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Effect of polymer concentration on the polymer adsorption-induced permeability reduction in low permeability reservoirs

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ABSTRACT

This study presented the effect of polymer adsorption-induced permeability reduction on oil recovery, particularly in low permeability system. The polymer injecting experiments were conducted in a quarter of five-spot pattern with concentrations generally applied. Especially, by using the field oriented two-dimensional sandstone, we attempted to analyze the combined effect of polymer retention for concentration and high velocity near injection on oil recovery.

Particularly in low permeable sandstone, oil recovery was not proportionally enhanced with increase in polymer concentration, rather decreased at concentrations above 1,000 ppm in this experiment. This could be understood by polymer adsorption phenomena corresponding to concentrations. The polymer adsorption layer formed at high concentration clogged effective pore radius by up to 59.8%, compared to clean sandstone and the permeability greatly decreased from 56 to 1.5 mD, resulting in rather decreased oil recovery. For this reason, there should be an optimum concentration for maximizing the oil recovery. It was also confirmed by shear rate analysis. At high concentration, the shear rate near injection where has the highest velocity was greater than critical rate. This means that polymer molecules adsorbed to mono-layer of adsorption by hydraulic force, and the adsorption became additionally thicker and hindered the oil flow.

1. Introduction

Polymer flooding is a mature technology in chemical EOR (enhanced oil recovery) method, which increases the sweep efficiency and the oil recovery. However, polymer retention in porous media such as adsorption onto grain surface and mechanical entrapment causes the mobility reduction. Particularly in low permeability reservoirs, polymer retention can be critical due to the polymer adsorption-induced permeability reduction, which yields negative effect on oil recovery. In this sense, several experimental studies have investigated the resulting effect of polymer adsorption during polymer flooding [1,2].

The amount of polymer adsorbed depends on the natures of the polymer and the rock surface. However, three phenomena have been observed regarding polymer adsorption: (1) Laboratory tests often indicate higher adsorption than field performance; (2) adsorption is significantly less in consolidated rock than in sand pack; and (3) adsorption increases with increasing water salinity. Abadli and Sadikhzadeh reported that laboratory results often cannot be extrapolated to predict polymer adsorption in oil reservoirs because of polymer retention in porous media [3,4].

The previous researches indicate a selective action of the polymer on a significant reduction in water permeability with respect to oil permeability. Cordova et al. [5] showed that polymer adsorption reduced the water permeability regardless of the wettability, and it improved the oil flow. Barreau et al. [6] used capillary tube filled with porous medium in the polymer flooding experiment. They yielded the thickness of polymer adsorption layer with the effective permeability change and found out that the adsorption layer could affect the fluid flow.

Zitha et al. [7] concerned with the influence of polymer concentration and permeability on the retention of high molecular weight non-ionic polyacrylamide (PAAm) during flow in granular porous media. They showed the residual flow resistance, determined by water flow following polymer, increased with polymer concentration. Also, Mishra et al. [8] investigated the effect of polymer adsorption and mobility control on additional oil recovery with different polymer concentrations. The result showed that with the increase in polymer concentrations, oil recovery increased. However, Park et al. [9] conducted experimental study of polymer

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flooding to low permeable system, and showed that increase in polymer concentration may not enhance the oil recovery. Meanwhile, Chauveteau et al. revealed that when polymer solution is injected at low shear rates, the adsorbed layer thickness is not dependent upon the injection rate. When polymer is injected at higher than critical shear rates, the adsorbed layer thickness increases gradually up to some maximum values, increasing with injection rate. Although polymer adsorption plays a significant role in relative permeability modification to control the water production, it results in permeability reduction of porous media [10,11]. The most of previous studies were conducted in one-dimensional core flow experiments which have limitations of having uniform fluids velocity in the system and no viscous fingering. In this work, we attempted to build a field oriented experimental system and comprehend the effect of polymer adsorption on reducing the mobility of injecting fluids and enhancing the oil recovery. Under the environment of having high shear rate of injected polymer solution near injection well we analyzed the effect of polymer concentration on polymer adsorption. Accordingly, the experiment was conducted in two-dimensional quarter of five-spot pattern using low permeability sandstone where the cross sectional area of stream tube is varied with the location, thus solution velocity adjacent to the injection port has the highest value. Also, we intended to explain how the effect of mobility control of injected fluids conflicted with the decrease in pore throat size by polymer adsorption layer in low permeable system.

2. Experimental system

For two-dimensional flow experiments, sister gray Berea sandstone slab in the dimension of 20 × 20×2 cm was used. Their properties were measured to be 20.1% of porosity and 41.2 mD of permeability, which was measured by injecting brine in direct line drive [12]. The plate samples were washed and dried in an oven at 100°C for 24 h and saturated with brine and oil to the target initial experiment condition [13,14]. The oil used in this study is Shell Morlina S2BL 10 which has 10 cSt at 40°C. And the 2% salinity brines were applied in the system using 83 wt.-% NaCl and 17 wt.-% $CaCl_2$. All experiments in this study were performed with HPAM (partially hydrolyzed polyacrylamide). The polymer 3330 s with molecular weight of 8 million Dalton was provided by SNF group and was used as received in dry powder form. Polymer solutions were prepared by dissolving the required amount of polymer in 2% NaCl brine, according to the procedure described in the “API (American Petroleum Institute) Recommended Practice 63”. Stock solutions of polymer at 5000 ppm by weight were prepared. Lower concentrations were diluted from the stock solution with the required amount of make-up brine. Polymer solutions were prepared by the slow addition of the polymer powder to the brine in a vortex created by a magnetic stirrer, Gentle agitation was maintained overnight for complete polymer dissolution. To remove all microgels, the polymer solution was filtered to have lower filtration ratio than 1.2.

A flooding apparatus (Fig. 1) has been set up to conduct two-dimensional horizontal polymer flooding experiments. The injection experiment system was set for reservoir condition by using the main components such as cylindrical plate holder for two-dimensional slab, fluid storage vessels, displacement pumps, back pressure regulators, effluent collector, and data acquisition system. The sandstone slab was horizontally inserted into the vessel with upper and lower side supports to apply confining pressure uniformly as shown in Fig. 2. The experiment was conducted in a quarter of five-spot pattern to represent more actual environment occurring viscous fingering and flow channeling in applying injection methods.

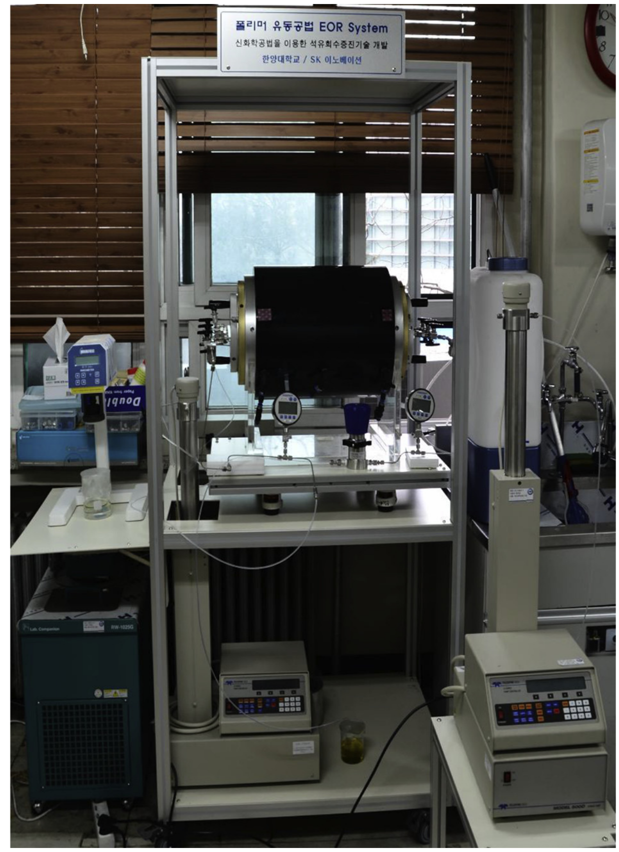

Fig. 1. Schematic of polymer flooding system.

The sandstone is fully saturated with brine to determine pore volume and measure initial permeability by injecting brine at various flow rates. And then the oil is injected with oil to confirm the irreducible water saturation to set an initial experiment condition [15]. Then, brine is injected to set the initial oil saturation as 60%. We conducted several experiment sets by using various polymer concentrations. After the polymer flooding is finished, only brine is injected to investigate permeability reduction solely by polymer adsorption with removing the polymer entrapment.

3. Results and discussion

This study examined how the continuous increase in polymer concentration to improve the oil-polymer solution mobility ratio influenced oil recovery in the case of polymer flooding in low permeability reservoirs. The concentration range in this test was 0–1,500 ppm, where a higher concentration would be expected to increase oil recovery. The permeability of the reservoir was

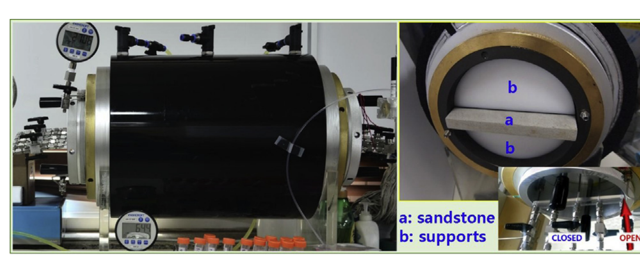

Fig. 2. Two-dimensional flow apparatus and opening port for a quarter of five-spot pattern.