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A critical review on use of polymer microgels for conformance control purposes

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ABSTRACT

Context: Polymer microgels are submicron-to-micron size, water-dispersible particles that are formed through use of a crosslinking agent. Their permeability reduction capabilities, when triggered, enable the strategic plugging of high-permeability channels so as to divert flooding fluid to the relatively unswept adjacent low-permeability zones. This improves macroscopic sweep efficiency, increasing hydrocarbon production and decreasing associated water production. Polymer microgel flooding thus serves to provide in-depth conformance control, distinguishing it from conventional polymer floods that offer primarily mobility control benefits.

Objective: This paper provides a literature review on the use of polymer microgel technology for conformance control purposes.

Method: Polymer microgel flooding is first introduced, and the motivation for their use over conventional polymer flooding is outlined. This is followed by a discussion on the characterization of polymer microgels as well as some theories on how they act as conformance control agents. In addition, an extensive survey of four different types of polymer microgels (Colloidal Dispersion Gels, Preformed Particle Gels, Temperature-Sensitive Microgels, and pH-Sensitive Polymer Microgels) is provided. Attention is mainly given to the microgel characteristics, laboratory observations, and field applications. The rheology and plugging mechanism of the different polymer microgels are also discussed in some detail.

Conclusion: Polymer microgel flooding is gaining popularity as a means of conformance control. Despite uncertainty around the precise mechanism by which microgels divert flow, numerous lab and field applications have demonstrated this technology's ability to improve sweep efficiency and enhance oil recovery.

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1. Introduction

With the global average oil recovery factor as low as 34% (Schulte, 2005), prolonging the life of mature hydrocarbon reservoirs is one of the foremost goals of the energy industry today. There are a variety of technologies that can facilitate mature field life extension: advanced reservoir characterization, artificial-lift optimization, conformance control, and various enhanced recovery schemes (Ali, 2012). The focus of this literature survey is the use of polymer-microgel-enhanced waterfloods as a means of conformance control. Ultimately, polymer microgel flooding is a form of chemical enhanced oil recovery that primarily targets *bypassed* oil.

Polymer microgels, added to injection water for waterflooding, serve as water-shutoff, conformance control and/or mobility control agents (Rousseau et al., 2005). This literature survey focuses on their use as conformance control agents. Conformance control is any process by which the sweeping of a reservoir is spread more evenly, approaching the ideal condition of a perfectly conforming drive mechanism (Borling et al., 1994). In the case of a waterflood, the injected water seeks the most permeable path, creating in many cases "thief zones". These thief zones, brought about by reservoir heterogeneity (geological layering, presence of natural or induced fractures, etc.), result in poor sweep efficiency and large amounts of unrecovered hydrocarbon (Fletcher et al., 1992; Pritchett et al., 2003; Sorbie, 1991). The different types of polymer microgels all fundamentally function to divert injected fluid away from thief zones and into adjacent matrix rock or low-permeability zones, thus increasing macroscopic sweep efficiency and improving hydrocarbon recovery (Borling et al., 1994; Ohms et al., 2009; Pritchett et al., 2003). To a certain extent, the polymer microgels also function to increase the viscosity of the aqueous phase, which in turn improves the mobility ratio in favor of decreased water channeling and delayed breakthrough (Sheng, 2011; Sorbie, 1991).

The increase in vertical and areal sweep efficiency brought about by the use of polymer microgels not only increases hydrocarbon production, but also yields a subsequent decrease in water production. The latter is important because water disposal costs are high and its disposal regulation is becoming increasingly strict. It has been estimated that for every barrel of oil produced worldwide, an average of roughly 3 barrels of water are produced as well, and the water disposal cost is estimated to be as high as $40 billion globally per year (Seright et al., 2003). Decreasing the amount of water produced can also decrease the load on surface facilities, and decrease corrosion and scale levels (Bai et al., 2008).

2. Polymer microgel motivation over polymer flooding or bulk gel treatments

Polymer flooding (Needham and Doe, 1987; Sheng, 2011; Sorbie, 1991), polymer in-situ gel flooding (Abdo et al., 1984; Avery et al., 1986; Kabir, 2001; Kim May, 1995; Norman et al., 2006; Seright and Liang, 1994; Seright et al., 2003; Sydansk and Southwell, 2000), and polymer microgel flooding (Al-Anazi and Sharma, 2002; Chauveteau et al., 2001; Coste et al., 2000; Cozic et al., 2009; Frampton et al., 2004; Mack and Smith, 1994; Spildo et al., 2009; Zaitoun et al., 2007) are three distinct improved oil recovery techniques, and it is important to be able to differentiate them from each other. Before proceeding with this distinction, a few key terms need be briefly defined. The Resistance Factor (RF) is used to quantify mobility reduction as a result of a polymer flood. It is simply the ratio of flooding water mobility to the polymer solution mobility. The Residual Resistance Factor (RRF) is used to quantify permeability reduction as a result of polymer flooding. It is the ratio of flooding water mobility before polymer flooding to the flooding water mobility after polymer flooding. Polymer in-situ gellation and microgels yield larger RRF values than polymer flooding because of their greater permeability reduction capabilities. This is a key reason why they are more effective conformance control agents. This will be discussed in more detail shortly.

Polymer flooding as an EOR technique is used primarily for *mobility control*. Polymer serves to increase the injecting aqueous fluid's viscosity (and decreases the mobility ratio). This leads to a more uniform areal and vertical displacement of oil in place. In a layered system, polymer's effect on mobility ratio leads to viscous crossflow effects that can improve the often poor vertical sweep efficiency (Sorbie, 1991). Polymer bulk gels and polymer microgels, on the other hand, are primarily for *conformance control*, and are for situations where there is very high permeability contrast. Note that conformance control primarily involves the improvement of *vertical* sweep efficiency. The fundamental distinction is that polymer gels and polymer microgels make use of a crosslinking agent. Crosslinkers enable polymer gels and polymer microgels to form polymer networks that are much more capable of plugging pores than polymer alone; this enables a more significant and longer lasting permeability reduction. This, in turn, can result in a long-term increased resistance to flow in high permeability streaks and subsequent fluid diversion effects, pushing oil out of areas that were previously unswept (Needham and Doe, 1987; Norman et al., 1999; Smith et al., 2000). As a result of these enhanced permeability reduction capabilities, polymer gels and polymer microgels are much more suitable for conformance control (Norman et al., 1999; Sheng, 2011).

The primary difference between polymer bulk gels and microgels is the concentration of reactants used in their respective formulations. Polymer microgels are formed using relatively lower concentrations of polymer and crosslinker. This results in the formation of a dispersion of many separate polymer microgel colloids (through primarily intramolecular crosslinking reactions), as opposed to a continuous intermolecular bulk gel network. This enables polymer microgels to be more easily injected. The lower concentration of reactants also yields a slower crosslinking reaction rate, which allows for much deeper reservoir penetration. With the temperature-sensitive and pH-sensitive microgels, discussed below, they can invade deeper into a formation until their gelation/pore plugging mechanism is triggered. Thus, polymer microgels are more suited for in-depth conformance control. In addition, polymer microgels can provide a much higher RRF in high permeability channels than do conventional uncrosslinked polymers (Mack and Smith, 1994; Norman et al., 1999; Smith et al., 2000).

Liu et al. (2006) outline and illustrate the different forms of conformance control chemical placement treatments, such as water shutoff (production well) treatments and profile control (injector well) treatments. In-depth fluid diversion treatments are an especially attractive form of conformance control as they improve overall sweep more significantly than near-wellbore treatments (especially when there is good communication/crossflow between the different layers/zones), and also yield lower losses in injectivity (Fletcher et al., 1992). Unlike production well treatments, they may also not require shut-in periods. Polymer microgel flooding serves as the most effective means of *in-depth* fluid diversion.

3. Polymer microgels

Cozic et al. (2008) define polymer microgels as micrometer-scale, fully water soluble, stable, and non-toxic polymer colloidal