Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Performance evaluation of optimized preformed particle gel (PPG) in porous media

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ARTICLE INFO

Article history:
Received 26 September 2015
Received in revised form 11 May 2016
Accepted 2 June 2016
Available online 16 June 2016

Keywords:
Conformance control
High salinity
High temperature
Preformed particle gel (PPG)
Resistance factor
Residual resistance factor

ABSTRACT

Preformed particle gels (PPGs) are used as conformance control agents to improve oil production and control excess water production. This paper talks about optimized PPGs that are designed for high-temperature and high-salinity oil reservoirs and their synthesize process. The influence of cross linker concentration, size of dry PPGs, injection rate, temperature, permeability, and brine salinity on resistance factor (RF) and residual resistance factor (RRF) of PPG in porous media are investigated. The focus of study is to see how PPGs would perform in porous media by creating flow resistance to injected fluid, hence enhancing the sweep efficiency. A set of 51-cm slim tubes packed with carbonate cores from one of the Iranian oil reservoir is used to evaluate the performance of optimized PPG at wide range of different temperatures and permeabilities.

PPG injection pressure increases with cross linker concentration, PPGs particle size, and brine concentration and injection flow rates but decreases with the increase of permeability and temperature during PPG injection. It was shown that increased injection rate does not increase PPG injection pressure to the same level and the reduction in water permeability caused by swollen PPG prepared in high salinity brine is higher than that prepared in low salinity brine. Synthesized PPGs can also change the permeability of different slim tubs to the same level. Resistance factor (RF) and residual resistance factor (RRF) increase with the increase in PPGs particle size, brine salinity and cross linker concentration. But, they decrease with the increase of temperature and the flow rate. Initially RRF increased gradually as the permeability of slim tubes decreased from 395 to 137 Darcy but a sharp increase in RFF caused by swollen PPG in low permeability slim tube was observed.

1. Introduction

Many hydrocarbon reservoirs are in communication with water-bearing rocks (Ahmed, 2006). These water-bearing rocks may be considerably larger than the hydrocarbon reservoirs they adjoin as to appear infinite in size. As the reservoir pressure depletes, water production increases. When the amount of produced water becomes excessive, oil production drops reducing the lifespan of most hydrocarbon wells (Bailey et al., 2000; Seright et al., 2003). High amount of produced water increases costs related to scale, corrosion, water/oil separation, and sometimes makes a well unproductive and economically inefficient (Bailey et al., 2000; Seright et al., 2003; Arabloo et al., 2015; Dalrymple, 1997). The annual cost of both

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http://dx.doi.org/10.1016/j.cherd.2016.06.004

Nomenclature

ΔP	pressure drop in (Psi)
μ	viscosity of liquid in (cp.)
RF	resistivity factor (unit less)
k	permeability in (Darcy)
T	temperature in (°C)
D_{th}	hydrodynamic pore diameter in (μm)
ϕ	porosity in (fraction)
PPG	preformed particle gel
MR	molar ratio
SR	swelling ratio (g/g)
DW	distilled water
PW	production water
BW	brine water
SW	sea water
Q	flow rate (ml/min)
D	PPG diameter (μm)
C	cross-linker concentration (weight percent, wt%)
S	water salinity (ppm)

treating and removing this water is estimated to be 40 billion U.S. dollars (USD) worldwide (Bailey et al., 2000; Arabloo et al., 2015).

One approach to decrease water cut production and improve the oil displacement and water flood process is to provide some means to block the water producing zones, or at least significantly increase the water flow resistance, selectively in these very high permeability geologic zones. If a treatment process is successful, water injection will sweep the oil reservoir in a more uniform fashion. Improving the water flood sweep efficiency has been the subject of many researches (Al-Anazi and Sharma, 2002; Bai et al., 2008; Chauveteau et al., 2001, 2003; Pye, 1964; Carlay and Delamide, 1996). Mechanical isolation, the use of selective advanced completions (e.g., sliding sleeves), and especially polymer gels to modify injection profiles or as water shut-off strategies are some of the most common approaches used to control conformance (Qiu et al., 2014). Gel treatment is one of the most important methods to correct reservoir heterogeneity (Chauveteau et al., 2001; Chauveteau et al., 2003; Elsharafi and Bai, 2012, 2013; Sang et al., 2014; Durán-Valencia et al., 2014). Traditionally in situ bulk gels have been widely used to control conformance (Qiu et al., 2014). A newer technology is applying preformed gels for this purpose because they can overcome some distinct drawbacks inherent in in situ gelation system, such as uncontrolled gelation times and variations in gelation due to shear degradation, dilution by formation water, and gelant compositional (Chauveteau et al., 2001, 2003, 2004a; Bai et al., 2007). Commercially available preformed particle gels (PPGs) for the purpose of water conformance control include swelling submicron-sized polymers called BrightWater (Pritchett et al., 2003; Frampton et al., 2008), microgels (Chauveteau et al., 2001, 2003), pH sensitive crosslinked polymer (Al-Anazi and Sharma, 2002; Huh et al., 2005; Rousseau et al., 2005; Zaitoun et al., 2007), and varied size preformed particle gel (PPG) (Bai et al., 2007).

PPGs are strength- and size-controlled, adjustable mechanical properties and adjustable swelling ratios, environmentally friendly, and they are stable in the presence of almost all reservoirs minerals and formation water salinities (Bai et al., 2009). PPG has only one component during injection, can be prepared with produced water, and also they can preferentially enter into fractures or fracture-feature channels while minimizing gel penetration into low permeable hydrocarbon zones (Bai et al., 2009). A variety of literature studies show that PPG has been successfully injected into reservoirs both with and without initial fractures and Real-time PPG injection pressure response were used to adjust PPG particle size concentration to better fit the reservoir (Bailey et al., 2000). PPGs have been applied in about 4000 wells in China to reduce fluid channeling in both water and polymer flooding (Bai et al., 2013).

Gel treatments depend heavily on the ability of these gels to extrude through fractures and channels (Seright and Lee, 1998; Seright, 1997a; Seright et al., 2001). Seright (1997b) has extensively investigated the extrusion of bulk gels through fractures and tubes. Seright (1997b) investigated microgel movement through sand-packed porous media. Bai et al. (2007) studied swollen particle gel transportation through porous media using sand pack and micro models. Muhammed et al. (2014) used a stainless steel screen plate with multiple holes to study the mechanism of passing swollen PPGs through the plate holes. They measured the stabilized extrusion pressure as a function of the flow rate and evaluated gel rheology in terms of its apparent viscosity as a function of the shear rate (Muhammed et al., 2014). Another study considered the shear-thinning properties of PPGs (Zhang et al., 2010), in which theoretical mathematical models using the general power law equation, were developed to predict the pressure gradient of swollen PPGs during its extrusion through fractures. Then, these models were modified to predict the effective viscosity of swollen PPGs. The results show that the effective viscosity of PPGs decreases with an increase in injection rate and increases with an increase in fracture width. Recently, Saghafi et al. (2016) synthesized a new PPG for harsh conditions. They improved the mechanical properties of the new classes of PPGs by adding the nano-clay montmorillonite Na^{+}. Interactions between microgels and the pore surface and pore throat of the rocks control the effective retention under reservoir conditions and thus their capability of reducing water permeability. In this case the depth of the microgels penetration depends on the retention level (Chauveteau et al., 2004b; Cozic et al., 2008). The adsorbed particle is elastic and deformable, and adsorption thickness decreases as the shear rate increases and increases as the concentration increases (Almohsin et al., 2014). Despite some limited works with the subject of performance evaluation of PPGs have been reported by researchers during the past decades, an investigation on the performance of a new class of PPG for treating oil reservoirs under extreme conditions of high temperature and salinity has not been fully studied. Moreover, the effects of cross linker, PPG particle size, flow rate, temperature, permeability and salinity on RF and RRF in porous media is not well understood. The interaction between the PPG and reservoir rock plays an important role in the performance of PPG for conformance control. Adsorption or retention of PPG in porous media affects the transport behavior and mobility of PPG through porous media. Thus, a deep understanding of this aspect may help to better design a successful PPG-assisted conformance control process. To achieve this mission, this article is aiming at investigating the effects of abovementioned important parameters on the performance of a newly synthesized PPG. Moreover, different PPG formulations under various experimental conditions were considered to thoroughly examine the performance. This article is organized as follows; in the next section, the material