



Use of Oil Field Water Shut off Techniques in Crude Oil Recovery from A Depleted Oil Field of Upper Assam Basin

KEYWORDS

water shut-off, water cut, polyacrylamide, cross-linker, porous media

Dhrubajyoti Neog

Assistant Professor, Department of Petroleum Technology, Dibrugarh University, Dibrugarh, Assam, Pin-786004

Dr (Mrs) Subrata Bogohain Gogoi

Associate Professor, Department of Petroleum Technology, Dibrugarh University, Assam, Pin-786004

Dr Pradip Bogohain

Associate Professor, Department of Applied Geology, Dibrugarh University, Dibrugarh, Assam, Pin-786004

ABSTRACT

The economic draining of crude oil from depleted oil reservoir with high water cut has been the oldest problem with significant impact on production cost of crude oil and post production effluent treatment technology to meet the environmental guidelines. This paper deals with in-situ reduction of produced water in high water cut porous rock formation of Upper Assam to reduce the amount of potential pollutant and maximise the crude oil production. When partially hydrolysed polyacrylamide with suitable cross-linker are injected into the core samples of a depleted oil field with varying degree of hydrolysis and molecular weight, gels are retained in the pores and permeability decreases. Polymer gels behaviour in porous medium as diverting or blocking agents to shut off the water producing layers is expected to deliver increasing oil production in the matured fields.

INTRODUCTION

Excessive water production is needed to avoid, minimize or delay to reduce the wastage of reservoir energy, occurrence of corrosion, scale deposit problem, etc., which ultimately results in higher operating costs, severe productivity loss and lower economic reserves. The problems of occurrence of water cut are complex in nature when several mechanisms of water invasion are active simultaneously. Moawad (2004) and Bedaiwi, Al-Anazi, Paiaman (2009) has recognized the mechanism of excess water influx into the well as water conning, regional rise of the water oil contact, presence of high permeability layer, and fractures that connect the aquifer to the well. Gawish (1996) found out the potential causes of water production as casing failure or the leak behind the casing due to weak cement layer or the channeling behind casing, perforation in the aquifer and barrier breakdown during stimulation. The flow of water through porous medium to the wellbore in separate paths than the in-situ flow channels are considered for primary water control. The reservoir heterogeneity, differing permeability and club of fractures and fracture network hinder the crude oil recovery during water flooding operations (Liu, Bai and Wang, 2010), (Jain, McCool, Green, Willhite and Michnick, 2004), (Grattoni, Al-Sharji, Yang, Muggeridge and Zimmermani, 2001) (Yadav, Mah-to). Seright (2003) and Moore (1989) used the strategy for diagnosing and solving excess water production problems by calculation of Productivity index to confirm the presence of fractures and/or other high-permeability anomalies. Reservoir heterogeneity causes low oil recovery and early excess water production in porous rock (Liu, 2006). Macroscale heterogeneity often results in very quick water breakthrough and very low recovery of hydrocarbon than microscale (Thomas and Bennion, 97-98). The techno-economics of water shut off is supported with proper identification of the water that actually offering hindrance to the crude oil production. Co-production of water along with crude oil during the late stages of production in the life of water flood is not realistic to avoid as it will cut down the crude oil production. Water shut off is under strong consideration to contain the sources of water that actually

competing with the crude oil production. Water abatement strategy needs the identification of nature and intensity of the problem before occurrence of the high WOR as the timely application of water control measures are able to reduce the excessive water production. High WOR is obvious in depleted porous rock and evaluation of remaining amount of hydrocarbon in the vicinity of the well justifies the treatment methods. Early identification of the fluid flow pattern around the wellbore highlights the potential causes of water production.

Oil and gas wells of Upper Assam basin is producing with increasingly high water cut. The system study of the polymer consists of chromium acetate/partially hydrolyzed polyacrylamide (Seright, Gillette and Wyoming, 1999), (Willhite and Pancake, 2008) or poly-ethyleneimine/copolymer of acrylamide and t-butylacrylate (Eoff, Dalrymple, Everett and Vasquez, 2006) with varying degree of hydrolysis and molecular weights (MW) as part of WSO application for conformance control in the selected porous rock of Upper Assam.

It has been recognized that organic or inorganic cross-linked partially hydrolysed polyacrylamides (PHPA) gel is an effective means of recovering a fraction of the remaining oil in porous media. WSO gels on investigation by Steady or Dynamic Shear measurement extract the time requirement to form the 3-D structure, gelation parameters, gelation time, activation energy (Broseta, Marquer, Blin and Zaitoun, 2000), (Prud'homme, Uhl, Poinatte and Halverson, 1983). Most of the wells of Upper Assam oil fields have been abandoned due to 100% water cut are potential to revive with water shut off systems by PHPA gel with Cr^{3+} , Al^{3+} and organic cross-linker by measurement of gel elasticity with elastic-modulus calculation method (Laurent, Janmey and Ferry, 1980). The toxicity of the polycrylamide is within the non-harming range of the environmental impact and several investigations in porous formation suggest effective reduction in water permeability more than that of oil by the use of polycrylamide polymer/gels (Albonico, Burrato, Lullo and Lockhart, 1993). The porous media of the Upper Assam fulfils the suggested criteria for water shut off by Reynold.

and Kiker (2003) with wells already shut-in or at the end of economic life, residual oil saturation, high WOR, declining oil and flat water production, presence of active water drive, and reservoir heterogeneity.

This study tries to investigate the possibilities of using partially hydrolysed polyacrylamide to increase the recovered oil from the porous formation by impacting the fractional flow, reducing water mobility and by diverting the injected water to the non-invaded zone as it is chosen as an alternative to the solution of water shut off techniques (Riley and Peter, 1987). The ratio of the mobility of water to the mobility of a polymer solution under the same conditions is also calculated (Jennings, Rogers and West, 1971).

EXPERIMENTAL STUDIES:

Materials:

The porous medium was obtained from two wells of producing field of Upper Assam area from a depth of 2483-2487m and 2506-4504.50m. The acrylamide of A1399 molecular biological grade C₃ H₅ NO MW 71.08g/mol (otto, chemical, aiochemics-reagents) with minimum assay 99.0%, maximum limites of impurities chloride (Cl) 0.005%, sulphate (SO₄) 0.005%, calcium (Ca) 0.001%, Iron (Fe) 0.0005%, copper (Cu) 0.005%, manganese (Mn) 0.0005%, magnesium (Mg) 0.0005%, zinc (Zn) 0.0005%, DNases/RNases not detected. Ammonium peroxodisulfate (Extra pure) (NH₄)₂S₂O₈ >>98%, MW 228.20g/mol choline (cl) <<0.002%, Heavy metals as Pb <<0.003%, Iron (Fe) <<0.001%, manganese (Mn) <<0.002%, residue on ignition (as sulfates) <<0.1% N,N,N,N' Tetramethylenediamine C₆H₁₆N₂ M.W 116.20g/mol were used as received. Properties of formation water samples collected from porous formation of Upper Assam area are analysed and depicted in Table 1. The density, viscosity, pour point, API gravity of the samples was determined and is depicted respectively in Table 2. The average molecular weight of polycrylamide used was within the range upto 10x10⁶ g/mol.

METHOD:

Porosity and permeability measurement:

Porosity of porous media was measured using TPI-219 Teaching Helium Porosimeter, Coretest systems. The basic principle behind the measurement is Boyle's Law which describes the relationship between the volume of a dry ideal gas and its pressure. The error estimated in porosity measurement is estimated around 5-9%. The measurements were performed several times for each porous media. The Air permeability (K_{air}) of various samples was calculated by Gas Permeameter, Vinci Technologies. The apparatus, using the differential pressure (ΔP), gas flow rate (Q) and core dimensions (L= length; A= area) calculated the value of permeability (K) using the formula:

$$K = \frac{\mu QL}{\Delta PA}$$

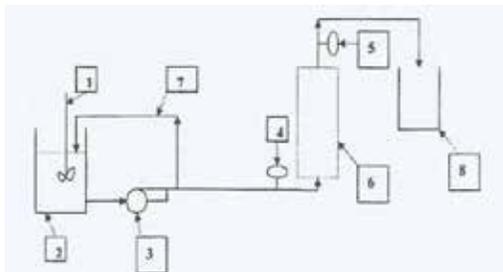


Fig 1: Permeability apparatus [1-Stirrer, 2- Sample reservoir, 3-Pump, 4&5-Pressure gauge, 6-Porous media, 7-By-pass, 8-Sample collector]

TABLE – 1 Formation water properties

Parameter	Unit	Values
pH	-	8.0
TSS	Mg/L	6.4
Turbidity	NTU	6.8
Oil content	Ppm	7
Filterability	L/30 min	0.660
Dissolved oxygen	Ppm	Nil
Residual chlorine	Ppm	0.6

TABLE- 2 CRUDE OIL PROPERTIES

API gravity	23-25 ^o
Pour point	29-30 ^o C
Viscosity	2.85 cp

Core Flood tests:

Experiments were conducted on five different porous media (core samples) collected from crude oil producing horizons of Upper Assam area. The cores under study were exposed to cleaning process using Soxhlet apparatus prior to measurement of porosity, permeability and pore volume in order to clean the porous sample from hydrocarbon, water and brine. The cores were dried for one day in an oven (70^oC) and fully saturated with brine under vacuum for 24 hours at room temperature. A schematic diagram of the experimental set up for the study of core recovery is shown in figure 2. Subsequent flooding with HPAM and Cross-linked polymer gel (Cr³⁺) were carried out to investigate the plugging abilities and reduction on permeability of the porous media.

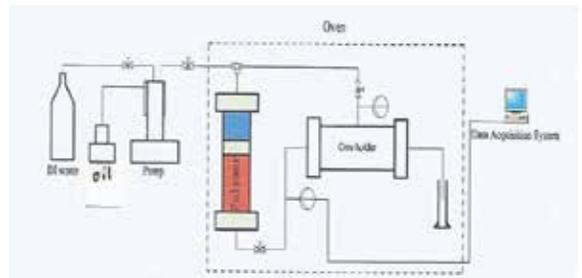


Fig 2: Schematic of core flooding experiment composed of pump, distilled water, oil, core holder or sand pack, accumulator used for polymer storage and pressure gauge or transducer to record injection pressure

Results and discussion:

Porosity and permeability measurement:

A total of 5 numbers of core samples were studied for porosity measurement. The values of porosity for the Well A core samples ranges from 21.23% to 25.3% and the values of porosity for Well B core samples ranges from 22.7% to 23.33%.

The air permeability values obtained from 3 numbers of core samples of well A ranges from 0.41-0.48md and the air permeability values obtained for 2 numbers of well B core samples ranges from average 0.44-0.45d (Table 3). From the values of K_{air}, using Klickenberg theory, the values of liquid

permeability (K_{liq}) were calculated. A relation between porosity and K_{liq} was also drawn which shows that with increase in porosity, K_{liq} also increases as shown in Fig.3.

Table 3 Showing the porous media

Porous media	K_{liq}	ϕ (%)
Sandstone, well A	.41-0.48d	21.23%-25.3%
Sandstone, well B	0.44-0.45d	22.7%-23.33%

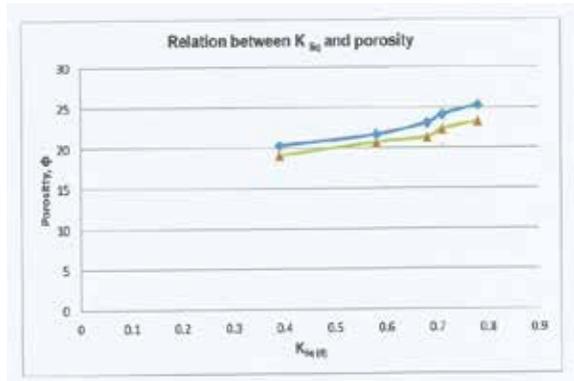


Fig 3: Relation between K_{liq} and porosity

Flooding experiments:

The pore volume was calculated based on the total volume of the core and its corresponding porosity. Two partially hydrolysed polyacrylamide (HPAMs) with molecular weight in the range of 1.7×10^6 and 3.5×10^5 were used for flooding the porous media. The degree of hydrolysis was in the range of 25-30%. Chromium acetate (Cr^{3+}) was used as the cross-linker. A measured amount of HPAM was slowly added to stirred water and then samples were stirred for 2-3 hrs until the HPAM dissolved in water. Under stirring, a specified amount of chromium acetate was added and the resulting solution was named as CLP. Core samples were kindly permitted from porous media of Upper Assam.

Water was injected into the core until the water cut reached 40% and then a specified volume of the HPAM or CLP solution was injected into the core. After the core was subsequently flooded with water until the water cut reached 98%.

After 0.05 PV, 0.10 PV and 0.15 PV of HPAM solutions and CLP permeability reduction was observed in the injected core sample, the incremental oil recovery values were 3.7%, 9.3% and 12.2% respectively, and as for the CLP solution, the incremental values were 6.8%, 13.6% and 17.4% respectively. However, % of permeability reduction was found in the range 30-50% and more was with CLP. Further analysis shows that the oil recovered by the HPAM solution was lower (4.1% to 6.2%) than that recovered by the CLP solution under the same displacement condition [Fig.4 (a)]. The considerable effect of both polymer and cross-linker concentration for enhancement of viscosity and gel strength are observed in fig 4(b) and fig. 4(c).

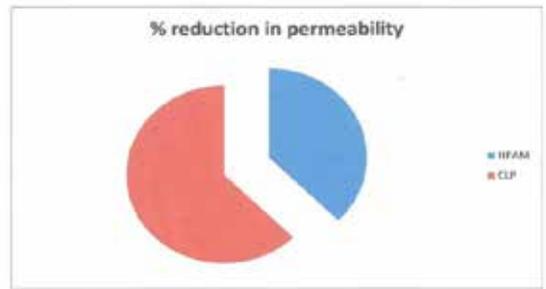


Fig 4: (a) Permeability reduction % for HPAM and CLP

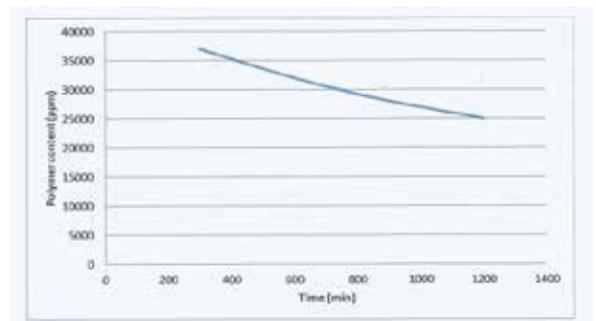


Fig 4: (b) Effect of polymer concentration on gelation time (Experimental condition: Polymer: Cross linker: 40:1, T 45°C)

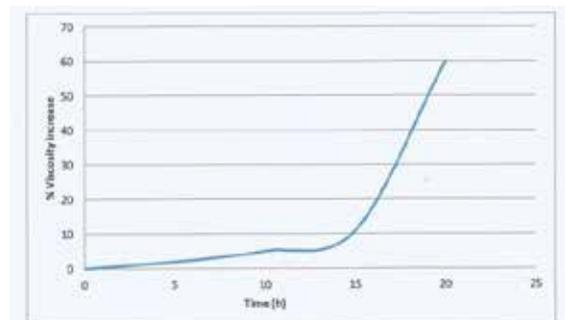


Fig 4 (C): Change in viscosity with time for Polymer concentration: Cross-linker: 10:1, T=60°C

Conclusion:

Studies on the efficiency of polyacrylamide/chromium (III) gel polymer as water shut off system reveal it as a good candidate for increasing water permeability in the selected porous media with high potential for water production. Reviving production from declining oil fields of high water cut with cost-effective water shut off system has become a major focus of Assam Asset. A good numbers of polymer gels have been used worldwide to drain out oil from most complex unswept portion of the reservoir rock. Undrained oil production from the wells nearing the end of economic production due to high water cut is one aspect of implementation of polymer gel technology and considered as one of the effective measure for water shut off system which can significantly contribute to the production from the older, depleted oil fields of Upper Assam basin with negative impact on environmental degradation. The properties of PAMS with suitable Cr^{3+} cross-linker are found to be suitable for crude oil recovery by chemically shutting off the water producing layers. It seems that increasing cross-linking concentration within specified ranges accelerate gel strength while gel strength decreases with excessive cross-linking. Gelation time can be controlled by adjustment of

composition of the gel used and depends on reservoir condition. In-situ plugging of the watered layers in porous rock is also dependent on reservoir temperature and water formation. In order to enhance the performance of the present polymer at a higher temperature organic cross-linkers can be used as cross-linker occasionally.

Acknowledgement:

The author wishes to acknowledge thankfully the financial support of University Grants Commission, India in the form of a Research Project to carry out the study.

REFERENCE

- Albonico P, Burrafato G, Lullo A D & Lockhart T P, (1993) Effective Gelation-Delaying Additives for Cr³⁺/polymer Gels, paper SPE 25221, presented at the SPE International Symposium on Oilfield Chemistry, New Orleans, USA, 3-6 March 1993 | Al-Muntasherhi GA, Nasr-El-Din HA, Al-Noaimi KR, Zitha PLJ, (2007) A study of polyacrylamide-based gels crosslinked with polyethyleneimine, Paper SPE 105925, Int Symp Oilfield Chem, Houston, Texas, February-March 2007 | Broseta, D., Marquer, O., Blin, N., Zaitoun, A., (2000). Rheological screening of low-molecular-weight polyacrylamide/chromium (III) acetate water shutoff gels. Paper SPE 59319 presented at the SPE/DOE Improved Oil Recovery Symposium, Tulsa, OK, pp. 3-5 | Bedaiwi E., Al-Anazi B. D., Al-Anazi A. F. and Aiaman A. M. P (2009) -Polymer Injection for Water Production Control through Permeability Alteration in Fractured Reservoir, Scientific paper, NAFTA 60(4) 221-231 | Eoff L, Dalrymple D, Everett D, Vasquez J, (2006) Worldwide field application of a polymeric gel system for conformance applications, SPE Prod Oper, 22, 231-235 | Gawish A. (1996) "Engineering Application of Biopolymers for Oil Field Processes". Ph.D.Thesis, Suez Canal University, Egypt | Grattoni C.A., Al-Sharji H.H., Yang C., Muggeridge A.H., Zimmerman R.W. (2001) Rheology and Permeability of Crosslinked Polyacrylamide Gel, Journal of Colloid Interface Science 240, 2, 601-607. DOI: 10.1006/jcis.2001.7633 | Jain R., McCool C.S., Green D.W., Willhite G.P., Michnick M.J. (2004) Reaction Kinetics of the Uptake of Chromium (III) Acetate by Polyacrylamide, Society of Petroleum Engineers Journal 10, 3, 247-255. SPE-89399-PA. DOI: 10.2118/89399-PA | Jennings, R. R., Rogers, J. H. & West, T. J. (1971). Factors influencing mobility control by polymer solution. Journal of Petroleum Technology, 23(3), 391-401 | Liu Y., Bai B., Wang Y. (2010) Applied Technology and Prospects of Conformance Control Treatments in China, Oil & Gas Science and Technology 65, 6, 859-878. DOI: 10.2516/OGST/2009057 | Liu, Y. et al. (2006) : "Application and Development of Chemical-Based Conformance Control Treatments in China Oil Fields," Paper SPE 99641 | Laurent, J.-L., Janmey, P.A., Ferry, J.D., (1980) Dynamic viscoelastic properties of gelatin gels in glycerol-water mixtures. J. Rheol. 24 (1), 87-98 | Moawad T (2004) "A stimulation case study for economically improved oil recovery and water Shut-off strategies on the basis of the stratified high temperature oil reservoir" Ph.D Tu-Clausthal, Germany | Moore, D.M (1989) "Impact of Super Permeability on Completion and Production Strategies," paper SPE 17974 presented at the 1989 SPE Middle East Oil Technical Conference and Exhibition, Bahrain, 11 March | Prud'homme, R.K., Uhl, J., Poinsatte, J.P., Halverson, F., (1983) Rheological monitoring of the formation of polyacrylamide/Cr³⁺ gels. SPE 804-808 | Reynolds, R.R., and Kiker, R.D (2003) Produced Water and Associated Issues — A Manual for the Independent Operator, Oklahoma Geological Survey Open File Report 6 | Riley, B. N. & Peter, H. D. (1987). Polymer flooding review. Journal of Petroleum Technology, 39(12), 1503-1597 | Seright, R.S., Lane, R.H., and Sydansk, R.D (2003) A Strategy for Attacking Excess Water Production," SPEEP pp 158-169 | Seright RS (1999) Mechanism for gel propagation through fractures, Paper SPE 55628, SPE Rocky Mount Region Meet, Gillette, Wyoming | Thomas F. Brent, Bennion D. Brant, Hycal Energy Research Laboratories Gregory Ltd. Anderson E., Bradford T. Meldrum. Aqueolic Canada Ltd PETROLEUM SOCIETY OF, CIM PAPER NO. 98-47, Water Shutoff Treatments - Reduce Water and Accelerate Oil Production | Willhite GP, Pancake RE (2008) Controlling water production using polymer gel system, SPE Res Eval Eng, 11, 454-465, 2008 | Yadav, U.S and Mahto, V and Sharma V.P " Modeling of Partially Hydrolyzed Polyacrylamide-Hexamine-Hydroquinone Gel System used for Profile Modification Jobs in the Oilfield" Department of Petroleum Engineering, Indian School of Mines, Dhanbad-826004, India