

RESEARCH PAPER

## Experimental study on Polymer Flooding in a Heterogeneous Porous Media-Part I: Effects of Copolymer and Silica Nanoparticles Composition

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### ABSTRACT

In the present study, acrylamide/2-acrylamido-2-methylpropane sulfonic acid (AM/AMPS) co-polymers were synthesized for enhanced oil recovery (EOR). The effects of silica nanoparticles (SNPs) on the copolymer solution viscosity and oil recovery factor were investigated. Chemical structure of the copolymers and viscosity of the resultant aqueous solutions were determined using Fourier-transform Infrared (FTIR) spectrometer and an Ostwald viscometer, respectively. The functionality of the AMP55 (50%AM-50%AMPS) copolymer in polymer injection test was studied using a glass micro-model. Additionally, the effect of SNPs on the solution viscosity and oil sweeping efficiency was studied. The results of Injection test indicated that the addition of the 2 wt.% SNPs in the AMP55 solution enhanced the recovery factor 15% and 400%, compared to the SNPs free copolymer solution and water flooding, respectively. The experiments led to the proper selection of the synthesized copolymer structure and SNPs content in its solution, to attain the maximum viscosity and oil sweeping efficiency.

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### 1. INTRODUCTION

Polymer flooding is one of the chemical enhanced oil recovery (EOR) processes that was introduced in 1960's to increase the recovery of the conventional reservoirs with high heterogeneity and mobility ratio of the fluids. In heavy oil reservoirs, viscous fingering would lead to unstable displacement, as a result of different mobilities of the flowing

fluids. For heterogeneous rock structures, instability is intensified. This phenomenon is a function of water saturation, permeability, and injection flow rate. Addition of polymer solution would reduce the mobility ratio of the injected fluid. For mobility ratios less than one, stable flow would occur. Some researchers investigated the role of effective process parameters in polymer flooding[1-3]. Main factors affecting polymer flooding include rheological characteristics

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of the polymer, polymer interaction with the reservoir rock, and wettability of the reservoir [4, 5]. Moreover, pore structure and geometry of the medium are of paramount importance [6-11].

There are many successful field experiences in polymer flooding [2, 12-19]. It is recommended to keep injection pressure values more than formation parting pressure for injectivity enhancement [4, 5, 20, 21]. Fluid displacement is represented by two dimensionless parameters, i.e. capillary number (Ca) and mobility ratio (M). Based on the dominance of each force, one of the phenomena of (1) viscous fingering, (2) capillary fingering, or (3) permanent displacement would occur. Viscous fingering occurs due to high difference in mobility values [22]. At low injection rates and domination of capillary force, numerous structures are produced at injection front which lead to the so-called capillary fingering and trapping a portion of the fluid.

Based on the previous studies, various natural and synthetic polymers and copolymers have been used for EOR processes. Meanwhile, one of the most efficient and resilient water-soluble polymers is AMPS acrylic-based copolymer. However, the effect of SNPs in AM/AMPS copolymer solution on the oil recovery has not been quantitatively studied in small-scale models such as micromodels. Therefore, studying the effect of the nanoparticles on the copolymer performance for oil recovery seems to be necessary. Micromodels have been introduced as an appropriate tool for EOR lab experiments as a basis for large scale studies. As displacement processes are visually investigated in micromodels, the complex mechanisms of immiscibility and miscibility are well-understood [23-26]. Zhou et al., [27] performed a polymer flooding experiment in micromodel to enhance the heavy oil flow efficiency. Various experimental conditions have been studied to investigate the effect of injection, water salinity, polymer type, flow rate, and its concentration in a five-spot glass micromodel [28]. Oil recovery was reported as a function of injected water and polymer. Different pore patterns and orientations have been studied using the micromodels.

Moreover, polymer adsorption and its effect on oil recovery have been studied in various saturations and wettabilities. The effects of pore structure and its non-homogeneity were also studied and oil recovery factor was calculated [29]. Different studies on micromodel have revealed that the efficiency of any reservoir type is enhanced using the polymer flooding. This includes changing the micro-flow line, enhancement of micro forces, and delay in breaking oil column as the stress distribution is changed [30]. The role of nano-particles in improving the polymer function in EOR processes is of paramount importance, especially for unconventional reservoirs with unfavorable conditions. Maghzi et al. [31] investigated the effect of SNPs on polymer flooding functionality. Results showed that the viscosity of the polymer solution containing SNPs was similar to the solution without SNPs. Increasing SNPs content caused a significant increase in the viscosity value. Yousefvand et al. [32] stated that the presence of SNPs inside the hydrolyzed polyacrylamide solution resulted in increasing the oil recovery factor (10%). Moreover, the wettability of the reservoir changed using the nanoparticles. Xin et al. [33] synthesized PAM/AMPS copolymers in the presence of modified silica nanoparticles (MSNPs) as the crosslinking agent. Maurya and Mandal [34] studied a polymer suspension induced with nanoparticles for EOR applications. Silica nanoparticles were applied with polyacrylamide to prepare the nano-polymer suspension. The viscosity of the prepared solution increased in comparison to the polyacrylamide solution. Moreover, Corredor et al., [35] studied an induced nanoparticle- polymer for the enhancement of polymer performance in oil recovery. Selected polymers were Xanthan gum and PHPA. Results indicated that the addition of 1-2 wt% SiO<sub>2</sub> nanoparticles to the selected polymers, improved the oil recovery in polymer flooding process by enhancing the mobility ratio, sweeping efficiency, and the capillary number of the process. However, Xanthan gum and PHPA were not applicable in harsh reservoir conditions including high temperature, high shear rate, and high salinity, in which the polymer structure would

degrade and exhibit low recovery factor [36-38]. In a similar study, Gbadamosi et al., [39], studied the performance of aluminium oxide nanoparticles with polyacrylamide to increase the oil recovery factor. The experimental results indicated that nanoparticles enhanced the rheological properties of the polymer. Moreover, the hydrodynamic radius was measured and the phase behavior of the solution was studied [40, 41]. In a simulation study, Druetta and Picchioni [42] studied a polymer flooding process. Results indicated 40-45% oil recovery factor. They also confirmed that using nano-induced polymers could improve the oil recovery factor by the synergistic effect of nanoparticle and the polymer [43].

Considering the above, the main goal of the present research is to synthesize sulfonated acrylamide copolymer and to study the effect of copolymer composition, copolymer solution concentration, and SNPs

on the viscosity of the synthesized copolymer. Moreover, a glass micromodel was fabricated using a non-homogeneous flow pattern. Polymer injection tests were implemented in porous media to investigate the effect of the above-mentioned parameters on oil recovery factor. The results were also compared with water flooding test.

## 2. Materials and Research Method

Heavy oil sample in this study was Bangal dead oil of Bangestan reservoir in south of Iran. Oil viscosity and its interfacial tension with polymer solution were 182cp and 22.55dyne/cm, respectively. Viscosity measurements were performed using Ostwald viscometry method. Pendant drop method was utilized for the measurement of interfacial tension of polymer solution with oil at 25°C. Physical properties of the oil sample and hydraulic properties of the micromodel are summarized in Table 1.

Table 1. Properties of micromodel and oil sample

Pore Diameter (μm)	Throat Diameter (μm) (layer A)	Throat Diameter (μm) (Layer B)	Throat Diameter (μm) (layer C)	Average Aspect Ratio	Coordination Number	Porosity (%)	Etched Thickness (μm)
720	270	200	130	3.94	4	23	156

Oil Viscosity (cp)	Interfacial Tension (dyne/cm)	Injection Rate (ml/min)
182	22.55	0.0007

### 2.1. Micromodel Experiments

Acrylamide (AM) monomer, potassium persulfate as initiator, acetone, and methanol were purchased (Merck Co., Darmstadt, Germany). 2-acrylamide-2-methylpropane sulfonic acid (AMPS) was provided from Aldrich Co.; the monomers were distilled under vacuum to remove the trace of inhibitors and then were stored in the refrigerator at 5°C before using. Silica nanoparticles were purchased from Tecnan Company with particle size in the range of 10–20 nm. The nanoparticles were dried in a vacuum oven at 60°C before using. For polymer flooding studies, a glass micromodel was prepared. Physical properties of the micromodel are represented in Table 1. Ambient pressure and temperature were selected for the tests

and injection was performed in a constant flow rate. The recovery factor and porosity of the system were calculated using the image processing of MATLAB Toolbox. Experimental set up is shown in Figure 1, containing a glass micromodel, injection pump, flow lines, digital camera, and a computer for recording and capturing videos and photos of the micromodel tests. A syringe pump (SPN1000HOM FNM) was applied for the injection of the polymer into the micromodel at constant rate of 0.0007 ml/min.

### 2.2. Synthesis of Polyacrylamide

The polymerization of acrylamide was performed using radical initiator of the potassium persulfate. [44] This was performed by preparing 10 wt.% of monomer solution in water.

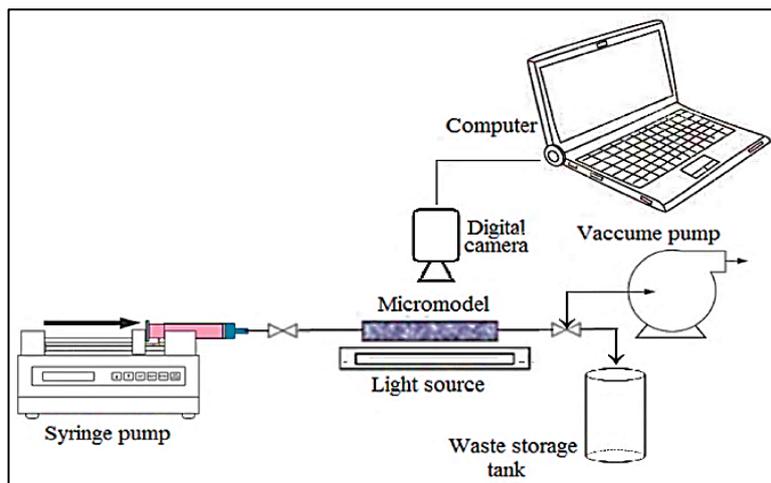


Figure 1. Schematic of the experimental set up

The solution was degassed for 15 minutes by a stream of nitrogen and then transferred into a four-span glass reactor equipped with a condenser and a stirrer. Potassium persulfate solution was prepared with concentration of 1000 ppm and added to the reactor after degassing for 20 min. The polymerization reaction was conducted for 2 hrs at temperature of 60°C. Finally, the resulted homo-polymer was deposited, purified and dried at 70°C for 1 hr.

### 2.3. Synthesis of Acrylamide Copolymer

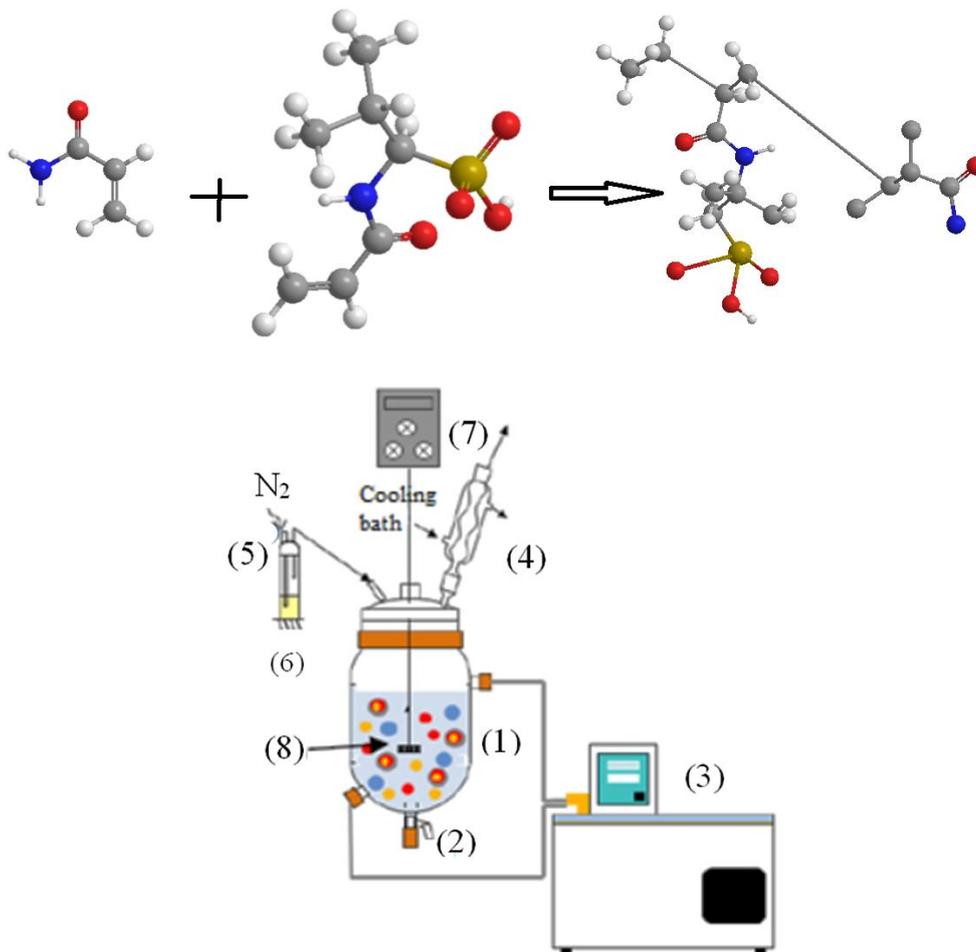
In this study, copolymers of AM and AMPS were synthesized using the free radical polymerization technique. Total concentration of monomers was 0.58 moles in all syntheses. The initiator of this reaction was potassium persulfate, which was added to monomer with ratio of 0.1 mol%. Solutions with four different ratios of AM to AMPS were prepared, including 90:10, 70:30, 50:50, and 30:70 (respectively nominated as AMP91, AMP73, AMP55 and AMP37).[45]

The polymerization of the monomers was carried out in the presence of a radical initiator in an aqueous medium. First, the solution of the two monomers was prepared in water. Then it was placed inside a four-span glass reactor at constant temperature of 25°C, and degassed with nitrogen for 20 minutes, while the solution was agitated by the stirrer. To ensure that the AMPS monomer

was neutralized to its sodium salt, sodium hydroxide was added to adjust pH at  $8.5 \pm 0.5$ . Potassium persulfate was dissolved in 10 cc of water with 0.1 molar ratio of monomer. Then it was degassed for 15 min and heated to 60°C for 6 hrs. The final solution was a viscous and transparent liquid. At the end of the reaction, the solution was cooled to room temperature. The product was obtained as a white solid, while acetone was added. The sediment was kept in vacuum cleaner at 40°C for 6 hrs to reach a steady and constant weight. Finally, it was converted to powder using masonry. A diagram for the polymerization process and reaction is represented in Figure 2.

### 2.4. Preparation of Copolymer Solution Containing SiO<sub>2</sub> nanoparticles

After the synthesis of copolymers, different solutions were prepared with concentrations of 250, 500, 1000 and 2000 ppm. Based on the results of the previous section, the best value for the copolymer viscosity belonged to AMP55 specimen. Therefore, various amounts of SNPs (1, 2, and 3 wt.%) based on total copolymer, were added to the AMP55 solutions. These solutions were designated as SIAMP250, SIAMP500, SIAMP1000 and SIAMP2000, corresponding to their copolymer concentrations (250, 500, 1000 and 2000 ppm). For preparing solutions containing the nanoparticles, the SNPs were dispersed into distilled water and magnetically stirred for 45 min.



(1) reactor vessel, (2) vessel outlet, (3) heating bath, (4) reflux condenser, (5) nitrogen line, (6) scrubber, (7) digital stirrer and (8) impeller.

**Figure 2.** Schematic for the polymerization process and reaction

To completely disperse the nanoparticles and provide uniform dispersions, the dispersions were placed in an ultrasonic homogenizer (500 W and 0.5 Hz) for 20 min. Thereafter, the prepared polymer solution and the nanoparticles were mixed together and further stirred using a mechanical stirrer at 150 rpm for 2 h.

### 2.5. Characterization

Acrylamide (AM) monomer, potassium persulfate as initiator, acetone, and methanol were purchased (Merck Co., Darmstadt, Germany). 2-acrylamide-2-methylpropane sulfonic acid (AMPS) was provided from Aldrich Co., Germany, and silica nanoparticles were purchased from Tecnan Company in

Iran with particle size in the range of 10–20 nm. These materials were used without initial preparation.

To characterize the synthesized AM/AMPS copolymer, Fourier Transform Infrared (FTIR) Spectroscopy was used to characterize the symmetric and asymmetric bonds of sulfonated groups in the copolymer structure and also the  $-NH_2$  and  $-CH_3$  groups on polyacrylamide (PAM). The viscosity of the prepared copolymer solutions with different concentrations was determined using Ostwald viscometry technique. Pendant drop method was used for the measurement of interfacial tension of polymer solution with oil at 25°C.

## 2.6. Polymer Flooding Tests

To study the effect of the synthesized copolymers on increasing the oil sweeping efficiency, polymer injection tests were performed with different concentrations of the copolymer and SNPs. Micromodel was fabricated and saturated with oil. Initial oil in place was determined using Photoshop and Matlab image processing toolbox. Then, the syringe pump containing the copolymer solution was attached to the injection point. Before the injection, the micromodel was left for an hour to reach equilibrium. Injection rate was  $0.0007 \text{ ml min}^{-1}$ . During the injection, the captured photos and videos were prepared to study the oil sweeping performance. The camera (Canon EOS 4000D, Lens 18-55 mm) with 30-1/4000 sec shutter (1/2 or 1/3 stop increments) was used for the photo capturing. Once again using image processing, the swept area was calculated and the oil recovery factor was reported. The injection tests were repeated for five times for each copolymer specimen and the average oil recovery factor

was reported.

## 3. Results and Discussion

### 3.1. FTIR Spectroscopy of the Copolymer

Figure 3a represents FTIR spectroscopy of the polyacrylamide (PAM). The absorption peaks appearing at  $3440 \text{ cm}^{-1}$  and  $2925 \text{ cm}^{-1}$ , are attributed to stretching vibration of  $-\text{NH}_2$  and  $-\text{CH}_3$  groups, respectively. The characterized band at  $1651 \text{ cm}^{-1}$  is related to amid carbonyl group.[46]

Figures 3b represents FTIR spectroscopy of the AM/AMPS copolymers with various contents of AMPS. The observed peaks at  $3428.53$  and  $1672.74 \text{ cm}^{-1}$  denote the stretching vibration of amino and amid carbonyl groups. Moreover, the absorptions at  $1041.33$  and  $1190.67 \text{ cm}^{-1}$  represent symmetric and asymmetric bonds of the sulfonated groups in the copolymer structure. However, some monomeric reactions would occur due to the disappearance of vinyl groups in the band at  $1600 \text{ cm}^{-1}$ .[45]

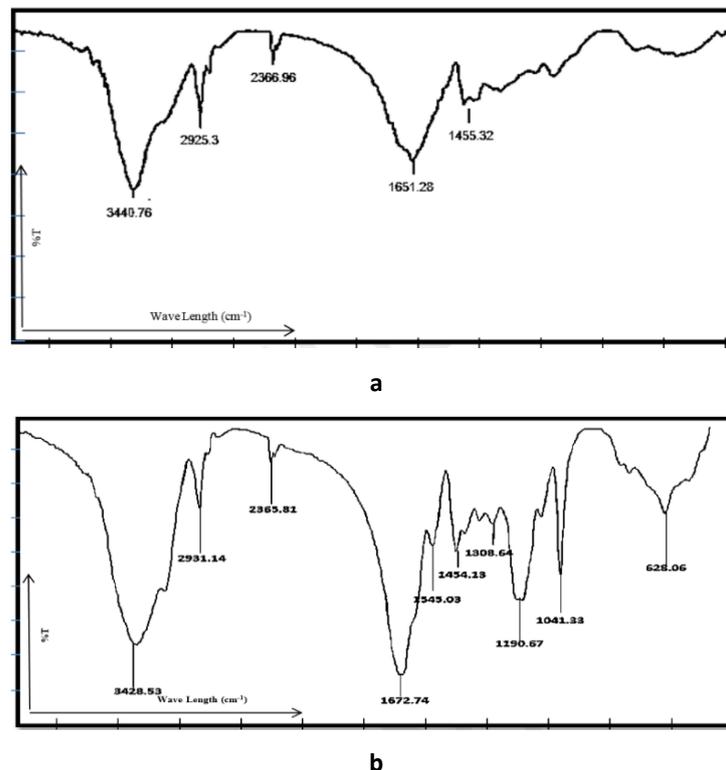


Figure 3. FTIR spectroscopy of a) polyacrylamide b) AM/AMPS copolymer with different compositions

### 3.2. Effect of SNPs on Copolymer Viscosity

Various amounts of SNPs were added to the solution of AMP55 copolymer with the highest viscosity. The results indicated that the addition of SNPs to the copolymer solutions would increase the solution viscosity. However, further increase in SNPs content represented an opposite effect. As shown in Figure 4, the incorporation of SNPs

up to 2 wt.% considerably increased the solution viscosity. On the contrary, further increase decreased the solution viscosity. The highest viscosity (42.8cs) was obtained for the SIAMP2000 solution containing 2 wt.% SNPs adding to AMP55 with solution concentration of 2000 ppm. At the same SNPs concentration, the viscosity of SIAMP1000 solution lowered to 21.9 cs.

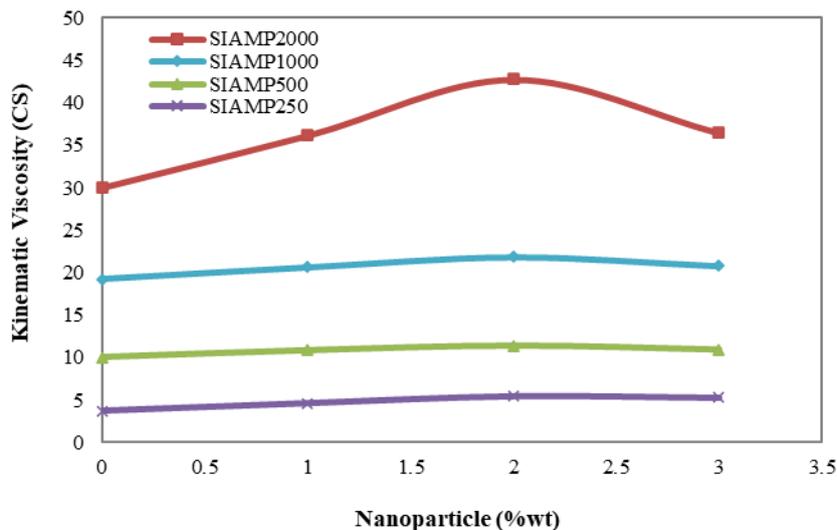


Figure 4. Viscosity of AMP55 copolymer as a function of SiO<sub>2</sub> Nanoparticle at 28°C

Acrylic copolymers synthesized in this study were of the anionic type. The negative charges on the copolymer chains resulted from hydrolyzing the AMPS functional groups would cause the stretching of the copolymer chain. This is due to the repulsive forces leading to increasing the chain hydrodynamic volume and, consequently, the viscosity of the solution. Good interaction between SNPs and the copolymer would form stronger polymer network with higher viscosity. Nonetheless, the highest AMPS units in the copolymer structure and increasing the SNPs above 2wt.% decreased the viscosity of the copolymer solution. Most dilute solutions exhibit a Newtonian behavior. Thus, the viscosity at given polymer concentration versus shear rate was assumed as a constant value. The viscosity of the solutions at different copolymer concentrations was determined using Ostwald viscometry

technique. The viscosity of 30 cSt for copolymer concentration of 2000 ppm, was obtained for AMP55 copolymer solution.

### 3.3. Polymer Flooding and Oil Recovery

In this section, the copolymer solution injection tests are discussed. Then the effect of the AMPS content in the copolymer structure and adding SNPs to the copolymer solution on the oil sweeping efficiency is investigated. For water flooding, since viscosity of the injected water is lower than oil, it cannot completely sweep the residual oil in piston wise motion. Instead, fingering effect quickly puts it at a production point. The prepared micromodel consisted of three different permeable layers. It is well-specified that the injected water initially goes through the larger paths with higher permeability in which the capillary forces are the smallest. Eventually, the fingering effect in low-permeable layer leads the water to the production point.

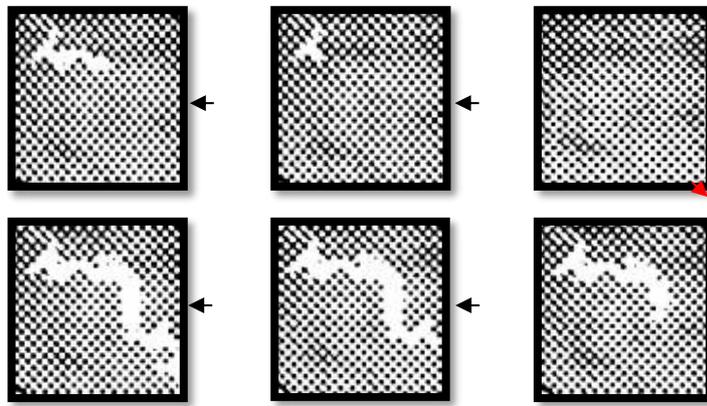


Figure 5. Water flooding test results

In this study, the recovery factor of 18.7% in water flooding was obtained. This process is illustrated in Figure 5. Increasing the concentration of the copolymer solution to the injected water resulted in recovery factor enhancement because of increasing the solution viscosity.

On the other hand, the viscosity enhancement would decrease the mobility of the solution and the mobility ratio between oil and solution. The results indicated that adding 250 ppm of the AMP55 to water increased the recovery factor from 7% to 26.91%. The oil recovery reached to 29.2% when the copolymer solution was duplicated,

i.e. 500 ppm. Similarly, the recovery factor at higher concentrations slightly increased. The quantitative comparison of the oil recovery factors and the kinematic viscosity of the solutions with different concentrations are shown in Figure 6.

### 3.3.1. Effect of Copolymer Composition

The incorporation of hydrolyzed AMPS units into the anionic groups in AMP91 structure led to increasing the oil recovery when compared with AM. This behavior is due to the solution viscosity enhancement by adding AMPS to the AM structure. The AMP91 became capable to penetrate into the middle permeable layer.

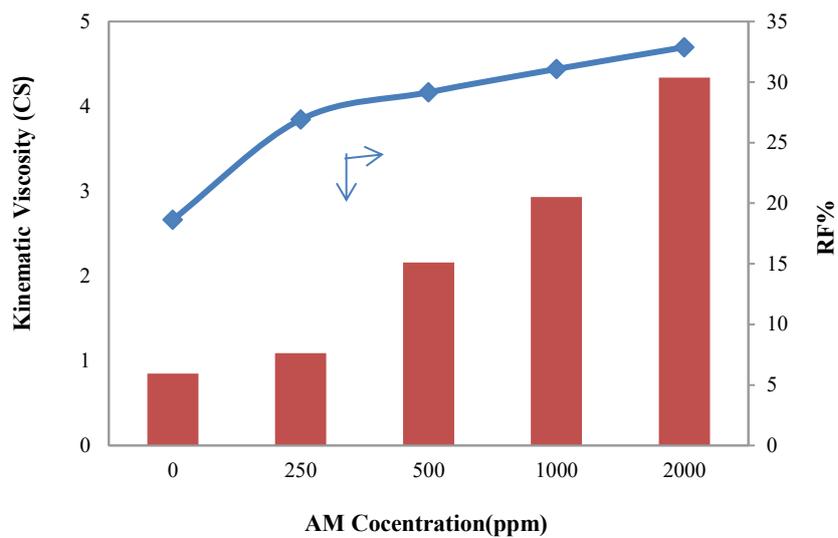


Figure 6. Comparison of the recovery factor and kinematic viscosity of the synthesized copolymer at different concentrations of AM

In this condition, viscous forces overcame capillary ones. Figure 7a depicts the front flow of the AMP91 solution with concentration of 2000 ppm at different time steps of the polymer flooding process. It is also inferred from Figure 7a that increasing the copolymer solution viscosity diminishes the fingering phenomena. Polymer flooding was also implemented using different AMP73 concentrations, i.e. 250, 500, 1000, and 2000

ppm. The results for the concentration of 20000 ppm are displayed here.

As shown in Figure 7b, the copolymer (at concentration of 2000 ppm) was able to enter the layers with medium and low permeability.

As it is obvious from Figures 8a and 8b, the copolymer has penetrated into all layers and has discharged oil into the low permeability layers.

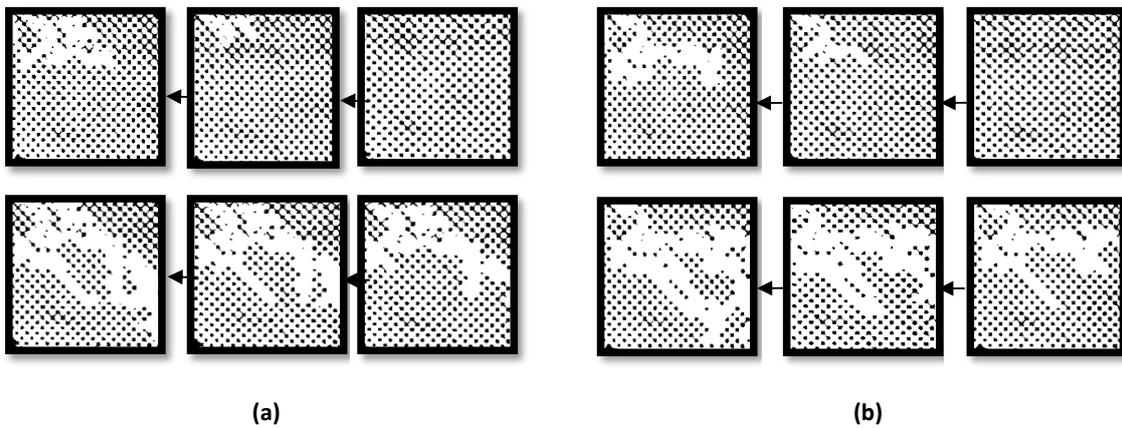


Figure 7. Displacement front of the synthesized copolymer with concentration of 2000 ppm, a) AMP91 b) AMP73

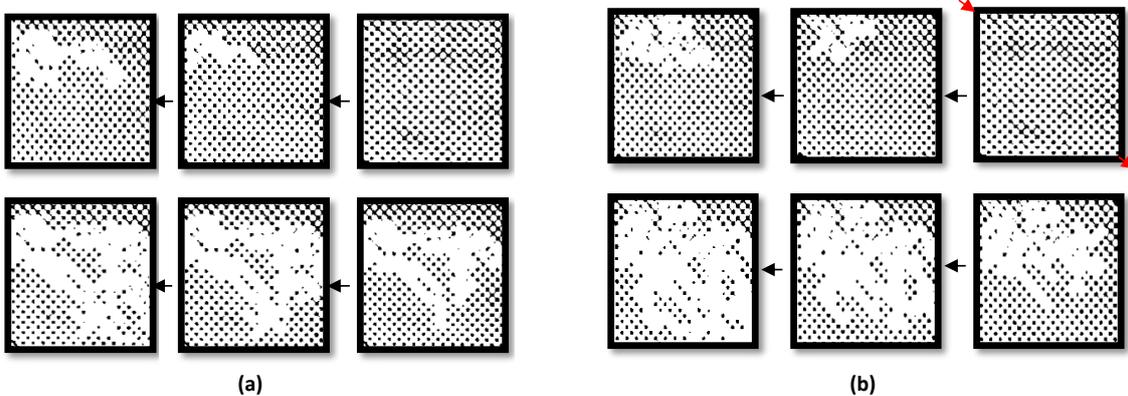


Figure 8. Displacement front for AMP55 polymer at various times steps a) concentration of 1000 ppm b) concentration of 2000 ppm

As stated before, the negative charge of the hydrolyzed AMPS units on the main copolymer chain caused the copolymer chains be elongated and increased the solution viscosity. For concentrations above 50% of AMPS, the chains became curl and spiral leading to reducing the solution viscosity. Based on the results of Figure 9, increasing

the AMP37 concentration enhanced the recovery factor from 32% to 39%. In fact, this behavior can be attributed to high percentage of AMPS units within the copolymer solution. The results of the injection tests were analyzed using image processing of MATLAB toolbox which is represented in Figure 9. As it is shown in the figure, increasing the

concentration of the solution increased the oil recovery factor which is due to increasing the solution viscosity and the amount of displaced oil. Meanwhile, AMP55 led to the best oil recovery factor. As it is obvious in this figure, increasing the solution concentration up to 250 ppm led to 14% increase in oil recovery factor, which is the best obtained value in comparison with the other prepared copolymers. Except for the AMP55, increasing the concentration of other copolymers up to 2000 ppm does not have significant effect on the oil recovery factor. By increasing the AMPS concentration up to 50%, the oil recovery factor increased significantly. The

best recovery factor of 62.3% was related to AMP55 at the solution concentration of 2000 ppm. At the same concentration, the recovery factor for the AMP73 and AMP37 solutions reduced to 40.7% and 38.9%, respectively. For the former copolymer with AM/AMPS ratio more than 70/30, the recovery factor was less than that of the AMP37 with AM/AMPS ratio of 30/70.

Figure 10 illustrates the effect of AMP55 solution concentration on the kinematic viscosity and oil recovery factor (RF). As can be seen, increasing the solution concentration considerably enhanced the viscosity and oil recovery.

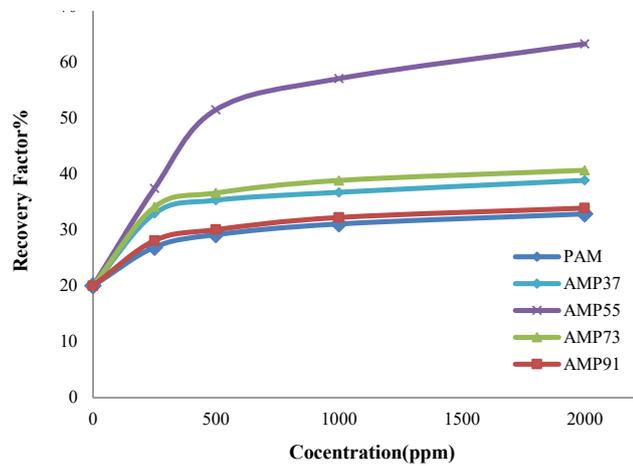


Figure 9. Recovery factor of various polymer solutions with different concentration

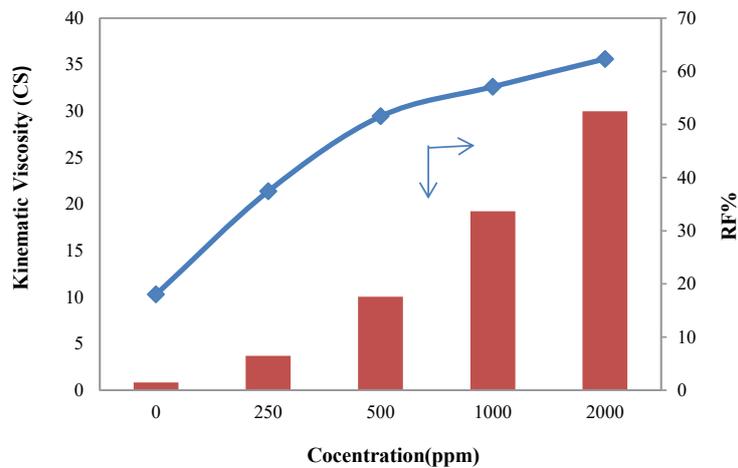


Figure 10. Viscosity effect of AMP55 on recovery factor in different concentrations of the polymer solution

The effects of both AMPS content and solution concentration on the RF is illustrated in Figure 11. As shown, increasing AMPS weight percent up to 50% at all solution concentrations, led to increasing the RF. Afterwards, further AMPS increase in the copolymer structure reduced the RF value. For the higher solution concentrations, i.e. 1000

and 2000 ppm, the RF reduction happened sharply. On the other hand, at AMPS contents below 50%, increasing the copolymer concentration did not have significant effects on the RF. As previously stated, the proper RF was obtained for the AMP55 copolymer at concentration of 2000 ppm.

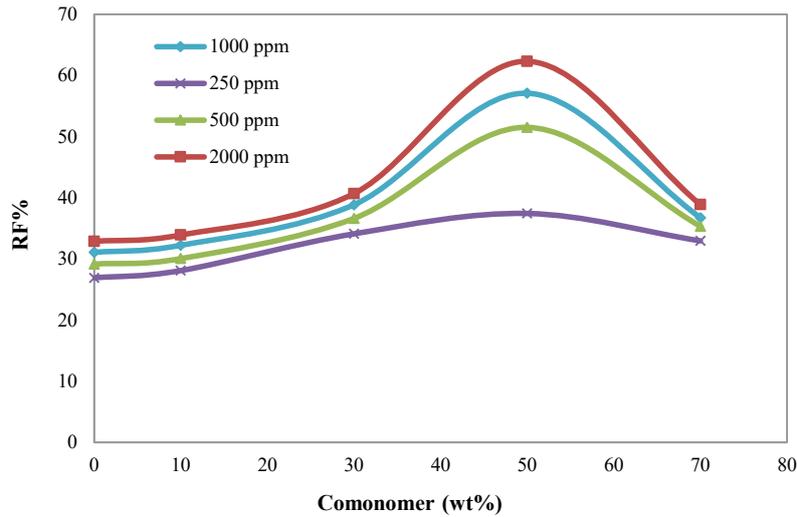


Figure 11. Effect of different weight percent of AMPS comonomer on oil recovery factors as a function of solution concentrations

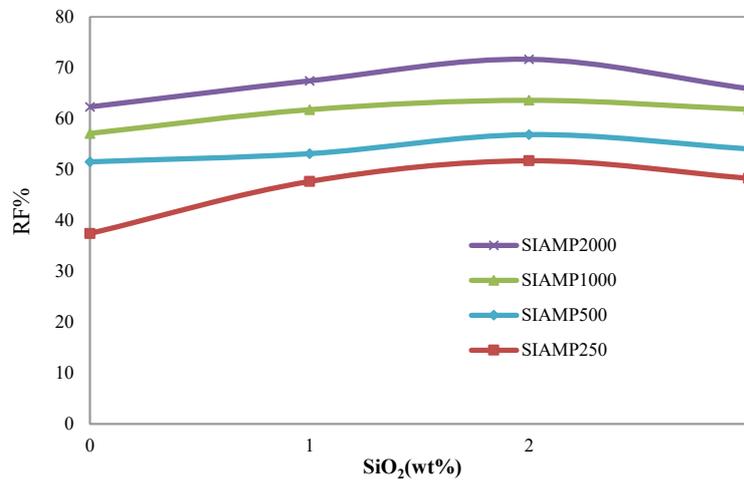


Figure 12. Oil recovery factor at different concentrations of AMP55 for various wt.% of SNPs

### 3.3.2. Effect of SNPs

To investigate the effect of SNPs on the copolymer performance and the RF value, various amounts of the SNPs (1, 2, 3 wt.%) were added to AMP55 solution. Based

on the viscosity results, the nanoparticles showed negligible effect on the solution viscosity change at the lower copolymer concentrations. Figure 12 shows oil recovery factor at different concentrations of AMP55

for various wt.% of SNPs. Moreover, the highest viscosity increase was attributed to AMP55 at the solution concentration of 2000 ppm. In other words, at higher copolymer concentrations, the addition of 2wt.% SNPs to the copolymer solution enhanced the RF to 71.7%. However, excessive increase in the SNPs content exerted negative effect on the solution viscosity and reduced the RF to 65.9% at the solution concentration of 2000 ppm. This can be inferred by comparing the results of the injection tests performed using the SIAMP250 and SIAMP500 dispersions containing 2 and 3wt.% SNPs, respectively. The results of the injection tests are shown in Figures 13a and 13b. As depicted in these

figures, the copolymer solution containing 2wt.% SNPs led to more sweeping efficiency in comparison to the copolymer solution with 3wt.% SNPs. The injection tests led to the same results for the solution at the lower concentration, i.e. SIAMP1000.

Figure 14 exhibits the effect of SNPs content on the RF and the kinematic viscosity at the solution concentration of 2000 ppm. The RF of the SIAMP2000 considerably increased by increasing SNPs. As it is obvious from the figure, increasing the concentration of SNPs led to increasing the viscosity and RF to the highest value. The proper RF and viscosity were related to the SIAMP2000 solution containing 2 wt.% SNPs.

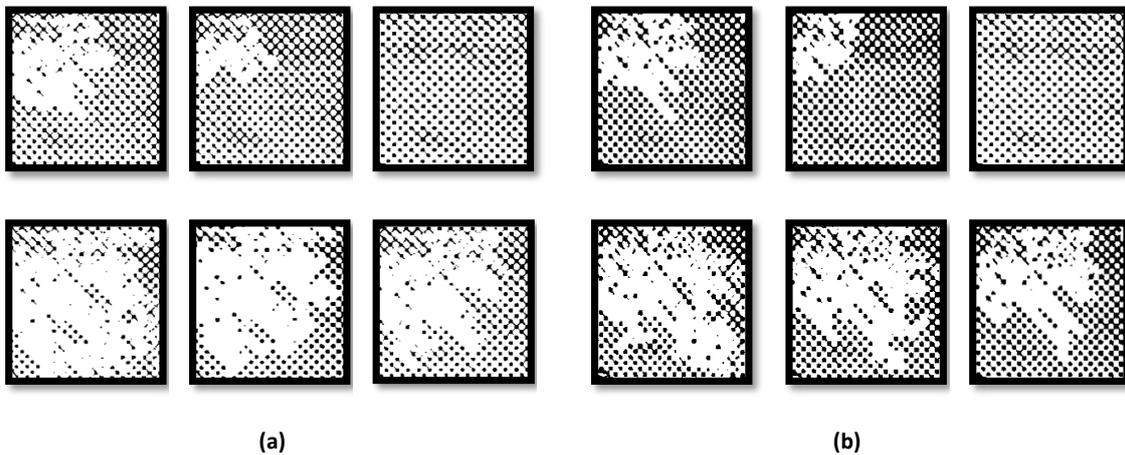


Figure 13. Displacement front of SIAMP2000 polymer solution at various time steps a) concentration of 2%wt. SiO<sub>2</sub> b) concentration of 3%wt. SiO<sub>2</sub>

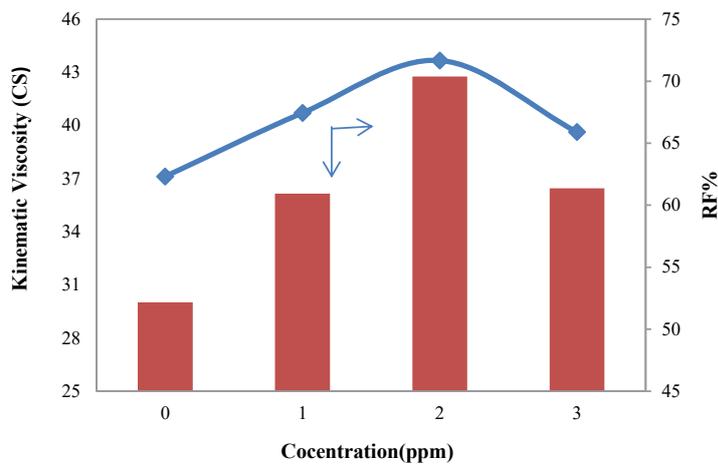


Figure 14. Effect of SIAMP2000 nano-suspension viscosity with different concentrations of SiO<sub>2</sub> on oil recovery factor

#### 4. Conclusion

In this communication, the AM/AMPS copolymers with various AMPS contents were successfully synthesized. Different solutions with specified concentrations of the synthesized copolymers were prepared and their viscosities were measured using Ostwald viscometer. The results showed that the viscosity of the copolymer solutions enhanced by increasing the AMPS concentration up to 50 wt.%. For more AMPS concentrations, the viscosity decreased for AMP91. The best recovery factor for the synthesized copolymers was reported 62.3% for the AMP55 solution. The highest viscosity was obtained for 2wt.% SNPs and increasing SiO<sub>2</sub> concentration did not considerably affect the recovery factor. The RF in this test was 71.7% leading to 15% increase in the polymer injection using the AMP55 solution. It should be mentioned although the aggregation state of the SNPs can be studied by microscopy analysis, the dispersion of the nanoparticles was not investigated. However, the dispersion of the nanoparticles was improved using ultrasonic homogenizer before adding to the polymer solution. This experimental study led to the optimization of the synthesized copolymer composition to attain the maximum viscosity and oil sweeping efficiency for the designed conditions of the experiments. However, some simulation studies are required to predict the oil recovery factor in different situations.

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## مطالعه آزمایشگاهی تزریق پلیمر در محیط متخلخل ناهمگن - بخش اول: اثر ترکیب درصد

### کوپلیمر و نانوذرات سیلیکا

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گروه تحقیقاتی پلیمرهای هوشمند و نانوکامپوزیت ها، دانشکده مهندسی شیمی، نفت و گاز، دانشگاه علم و صنعت ایران، تهران، صندوق پستی ۱۳۱۱۴-۱۶۸۴۶

#### چکیده

در این مطالعه کوپلیمر آکریل آمید/۲-آکریل آمیدو-۲-متیل پروپان سولفونیک اسید (SPMA/MA) بمنظور ازدیاد برداشت سنتز شد. تاثیر نانوذرات سیلیکا (SPNS) بر ویسکوزیته محلول کوپلیمر و ازدیاد برداشت نفت مورد بررسی قرار گرفت. ساختار شیمیایی کوپلیمر و ویسکوزیته محلول تهیه شده به ترتیب با استفاده از طیف سنجیتبدیل فوریه فروسرخ (RITF) و ویسکومتر استوالد تعیین شدند. عملکرد کوپلیمر SPMA ۵۵ (MA-%۵۰ SPMA-%۵۰) در تست های تزریق پلیمر در میکرومدل شیشه ای مورد بررسی قرار گرفتند. علاوه براین، تاثیر نانوذرات سیلیکا بر ویسکوزیته و قابلیت جاروب نفت مورد مطالعه قرار گرفت. نتایج تست های تزریق نشان داد که افزودن ۲٪ وزنی از نانوذرات سیلیکا به محلول SPMA ۵۵ موجب افزایش ازدیاد برداشت نفت به میزان ۱۵٪ و ۴۰٪ در مقایسه با حالت بدون نانوذرات سیلیکا و تزریق آب گردید. آزمایشات انجام شده منجر به انتخاب صحیح ساختار کوپلیمر تهیه شده و محتوی نانوذرات سیلیکا گردید تا حداکثر میزان ویسکوزیته محلول و حداکثر میزان جاروب نفت حاصل شود.

#### مشخصات مقاله

تاریخچه مقاله:

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کوپلیمر

نانوذرات سیلیکا

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