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A study of mixing performance of polyacrylamide solutions in a new-type static mixer combination

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ABSTRACT

In this paper, the performance of a Kenics and SMX static mixer combination is investigated with regard to the specialty of tertiary oil recovery. The experiment has the same scale with industrial process as the diameter of test static mixers are 50 mm and the effective length are 1500 mm. The experiment mainly focuses on degradation of polyacrylamide solutions of different concentrations and different relative molecular mass, the pressure drop of the static mixer combination and mixing performance of polyacrylamide solutions through the static mixer combination. The experimental results show that the degradation rate of polyacrylamide solutions and non-uniformity degree are positively related to polyacrylamide solution concentrations, relative molecular mass of polyacrylamide and liquid phase flow rate. With more solvent distributed among the macromolecular chain entanglements, the flow resistance of macromolecules is reduced, which leads to the reduction of the viscosity of HPAM solution. This phenomenon mainly accounts for the degradation of polyacrylamide solutions. In this study, the pressure drop of the static mixer combination and non-uniformity degree of product solution have obvious advantages compared with other static mixers used in the same way. The results show that the static mixer combination is very suitable for mixing process of polymer solution and water from oilfield.

1. Introduction

Static mixers, also known as motionless mixers [1], are widely used in many process industries, such as refining, power generation, chemical industry, gas treatment, and air-conditioning [2–5]. Compared with a conventional agitator, static mixer can provide a more controlled and scalable rate of dilution in fed batch system and also homogenize feed streams with a minimum residence time with less energy consumption [6,7]. Among all kinds of static mixers, Kenics and SMX static mixers designed by Sulzer Ltd. are widely used in the mixing of high viscosity liquids and liquids with extremely diverse viscosity especially in polymer processing. In the development process of improving oil recovery efficiency in China, polymer oil extraction is one of the fastest developing methods [8,9]. In the enhanced oil recovery (EOR) process, especially in polymer flooding process, a static mixer is used to mix the high concentration of partially hydrolyzed polyacrylamide (HPAM) solution and water. In order to improve the effect of EOR, HPAM solution through a static mixer should have smaller degradation rate and better mixing quality. Nonetheless, the traditional static mixers used alone in the EOR system have several inherent shortcomings as follows [1–3]: (1) large back mixing due to the conventional chaotic motion; (2) additional energy consumption caused by high pressure drop in SMX static mixer; (3) undesirable mixing performance. To overcome these drawbacks, flow field characteristics of Kenics and SMX static mixers used in EOR process have been investigated deeply [10]. Meijer et al. [11] made a quantitative comparison of static mixers. Meng et al. [12] made a numerical study of mixing performance of static mixers with multi-twisted leaves like Kenics mixer. From 1990s, static mixers used in EOR process have been studied increasingly in open-literature, but barely no research focused on the Kenics and SMX static mixer combination and the experiment scales were quite small.

In the present study, a Kenics and SMX static mixer combination were used to assess its performance and compare with other static mixers used in EOR process. Degradation experiments were made to study the degradation characteristics of static mixers. Meanwhile, the impact on pressure drop and non-uniformity degree

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Nomenclatures

Latin letters

a	Rheological index
D	Diameters of static mixers, m
E	Liquid viscosity degradation rate, %
k	Consistency coefficient
L	Length of static mixers, m
m	Viscous coefficient
n	Rheological index
Q_i	Flow rate of HPAM solution, m^3/h
S	Sample variance
u_{av}	Average velocity of solution at inlet of the static mixers, m^3/h
u_{max}	Maximum viscosity value of the measurement samples MPa s
u_{min}	Minimum viscosity value of the measurement samples, MPa s
u_1	Viscosity of HPAM solution at inlet of the static mixers, m^3/h
u_2	Viscosity of HPAM solution at outlet of the static mixers, m^3/h

Greek letters

η	Viscosity, mPa s
ΔP	Pressure drop, Pa
ξ	Non-uniformity degree, %
μ_n	Viscosity of the nth measurement sample, mPa s
ρ	Fluid density, kg/m^3

caused by concentration of solution, relative molecular mass of HPAM, the flow rate of water and solution was made detailed study. Compared with other static mixers used in the EOR process, this static mixer combination has a better mixing performance with less mechanical shearing impact on polymer solution and less energy consumption.

2. Experimental details

2.1. Chemical materials

The chemical system used in the study was ultra-high molecular weight partially hydrolyzed polyacrylamide (referred to as HPAM) in water dispersion. Four kinds of HPAM were purchased from Daqing Oilfield Limited Liability Company, and the specifications of them were shown in Table 1. The solvent was distillated water. Initially, both of them were saturated with each other in order to prevent any interaction between them.

2.2. Preparation of HPAM solution

HPAM solutions were prepared at different concentrations of 4000 mg/L, 5000 mg/L, 6000 mg/L, and 7000 mg/L, respectively.

Table 1
The specifications of the HPAM.

Relative molecular mass	Hydrolyzation (%)	Solid content (%)
1.2×10^7	30	90
1.9×10^7	30	90
2.5×10^7	30	90
3.5×10^7	30	90

HPAM solutions with different concentrations were prepared by adding appropriate amount of HPAM powder to the deionized water. After that, the aqueous phase was stirred about 60–120 min to dissolve HPAM powder completely by mechanical agitation method. Finally, the prepared solution was pumped into the system.

2.3. Apparatus and method

The experiments were performed in the lab scale plant shown in Fig. 1. A Sulzer Kenics static mixer and a Sulzer SMX static mixer were used in these experiments. Table 2 lists the main characteristics of these two mixers. A single SMX mixing element has 8 cross-bars.

A Brookfield DV-II + PRO Viscometer (BI-200SM, Brookhaven Instruments, NY, US) was used in the study to measure the viscosity of the solution.

A HAAKE rheometer with cone and plate measuring system was used for the tests. 30/1° cone and plate measuring system (cone-plate radius of 60 mm, cone-plate angle of 1°) was selected for oscillation tests to determine rheological parameters.

In the line diagram of the experiment setup shown in Fig. 1, HPAM solution was firstly prepared by mechanical agitation in stirred tank, 1, then pumped by means of a liquid metering pump, 3 to a pulsed damper which was used for preventing backflow of liquid, and eventually pumped by another liquid metering pump, 4. When deionized water from the water storage tank, 10 was introduced into the apparatus via the metering pump, 11, the HPAM solution and deionized water were put in contact in a "tee" joint just prior to the SM entrance. Two liquid sampling ports were set at the inlet, 8 and outlet of the static mixers, 9. Pressure values of static mixers (SM), were continuously measured with time by the pressure sensors until they reached constant values. Then the mixed product was gathered in a storage tank, 12.

The experiment consisted of two parts, the HPAM solution viscosity degradation experiment and the mixing experiment. The viscosity degradation of HPAM solution was carried out by first bringing the apparatus to steady state conditions. At this moment, HPAM solution was introduced into the apparatus via the metering pump, 4. When the flow rate and pressure came to be stable, sample liquid was gathered at the import and export of the static mixers. Solutions with different relative molecular weight of HPAM and concentrations were used in the experiment to collect more data. Viscometer was used in the experiment to measure the viscosity of the sample solutions.

The second part was mixing experiment. In this experiment, HPAM solution was introduced into the apparatus via the metering pump P01, in the mean time, deionized water from the water storage tank was introduced into the apparatus via the metering pump P02. The flow ratio of HPAM solution and deionized water was 1:1. The HPAM solution and deionized water were put in contact in a "tee" joint just prior to the SM entrance. Two phase flows passed co-currently through the static mixer where two-phase mixing occurs. Simultaneously, flow rate of HPAM solution and deionized water, and pressure of static mixer combination (SM), were continuously measured with time until they reach constant values. When the flow rate and pressure came to be stable, liquid samples were gathered at the import and export of the static mixers. Solutions with different relative molecular weight of HPAM and concentrations were also used in the mixing experiment to collect more data. Viscometer was used in the experiment to measure the viscosity of the solutions.