The potential of polymer for enhanced oil recovery process on oil refinery: A literature research

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Abstract. The objective of this research is to obtain evidence that polymer can be utilized as injection fluid in Enhanced Oil Recovery process. Polymer is one of chemical compounds in Chemical Enhanced Oil Recovery (CEOR). The method utilized in this research is reference collection regarding Enhanced Oil Recovery which further observed and reviewed, especially the ones connected with polymer utilization as injection fluid. Polymer injection is a method conducted after primary and secondary recoveries processes. The clearest and most significant mechanism of polymer application is to improve sweep efficiency by decreasing thickness level and improving water injection profile. Polymer injection is a tertiary recovery step, conducted after oil can no longer be produced although the capacity only reaches 60%. This means that there is still 40% of total capacity yet to be produced. This polymer injection is commonly utilized to obtain remaining oil reserve because of its relatively simple application, low cost, and able to produce a relatively large volume of oil reserve.

1. Introduction

Oil recovery process can be done by conducting exploration on new refineries or by optimizing oil recovery in existing or old oil refineries. The main factor of the decrease of oil production in Indonesia is that most of Indonesian oil refineries are old and the inability to recover new oil refinery. Chemical injection is one of the efforts to improve oil recovery, or what is known as Enhanced Oil Recovery (EOR) process. Injection is conducted in order to improve swiping effectiveness in reservoirs and to provide a mean to control water mobility against oil by increasing injection water viscosity. Injection of high viscosity fluid can be individually conducted or combined with other chemical compound, which would be able to increase oil recovery level in reservoirs [1]. EOR method is able to optimize oil recovery on old refineries up to 70% of total OOIP, meanwhile conventional steps (both primary and secondary) are only able to produce 20-40% of total oil capacity [2]. In secondary recovery stage, there is at least 40% of obtainable oil, trapped in formation granules. To improve oil recovery, methods to recover the trapped oil are required to make sure that they can be produced accordingly. One of numerous available EOR methods is by doing polymer flooding. Oil recovery process can be categorized into three phases, namely primary, secondary, and tertiary phases. In primary phase, a natural process applied is highly dependent on the content of natural energy in the reservoir. Secondary production technique (secondary oil recovery) is conducted when oil production experience decreases due to lower reservoir pressure. Secondary oil recovery [3] can be done by injection fluids like water and/or gas into the reservoir to increase the pressure and volume of oil swiping inside the reservoir. In pressure recovery method, gas is injected in the formation (hydrocarbon formed around the reservoir) inside a well, while
also covering other wells until the pressure level is restored along the reservoir. Tertiary oil recovery [4] is conducted because primary and secondary oil recoveries technique are unable to produce optimal level of oil from the reservoir (less than 40%) and left a high volume of oil inside the reservoir. Tertiary production technique, which also known as Enhanced Oil Recovery (EOR) is conducted by injecting special fluids, which consists of thermal injection, gas dissolution process in oil (miscible gases), and chemical technique. EOR method is defined as a method that involves material injection process which can cause alterations in the reservoir such as oil composition, temperature, mobility ratio, and interaction characteristic between rocks and fluids. Several EOR methods are applicable after primary phase or even at oil seeking stages. One of EOR methods is chemical injection, which is an injection of chemical compound such as surfactant, polymer, and alkaline. Chemical injection possesses a great prospect for reservoirs that already use water injection but still unable to obtain economically potential oil volume.

2. Methodology

On chemical technique, chemical compounds (polymer or surfactant) are injected inside the reservoir to alter the nature of oil and to help it flow easily into the production wells. Chemical techniques (polymer or surfactant) are able to improve oil swiping and rush efficiencies in the reservoir. Surfactant is able to lower interface tension between oil and water, which able to carry oil inside rock pores into the production well, while polymer would be able to increase fluid viscosity and optimally drive the oil. Polymer is utilized as thickener to produce higher injection fluid viscosity, meanwhile polymer in the solution will form inter-polymer network [1] (Figure 1). Injection by using polymer to improve oil recovery was first introduced as Enhanced Oil Recovery in early 1960s. Today, more than 90% of polymer injections in the field are using PHPA [5]. Since that time, chemical EOR method is vastly developed into a commercial subject, which leads to a high number of publications regarding its utilizations on various reservoir cases.

![Figure 1. Polymer Injection process in enhanced oil recovery [6,7].](image)

Polymer injection is directly connected with swiping efficiency improvement by lowering mobility ratio (M), as described in the following formula [8]:

\[
M = \frac{\gamma_{\text{displacing fluid}}}{\gamma_{\text{displaced fluid}}} = \frac{k_{rw}/\mu_w}{k_{ro}/\mu_o}
\]

krw = water effective permeability, kro = oil effective permeability, \(\mu_w\) = water viscosity and \(\mu_o\) = oil viscosity.

Polymer, or also known as macromolecule is a series of very long simple molecules formed by small and simple chemical units’ recurrence [5]. Polyacrylamide is a non-ionic synthetic polymer synthesized...
from acrylamide monomer, and commonly made based on free radical mechanism. Polyacrylamide molecule is a highly flexible molecule, with a long chain and relatively small molecule diameter that makes this polymer sensitive to mechanical damage and degradation. To improve its effectiveness in increasing oil recovery, polyacrylamide is reacted with strong base (NaOH and KOH) which known as partially hydrolyzed polyacrylamide (PHPA) [9].

The common thickening agent used in this process is polymer. This method possesses an advantage to lower total water volume required to achieve oil saturation and increase sweeping efficiency by improving oil-water mobility ratio [10].

Figure 2. Polymer flooding scheme [9].

Polymer improves sweeping efficiency during water flooding. The method is by adding water soluble polymer before reinjection process into the reservoir. Low concentration polymer (generally 250-2000 mg/L), from synthetic or biopolymer types is utilized. The most significant and clear mechanism of polymer application is to improve sweep efficiency by decreasing thickness, improving water injection profile. When polymer is added in other EOR process (for example surfactant or base flow), plays an important role in synergism mentioned by Sheng [11]. Polymer can also produce economic impact because the level of water injected and produced is compared with water flow [11]. Biopolymer is used in several projects, although it was also used in jobs conducted in 1970s and 1980s. Polymer that contains other polyacrylamide (PAM) used in enhanced oil recovery is categorized as hydrophobic attaching polymer [12]. Hydrophobic attaching polymer contains one or more water soluble monomer (acrylamide) and small fraction (0.5 to 4%) water insoluble monomer (hydrophobic).

3. Results and discussion

To recover the remaining oil reserves in a reservoir, a driving fluid is required to remove oil from the reservoir, one of which is by polymer injection. On enhanced oil recovery (EOR) methods, polymer is commonly used to extract remaining oil reserves because polymer injection is identical to water flooding, where polymer injection is done after the water injection has been carried out in the reservoir and polymer injection method can be done if the reservoir still possesses economical oil content to produce after water injection. In production process by water injection, it is often that water flows unevenly before oil, mostly in heterogeneous reservoirs. The effectiveness of polymer injection is influenced by viscosity, molecular weight and polymer concentration. Changes in the amount of water and salinity in polymer solution will affect the viscosity. Higher molecular weight polymers will provide higher viscosity and can reduce the volume of polymer used but still be able to pass through pores in the rock reservoir effectively. The higher concentration of the polymer being injected can shorten the injection time and increase the recovery factor thereby reducing the residual oil formation [13].
However, it must be considered that the greater the concentration of the polymer to be injected requires a greater injection pressure. At certain values, the concentration of polymer injected does not have a significant effect on the efficiency of polymer injection. Polymer injection is directly related to increasing sweeping efficiency by reducing mobility ratio.

On oil production by using EOR technique, polymer plays a strong role as agent to improve water performance injected in the reservoir by obstructing areas with high conductivity as cross-linked agent inside the reservoir. In this process, polymer is injected with an inorganic metal ratio that will be cross-linked so polymer molecule will surround the metal surface, and as agent to lower water mobility or water-oil ratio (WOR).

Polymer can improve driving fluid viscosity (water) and optimize oil driver and pusher. Water soluble polymer injection is used as viscosity improvement agent that can control water base mobility to improve sweeping efficiency. Polymer will lower negative effect caused by permeability and fracture variations in heterogeneous reservoir. Polymer injection consists of several stages which are pre-flush (reservoir conditioning), additional oil recovery (oil bank), and polymer solution injection to control fluids mobility, fresh water buffer to protect polymer also driving injection or driving fluid (water).

Cellulose derivative polymers commonly utilized in EOR application are carboxymethyl cellulose (CMC), hydroxyl ethyl cellulose (HEC), and xanthan gum. HEC and CMC possess decent endurance on shear rate and high temperature. Xanthan gum possesses decent thermal endurance because of its complex structure that leads to a very low xanthan gum viscosity decrease when temperature rises. Xanthan gum also possesses endurance against decent salinity so xanthan is more often used in EOR than any other polymers. Other type of polymer used in EOR is polyacrylate that possesses good endurance against shear rate and possesses a better thermal stability than any other polymers, but low endurance on low salinity because of carboxyl group existence. A good polymer should possess the following characteristics: (a) Do not have -O- bind in its main chain to improve thermal stability, (b) Possesses negative ionic hydrophilic group to decrease polymer absorption on rock surface, (c) Possesses high viscosity that would affect polymer injection effectiveness and (d) Possesses non-ionic hydrophilic group to improve endurance against chemical compounds.

Factors that affect polymer quality are salinity and hardness. Salinity is an acidic level of a reservoir that could disrupt polymer chemical binding. Hardness is the number of cation in polymer mixture and reaction with fluids in reservoir.

![Figure 3. Oil pushing scheme with polymer [14].](image)

Polymer improves sweep efficiency during water flooding. The method is to add water soluble polymer in the water before it is injected into the reservoir by using low concentrate (250-2000 mg/L) synthetic or biopolymer polymers biopolymer. Permeability core decrease is marked by the increase of polymer injection pressure. On the beginning of polymer injection, polymer flow with high pressure so that polymer will be able to flow through rock pores. Along with the polymer injection process, polymer
solution will be absorbed into core Berea rock sample. This factor is the cause of permeability decrease [15]. Permeability value decrease on polymer injection will lower injection rate. Besides that, by the increase of polymer viscosity, polymer injection rate will be lower [16]. Recovery improvement mechanism with polymer can be produced by improving driver fluid viscosity, lower driver fluid mobility, and communicate with a wider reservoir volume. The limit is met when oil viscosity is too high the injected polymer should possess higher viscosity to reach expected mobility control. A good result will be achieved when polymer flooding is started before water-oil ratio (WOR) [17]. The existence of clay will improve polymer absorption. If there is a fracture, gel-shaped polymer or cross-linked polymer technique should be implemented. Screening criteria of polymer injection is as follow:

The reasons as to why this polymer injection is commonly utilized to recover oil reserves are because of its relatively simple application technique, low cost, and relatively high capacity of oil recovery [18]. Because of its simple polymer injection application with relatively low cost if compared with any other EOR methods, polymer injection method possesses high level of efficiency. There are a number of parameters that might influence polymer injection process, but the most important ones are reservoir temperature, formation water salinity, divalent compound, clay compound, oil viscosity, and the ability to form a formation. Median value of important parameter of polymer flowing project is real. The values of each parameter are analyzed by using rank and percentage, and the values emerge at 50th percentage. EOR screening criteria are weighted median of the field project and their pilots, and quality based on project and test numbers. Laboratory data is not utilized to obtain criteria because laboratory data cannot be used as guidance. The salinity of reservoir water might be close with the injected water before polymer injection. Water salinity before polymer injection is highly different than the original water formation. Because of that, reservoir water salinity before polymer injection must be utilized in screening filtering criteria, not from water formation as conducted screening criteria. Besides that, formation water salinity can influence polymer performance by mixing with injected polymer slug. If pre-flush is conducted, salinity of original formation water will produce a smaller effect on polymer-flood performance. Polymer performance might be directly influenced by water salinity. Water salinity used to mix polymer solution is more important because it would directly affect polymer solution viscosity. Polymer injection is an improvement of water injection, which is conducted by dissolving polymer into injection water aimed to improve oil sweeping efficiency [19].

4. Conclusion
Polymer injection is commonly used because of its relatively simple application and relatively higher recovery level. Polymer injection effectiveness is influenced by viscosity, molecule weight and polymer concentration. The function of polymer is to improve mobility ratio so that water flow will not overtake oil flow, and increasing sweep efficiency. Polymer applied in EOR technique should possesses characteristics of water soluble, high viscosity at low concentration, decent thermal endurance (not degraded at high temperature), and also decent mechanic and salinity stabilities. Polymer works by improving oil driver fluid viscosity and improves sweep efficiency during water flooding. The reasons why this injection is commonly used to recover oil reserves are because it’s relatively simple application technique, low cost, and relatively high level of oil recovery. Reservoir water salinity before polymer injection should be used in screening criteria, not from formation water as conducted screening criteria.

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