Alkaline–Surfactant–Polymer Flooding Mechanisms

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Contributor: Xiuyu Wang, Fuqiong Wang, Mohanad A. M. Taleb, Zhiyuan Wen, Xiulin Chen

Chemical flooding, expecially alkali–surfactant–polymer (ASP) injection plays an important role in enhancing oil recovery under many synergetic mechanisms, in which there are four main mechanisms that have been widely used, including improving the mobility ratio between the heavy oil and the displacing phase, lowering the interfacial tension between oil and water (IFT), altering the rock wettability (oil-wet to water-wet) and emulsifying oil and water. Laboratory tests and pilot trials of ASP injection showed that the oil recovery of the emulsified system is 5% more than the cases where no emulsions existed.

Keywords: chemical flooding ; ASP flooding ; emulsions ; enhance oil recovery

1. Introduction

The alkaline–surfactant–polymer (ASP) flooding technology consists of a mixture of chemicals and methods that is used to optimize the recovery of heavy oil [1]. The scenario of how this technique works is manifested in the main mechanisms of ASP flooding. Therefore, before presenting the interactions and synergy of ASP, the main mechanisms of each component are first discussed individually.

2. Polymer Flooding Mechanisms

Polymer flooding is an EOR technique in which a high-viscosity polymer solution is injected into the formation to reduce the mobility ratio, increase the swept volume, and, hence, improve the oil recovery [2]. In other words, polymer injection is similar to waterflooding except that the polymer is diluted in water to increase the viscosity of the solution [3]. Consequently, increasing the viscosity of the polymer slug widens the swept area by preventing viscous fingering [4]. Over the past decade, many studies have focused on polymer flooding and how it works under different conditions. After many extensive types of research, it was found that polymer viscoelastic behavior results in some mechanisms that enhance heavy oil recovery. Sheng et al. [5]. summarized four recovery mechanisms related to polymer viscoelasticity: (1) the pulling mechanism, (2) oil-thread flow mechanism, (3) stripping mechanism and (4) shear-thickening mechanism.

2. Surfactant Flooding Mechanisms

Surfactants are generally used to overcome the immiscibility between water and oil by reducing the interfacial tension (IFT) between them and changing the wettability of the reservoir rocks to water-wet so that the seepage and, eventually, the recovery of the residual oil in the formation are enhanced. According to the nature of the hydrophilic head, surfactants can be classified into four main categories: anionic surfactants, cationic surfactants, non-ionic surfactants, and zwitterionic (amphoteric) surfactants [6][7]. The effects of surfactants are generally linked to four main mechanisms: reduction in the interfacial tension, alteration of the wettability, and emulsification and foam generation, through which surfactants prove to be beneficial as a chemical EOR (CEOR) method.

3. Alkali Flooding Mechanisms

Alkaline (or caustic) flooding is a chemical method that can be used to increase the oil displacement efficiency and, consequently, more of the remaining oil can be produced [8]. The benefits of this process are based on the reaction between sodium hydroxide (NaOH) with the naturally occurring organic acids in crude oil, which results in soap production at the oil–water interface. In situ production of this type of surfactant results in a reduction in the interfacial tension (IFT) between oil and water. Alkaline basicity (pH) ranges from 8 to 14, where 14 is considered to be a very strong alkaline agent. The use of a strong alkali does not necessarily provide incremental oil recovery because the use of strong alkalis is more likely to result in a loss in production capacity and scaling problems [9].

4. ASP Flooding Synergy and Its EOR Applications

ASP flooding is a mixture technique that injects alkali (A), surfactant (S), and polymer (S) solutions into the reservoir formation to improve the exploitation of crude oil. After carrying out extensive studies, it was proved that the integrated synergistic mechanism of each component of the injected alkali–surfactant–polymer slugs is the main reason for the significant success of ASP injection and why it is regarded as the most prominent CEOR technique [1]. Chen et al. [10] conducted a laboratory experiment on several core samples to investigate the impact of the synergistic mechanisms of injecting a multi-component chemical system (ASP) on improving crude oil recovery compared to single-component (polymer, alkali, surfactant) and double-component chemical systems (AS, AP, SP). The results of these experiments showed that the injection of the multi-component chemical system (ASP) achieved the highest recovery percentage of crude oil compared to the other systems, which proves the effects of the contribution of the synergistic mechanisms within the ASP flooding components.

Now, to provide a deeper insight into ASP synergy, which makes it more efficient than other CEOR techniques, the potential effects of ASP components were investigated on the solution viscosity, IFT, and the amount of A/S/P adsorption [11]:

(1) The effects of ASP components on viscosity: The solution viscosity is primarily controlled by the amount of polymer followed by the alkali concentration and lastly, the surfactant concentration, as shown in **Figure 1** [10].

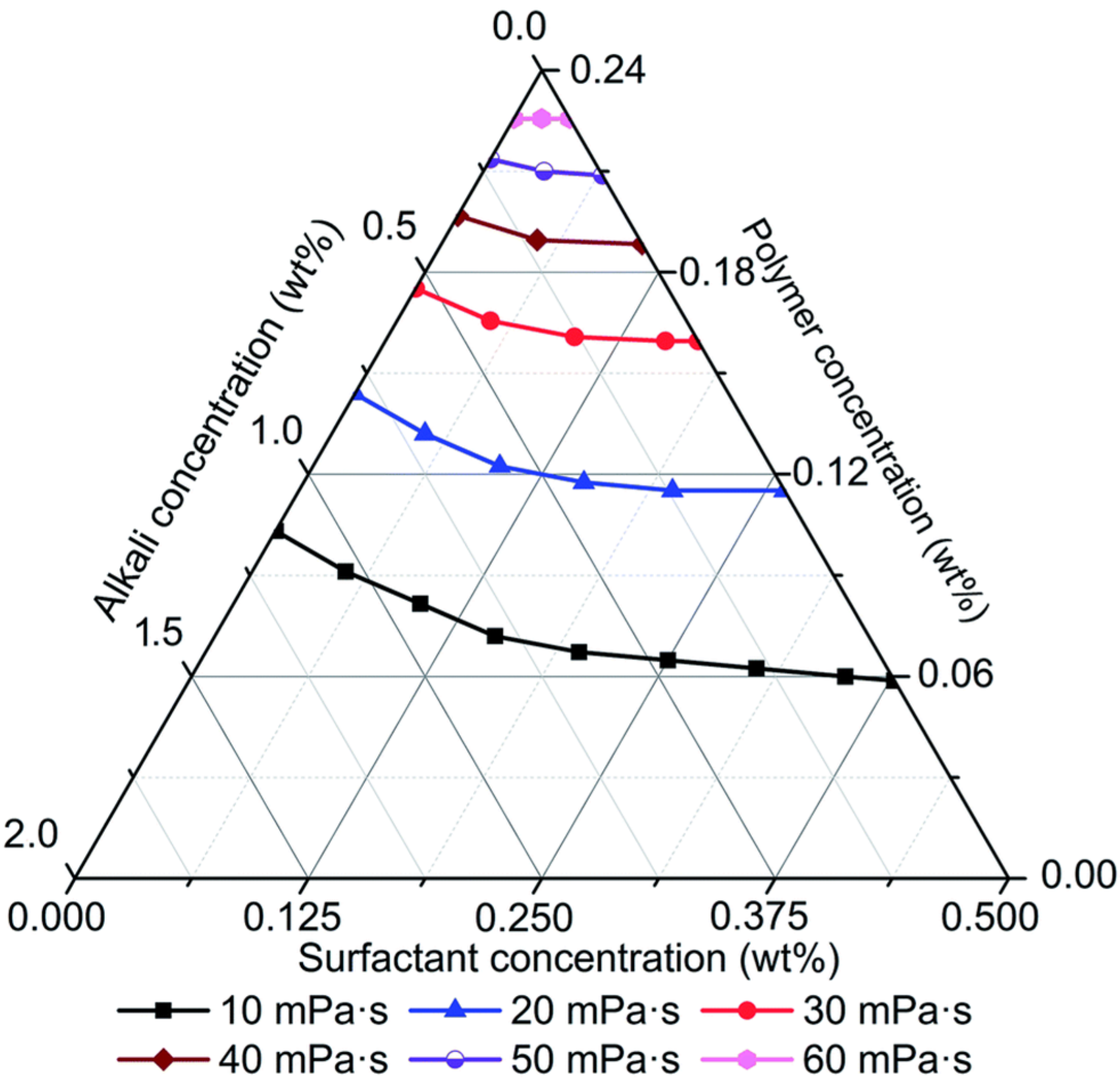

Figure 1. Effects of ASP components on viscosity[10].

(2) The effects of ASP components on the interfacial tension (IFT): The surfactant is the primary component that controls the changes in IFT during ASP injection, followed by alkali and, finally, polymer, as shown in **Figure 2,** in which SASP means strong alkali-surfactant-polymer, while, WASP means weak alkali-surfactant-polymer.

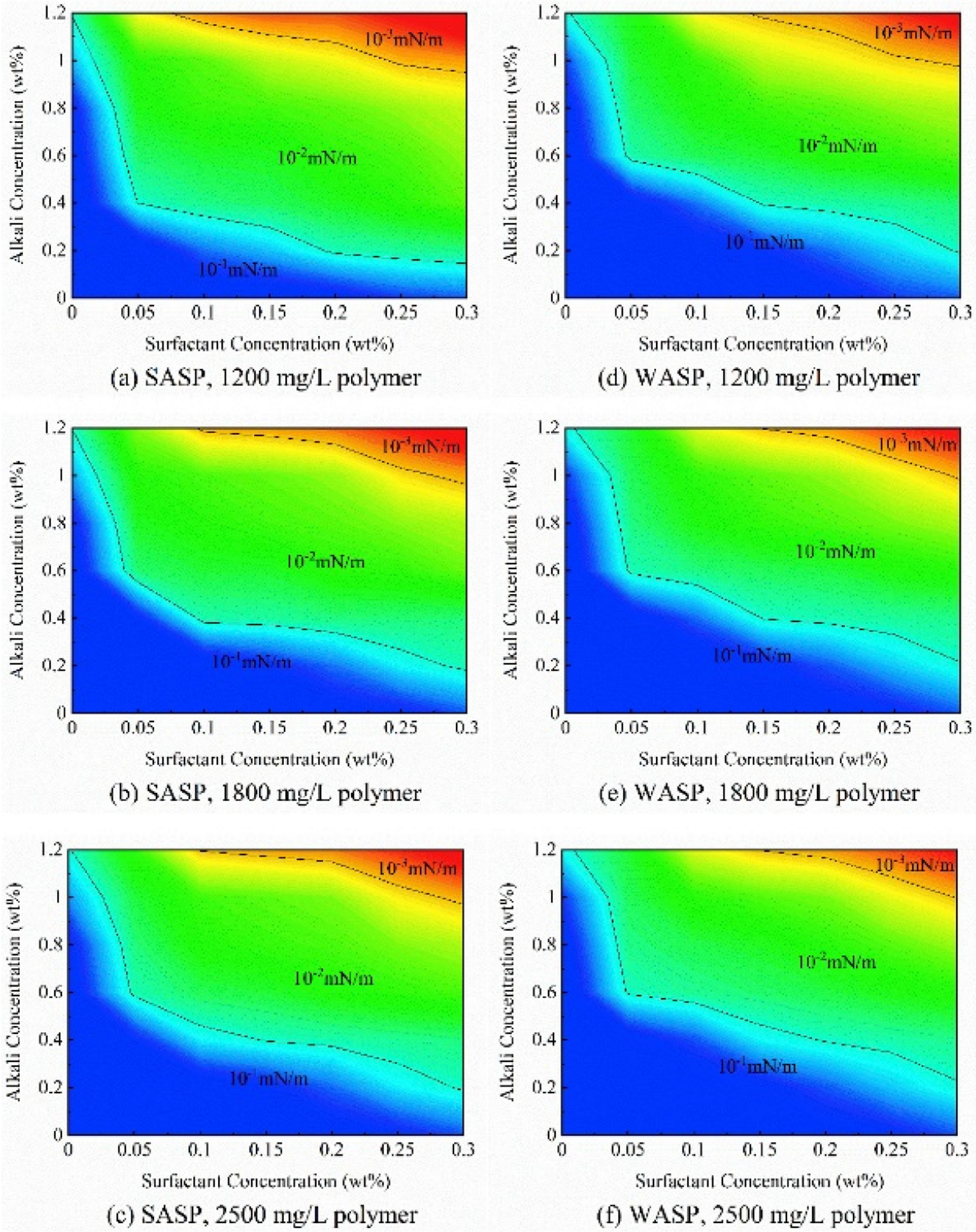

Figure 2. Effects of ASP components on IFT [12].

Field trials are considered to be essential for ASP flooding projects to move from the stage of laboratory experiments to the final stage of field applications. During the implementation of pilot tests, petroleum engineers should carry out proper measurements of the injection system, i.e., the injection mode and well pattern/spacing, to ensure the highest, most economic oil recovery is achieved under a certain set of conditions. According to several previous studies, 32 ASP flooding field trials have been reported so far worldwide, including 19 inshore projects in China, 7 inshore projects in the USA, 3 inshore projects in Canada, 2 inshore projects in India, and finally, one offshore project in Venezuela. The basic information of these projects is summarized in **Table 2** [1][13][14][15][16][17][18][19][20][21][22][23][24][25].

Table 2. Summary of recent ASP field trails.

Location	Field	Wells No. (P/J) *	Well Spacing /ft	Total Chemicals, PV × Concentration/%			Oil Recovery (%)
				Alkali	Surfactant	Polymer	
USA	Cambridge	–	–	38.38	3.07	4.53	28.00
	West Kiehl	–	–	20	2.5	2.63	26.00
	Tanner	2/1	656.5	25.1	2.51	2.51	17.00
	Mellot Ranch	3/2	–	30.1	3.01	3.91	–
	Lawrence	6/12	230.0	25	43.75	5.5	24.00
	Sho-Vel-Tum	4/1	233.3	88	15	4.38	20.00
	Brookshire	4/1	–	–	–	–	21.00
Canada	Little Bow	–	–	24	15	27	5.70
	Taber South	45/18	–	25.5	5.1	4.08	7.30
	Mooney	–	–	–	–	–	–
India	Viraj	9/4	738.2	30	4	2.8	–
	Jhalora	6/1	–	75	7.5	6.9	–
Venezuela	Lagomar	–	–	17.5	7	5	–
China (Daqing)	S-ZX	9/4	347.8	40	9.6	5.54	21.40
	X5-Z	4/1	459.3	48.47	11.84	8.57	25.00
	X2-X	9/4	656.2	132.24	20.79	9.96	19.40
	S-B	4/3	246.1	57.6	12.96	10.24	23.34
	B1-FBX	12/6	820	132.24	20.79	9.96	20.63
	X2-Z	27/17	820.2	46.31	8.17	9.92	18.10
	SB-B2-Z	4/3	246.1	77	10.5	12.36	24.66
	SL-GDX	13/6	820	132.24	20.79	9.96	15.50
	N-5	39/29	574.1	–	–	–	19.80
	B-1E	63/49	410.0	–	–	–	30.00
	B-2X	44/35	410.0	–	–	–	29.40
	S6	160/144	574.1	–	–	–	–
	X1-2D	143/112	492.1	–	–	–	18.50
	X6-EI	112/102	462.6	–	–	–	18.50
	X6-DII	109/105	462.2	–	–	–	19.00
China	Karamay	9/4	164.0	47.18	10.11	6.04	25.00
China (Sheng-li)	Gu-dong	9/4	164.0	60	15.2	4.6	26.00
	Gu-dao	13/6	695.5	37.08	9.27	8.07	15.50
China (Jilin)	Hong-gang	–	656.2	13.5	1.08	2.70	–
China	ZY-HZ-J	5/4	–	–	–	–	0.61
China (Yu-men)	L-J-M	4/1	229.7	95.86	214.2	4.21	1.82

* (P/J): The numbers of producers to injectors.

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