SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 41, Number 1, April 2018: 3 of 5
RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY LEMIGAS
Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

ASP INJECTIVITY ANALYSIS AS PREPARATION FOR FIELD IMPLEMENTATION

ANALISIS INJEKTIVITAS ASP UNTUK PERSIAPAN IMPLEMENTASI LAPANGAN

Sugihardjo
"LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
Email: sugihardjo@lemigas.esdm.go.id; E-mail: ekolelono@esdm.go.id

First Registered on January[rd] 2018; Received after Correction on February 8[th] 2018
Publication Approval on: April 30[th]2018

ABSTRAK

Percobaan laboratorium ini merupakan gambaran penyiapan bahan injeksi kimia ASP yang akan diaplikasikan di lapangan, untuk menentukan parameter injektivitas dan perubahan sifat sifat fluida selama mengalir pada media berpori. Maka, percobaan fokus pada injektivitas yang digambarkan oleh perubahan permeabilitas. Disamping itu, tegangan antar muka, penurunan viskositas, juga adsorpsi larutan injeksi pada permukaan leher pori juga diamati. Larutan kimia ASP telah disiapkan untuk percobaan, campuran dari 0.3% Surfaktan-A, 1000ppm Polymer KP, dan 0.2% NaOH Alkali. Campuran ini telah dievaluasi sifat-sifat fluidanya seperti: tegangan antar muka, viscositas dan beberapa parameter lainnya yaitu: kompatibilitas, stabilitas suhu, kelakukan fasa, dan filtrasi dimana sangat cocok untuk peningkatan perolehan minyak pada lapangan minyak target. Tahap selanjutnya adalah untuk menguji interaksi batuan dan fluida injeksi yang mungkin dapat mengubah sifat sifat fluida dan batuan. Injeksi ASP pada batuan karbonat pada percobaan ini mungkin dapat menghasilkan kerusakan permeabilitas dan hampir menyumbat leher pori. Penurunan permebailitasnya sangat tajam mendekati nilai PRF pada level 88.76%. Kerusakan ini tidak dapat diperbaiki dengan injeksi air berikutnya yang ditunjukkan dengan penurunan permeabiltas yang permanen. Sifat sifat larutan ASP termasuk tegangan antar muka dan viscositas menunjukkan bahwa harga tegangan antar muka kelihatan konstan sedangkan harga viskositsnya turun menjadi hanya 32.6% dibanding harga awalnya. Namun sedemikian adsorpsi masih dikategorikan normal.

Kata Kunci: injektivitas, faktor penurunan permeabilitas, faktor tahanan, faktor tahanan tersisa

ABSTRACT

This laboratory experiment is a highlight of the preparation of ASP (Alkaline-Surfactant-Polymer Mixture) chemical injection for field implementation to determine the injectivity parameter and the effect of fluid properties change during flow into the porous media. Therefore, the experiments were focus on injectivity which is represented by permeability change. Besides, IFT and viscosity reduction, and also adsorption of injected chemical on the surface of pore throat were also investigated. ASP chemical solution has been prepared for experiments, the mixture consists of 0.3% of Surfactant-A, 1000 ppm Polymer KP and 0.2% alkaline of NaOH. This mixture has been evaluated the bulk properties for instance: IFT, viscosity and other parameter such as: compatibility, thermal stability, phase behavior, and filtration that are suitable for enhanced oil recovery for the target oil field. The next step is to examine the interaction between rock and injected fluid that may change the fluid and rock properties. ASP injection in carbonate rock in this experiment may result in permeability damage and almost totally block the pore throat. Reduction of permeability is very significantly approaching the value of PRF of level 88.76%. The damage could not be revocable after post flush of water that is indicated that the permeability reduction is permanent. Fluid properties of the ASP including IFT and viscosity show that the IFT looks constant and no significant change, on the hand the viscosity of the fluid drops down to almost 32.6% from the original. However, the adsorptions are still categorized as normal.

Keywords: injectivity, permeability reduction factor, resistance factor, residual resistance factor

How to cite this article:

Sugihardjo, 1, 2018, ASP INJECTIVITY ANALYSIS AS PREPARATION FOR FIELD IMPLEMENTATION, *Scientific contributions Oil and Gas*, 41 (1) pp, 29-39. DOI: 10.29017/SCOG. 41.1.29-39.

I. INTRODUCTION

Chemical injection such as Surfactant-Polymer (SP) or Alkaline-Surfactant-Polymer (ASP) had been implemented as field trials in some mature oil fields in Indonesia, for instance Minas field with ASP, Kaji field with SP, and Tanjung field with ASP injections. The results indicated that some of them are very successful to improve oil recovery and the other still need improvement of the chemical formula to get better chemical properties. Moreover, some other mature fields are still in the phase of study in the laboratory to pursue appropriate chemical composition.

Daqing is the best example for successful polymer injection in China. Laboratory research began in the 1960s, investigating the potential of enhanced oil recovery (EOR) processes in the Daqing Oil Field. For polymer flooding technology, from a single-injector polymer flood with small well spacing began in 1972. During the late 1980s, a pilot project in central Daqing was expanded to a multi-well pattern with larger well spacing. Favorable results from these tests along with extensive research and engineering from mid 1980 through the 1990s, confirmed that polymer flooding was the method of choice to improve areal and vertical sweep efficiency at Daqing, as well as providing mobility control. Consequently, the world's largest polymer flood was implemented at Daqing, beginning in 1996. By 2007, 22.3% of total production from the Daqing Oil Field was attributed to polymer flooding. Polymer flooding should boost the ultimate recovery for the field to over 50% original oil in place (OOIP), 10-12% OOIP more than from water flooding. (Dong et al. 2008). Wang et al. (2006) said that that Daqing polymer flood was success commercially, it has become an important supporting technology for both the stable output of Daqing Oilfield and the development improvement of the mature oilfields. In Daqing Oilfield, the polymer flooding annual output has exceeded 10 million tons; water cut reduction rate has been kept 24.8% for 2 years. In the testing blocks, the average incremental oil recovery over waterflooding is 10.99%. The successful of polymer flood in Daqing oil field depend on the key aspects of the design, these factors include (1) recognizing when profile modification is needed before polymer injection and when zone isolation is of value during polymer injection, (2) establishing the optimum polymer formulations and injection rates, and (3) time-dependent variation of the molecular weight of the polymer used in the injected slugs (Wang et al. 2008).

On the other hand reported that polymer can be injected with other chemicals such as: alkaline and surfactant. Sheng et al. (2013) wrote a comprehensive Review of Alkaline-Surfactant-Polymer (ASP) Flooding. Alkaline-surfactant-polymer (ASP) flooding is a combination process in which alkali, surfactant and polymer are injected at the same slug. Because of the synergy of these three components, ASP is the current world-wide focus of research and field trial in chemical enhanced oil recovery. The reviewed topics include the following topics: ASP synergy and its EOR mechanisms, screening criteria, laboratory work, numerical simulation work, summary of pilots and large-scale applications, project economics, chemicals used, water quality, salinity gradient, mobility control requirement, problems associated with ASP flooding. The laboratory tests for polymer include aqueous stability test, viscosity at different shear rates, and filtration test. The filtration test is almost similar to injectivity test at ambient condition in the absence of porous media. Recent progress on ASP injection and effects analysis of ASP flooding field tests was reported by Zhu et al. (2012). It was found that three factors are responsible for successful ASP flooding field tests: good performance of oil displacement agents, good profile control and oil displacement ability, reasonable well pattern and well spacing.

Based on the above arguments that chemical flooding still becomes important EOR technology that can be used to improve oil recovery in mature oil fields. Even though field trials of chemical injection have been dropped significantly because of the plunge of the oil price and stayed at the level 50USD per barrel which is too low to get profit from Chemical injection, except some formulations of low price of chemicals have been invented by chemical specialists. However, research works should not be stopped due to the oil price. Researches must be continued in all situation of oil prices. When the oil price is getting better then field implementation is ready to be carried out.

The nature of the polymer solution is to make viscous solution. This property can be used to improve mobility of injected fluid during implementation of EOR technology of chemical injection. The selection of the polymers and its concentrations are based on the measured viscosity; the viscosity must be at least similar or above the viscosity of displaced oil to create more favorable displacement efficiency. (Sugihardjo 2011). The injectivity of polymer during polymer flood have been investigated by Behr et al. (2017) focusing on prediction of polymer Injectivity in damaged wellbore, Dupas et al. (2013) wrote the impact of polymer mechanical degradation on shear and extensional viscosities: towards better injectivity forecasts, Glasbergen et al. (2015) discussed injectivity loss in polymer floods: causes, preventions and mitigations. Seright et al. (2008) about Injectivity Characteristics of EOR Polymers, Skauge et al. (2016) presented radial and linear polymer flow - influence on injectivity, Sharma et al. (2016) presented polymer injectivity test in Bhagyam field, while Skauge et al. (2016) investigates radial and linear polymer flow - influence on injectivity, and Yerramilli et al. (2013) gave novel insight into polymer injectivity for polymer flooding.

The summary of current papers mostly focuses on the use of high viscosity polymer and the interaction with the rock during flowing in the porous rocks with different mineralogy. The degradation of polymer may take place during flooding due to oxidation, shear, salinity, hydrolysis, and precipitation. However, for injectivity problem may arise because of the high adsorption of polymer on the surface of rock and in turn this will reduce the permeability of the rock significantly. Investigation of the polymer and rock mineral becomes important criteria that mast be investigate before injected polymer into a reservoir.

There are so many kinds of laboratory tests which need to be done that in practice we would not afford to do every laboratory test needed. Including Injectivity test of polymer solution normally is investigated in the laboratory before it will be implemented in the fields. So here is the high light the Surfactant- polymer injectivity experiment that has been done in the laboratory scale. Even though this evaluation is a mixture of surfactant and polymer, however the problem of injectivity is caused by the polymer itself.

The objective of injectivity test is actually to evaluate the effects of polymer or polymer on ASP mixture injection on permeability. Assumed that the reduction of permeability should be low enough and therefore will not significantly affect the capability of the rock to be flooded by the injected fluid.

II. METHODOLOGY

The injectivity experiment was performed using a core flooding equipment. Figure 1 shows the detail picture of this equipment. The rig consists of a 1.5-inch diameter of Hassler type core holder and core length can be inter-changeable among the three sizes such as: 3 inches, 1 foot, 1-meter long. In this experiment the three inches' core holder has been used. For the three inches' core holder are available 2 DPT (differential pressure transducer) measuring differential pressure of inlet and a port in the middle of the core and between inlet and outlet. The core holder was given an overburden pressure to keep the core tightly stick to the rubber sleeve. It was connected with three piston-equipped tubes, which contained the flooding fluid, i.e. formation water, crude oil, and ASP solution. The tubes were provided with fluid regulating valves to enable the selection of fluid to flow into the core in the core holder.

A computer controlled quizix pump was used to force the injection fluid into the tubes. Besides that, a digital pressure indicator to control the flow of the fluid. In and out the core holder, it was also provided with a number of pressure transducers to observe the fluid movement in core and to observe the pressure difference in each segments of the core. In order to maintain a stable pressure in the core holder, it was equipped with a backpressure regulator. The fluid coming out of the core was directed to a separator and the liquid collected in a fraction collection so that both oil phase and water phase production can be measured as the function of time. The injection fluid taken, core holder, backpressure regulator and other accessories were placed in a circulation oven, which was equipped with temperature control. The system

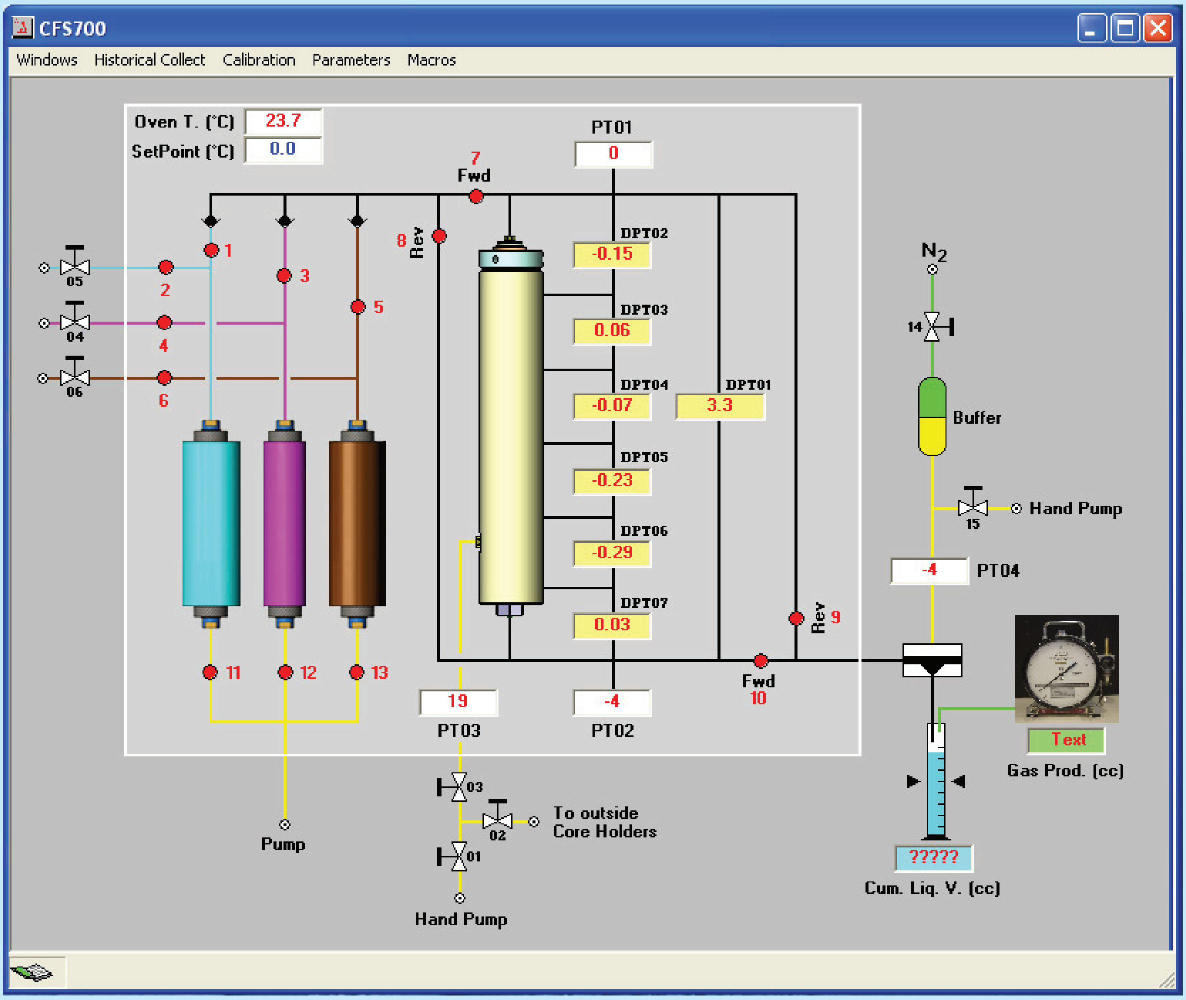


Figure 1
Lay out of the coreflooding rig.

of pressure and temperature were detected at various locations by means of calibrated thermocouples and transducers. The data collected during injection/ flooding included pressure, flow rate, pressure difference, production and injection times were directly recorded in a computer. Those data, then has been evaluate to determine the range of permeability reduction, it means that the injectivity of the core can be defined straightly. In addition to that the data collected during core flood can be also calculated several rock and fluid parameters such as: Dynamic Adsorption, effluent IFT, effluent viscosity, effluent pH, and also recovery factor of oil. Those properties of rock and fluid, then they can be compared to the original before injection, and therefore they can be evaluated the degree of changes and of course the degree of damage or improvement. Moreover, in this experiment was focused on the measurement of injectivity and also dynamic adsorption.

A. Experiment Procedure

This test was done using native carbonate core samples. The tests are to study the effect on ASP injection to the change of the permeability of the cores, improvement or damage compare to the original permeability. Beside the dynamic adsorption was also calculated. The procedure of the tests is mentioned in the following paragraphs:

The detail of the core flood tests is described below:

1. Saturate core with formation brine and load into core holder and set the temperature at reservoir temperature condition
2. Inject injection brine several pore volumes and measure the permeability. Note: viscosity of brine was 0.77 cp at 94°C
3. Inject ASP solution several pore volumes and measure the permeability

4. After that, inject injection brine and investigate changes of the permeability. Keep injection until the permeability constant
5. The effluents were collected during the injectivity test and analyzed for their IFT and viscosity. Measure also the concentration of polymer and surfactant.

B. Injectivity Determination

The recorded data from core flooding experiments consist of rate, inlet and outlet pressure (differential pressure) as the function of time. Combining those data with the basic core data can be employed to calculate the permeability, and permeability reduction. Calculate PRF (Permeability Reduction Factor), which can indicate the degree of the permeability reduction. 100% indicates totally blocking and 0% indicates no damage at al. The formula of PRF is written as follow:

$$PRF = \frac{Kw - Kobv}{Kw} \times 100\%$$

Where:

Kw : Permeability to synthetic water

Kobv: Observed permeability

Calculate RF (Resistance Factor) = (Kw/mw)/(Kch/mch)

RRF (Residual Resistance Factor) = (Kw/mw)1/(Kw/mw)2

(Kw/mw)1 = mobility of water before chemical injection

(Kw/mw)2 = mobility of water after chemical injection

(Kch/mch) = mobility of chemical injection

C. Dynamic Adsorption Determination

Interaction between injection fluids such as polymer and surfactant with porous media or rock minerals is demonstrated by adsorption and desorption of the chemical solution in the surface of the rock. The adsorption of both chemical is normally very low in sandstone compare to carbonate reservoir. Carbonate rock adsorbs much higher polymer and surfactant solution. Therefore, ASP injection is preferred in sandstone reservoir. However, currently there are increasing the use of ASP in carbonate reservoir due to the lower price of polymer and surfactant production.

Dynamic Adsorption Test of Polymer

Objective is to determine the amount of polymer lost during flow of a water soluble polymer solution through porous media at dynamic condition.

- Take effluent sample periodically and determine final concentrations using Spectrophotometer Ultra Violet.
- Run replicates with adsorbent and samples without adsorbent to ensure against errors.
- Calculate dynamic polymer adsorption.
- Compare viscosity before and after adsorption.

Dynamic Adsorption of Surfactant

Objective is to determine the amount of surfactant lost during flow of a water soluble surfactant solution through porous media at dynamic condition.

- Take effluent sample periodically and determine final concentrations using
- HPLC (High Performance Liquid Chromatography).
- Run replicates with adsorbent and samples without adsorbent to ensure against errors.
- Calculate dynamic surfactant adsorption.
- Compare IFT before and after adsorption

Calculation of the dynamic adsorption is as follows:

$$A = \frac{Wi\,Ci - (We1Ce1 + We2Ce2 \ldots\ldots + WenCen)}{Wr}$$

Wi : Weight of injected chemical, g

Ci : Concentration of injected chemical, ppm

We1 : Weight of effluent of tube1, g

Ce1 : Concentration of effluent of tube1, ppm

Wr : Weight of rock, gram

A : Chemical adsorption, microgram per gram solid

D. Material Preparation

The experimental materials consist of brine, chemicals and rock. The chemical solution is a mixture of 0.3% of Surfactant-A, 1000 ppm Polymer KP, and 0.2% alkaline of NaOH. This mixture has been evaluated for the IFT, viscosity and other parameter such as compatibility, thermal stability, phase behavior, and filtration that are suitable for enhanced oil recovery for the target oil field. Figure 2 and 3 depict IFT and viscosity of the ASP. The IFT is almost similar to the original surfactant only, and

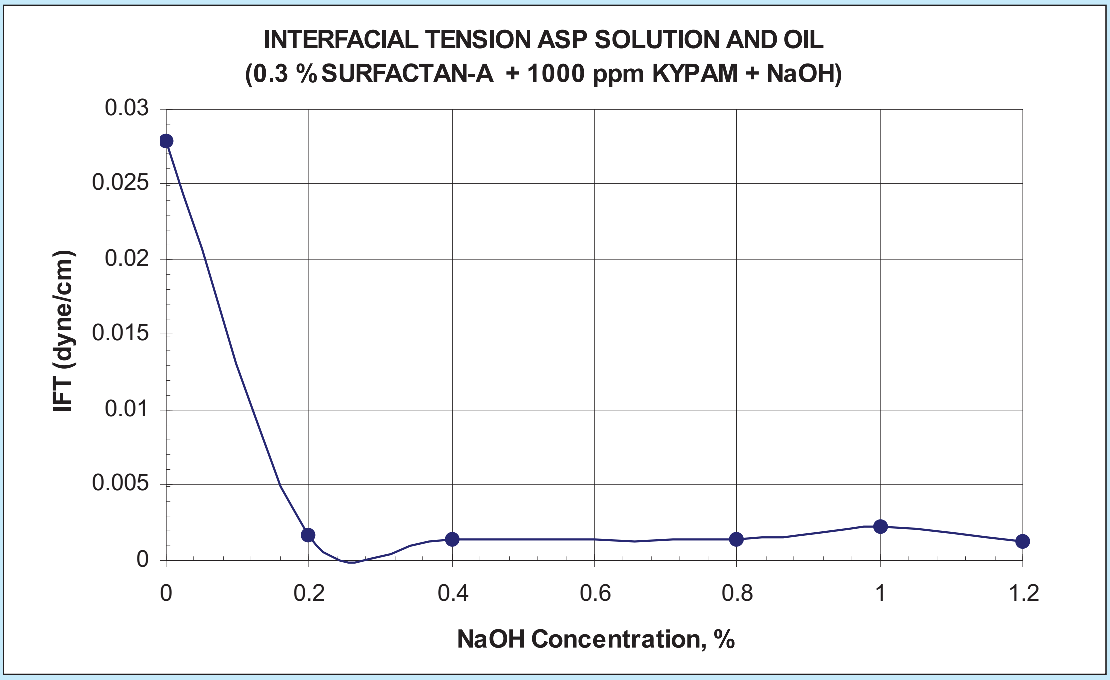
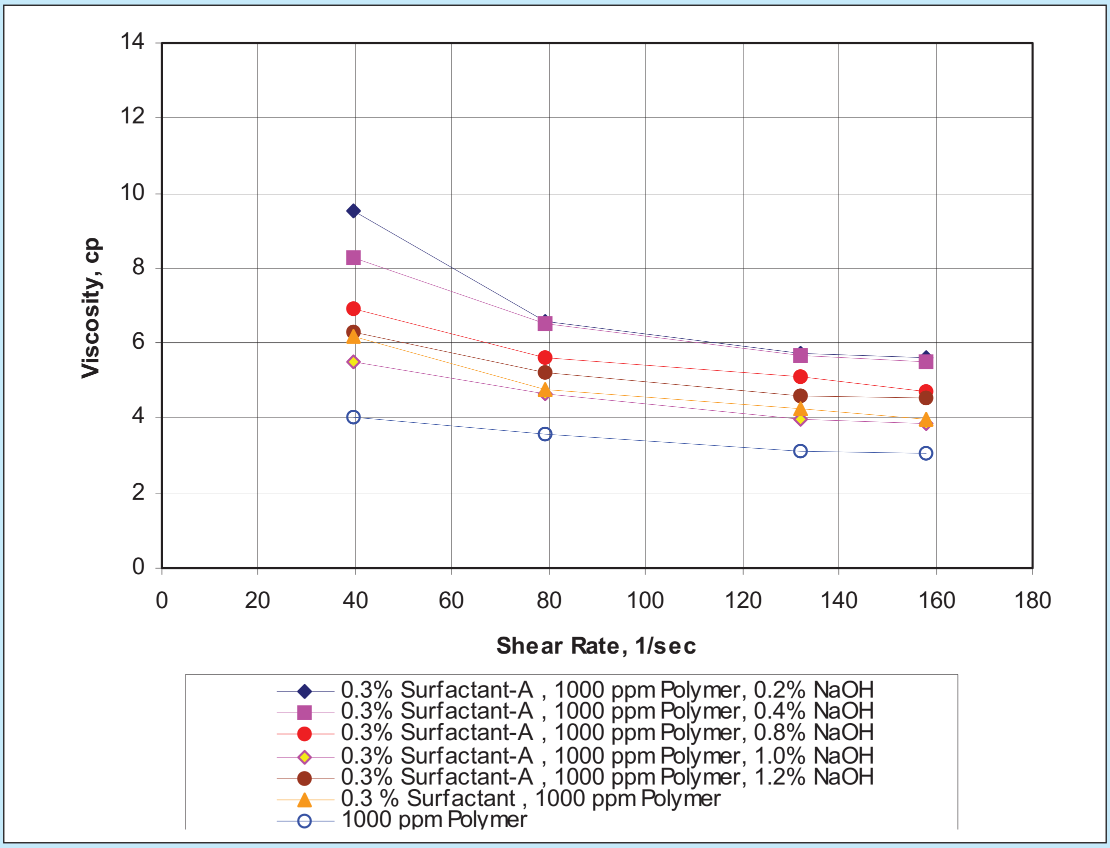


Figure 2
IFT of ASP.



Figue 3
Viscosity of ASP.

the viscosity of polymer is also similar to the pure polymer at the same concentration. Parameters IFT and polymer before injected are very important as a control to the same parameters after injection.

Core plugs with a dimension of approximately 3cm diameter and 7cm long were prepared for this experiment. Table 1 shows the petrophysical data of the core plugs taken from target well. All the plugs consist of Limestone rock (Table 2 X-Ray Diffraction Analysis)

III. RESULTS AND DISCUSSION

A. Injectivity Test Results

Base on the consideration that almost all core has the same rock properties, therefore, only core#3 had been chosen for the injectivity experiment. Initial water injection came up with the permeability of 166 mD (Figure 4). This value has been used as the base line to evaluate the effect of the injectivity test of the ASP solution.

Table 1
Rock petrophysical properties

Core No.	Depth (ft)	Length (cm)	Diameter (cm)	Bulk Volume (cc)	Grain Volume (cc)	Pore Volume	Grain Density (gr/cc)	Porosity (%)	Gas Permeability (mD)
1	2836.0	7.647	3.810	87.183	56.198	30.982	2.702	35.540	687.00
2	2837.5	7.226	3.809	82.34	53.644	28.696	2.703	34.851	598.80
3	2838.5	6.452	3.812	73.636	47.427	26.209	2.703	35.592	491.70
4	2837.0	7.350	3.809	83.753	55.166	28.587	2.701	34.133	279.30

Table 2
X-Ray Diffraction Analysis Results

Rock Type	Illlite	Chlorite	Calcite	Quartz	K- dsFel	Plagioclase
Limestone	-	-	100	trace	-	-

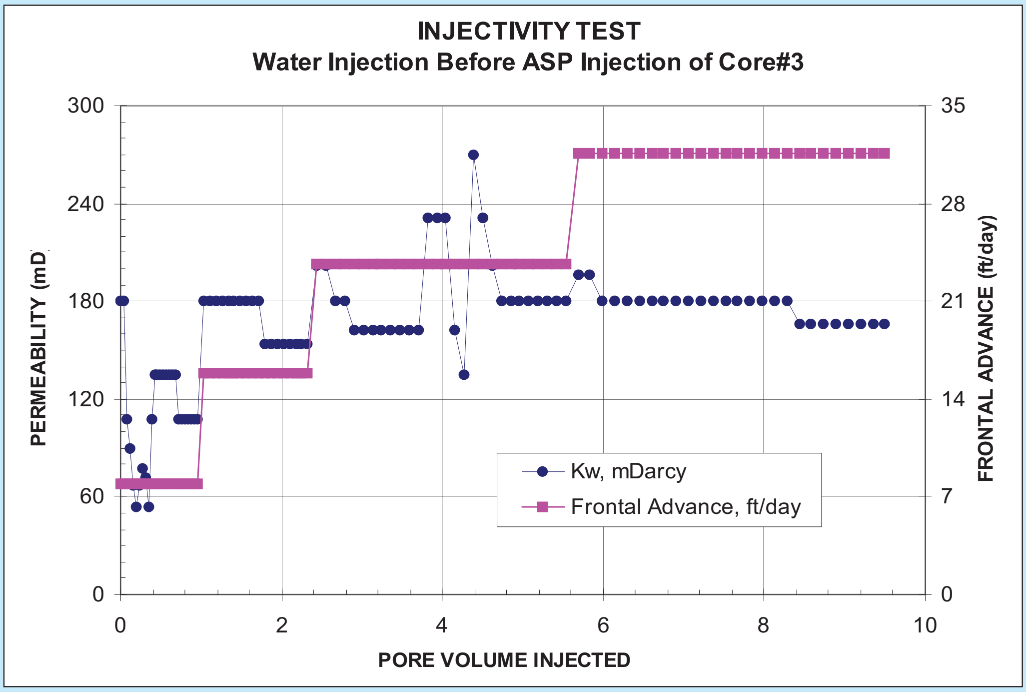


Figure 4
Permeability of water measurement.

After that the core was injected with ASP solution for several pore volumes. At initial injection the permeability sharply decreased to a level of 105 mD, and then followed by steady decrease to a level of 18.65 mD or 88.76% PRF after approximately 6.6 PV of ASP solution injected. Figure 5 shows this result. This indicates that the interaction of the ASP with the rock occur very intensively. It may because of reaction between the polymer and the rock mineral.

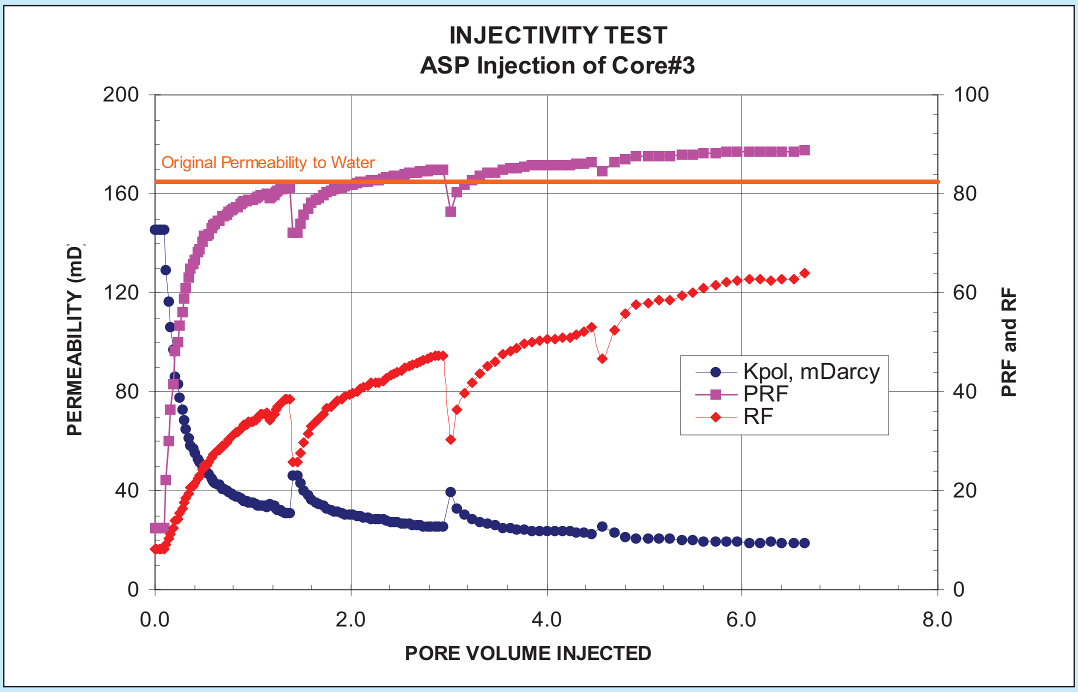


Figure 5
Permeability of ASP Injection.

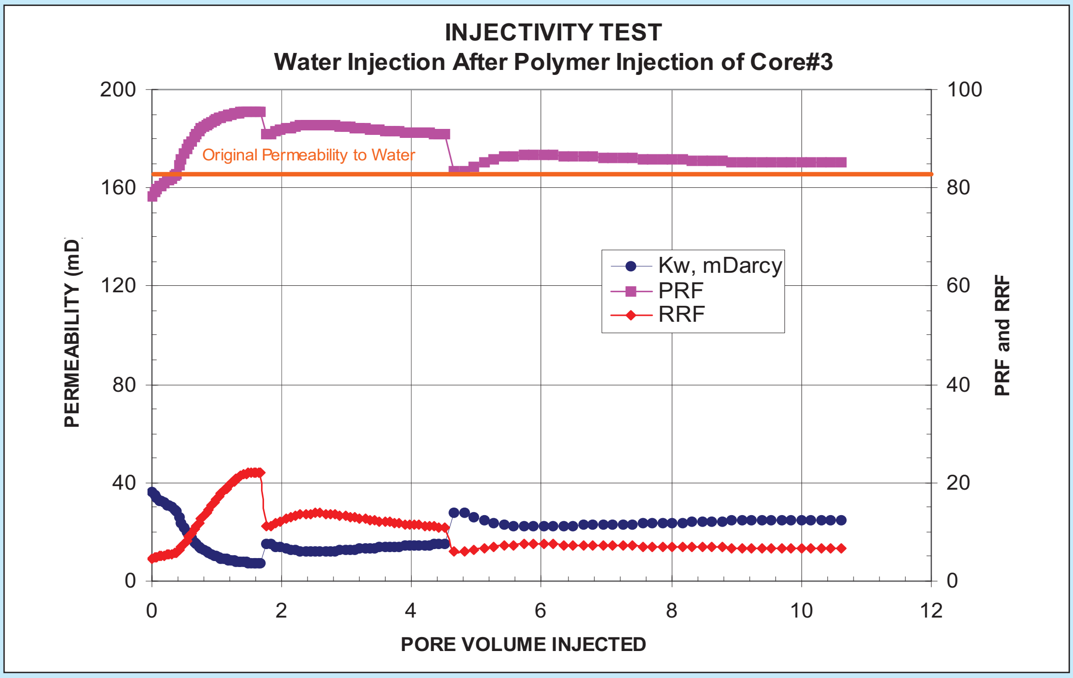


Figure 6
Permeability of post flush water.

Next step is post brine injection to see if the permeability damage could be recovered. This following brine injection obviously was could not improve the permeability impairment anymore, and the permeability still constant at level 24.8 mD or the value of RRF in the order of 6.69. This indicates that the permeability reduction is permanent and could not be recovered back again. Figure 6 presents the detailed result of the posh brine injection.

During the injectivity test, the effluent was also collected, Figure 7 is the picture of the effluent during injectivity test. The above glass picture is the original condition of ASP liquid before injecting, and several tubes of the effluent coming out from the core during the injectivity test. Normally, ASP solution has a white color.

The effluent viscosity reduces down to the level of 3.78 cp from the original of 5.6cp, see Figure 8. Moreover, IFT the effluent solution and the oil is only decrease a little bit, see Figure 9.

Adsorption is to determine the amount of chemical concentration solution lost during flow in porous media or reservoir rock with dynamic methods. Normally the adsorption of the injected chemicals on to the surface of limestone rock is rather high compare to sandstone. The degree of the adsorption is very critical to reduce concentration of chemicals in the solution and in turn it will reduce the quality of the chemicals property such as: ASP viscosity and IFT. In this experiment the adsorption is categorized as normal below 400 microgram/gram of rock. Table 3 is the results of the adsorption measurement.

IV. CONCLUSIONS

Injectivity test using coreflooding experiment is the first important step should be done for chemical solution such as: ASP before implementing into the fields in order to know the degree of the permeability reduction to anticipate any problems in the field implementation such as formation damage and chemical properties degradation.

Table 3
Adsorption measurement

Surfactant Adsorption	307	microgram/gram
Polymer Adsorption	185	microgram/gram

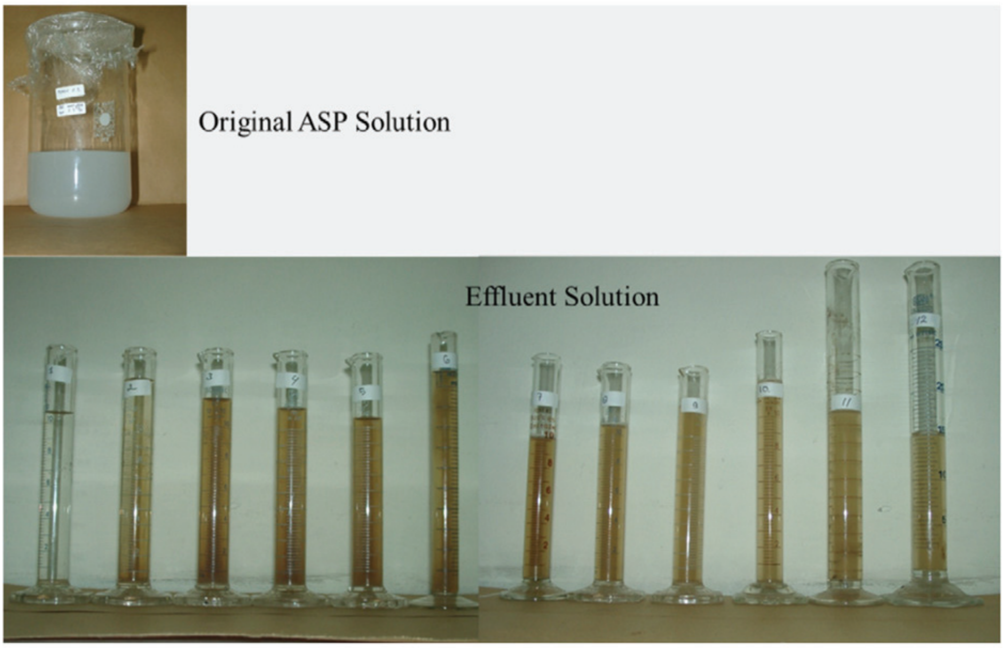


Figure 7
ASP solution and the effluent.

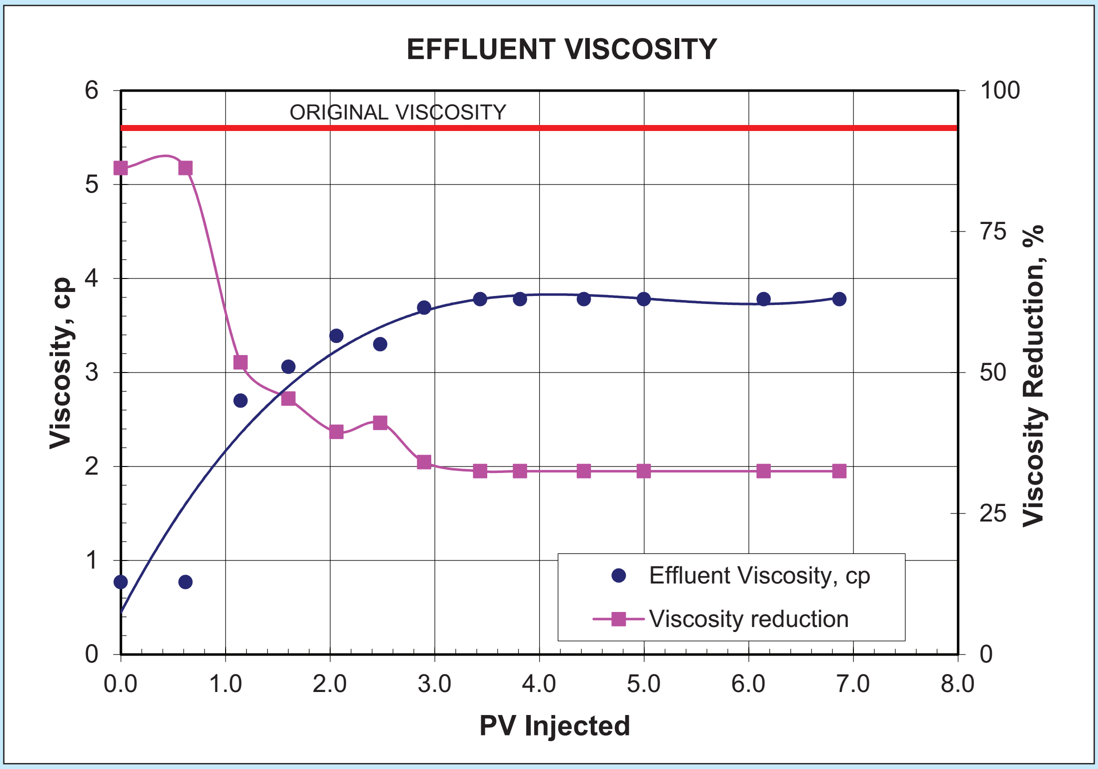


Figure 8
Effluent viscosity.

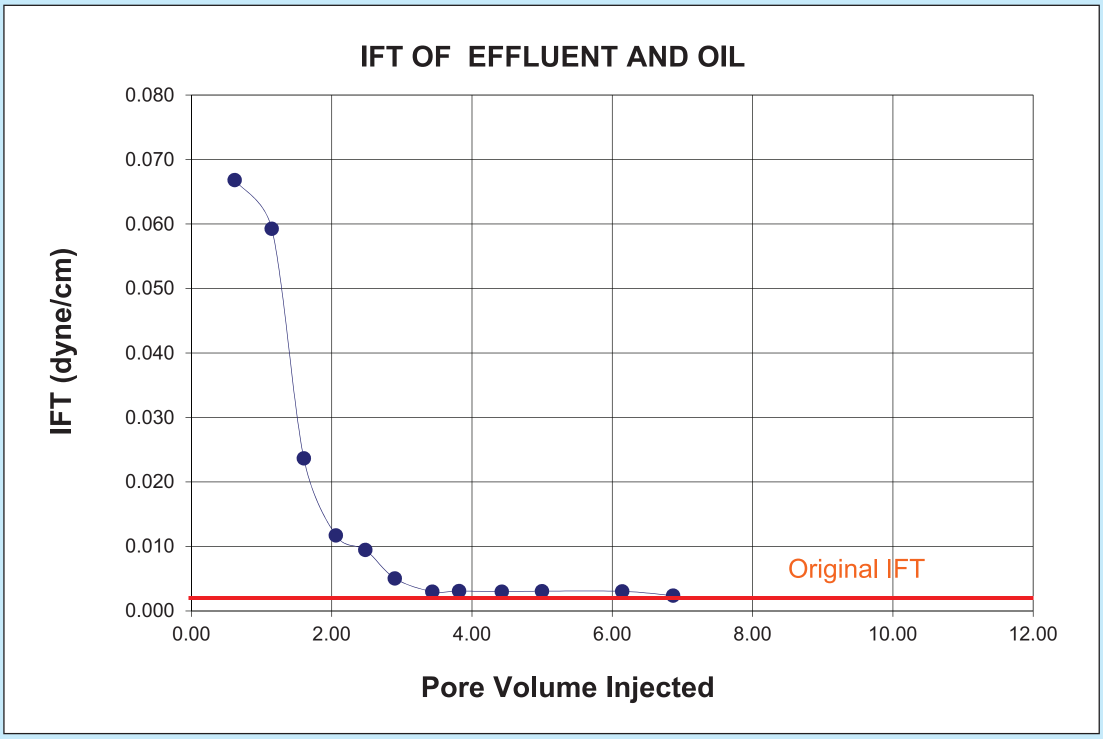


Figure 9
Effluent IFT.

This injectivity experiment indicates that ASP injection in carbonate rock can reduce permeability significantly at the level 88.76% PRF, the damage could not be revocable after post flush of water and the value of RRF still staying in the order of 6.69. This indicates that the permeability reduction is permanent.

Fluid properties of the ASP including IFT and viscosity showed that the IFT looks constant and no significant change, on the hand the viscosity of the fluid drops down to almost 32.6% from the original. However, the adsorptions are still categorized as normal.

The reduction of the ASP solution viscosity and changing the color of the effluent from white to a little bit brown may be caused the interaction between the ASP solution especially polymer content with the mineral at the rock surface occurs very intensively.

Experiment using carbonate rock, sometime is very difficult to take the representative rock sample. Porosity in the carbonate rock may not only consists of intergranular porosity but may also fracture, vuggy, and caves that may be very large size that could not be represent in the small core such as: core plug. Therefore, this experiment just to give indication that injected chemical into carbonate rock must be very careful. More detail study is need using a bigger core size.

REFERENCES

Behr, A., and **Rafiee, M.** (2017). Prediction of Polymer Injectivity in Damaged Wellbore by Using Rheological Dependent Skin. Society of Petroleum Engineers SPE-186054-MS.

Dong, H.Z., Fang, S.F., Wang, D.M., Wang, J.Y., Liu, Z., Hong, W.H. (2008). Review of Practical Experience & Management by Polymer Flooding at Daqing. Society of Petroleum Engineers SPE 114342

Dupas, A., Hénaut, I., Rousseau, D., Poulain, P., Tabary, R., Argillier, J.F., and **Aubry, T.** (2013). Impact of Polymer Mechanical Degradation on Shear and Extensional Viscosities: Towards Better Injectivity Forecasts in Polymer Flooding Operations. Society of Petroleum Engineers SPE 164083.

Glasbergen, G., Wever, D., Keijzer, E., and **Farajzadeh, R.** (2015). Injectivity Loss in Polymer Floods: Causes, Preventions and Mitigations. Society of Petroleum Engineers SPE-175383-MS.

Seright, R.S., Seheult, J.M., Talashek, T. (2008). Injectivity Characteristics of EOR Polymers. Society of Petroleum Engineers SPE 115142

Sharma, K.K., Mishra, S., Kumar, P., Pandey, A., Jain, S., Ghosh, P., Mishra, L., Koduru, N., Agrawal, N., and **Kushwaha, M.K.** (2016). Polymer Injectivity Test in Bhagyam Field: Planning, Execution and Data Analysis. Society of Petroleum Engineers SPE-179821-MS.

Sheng, J.J. (2013). A Comprehensive Review of Alkaline-Surfactant-Polymer (ASP) Flooding. Society of Petroleum Engineers SPE 165358.

Skauge, T., Skauge, A., Salmo, I. C., Ormehaug, P. A., Al-Azri, N., Wassing, L. M., Glasbergen, G., Van Wunnik, J. N., and **Masalmeh, S. K.** (2016). Radial and Linear Polymer Flow - Influence on Injectivity. Society of Petroleum Engineers SPE-179694-MS.

Sugihardjo. (2011). Polymer Properties Determination for Designing Chemical Flooding. Scientific Contributions Oil & Gas, Volume 34, Number 2, ISSN: 2089-3361. LEMIGAS Research and Development for Oil and Gas Technology.

Wang, D., Seright, R.S., Shao, Z., Wang, J. (2008). Key Aspects of Project Design for Polymer Flooding at the Daqing Oil Field. Society of Petroleum Engineers SPE 109682

Wang, Y., He, L. (2006). Commercial Success of Polymer Flooding in Daqing Oilfield—Lessons Learned. Society of Petroleum Engineers SPE 100855.

Yerramilli, S.S., Zitha, P.L.J., Yerramilli, R.C. (2013). Novel Insight into Polymer Injectivity for Polymer Flooding. Society of Petroleum Engineers. This paper was prepared for presentation at the SPE European Formation Damage Conference and Exhibition held in Noordwijk, The Netherlands, 5–7 June 2013.

Zhu, Y., Hou, Q., Liu, W., Ma, D., Liao, G. (2012). Recent Progress and Effects Analysis of ASP Flooding Field Tests. Society of Petroleum Engineers SPE 151285.