core at different pressure drops to determine the plugging ability of polymer gel system.

Brine flow (cc/min)	Differential pressure (psi)	Permeability of core(K_i) (mD)
0.6	13.90	7.58
0.8	18.10	7.24
1.0	22.00	7.16
1.2	24.70	7.51
1.5	30.60	7.35

Table
Return

5.

permeability of core after polymer treatment with respect to brine

The reduction in permeability in the core after insitu gelation was calculated using following formula:

$$\text{Reduction in Permeability} = \left(1 - \frac{\text{Absolute permeability after gel treatment}}{\text{Absolute permeability before gel placement}} \right) \times 100$$

The post gelation permeability and permeability reduction for brine were 7.36 mD and 93.61% respectively which shows the suitability of this gel system for profile modification jobs.

4. Conclusions

The following conclusions are drawn for the present investigations:

1. With increase in crosslinker concentration the decrease in gelation time of partially hydrolyzed polyacrylamide-chromium-thiourea gel system decreases.
2. The partially hydrolyzed polyacrylamide -chromium acetate -thiourea gelant has good plugging ability. The reduction in permeability in the Berea sandstone core sample observed due to this system was 93.6% at 80°C which shows the potential of this crosslinked polymer gel system for its application in the profile modification job.

Nomenclature

<i>K</i>	<i>permeability</i>
<i>Q</i>	<i>flow rate</i>
<i>μ</i>	<i>viscosity</i>
<i>L</i>	<i>length</i>
<i>ΔP</i>	<i>pressure drop</i>
<i>A</i>	<i>area</i>
<i>mD</i>	<i>milli Darcy</i>
<i>cc</i>	<i>cubic centimeter</i>
<i>mm</i>	<i>millimetre</i>
<i>psi</i>	<i>per square inch</i>
<i>ml</i>	<i>millilitre</i>
<i>cP</i>	<i>centipoise</i>
<i>min</i>	<i>Minute</i>
<i>ppm</i>	<i>parts per million</i>

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About the authors:

Rahim Seikh has completed his M. Tech. Degree in Petroleum Engineering from Indian School of Mines, Dhanbad in 2009. His M. Tech. dissertation work was in the area of Profile Modification and Water Shut off Jobs.



Dr. Vikas Mahto, presently serving as Associate Professor, has joined Petroleum Engineering Department of Indian School of Mines, Dhanbad in 2004 as Lecturer after completing his Ph.D. Degree in Petroleum Engineering from the same institute. He has fifty publications in the different national/international journals & conferences of repute. He has completed three research projects sponsored by UGC-ISM, UGC New Delhi and CSIR New Delhi. He is currently involved in the several works in the area of Drilling Fluid Design and Analysis, Application of nanoparticles and nanofluids in different oilfield operations, Water shut off jobs and Conformance Control, Flow Assurance Problems in the oilfields, EOR Techniques and Artificial Lift Techniques. He is Associate Editor of IST Transactions of Environmental Systems- Theory and Applications and International Journal of Chemical Research. He is reviewer of many international journals like Journal of Petroleum Science and Engineering, Petroleum Science and Technology, Applied Clay Science, Chemical Engineering Journal, International Journal of Petroleum Engineering, Scientific Journals International, Chemical and Bioengineering, Advances in Sustainable Petroleum Engineering Science etc. and member of many International Boards like International Journal of Petroleum Engineering, Scientific Journals International etc.