https://doi.org/10.53656/nat2022-5.02

From the Research Laboratories

IMPROVEMENT OF OIL RECOVERY IN HYDROCARBON FIELDS BY DEVELOPING POLYMERIC GEL-FORMING COMPOSITION

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Abstract. The paper presents the results of laboratory and field experiments on a developed polymer gel-forming composition "PSB" that enhances oil recovery. In this composition, two aqueous solutions are used: a polymeric gelling agent and an inorganic crosslinker. An alternating injection of solutions that are mixed directly in the reservoir allows a bulk gel to be formed that blocks water or gas breakthroughs. This leads to an increase in oil production, and a decrease in water cut, resulting in more efficient wells.

On five wells in a hydrocarbon field that was located within the Permian-Carboniferous deposits, a series of field tests were conducted. It has been observed that wells treated with this developed polymer gel-forming composition "PSB" show a decrease in water cut, a decrease in liquid flow rates, and an increase in oil production. This technology led to an increase in oil flow rates of 5 tonnes per day per well (2 times) and a decrease in water cut of 10-40%, confirming its effectiveness. According to the values of the cumulative effect as of February 2016, this effect continues to increase oil production by 20-600 tons per well.

Keywords: Oil recovery; Polymers; Crosslinkers; Gel-forming composition; PSB

Introduction

As the oil industry has grown, it has become increasingly important to achieve the highest oil recovery factor. Yet, there is only an average oil recovery factor of 20% to 40% worldwide (Muggeridge et al. 2014; Al-Obaidi 2007). Recovery factors are heavily influenced by several enabling technologies. Limiting water and gas breakthroughs in producing oil wells is considered to be an important aspect of work to improve oil recovery and increase the efficiency of oil production (Batalov et al. 2018; Al-Obaidi 2020; Al-Mumen et al. 2008; Al-Obaidi & Khalaf 2020). Thus, in the oil industry, gelling compositions based on polymers and crosslinkers are employed to waterproof and prevent gas breakthroughs in production wells. This results in improved recovery of crude oil. In wells where technical methods cannot stop the breakthroughs of water and gas, such as placing perforations and setting packers, the injection of hardening agents, such as gel-forming or high-viscosity plugging compositions, are used (Kabir 2001; Al-Obaidi 2015; Smirnov & Al-Obaidi 2008; Du, Bu, Shen & Cao 2019). These can be compositions based on cement, curable resins, cross-linked polymers, or gel-forming solutions of inorganic salts. As for water insulation, there is a wide range of effective methods, but there are fewer compounds capable of containing gas breakthroughs (Wisen, Chesnaux, Werring et al. 2019; Al Brahim, Bai & Schuman 2022; Al-Obaidi, Smirnov & Khalaf 2020; Jayakumar & Lane 2012). Additionally, the composition reaction time is an important issue – in the event of too fast reactions, there is a technological risk of not having enough time to inject a sufficient amount, which may result in wellbore blockages. In the case of a long reaction time, it is difficult to create a complete plugging slug in the right place in the formation (Al-Obaidi 2022; Nguyen, Tu, Bae et al. 2012; Al-Obaidi, Chang & Hofmann, 2022; Altunina & Kuvshinov 2007). For hot reservoirs or steam-cycled reservoirs, the solution is the use of thermotropic compositions, in which gelation occurs under the influence of reservoir temperature (Ahmad, Samsuri & Amran 2019; Altunina & Kuvshinov 2008; Gussenov, Nuraje & Kudajbergenov 2019; Kuvshinov, Kuvshinov & Altunina 2013). As for cold wells, this paper proposes a component-by-component injection of a gel-forming agent and a crosslinker, the mixing of which occurs directly in the formation due to the dispersion of the liquid when moving in a porous medium (Bjørsvik, Høiland & Skauge 2008; Al-Obaidi & Khalaf 2019; Fattakhov, Kadyrov & Galushka 2014; Al-Obaidi, Hofmann, Smirnov et al. 2021).

Methodology

Polymeric gel-forming composition PSB

The Polymeric gel-forming composition PSB is a system of two aqueous solutions: solution 1 (gelling agent) is based on a water-soluble polymer, adduct of an inorganic acid and a polyhydric alcohol; solution 2 (crosslinker) is based on a salt of an inorganic acid and a polyhydric alcohol (Kuvshinov, Kuvshinov & Altunina 2019; Al-Obaidi, Kamensky, Hofmann & Khalaf 2022; Lei, Sun, Lv et al. 2022; Zhang & Hoogenboom 2015). The PSB composition uses a polymer whose films have the lowest gas permeability among industrial polymers with an upper critical dissolution temperature (Hofmann, Al-Obaidi & Khalaf 2022; Hassan, Al-Shalabi & Ayoub 2022; Jouenne 2020). When alternating injections of the solutions are mixed directly in the reservoir, they form a bulk gel that prevents water or gas from breaking through, leading to improved well efficiency and increased oil production.

Results and discussions

Laboratory studies

An investigation was conducted into the physicochemical and rheological properties of PSB composition solutions and gels produced from alternating injections of gelling agent solutions and crosslinker solutions in various ratios, from 1:1 to 15:1. A crosslinker solution induces the formation of gel almost instantly and enhances the adhesion of gel to carbonate rock.

Viscosity measurements of solutions and gels were performed using a vibration viscometer (Rheokinetics) equipped with a tuning fork sensor (Bogoslovsky, Kozhevnikov & Stasyeva 2020; Bogoslovsky, Kozhevnikov, Galkin & Altunina 2020; Chang, Al-Obaidi & Patkin 2021). The measurements were taken immediately after gel formation and after thermostating of the gel for 14 hours. In the 14 hours following conditioning, gel viscosity increases between 10-50%, reaching a maximum of 3.4-4.3 times. The results of the study are shown in Figure 1. Based on these results, gels that have the highest viscosity are obtained when a gelling agent and a crosslinker are mixed at a ratio of 5:1 - 10:1. As shown in figure 1, the viscosity of the gels increases during the thermostating process, reaching values between 1550 and 1900 mPa s.

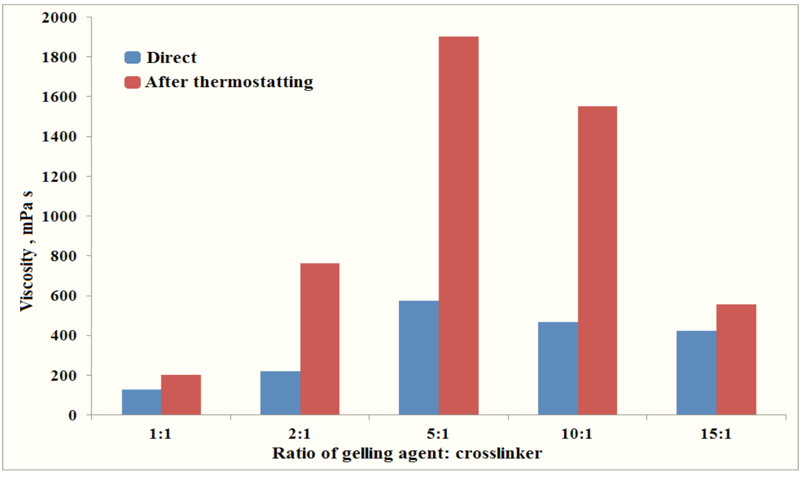

Figure 1. Viscosities of PSB composition gels obtained with different ratios of gelling agents and crosslinkers for limiting water inflow and gas breakthrough

Under laboratory conditions on a high-pressure flow unit, PSB gel-forming composition was examined for its ability to limit gas breakthrough and water inflow. Linear and heterogeneous reservoir models were used to investigate the flow characteristics of gel-forming compositions at temperatures ranging between 9 and

24°C. The studies were conducted using a model of a flow medium (reservoir) consisting of one or two parallel columns in order to study the fluid flow at a constant flow rate. Bulk reservoir models prepared from disintegrated marble (fraction 0.16-0.5 mm), formation water model with salinity 15.33 g/l, or freshwater were used. The permeability of the models was in the range of 6.6-87 μm^2.

Using PSB gel-forming composition, the following experiments were carried out on carbonate rock models at a temperature of 20-24°C in an attempt to simulate water inflow limitation and gas breakthrough in producing wells:

a) Injection of the gelling agent of the PSB composition without a crosslinker;
b) Injection of a hot solution of the crosslinker at a concentration of 30% and then injection of the gelling agent;
c) Alternately injection of a crosslinker at a concentration of 2% and then gelling agent, followed by a crosslinker and gelling agent again.

The injection of a hot solution of a 30% crosslinker, followed by the injection of a gelling agent, was performed at a temperature of 20°C in a marble rock model with an initial gas permeability of 6.808 μm^2. This led to the formation of a practically impenetrable screen, and no flow was observed when the pressure drop increased to17 atm/m.

In a rock model containing disintegrated marble with an initial gas permeability of 5.712 μm^2, alternating injections of solutions were carried out at a temperature of 20°C. By using a 2% crosslinker, water, gelling agent, water, and crosslinker again, an impervious screen was created, through which water could flow at a pressure drop of 13 atm/m. A further injection of the gelling agent of the PSB composition created an almost impenetrable screen, where no water could pass even when the pressure dropped to 149.5 atm/m (Fig. 2).

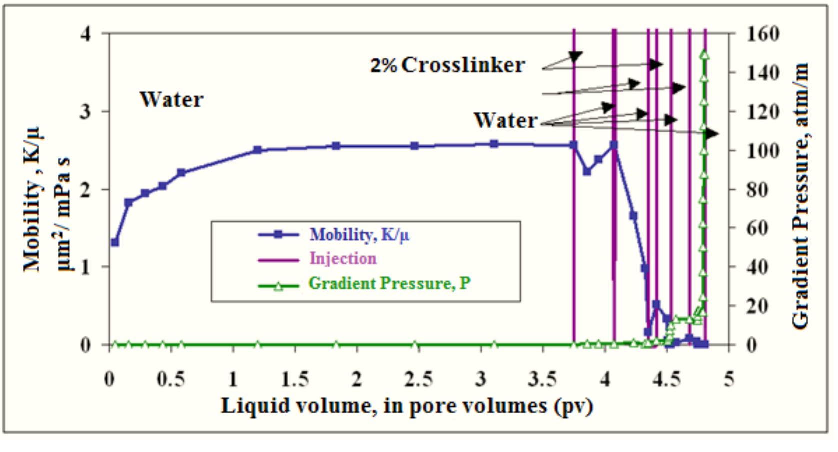

Figure 2. Change in mobility and pressure gradient with alternating injection of PSB components in a rock model made from disintegrated marble

The PSB composition has been studied for its ability to prevent gas breakthrough through leaks in a cement ring. Columns filled with ground cement stone were used in this study to simulate a porous medium. The initial gas permeability of the models was within 2–3 μm^2. The experiments were conducted at temperatures ranging from 0 to 40°C. Figure 3 shows the results of a flow experiment using a PSB composition. It displays the change in pressure gradient in the column and the fluid mobility in the forward and reverse flow of water, gas, and the solution of PSB composition.

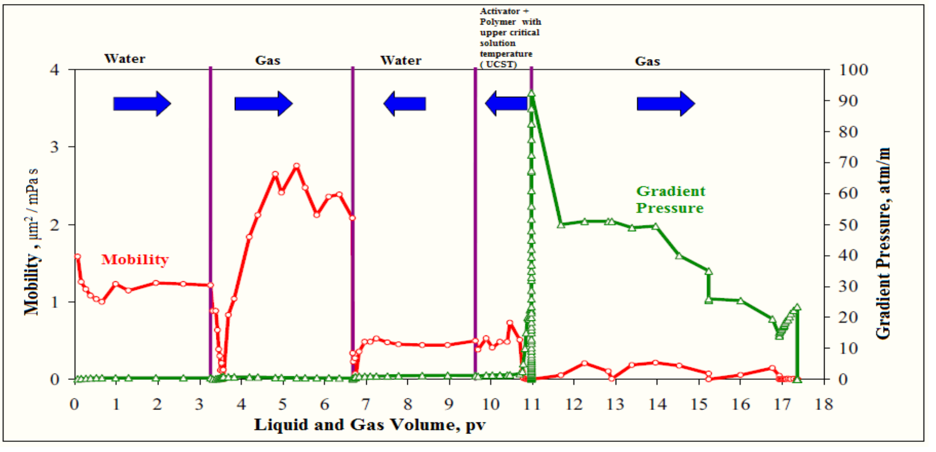

Figure 3. The influence of PSB composition injection – 2% crosslinkers, water and gelling agents - on the change in pressure gradient and fluid mobility during gas flowing (before and after gel formation) at a temperature of 20°C

In this diagram, arrows indicate which direction the flowing is going. Initially, a crosslinker solution is injected to improve the adhesion of the polymer to the cement stone and pipe surfaces, and then the gelling agent is injected. In this case, even after a gas breakthrough, the pressure gradient remains high when the gas is flowing in a volume bigger than the pore volume of the porous medium.

Experiential-industrial tests

First field tests of the composition were conducted at the mid of 2021. The composition was tested at five production wells in a hydrocarbon field, which is part of the Permian-Carboniferous deposit. For each well, preparation and injection of 96 m^3 of the composition, 48 m^3 of the polymer solution, and 48 m^3 of the crosslinker solution were performed. A liquid flow rate of 30 – 50 m^3/day, oil flow rates of 0.3 – 9 t/day, and water cut rates of 73 – 98 percent were measured in the wells prior to treatment. It is generally observed that wells treated with PSB show a decrease in water cut, a decrease in liquid flow rates, and an increase in oil production. The average increase in oil production rate is 5 t/day, and the water cut reduction is 10 – 40%. Data from February 2022 indicate that the cumulative effect of the treatment continues to increase oil production by 20 – 600 tons per well.

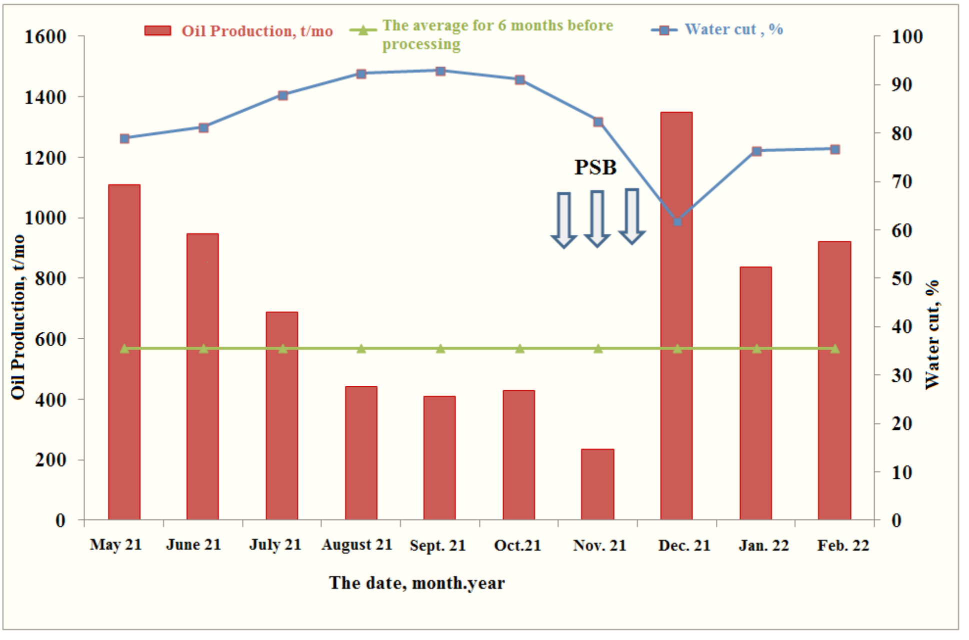

Figure 4. The results of PSB treatment of production wells of the Permian-Carboniferous deposit of a hydrocarbon field, a summary graph for 5 wells, as of February 2022

Conclusions

The results of laboratory physicochemical, rheological, and flowing studies have shown the potential of using the PSB gel-forming composition in the technology of water inflow limitation and gas breakthrough in production wells. This technology can be used at temperatures ranging from 0 to 50°C, in oil fields with terrigenous and carbonate reservoirs, in various geological and physical conditions, and at different stages of field development. Based on the results of tests conducted on a Permian-Carboniferous deposit with high viscosity oil, PSB composition is recommended for further experimental work and industrial implementation. A reduction in water cut, a decrease in liquid flow rates and increase in oil production are observed in wells treated with PSB. On average, oil production increased by 5 t/day, and water cut decreased by 10 – 40%.

According to the cumulative effect as of February 2022, every well has produced an additional 20 – 60 tons of oil.

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