

Selection Method of Flow Modifier Polymers for Chemical Enhanced Oil Recovery

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Abstract

Chemically enhanced oil recovery methods can provide a solution to increase oil recovery. Of these, surfactant- polymer flooding is common. Efficient selection of polymers and surfactants is essential for a successful EOR project. Detailed selection of polymers is a lengthy task that involves a number of studies. Our goal is to create a fast polymer selection method based on which the most promising polymer can be selected.

Keywords: *polymer selection, dynamic viscosity, hydrodynamic diameter, enhanced oil recovery.*

1. Introduction

Enhanced oil recovery methods are often used to enhance crude oil recovery. [1]. Among the tertiary oil recovery methods, the use of water-soluble polymers is widespread. Oil yield can be enhanced with the increased viscosity of the water phase by the use of polymers. [2, 3]. This method is often used together with surfactant flooding. Besides, for a successful EOR project efficient selection of the polymers and surfactants is essential [4]. Many variants of the polymers used for these purposes are known. Polymer manufacturers generally make suggestions for polymer products that can be potentially used, but their number is still numerous. [5, 6]. Their selection is a long task involving a number of studies [7, 8]. At the end of this process, the most efficient polymers are selected, with which the selection of surfactants can be continued.

Our goal was to create a fast polymer selection method that can be used to select the polymer products that are expected to be the most suitable for the purpose and based on this, the selection of surfactants can be started before the more detailed polymer selection procedure is completed. Nevertheless, it is not the aim to omit the full testing procedure of polymers.

2. Materials

For the experiments, the various viscosity-increasing polymers (Section 2.2) were dissolved in synthetically prepared model brine (Section 2.1). The polymers were added to the brine at a concentration of 1 g/L, and the solutions were stirred in a closed vessel at laboratory temperature for 8 hours using a magnetic stirrer. After the stirring time, the solutions were stored overnight.

2.1. Brine

Synthetic brine, freshly prepared before use, was utilized for the experiments. The composition of this synthetic brine is shown in **Table 1**.

Table 1. *Used salts for prepared synthetic brine*

Used salt	Concentration, g/L
NaCl	0.5
CaCl ₂	0.2
NaHCO ₃	2.6
CH ₃ COONa	2.6
Sum	5.9

Each of the salts which was used in the assays is an anhydrous analytical grade chemical.

2.2. Polymers and its solutions

In our work, aqueous solutions of synthetic copolymers from polyacrylamide and acrylonitrile tertiary-butyl sulfonate were investigated. Furthermore, the mentioned compounds had similar molecular structure which are commonly used in practice. The tested polymers were available in granulated form. The most important properties are summarized in **Table 2**.

Table 2. The investigated polymers and their properties [9]

Type of polymer	Average molecular weight	Anionicity
FP AN125VLM	very low	medium
FP AN125	medium	medium
FP AN125SH	high	medium
FP AN125VHM	very high	medium

There was a difference in the average molecular weight of the used polymers.

3. Product analysis

In order to characterize the polymer solutions, their solubility was investigated, also, the dynamic viscosity was measured and the hydrodynamic permeability was determined.

3.1. Examination of solubility

Solubility was examined visually. In order to be able to assign a physical amount, the light transmittance (transmittance) of the solution was measured spectrophotometrically with an Avantes spectrophotometer. The tests were performed with light at a wavelength of 520 nm and taken as 100 % when the light was completely transmitted by the solution and 0 % when the irradiated light did not pass through the solution in the 1 cm measuring cell.

3.2. Viscosity

In our experiments we used an automatic viscometer of the SVM 3000 Stabinger Viscometer type manufactured by Anton Paar to measure the dynamic viscosity of the solutions. Viscosity is measured on a rotating basis. The device performs the tests at a constant shear rate of 100 1/s and determines the dynamic viscosity.

3.3. Determination of hydrodynamic diameter

In our experiments, a Malvern Nano ZS instrument was used to measure the hydrodynamic di-

ameter of the polymer in solution. Measurements were performed at 25 °C.

4. Results

The measurement results of solubility of the polymers are summarized in Section 4.1, the data of the hydrodynamic diameter tests in Section 4.2 while the dynamic viscosity data are summarized in Section 4.3.

4.1. Solubility of polymers

The solubility of polymers is one of the key criteria for their applicability, so this property was considered a selection condition. Polymers that were not completely soluble were excluded from further studies. The results are summarized in **Table 3**.

Table 3. The solubility of used polymers during the analysis

Type of polymer	Transmittance, %	Attendance
FP AN125VLM	100	transparent
FP AN125	100	transparent
FP AN125SH	100	transparent
FP AN125VHM	100	transparent

All of the polymers tested were dissolved in the used brine. No turbidity or precipitation was observed and all of them were found to be suitable for further investigation

4.2. Dynamic viscosity of polymer solutions

The dynamic viscosity data of the polymer solutions at 80 °C are summarized in **Table 4**.

Table 4. Dynamic viscosity of polymers at 80 °C

Type of polymer	Dynamic viscosity (80 °C), mPa·s	Ranking
FP AN125VLM	1.58	-
FP AN125	2.52	3
FP AN125SH	2.88	2
FP AN125VHM	4.09	1

Based on the values measured at 80 °C, the highest dynamic viscosity was considered the best result. Furthermore, it was determined as a condition that the dynamic viscosity of the polymer solution be higher than the value of the crude oil measured at 80 °C, which is 2.43 mPa·s. Based on the latter, FP AN125VLM did not meet the criterion.

4.3. Hydrodynamic diameter of polymers

The test results for the hydrodynamic diameter of the polymers in solution are summarized in [Table 5](#).

Table 5. Hydrodynamic diameter of polymers

Type of polymer	Hydrodynamic diameter, nm
FP AN125	385.9
FP AN125SH	420.8
FP AN125VHM	777.7

The solution of polymers injected into the reservoir must pass through the porous rock. The hydrodynamic diameter of polymers in solution has been the subject of a number of studies on the relationship between the pore throat of a petroleum reservoir rock and polymer filtration[10]. Oort et al. [11] were the first to formulate the “1/3: 1/7 rule”, according to which if the hydrodynamic diameter of the polymer exceeds 1/7 of the diameter of the pore pores, it will become trapped in the pores and lead to polymer loss. In the case of the oil field where the tests were based, the average pore throat diameter was 5 µm. Therefore, the maximum hydrodynamic diameter was taken to be 714.2 nm and the polymer for which this value was higher (FP AN125VHM) was excluded from the test series.

5. Conclusion

At first, solubility was examined in the study of polymers. Based on this, all of the polymers met the requirements. Subsequently, the dynamic viscosity data of the solutions were examined, where the criteria was that the dynamic viscosity of the polymer solution should be higher than the dynamic viscosity of the crude oil. The function of the polymers is to increase the dynamic viscosity, so a ranking was made based on the results. Afterwards, the hydrodynamic diameter of the polymers in solution was investigated, where the diameter of the average pore tube throat must be less than 1/7. The tests and criteria are summarized in [Table 6](#).

Table 6. Experiments and criteria

Experiment	Criteria
Solubility	Complete dissolution, transparent solution
Dynamic viscosity	Higher crude oil viscosity, maximum viscosity increasing effect
Hydrodynamic diameter	Smaller, than 1/7 pore throat diameter

Based on the criteria system, two polymers were found to be suitable at the end of the selection. These were polymers FP AN125 and FP AN125SH. Regarding the dynamic viscosity data, the latter is preferred. Displacement studies with these two polymers (using surfactants) were also performed at the Institute of Applied Earth Sciences of the University of Miskolc.

Table 7. Displacement experiments of polymer-surfactants

Type of polymer	Excess oil yield, %
FP AN125	26.6
FP AN125SH	31.9

In case of the polymer (FP AN125SH), it was also considered to be advantageous, a higher oil yield of more than 5 % was obtained.

The developed polymer selection method has been found to be suitable for making a preliminary quick decision on which polymer can be the most effective for cEOR purposes as well as for further studies with surfactants.

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