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Formation damage during alkaline-surfactant-polymer flooding in the Sanan-5 block of the Daqing Oilfield, China

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A B S T R A C T

Alkaline-Surfactant-Polymer (ASP) flooding is an emerging chemical Enhanced Oil Recovery (EOR) technology which has significantly enhanced oil recovery of Daqing Oilfield. ASP flooding benefits from the synergy effects of alkali, surfactant and polymer to improve both volumetric and displacement efficiencies and meanwhile lower surfactant adsorption. However, ASP flooding also induces some negative formation damage effects such as scaling, adsorption, and mineral dissolution. In this paper, we investigated the formation damage caused during ASP flooding in Block Sanan-5 in Songliao Basin – one of the most productive blocks of Daqing Oilfield in China.

It was found that the distribution of formation damage caused by ASP flooding followed flow paths of chemical solutions and was dependent on well locations. The severity of damage varies as distance increases from the near-injection-well area to the near-production-well area. Understanding the effects of well locations on formation damage during ASP flooding could provide more accurate evaluation of formation damage and helped to guide reservoir development strategies. To analyze the well location factor, we collected scaling samples and more than 970 m of core samples from Block Sanan-5 of Daqing Oilfield covering different wells on various flow paths before and after ASP flooding. The changes of some key petrophysical parameters such as porosity and permeability before and after ASP flooding were investigated. A series of experiments, including Scanning Electron Microscopy (SEM), Casting Thin Sections (CTS), X-Ray Diffraction (XRD) and ion analysis of produced water were performed to test properties of core samples. In addition, absorption of different components in the ASP solutions was also measured.

Experimental results indicate that the ASP flooding has considerably different influences on different parts of flow paths. After ASP flooding, permeability distribution of core samples exhibits different variability trends from the near-injection-well areas to near-production-well areas. Due to absorption of alkali and polymer, grains migration and scaling of calcium and magnesium, permeability decreases at the near-injection-well area, then increases at an intermediate distance and decreases again at the near-production-well. Moreover, porosity of samples shows a similar tendency with variability of permeability, which is interpreted by the strong mineral corrosion due to high concentration of alkali in the near-wellbore area, while its extent of variation is smaller than permeability.

1. Introduction

Chemical flooding using an alkaline-surfactant-polymer (ASP) is a flexible technique that is applicable to many reservoirs. The research on this subject is comprehensive and meticulous (Wang et al., 2014; Denney, 2013; French, 1996; Duan et al., 2014; Zhang

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et al., 2016; Tang et al., 2013; Korrani et al., 2016). In brief, surfactants lower the water-oil interfacial tension so that isolated oil is mobilized and remove the residual oil film, the alkali forms soap with acidic crude oils and lowers the surfactant adsorption, and the polymers increase the viscosity of the aqueous phase, pulling out bypassed oil and reducing bypassing (Pope et al., 1979). Due to the alkaline agents and other ions in the ASP fluid that are incompatible with the reservoir, some reactions will occur during the migration of the ASP fluid (Wang and Wang, 2003). Considering the distance between wells, the reactions and mechanisms occurring during the fluid migration are not all of the same, varying from the injection well areas to production well areas, such as:

$$KAlSi_3O_8 + Na_{1-x}Ca_x[Al_{1+x}Si_{3-x}O_8] + OH^- \rightarrow Al(OH)_3\downarrow + K^+ + Na^+ + Ca^{2+} + SiO_3^{2-} \tag{I}$$

$$SiO_2 + 2OH^- \rightarrow SiO_3^{2-} + H_2O \tag{II}$$

$$Ca^{2+} + 2OH^- \rightarrow Ca(OH)_2\downarrow \tag{III}$$

$$Na^+ + AlO_2^- + 3SiO_3^{2-} + 3H_2O \rightarrow NaAlSi_3O_8 + 6OH^- \tag{IV}$$

Therefore, various effects on the reservoir properties, such as permeability and porosity, could occur through these reactions and mechanisms in the entire flowing path area. Oil recovery by ASP flooding benefits from some of these reactions and mechanisms above.

However, some other the reactions and mechanisms may not enhance the oil recovery. These include chromatographic separation (Hao et al., 2015; Liu et al., 2015), adsorption and retention (Volokitin et al., 2014; Li et al., 2001), corrosion (Wu et al., 2015; Alwi et al., 2014a,b; Rathnaweera et al., 2015; Ciantia et al., 2015), changing mineral composition (Li et al., 2015; Wang and Wang, 2003), grain migration (Yuan et al., 2015) and scaling problems (Denney and Others, 2008; Karazincir et al., 2011; Wang and Cheng, 2003; Yuan et al., 2011). The previously noted roles of alkaline agents, are attributed to their ability to increase the pH (Kazempour et al., 2012). Simultaneously injecting a chemical displacing fluid containing alkali into a reservoir may lead to silicate mineral dissolution, secondary mineral precipitation and even mineral migration possibly resulting in changes of permeability and porosity (Yuan et al., 2016). Numerous experiments have been published on mineral dissolution in silicate minerals (Fu et al., 2009). Sydansk (1982) studied the interaction of a sodium hydroxide solution with sandstone at elevated temperature and found the following: (a) significant dissolution silicate minerals, (b) sandstone weight loss, (c) increased porosity, (d) propagation of significant concentrations of water-soluble silicates, (e) in situ formation of new immobile aluminosilicate materials, (f) changes in permeability and (g) hydroxide ion consumption. Numerous researchers have reported that mineral dissolution and precipitation reactions in the subsurface porous media can alter the structure of the pore network and may impact porosity, permeability and flow paths (Cai et al., 2009; Colon et al., 2004; Crandell et al., 2012; Emmanuel and Berkowitz, 2005; Um et al., 2005). Therefore, alkaline agents play an important role in formation damage to the reservoir caused by ASP flooding and directly influence the degree of damage in the different locations in the flow pathway.

It is important to understand the effects of ASP flooding because ASP flooding affects the reservoir in ways that differ from water flooding (Wang, 2001a,b, 2003). Hou (2005) studied the synthetic effects of an ASP solution on the interfacial and rheological properties on displacement oil using an interface tensiometer and rheometer; Sedaghat et al. (2015) used pore-level experimental investigation to evaluate ASP formulations for heavy oil; Li et al. (2014) researched the adsorption properties of an ASP flooding system in the central Saertu sub reservoir in Daqing by static core adsorption experiments and dynamic core flooding experiments; Kalwar et al. (2014) designed a new approach for ASP flooding in high saline and hard carbonate reservoirs. He et al. (2015) studied reservoir pore-throat structural changes after strong base ASP flooding in the Daqing oilfield through mercury injection, scanning electron microscopy (SEM) and casting thin section (CTS) analysis; Kumar and Mohanty (2010) reported on a selected alkaline-surfactant system for viscous oil that was tested in a sand pack flood; Jia et al. (2006) studied the factors influencing the ASP displacement efficiency in the Daqing Oilfield using a micro-displacement experiment. Weatherill (2009) studied surface development aspects of ASP flooding. Farajzadeh et al. (2013) researched effect of continuous, trapped, and flowing gas on performance of ASP flooding. The results from a large numbers of investigations on related topics have been reported through the laboratory experiments noted above. However, the former relevant formation damage studies mainly focused on the laboratory simulations rather than field pilot testing. Because the limited laboratory simulations could not be compared with the entire reservoir in scale, analyzing core samples from different positions in the flow pathway would be more comprehensive. Therefore we collected more than 3000 feet of core samples from the Sanan-5 Block of the Daqing Oilfield, from areas of injection, production and inspection (located in the middle of flow path) well areas to discover whether the distribution of formation damage caused by ASP flooding follows the flow paths of chemical solutions and is dependent on well locations.

2. Geologic setting and production history

The Songliao Basin, the largest oil production base in China, is a large-scale Mesozoic and Cenozoic continental sedimentary basin situated in the northeastern China (119°40′-128°24′ E longitude and 42°25′-49°23′ N latitude). It is 750 km long and approximately 350 km wide, extending through three provinces of China, with total area of 260,000 km^2 (Fig. 1A) (Wei et al., 2010; Zhao et al., 2011).

The Daqing placanticline, a typical inversion structure, is located in the central depression of the Songliao Basin. It is approximately 140 km long from south to north and from 6 to 30 km wide. The top of this structure is 1050 m below sea level, the thickness and its area are 524 m and 2800 km^2, respectively (Fig. 1B).

The Saertu Oilfield is located in the middle of the Daqing placanticline. The length from south to north of this oilfield is 32 km, the width in northern part of the oilfield is 20 km and 12 km in the southern part. The oil-bearing area is approximately 200 km^2. The oil-bearing reservoir is in the Lower Cretaceous strata that includes the Qingshankou, Yaojia and Nenjiang formations (Fig. 1B) (Li Mingyuan, 2009).

The Sanan-5 Block is located to the south of Saertu anticline and Line-30 and north of Line-3 Sanan-4 area, and it reaches the boundaries of the Putouhua II oil reservoir in the east and west. The oil-bearing area is approximately 12 km^2. The average dip angle is 3.7° in the east and 18.5° in the west (Li Chen, 2010).

The depth of the oil-bearing strata in the Sanan-5 Block ranges from 775 to 1196 m. These include the Saertu, Putaohua and Gaotaizi strata and are divided into 41 sandstone layers and 130 substratum layers. The effective thicknesses of the oil-bearing strata are approximately 60 m in the center, 30 m in the south, and 40 m in the north of the oilfield (Li Chen, 2010).