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# Polymer Injection Performance in Multi Porous Medium

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**Abstract:** *Polymer injection as come of age in Chemical enhanced or improved Oil recovery (CEOR/CIOR) over the years. The technology as grew from several experimental studies to several field applications. Numerous Researches have been performed to study the recovery potential of Polymer flooding technique in different homogenous medium such as sand packs, beads pack and some consolidated media at different conditions. But in this research attempt is been made to study the performance and behaviour of a synthetic Polymer, Hengflo 63020, in deferent porous media at the same reservoir conditions in a four series core flood experiments involving two Robu cores of different pore geometry and Properties, a Berea sandstone Core and a Bentheimer sandstone core.*

*Result shows that at elevated temperature of 73˚C, Hengflo 63020 has a potential to recover up to 32% additional Oil in Bentheimer Sandstone of 1300md, 12% additional Oil in Berea Sandstone of 158md, 28% in a special ROBU core of permeability of 3662md and 18% in another ROBU core of permeability of 2178md. The performance of Hengflo 63020 indicates a good recovery Potential in heterogeneous reservoir with permeability variation as of the four cores used in this research. Hengflo 63020 Polymer flooding as shown to be capable of reaching a displacement efficiency of 68.182% in a sandstone reservoir at a temperature of 163˚F and this establishes the viability of a Polymer injection Oil recovery technique*

**Keywords:** *Hengflo 63020, Polymer flooding, Oil recovery, Niger Delta. Viscous Oil. ROBU, Berea, Bentheimer.*

## 1. Introduction

The oil recovery by primary energy from the reservoirs is usually about 15 to 25 percent of the Initial Oil in place. Also, Secondary recovery techniques have also been found to further increase recovery by additional 15 to 25 percent leaving behind a recoverable oil of over 30 percent.

However for viscous or heavy Oil, at the end of primary recovery, there is still 85-95% of the original oil resource left in place, furthermore, literatures show that 40% to 55% of oil reserves are usually left in-situ after primary and secondary recovery processes such as water flooding. This remaining reserve has to be recovered by Enhanced Oil Recovery processes [1, 2].

A number of enhanced oil recovery methods or processes are used to recover more Oil from the Reservoir such as thermal recovery process among which are In-Situ Combustion (ISC) or High Pressure Air Injection (HPAI), Steam/Hot water injection, Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD), also Miscible Gas Injection Process which includes First contact miscibility and Multiple contact miscibility. Another enhanced oil process is Chemical Process which involves Low IFT processes and Mobility control processes (Such as Polymer flooding, Surfactant Polymer flooding and alkaline surfactant Polymer).

Polymer flooding involves the injection of viscous liquid alongside with water to improve the displacement of oil through the reservoir pore spaces. This method simply implies the control of the mobility of the injected water for better mobilisation of left behind or bypassed Oil. Polymer solutions are designed to develop a favourable mobility ratio between injected polymer solution and the oil bank being displaced ahead of the polymer.

The ability of chemical of a Polymer slug to recover oil does not just depend on the rheological and elastic properties of the slug but also largely on the fluid storage capacity, the ease of fluid flow, permeability, the rock’s fluid affinity called wettability and the pore geometry of rock. These rock properties are indicative of the rock heterogeneity.

Several works have been conducted with homogeneous porous models with uniform pore spaces. Worthy of note are some of these researches.

Bentheimer core has been used over the years for petroleum engineering research works. [3]Tahir et al in 2017 generated and compile data on the apparent and shear viscosity of Polymer during a flooding process. Their results helped to describe the parameter that defines polymer viscoelastic properties. Other works includes Vincent Bing lee in 2015[4].

Berea core for over 30 years has gained general acceptance in the oil and gas industry for experimental researches. Many researchers have performed several works with the Berea sandstone, such as Polymer injection, Surfactant Polymer flooding, Alkaline Surfactant Polymer injection, Surfactant injection, wettabilty alteration and even nano-particles injection tests. [5, 6, 7, 8, 9, 10].

[11]Udofia et al 2015 did some extensive works on ROBU cores to study the Multiphase Flow Transport Properties for Model Calibration. Their results show that measurements of drainage capillary pressure, resistivity index, spontaneous imbibition and relative permeability on ROBU cores follow same trend like other natural porous rocks in the literature when properly scaled and appear promising. This thesis concluded that specially manufactured synthetic model rocks (ROBU) with well-defined pore pattern can be considered to be sufficiently homogeneous based on the two-phase flow properties examined. Reliable experimental data from rocks of uniform pore pattern to be used for network model predictions has been generated. Their results show that synthetic model rocks (ROBU) can compare favourably with the naturally occurring model rocks that are presently being used and that high precision and well-defined experimental data from synthetic core plugs can be used for proper calibration and validation of multiphase flow models after comparison with those reported in the literature. Hence, the network models should be calibrated using ROBU cores before considering natural model cores (Bentheimer, Berea, Mt. Gambier, etc.) for its validation

Over the years, laboratory studies of Niger Delta Oil recovery by chemical slug were carried out by some researchers.[11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25]

## 2. EXPERIMENTAL

### 2.1. Materials

This experimental study involves the use of materials such as consolidated Special core samples, Hengfloc 63020 Polymer, Niger Delta Crude Oil, Brine and High pressure and high temperature flooding rig, Reagent preparation apparatus, and Data acquisition and processing equipments.,

#### *2.1.1. Special Core Samples*

In this research, four special synthetic core samples were used namely Bentheimer Sandstone, two ROBU (with uniform and well-defined pore pattern and wettability in compliance to ASTM E128-99, ISO 4793-80 and BS 1752-83 standards) and Berea core. These cores have evenly arrayed pore spaces or geometry making them homogeneous rock pieces.

#### *2.1.2. Hengfloc 63020 Polymer*

Hengfloc 63020 is a synthetic polymer purchased from Hengju Benju Company Canada in North America. It has a medium anionic charge and an ultra-high molecular weight ranging from 18 to 26.

#### *2.1.3. Crude Oil*

The crude Oil used was obtained from Niger Delta. The Niger Delta basin consist of Oil with variable properties, API gravity ranging from 14 to about 50° depending on the depth and types of formation they are found. In this study a crude oil of 27° API at 25°C and 39° API at 73°C was used.

#### *2.1.4. Brine*

A Salt solution of 2wt% of sodium Chloride was prepared with freshly prepared with distil water on REMI magnetic stirrer for 30minutes and filtered through a whatman Schleiecher & Schuell filter paper (ash-less) 42 from whatman international ltd, maidstone England to remove undisolved particles and impurities.

#### *2.1.5. High Pressure and High Temperature Flooding Rig*

The flooding rig consists of core holder, three high pressure pumps (Teledyne ISCO syringe displacement pump) 500D used for the brine, crude oil and polymer slugs. Core Holder with pressure transducers the injection end and at the Core holder Overburden pressure inlet. Heating mantles with Udian temperature controllers were also used to raise and maintain the core holder temperature at the desired temperature 73˚C, and measuring cylinders for collecting effluent.

*2.1.6. Reagent Preparation Apparatus*

The reagent preparation apparatus involves 250ml, 500ml, and 1000ml measuring cylinders, 100ml, 250m, 500ml 1000ml, 2000ml beakers, spatulas, Ohaus Digital weigh balance, HJ-3D constant temperature magnetic stirrer, produced by B.Bran Scientific & Instrument company, England, NDJ-8S Digital rotational Viscomter.

*2.1.7. Data Acquisition and Processing Equipments*

The data acquisition equipments include an high resolution digital Video Camera and a core i3 computer system with data analyzing Microsoft software.

**2.2. Methodology**

The experimental procedure began with Fluid Preparation, then Fluid rheological properties determination, Core Cleaning and Core drying, Core Petrophysical properties determination and the Core Flooding.

*2.2.1. Fluid Preparation*

a. **Brine:** The salt solutions were prepared from a combination of sodium Chloride and distil water. A 2wt% solution was prepared over a Remi magnetic stirrer for about 30minutes until all the salt crystals were dissolved. The salt solution was further filtered through a 5 micron filter to ensure a clear solution.

b. **Polymer Slug:** Hengflo 63020 polymer produced by Henju Benju was used for this experimental study. A Polymer slug of 2000ppm in brine was prepared over a remi magnetic stirrer or about 6o minutes to ensure a homogenous slug solution. The Polymer solution was left to hydrate for 24 hours. The Polymer slug Viscosity was measured and there it was conditioned at 73˚C. The viscosity was also measured after which it was injected for Oil recovery.

c. **Oil:** A mineral oil obtained from Niger delta I west Africa was used for this study. The Oil which was blackish brown had a viscosity of 250cp at 25˚C, 106cp at 73˚C, a specific gravity of 0.8921 at 25˚C and an API gravity of 27 degrees was used. The Oil was filtered through a 5 micron mesh to remove any form of fines that ma clog the pore network of the core.

*2.2.2. Fluid Rheological Properties Determination*

The viscosity of the Oil and Polymer slug was measured with NDJ-8S Digital rotational Viscometer and the result is presented in tables 1 and 2.

*2.2.3. Core Cleaning and Core Drying*

A Soxhlet extraction apparatus was used to clean each of the cores for 72 hours until the solvent in the extraction chamber is clear. The solvent used for cleaning the cores was a combination of 50% of methanol and 50% of Toluene solvent. After cleaning, the cores were carefully transferred into the Oven for drying at 60˚C until for about 24 hours until there was no change in the mass of the cores.

*2.2.4. Core Petrophysical Properties Determination*

To determine the Porosity of the cores, the core dimensions were measured with a digital veneer Calliper. The Bulk volume was determined with the expression below (equation 1).

$Vb = \pi D^2 \mathrm{h}/4$ ........................................................................................................................eq. 1

Where

Vb = Bulk Volume

D = diameter of Core

H = length of Core

And the dry weight of the cores was measure with digital mass balance. The Cores were vacuumed in a saturation chamber for about 12 hours until there was no more gas in the chamber. Then, the cores were saturated with the synthetic brine in the chamber and were also pressurised to 2000psi for 24 hours in a high pressure vessel to ensure proper saturation. The wet weight of the cores wet measured and the density of the brine determined. The Porosity of the cores were determined gravimetrically using the core wet weight, dry weight, the density of the brine and the bulk volume of the core.

$$\theta = \frac{\left\{\frac{Ww-Wd}{\rho}\right\}}{Vb} \quad \text{.......eq. 2}$$

Where

θ=Porosity

Ww=Core Wet weight (g)

Wd=Core dry weight (g)

ρ=Brine Density (g/cc)

Vb = Bulk Volume (cc)

The liquid Permeability of all the core samples was measure using the synthetic brine and determined with the Darcy law. The brine was injected through the core a constant velocity between 15cc/mins to 30cc/mins depending on the capillary entry pressure and the pressure drop across the cross sectional length, L of the cores were measured with the pressure transducer.

$$Kl \;= \mu.\frac{qL}{(dP.A)} \quad \text{.......eq. 3}$$

Where

Q=Flow rate

Kl=Permeability

A=Core cross sectional Area

μ =Brine Viscosity

dP= Pressure drop across the core

L =Core length

*2.2.5. Core Flooding*

The core flooding processes was carried out at 73˚C or 163 ̊F in other to evaluate the performance of Hengflo 63020 and to compare with the work of Vincent Bing lee in 2015, Levitt 2006, Heesong Koh in 2015 and work of Adijat et al. in 2016. [4, 8, 26, 27]

Oil saturation was done at 1cc per minute by oil displacing water through each of the cores until no water production that is to attain initial Oil saturation. The volume of the water displaced was used to evaluate the volume of Initial Oil in place and Initial water saturation. Water flooding or Brine injection was done at 1cc/min until 3 PV was injected and the Oil recovery was recorded. Thereafter 3 PV of Polymer slug flooding was conducted also at 1cc/min. The Oil recovery by the Polymer was also measured and percentage recovery calculated. The same processes were performed for the cores (Bentheimer, Berea, and two types of ROBU cores.

## 3. Results and Discussion

Table 1 and 2 presents the result of the Oil and Polymer properties test. At the ambient temperature, 25˚C, the Oil has a viscosity of 250cp, a specific gravity of 0.8921with API gravity of 27 degrees at 25˚C and 106cp, a specific gravity of 0.8816 and API gravity of 29 degrees at 73˚C. The Polymer slug at laboratory condition measured 4.4cp and 2.6cp at73˚C on the digital viscometer. The oil used by Adijat et al, in 2016,[27] was light or less viscous oil of 2.5cp at 25˚C and 42.86 API degrees.

**Table1.** *Oil Properties*

| Viscosity(cp) | Density (g/cc) | API gravity | Temperature (°C) |
|---|---|---|---|
| 106 | 0.8816 | 29 | 73 |

**Table2.** *Polymer Properties*

| Viscosity(cp) @ 25˚C | Viscosity(cp) 73˚C |
|---|---|
| 4.4 | 2.6 |

The Oil Initial Oil saturation of the Benthiemer Sandstone with a Porosity of 21.502%, was 74.138% with an initial water saturation of about 26%. Water flooding was able to mobilise about 54% of Oil at 3VP water injection. The Polymer Flooding increased the total produced Oil to 85% with a displacement efficiency of 68.128% and leaving behind a residual Oil saturation of about 15% as shown in the Table 3 and 4.

The second sample which is the Berea Sandstone of porosity of 20.2% was saturated with until the Oil saturation became about 74% and Initial water saturation about 26%. 3VP of water flooding produced 53% of Oil. Polymer flooding produced extra 12% of Oil in place.

**Table3.** *Experimental result in cubic centimetre*

| | Bentheimer (T1) | Berea (BR1) | ROBU (A1) | ROBU (B1) |
|---|---|---|---|---|
| Length(cm) | 5.998 | 5.478 | 5.057 | 4.786 |
| Daimeter (cm) | 2.515 | 2.515 | 2.555 | 2.545 |
| Pore Volume (cc) | 6.407 | 5.502 | 7.187 | 10.544 |
| Bulk Volume (Vb) (cc) | 29.796 | 27.214 | 25.928 | 24.346 |
| Porosity(%) | 21.502 | 20.217 | 27.696 | 43.307 |
| Initial Oil Saturation (Soi) cc | 4.75 | 4.05 | 5.7 | 8.25 |
| Initial Water Saturation (Swi) cc | 1.657 | 1.452 | 1.487 | 2.294 |
| Oil Rec., For Water Flooding (Wr) cc | 2.55 | 2.15 | 3.15 | 5.15 |
| Oil Rec., For Polymer Flooding (Pr) cc | 1.5 | 0.5 | 1.6 | 1.5 |
| Liquid Permeability(md) | 1300 | 158 | 3662 | 2178 |

**Table4.** *Experimental result in Percentage*

| | Bentheimer (T1) | Berea (BR1) | ROBU (A1) | ROBU (B1) |
|---|---|---|---|---|
| Porosity(%) | 21.502 | 20.217 | 27.696 | 43.307 |
| Initial Oil Saturation (Soi) % | 74.138 | 73.61 | 79.31 | 78.244 |
| Initial Water Saturation (Swi) % | 25.862 | 26.39 | 20.69 | 21.756 |
| Oil Rec., For Water Flooding (Wr) % | 53.684 | 53.086 | 55.263 | 62.424 |
| Oil Rec., For Polymer Flooding (Pr) % | 31.579 | 12.346 | 28.07 | 18.182 |
| Total Recovery (%) | 85.263 | 65.432 | 83.333 | 80.606 |
| Residual Oil Sat. (%) | 14.737 | 34.568 | 16.667 | 19.394 |
| Displacement Efficiency (Edp) | 68.182 | 26.316 | 62.745 | 48.387 |

A 27.7% porosity ROBU core with 3662md Permeability was 79.31% Oil saturated. About 55% of the oil was produced by water flooding. Polymer flooding mobilised 28.07% of oil leaving 16.667% of Oil in Place and achieving 62.745% displacement efficiency.

The other Synthetic core, ROBU core with Permeability 2178md and Porosity 43.307%, had an Initial Oil saturation of 78.244%. Water flooding Produce 62.424% of the oil and Hengflo 63020 Polymer slug added 18.182% to the oil recovery bringing the total oil recovery to 80.606% with 48.387% displacement efficiency.

## 4. Conclusion

It is worthy of note to recognise that the Polymer slug recovered over 31% of Oil in Bentheimer rock. This indicates that Bentheimer Sandstone is a better candidate for recovery by Polymer flooding as compared with the other samples. However, The Oil recovery 28.07% in the first ROBU core, A1, and 18.18% in the second ROBU core B1 are also encouraging values for consideration for a successful Polymer flood at elevated temperature.

From the research result, it can be concluded that in a multi-porous media with Petrophysical Property mix as those presented in this study will experience a favourable Oil recovery by Hengflo 63020. A heterogeneity combination of such potentially will have favourable oil displacement efficiency.

Hengflo 63020 Polymer flooding as shown to be capable of reaching a displacement efficiency of 68.182% in a sandstone reservoir at a temperature of 163℉ and this establishes the viability of a Polymer injection Oil recovery technique as also noted by Heesong Koh (2015) and Adijat et al (2016).[26, 27]

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