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Comparison of the chemical flood recovery efficiency via experimental studies on the Pre-Caspian Basin core samples

This article examines the polymer and ASP flooding effects on the X field. Experimental studies were carried out on core material from heavy oil to compare the effectiveness of these methods. Core data as a sampling depth, porosity, permeability and core volume, as well as properties of reservoir oil and water were determined before filtration tests. At early stage of the study, an optimum composition of alkali-surfactant system for combined flooding has selected. At the second stage, type of the polymer and its optimum concentration has been determined, both for the polymer and for the ASP flooding methods. The one-concentration values have been used for a comparative analysis of the both flooding methods. At the final stage, the filtration tests have been performed on the PLS-200 unit for the comparative evaluation of polymer or ASP flooding efficiency. The studies represent increased displacement coefficient through both recovery methods. For this field, the maximum total displacement coefficient with a value of 0.68 unit fraction is achieved when a solution of both the polymer and the polymer in combination with surfactant and alkali solutions affect. However, the maximum displacement with coefficient 0.19 has been achieved by the ASP method.

Keywords: core samples, polymer flooding, ASP flooding, heavy oil, surfactant, alkali, concentration, displacement coefficient.

Introduction

Nowadays the hydrocarbon resource can be characterized by a significant increase in hard-to-recover heavy oil reserves. The Pre-Caspian Basin remained highly concentrated on reserves of heavy oil and natural bitumen; there is an increasing tendency due to the depletion of light fraction. The yields are currently low; the water breakthroughs are more rapid in more permeable layers and inter-layers, the field development becomes less profitable.

Oil reserves of such fields can be recovered with the use of tertiary recovery, for example, chemical flooding method. These methods are not an innovation and have used around the world for more than 30 years. However, due to the development of technology and chemical industry, oil companies again turned their attention to chemical methods. The main Chemical Enhanced Oil Recovery (EOR) includes technologies based on injection of surfactants, alkalis, gel and sedimentation reagents, and polymer solutions [1, 2]. Such flooding methods are widely used in countries such as Russia and China. For example, 80 % of applied tertiary methods refer specifically to chemical EOR in Russia [3]. Also, there are successful examples of polymer flooding in the Daqing and Shenglioil fields in China, where in 2004, oil production increased to 14 % due to the polymer injection and increased to 25 % due to surfactant / alkali / polymer injection [4].

It was agreed to carry out a laboratory test at one of the local oilfields based on such successful chemical methods abroad. The polymer and polymer / surfactant/ alkali systems are the most acceptable in order to remove highly water cut heavy oil. The polymer greatly influences the water viscosity, because of which the solution mobility ratio was reduced and displacement efficiency was increased [5, 6]. The use of water-soluble polymers allows improving the front of oil/water displacement, to extent the water-free operation, which as a result contributes to the increased oil recovery [7, 8]. The combination includes surfactant solutions to reduce the interfacial tension between oil and water, which leads to improved rheological and filtration properties of the oil and microemulsions stabilized by surfactants.

In many websites and articles, both a polymer and ASP flooding methods are applied at various fields with theoretical justification, the field and experimental data [9–15]. Based on the review results, both methods have demonstrated good oil displacement properties, suitable for heavy oil located at the West Kazakhstan field. Therefore, in order to identify an effective flooding method, the laboratory tests have been carried out on core samples from Pre-Caspian Basin. When selecting test samples, factors such as reservoir type, average porosity and the permeability, reservoir temperature and water salinity have been taken into account [16]. Based on the above, the laboratory tests have been carried out on X field chosen as comparative study for heavy oil displacement and identification of an effective method. Data on core samples from his field is presented in Table 3 and the parameters of the reservoir water are presented in Table 1.

Experimental

Experience with late stage development project has shown the high water cut and high level of viscosity. The field has several productive horizons, which has represented by sandy siltstone with the medium- and high-permeable layers having average porosity of 34 %. The net pay thickness reaches up to 10 meters and has a reservoir temperature of about 24–30 ºC, which are acceptable indicators for polymer flooding.

Cretaceous deposits were selected for the study; core samples with a diameter of 3.8 cm and 5.8 cm have been used. The studies were carried out on four core models with porosity about 33 %. To determine the effect of permeability the cores were selected varying within the range of 400–2300 mD. Core sampling was made manually with subsequent laying out. Upon selection, all samples have been sent for the extraction from mineral oils, water and salts [17, 18]. After core preparation, the next step was to prepare oil and reservoir water. Oil sample was selected manually from the field; water was prepared under laboratory conditions. The reservoir water was prepared based on its chemical composition using the salt types specified in Table 2 [19].

Table 1

Reservoir water parameters (initial data)

Horizon	Ion content (mg/L)					
	HCO_3'	Br	Cl'	Na'+K'	Ca''	Mg''
M-II	268.0	8.22	71672.0	41069.0	2405.0	1459.0

Table 2

Necessary salt amounts to create reservoir water

No.	Salts	M-II g/L
1	Sodium bicarbonate ($NaHCO_3$)	0.369
2	Sodium bromide (NaBr)	0.011
3	Magnesium chloride ($MgCl_2 \cdot 6H_2O$)	12.204
4	Calcium chloride ($CaCl_2$)	6.660
5	Sodium chloride (NaCl)	78.047
6	Potassium chloride (KCl)	19.571
	Total mineralization	116.861

The next step was the selection of the surfactant / alkali / polymer systems. The lauryl sulfate was used as a surfactant; the sodium hydroxide was used as an alkali. These reagents were prepared in the reservoir waters in the desired concentrations and mixed until complete dissolution has occurred. A phase behavior study of the surfactants and alkali at the oil/water interface was made for the selection of a suitable ASP solution. The following factors have been taken into account for selecting the most suitable polymer for this field:

– high water solubility;
– high viscosity at a given concentration;
– emulsion stability;
– economic parameters.

Based on the above characteristics a FloPaam 5205 VHM polymer having a concentration of 2500 ppm has been selected for the study. Then the main experiment has implemented on the filtration unit. PLS-200 system with four hydrostatic core holders was used for filtration tests. Core samples have been initially saturated with water, and then inserted into the hydrostatic core holders of the equipment [20].

The saturation process of the water samples was performed on an automatic saturator (AST-600), which allows selecting the time of air extraction and saturation pressure in an automated manner for fast and complete saturation of the core samples. The studies were carried out on four core samples. The filtration tests were carried out using two-cylinder high-pressure syringe pumps and piston displacement cylindrical tanks for the supply of reservoir water and polymer solutions. All experimental studies were carried out at the lack of back pressure, since the liquid volumes were calculated by the method of material balance. The experiment was carried out in the following sequence:

1. Samples were saturated 100 % with water, which then was displaced by oil to create reservoir conditions.

2. The stage of water/oil displacement was carried out to determine the displacement coefficient. In this regard, measuring tubes were installed at the core holder outlet to count the recovered oil. The water/oil displacement coefficient was determined by the ratio of the displaced oil V_o to the initial oil volume and was calculated by the following formula:

$$\beta = \frac{V_o}{V_{init\ o}}.$$

3. After the injection of 6–8 pore volume and bringing the water cut to the 95–99 %, a selected alkali / surfactant system was injected at a 1–1.5 of the pore volume (only for ASP flooding).

4. Then 2500 ppm polymer solution was injected. Polymer injection continued until the water cut reached 99 % when the pressure was stable.

Results and discussion

Filtration studies on the effectiveness of polymer systems (polymer and ASP flooding) were carried out on four core samples. Table 3 represents the investigation data indicating the sampling intervals and the typical parameters.

Table 3

Core samples and results

Name	Value			
Core data				
Model number	No.1	No.2	No.3	No.4
Depth, m	258.75	258.75	258.85	260.8
Diameter, cm	3.82	3.83	3.81	3.8
Cross section area, cm^2	11.47	11.52	11.42	11.34
Pore volume, cm^3	24.69	24.68	21.58	27.05
Air permeability, mD	724.1	1460	393.5	2370
Porosity, %	37.27	36.76	32.87	37.27
Experiment data				
Flooding method	ASP		Polymer	
Temperature, °C	20			
Oil viscosity in the experiment, mPa·s	407.4			
Water viscosity in the experiment, mPa·s	1.05			
Polymer concentration, ppm	2500			
Alkali/Surfactant concentration, gram	0.02/0.6	0.02/0.8	0	0
Experiment results				
Displacement coefficient in water injection, unit fraction	0.51	0.49	0.412	0.58
Residual oil saturation after water injection, unit fraction	0.265	0.315	0.476	0.343
Displacement coefficient in polymer injection, unit fraction	0.60	0.68	0.51	0.68
Residual oil saturation after polymer injection, unit fraction	0.22	0.20	0.416	0.275

For the filtration studies on ASP flooding it was necessary to predict the phase behavior of all the injected liquids. For this purpose, the different alkali/surfactant solutions were prepared in the reservoir water. According to the experiment the following results were achieved:

– the surfactant concentration of 0.02 % reacts without sedimentation,

– the alkali concentration of 0.6 % and 0.8 % demonstrates the low sedimentation at the Cretaceous horizon. Therefore, the following concentrations were chosen for filtration studies:

a) 0.02/0.6;
b) 0.02/0.8.

Surfactants and alkalis should not be used for polymer flooding. The results of the filtration studies are shown in Figure 1.

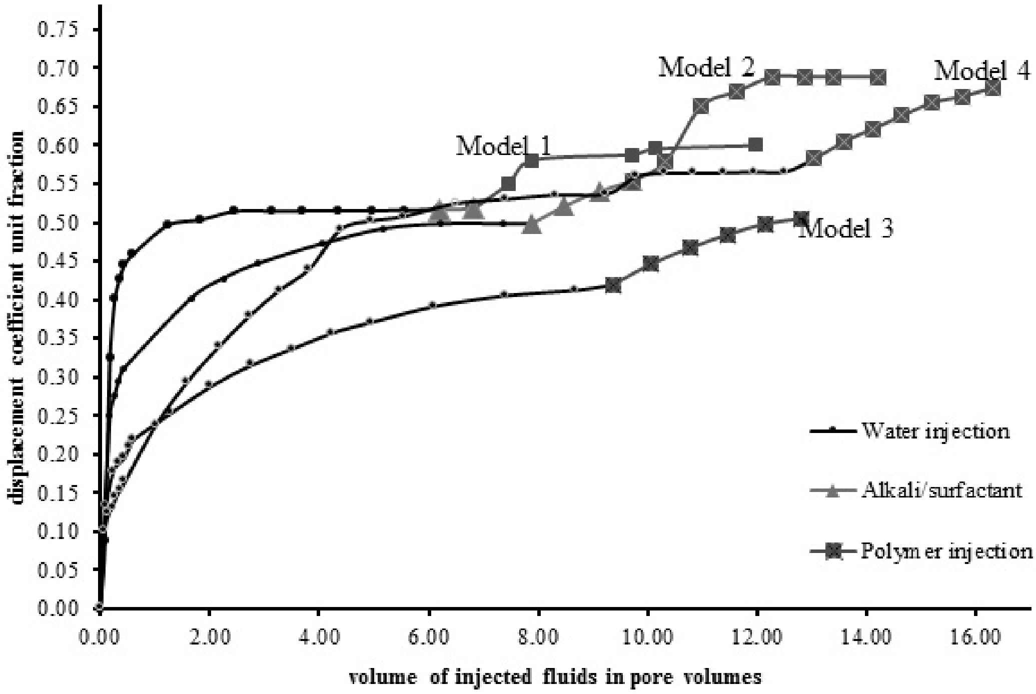

Figure 1. The values of displacements at a polymer and an ASP flooding method

In the Figure above, models 1 and 2 are related to ASP flooding method. Oil displacement by water injection reaches 0.51 unit fraction for the first model and is 0.49 unit fraction for the second model. Then remained oil is displaced by surfactants / alkali solutions, which gave absolutely different results for the both model. For example, the first model, which has a surfactant concentration of 0.02 and alkali concentration of 0.6, does not provide additional extraction. However, an increase in alkali concentration to 0.8 for the second model showed an increase in displacement coefficient for 5 %. Models 3 and 4 demonstrate only polymer flooding, where oil initially displaced by reservoir water then by polymer solution. Based on the results of all four models, a polymer flooding has shown the low displacement equal to 0.51 unit fraction, and both polymer and an ASP flooding have shown the maximum displacement equal to 0.68 unit fraction. In addition, there were signs of increase in displacement coefficient when increase the permeability. The relationship between the displacement coefficient and permeability has shown in Figure 2.

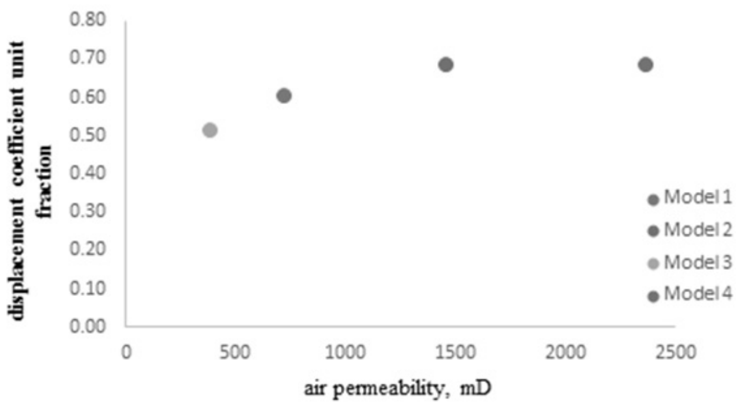

Figure 2. Dependence of displacement coefficient on core sample permeability

Conclusion

The following results have been obtained during the experimental studies. Firstly, when choosing a surfactant/alkali system, it is not enough to study only the phase behavior of polymer solution at the oil/water interfaces; the key element to achieve the effectiveness of solutions is to carry out filtration tests. Secondly, filtration tests with polymer concentration 2500 ppm have shown an equally high displacement coefficient for both flooding methods. However, this value of 0.68 unit fraction was achieved by polymer and water injection. To obtain more accurate data on the effect of chemicals, the displacement coefficient was calculated only for injected solutions without effect of water displacement and study showed the following results:

a) for model 1, the displacement coefficient increases by 9 % for polymer flooding; there is no displacement due to combined surfactant/alkali flooding;

b) for model 2, the displacement coefficient increases by 5 % in surfactant and alkali injections and increases by 14 % in polymer flooding and showed 19 % increase due to the chemical flooding;

c) for models 3 and 4, the displacement coefficient increases by 10 % in polymer flooding.

Based on these results, the maximum incremental production of 19 % has achieved only with ASP flooding. Undoubtedly, the oil/water displacement also depends on the permeability, which has shown in Figure 2. However, the incremental production for the first core model reached 9–10 % at a lower permeability of 724 mD within ASP flooding and at a higher permeability of 2370 mD within polymer flooding. This is another proof of effectiveness of the ASP flooding method. The laboratory results prove that an ASP flooding is more developed and effective oil recovery method compared to polymer flooding.

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А.Ж. Наукенова, Ж.Б. Куатов, Б.Е. Бекбауов, Р.Б. Мербаев

Мұнай беруді арттырудың химиялық әдістерінің тиімділігін Каспий маңы ойпаты тау жыныс үлгілерінде эксперименттік зерттеулерді жүргізу арқылы салыстыру

Мақалада физика-химиялық әдістермен X кен орынында қойнау қатқа әсер етуде полимерлі және аралас су тоғытуды қолдану қарастырылды. Осы әдістердің тиімділігін салыстыру мақсатында тұтқырлығы жоғары мұнайлы керн үлгілерінде эксперименталды зерттеулер жүргізілді. Керн деректері: кернді іріктеу интервалы, керннің кеуектілігі, өтімділігі және көлемі, сондай-ақ қабаттық мұнай мен судың қасиеттері фильтрациялық зерттеулер өткізілгенге дейін анықталды. Зерттеудің бірінші кезеңінде аралас су тоғыту үшін БАЗ және сілті ерітінділерінің оңтайлы арақатынасы таңдалды. Екінші кезеңде полимерлік және аралас әдістер үшін полимердің түрі таңдалды және оңтайлы концентрациясы анықталды. Су тоғытудың екі тәсілін салыстырмалы талдау үшін концентрациясының бір мәнін пайдалану шешілді. Қорытынды кезеңде полимерлік және аралас су тоғыту әдістерінің тиімділігін салыстырмалы бағалау үшін фильтрациялық зерттеулер PLS-200 қондырғысында орындалды. Жүргізілген зерттеулер нәтижесінде анықталғандай, осы екі әдіспен қойнау қатқа әсер ету кезінде ығыстыру коэффициентінің өсуі байқалды. Осы кен орнында полимер ерітіндісімен мен полимердің БАЗ-бен және сілті мен комбинациядағы ерітінділері мен қойнау қатқа әсері кезінде ең жоғарғы жиынтық ығыстыру коэффициентінің мәніне 0,68 үлестік бірлік қолжеткізілді. Алайда егер қойнау қатқа тек химиялық әсерді ескерсек, онда ығыстыру коэффициенті сәйкесінше 0.1 және 0.19 тең болады, бұл аралас әдіс тиімділігін көрсетеді.

Кілт сөздер: тау жыны сүлгілері, полимермен су тоғыту, комбинациялық су тоғыту әдісі, тұтқырлығы жоғары мұнай, БАЗ, сілті, концентрация, ығыстыру коэффициенті.

А.Ж. Наукенова, Ж.Б. Куатов, Б.Е. Бекбауов, Р.Б. Мербаев

Сравнение эффективности физико-химических методов увеличения нефтеотдачи путем экспериментальных исследований на керновых образцах месторождений Прикаспийской впадины

В статье рассмотрено полимерное и комбинированное заводнение для физико-химического воздействия на пласт месторождения X. Для сравнения эффективности данных методов были проведены экспериментальные исследования на керновых образцах, содержащих высоковязкие нефти. Данные керна (интервал отбора, пористость, проницаемость, объем, а также свойства пластовой нефти и воды) были определены до проведения фильтрационных исследований. На первом этапе исследований было подобрано оптимальное соотношение растворов ПАВ и щелочей для комбинированного заводнения, на втором этапе были выбраны тип полимера и оптимальная концентрация как для полимерного, так и для комбинированного метода. Для сравнительного анализа двух способов заводнения было решено использовать одно значение концентрации. На заключительном этапе для сравнительной оценки эффективности полимерного и комбинированного заводнения были выполнены фильтрационные исследования на установке PLS-200. В результате проведенных исследований установлено, что при обоих методах воздействия на пласт наблюдалось увеличение коэффициента вытеснения. Для данного месторождения максимальный суммарный коэффициент вытеснения со значением 0,68 доли ед. достигается при воздействии раствором как полимера, так и полимера в комбинации с растворами ПАВ и щелочи. Однако если учесть только химическое воздействие на пласт, то коэффициент вытеснения будет равным 0,1 и 0,19 соответственно, что показывает эффективность комбинированного метода.

Ключевые слова: керн, полимерное заводнение, комбинированный метод заводнения, высоковязкая нефть, ПАВ, щелочь, концентрация, коэффициент вытеснения.

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