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Full Length Article

New laboratory study and transport model implementation of microgels for conformance and mobility control purposes

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HIGHLIGHTS

- PPG experiments in Berea sandstone cores were successfully performed.
- PPG design variables are treatment size, permeability contrast, and crossflow.
- Mathematical models for resistance and residual resistance factor were developed.
- The gel transport models were implemented in a reservoir simulator (UTGEL).
- The pilot scale simulations showed PPG improves recovery by 14% over waterflood.

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ABSTRACT

Water management in mature waterflooded reservoirs is a top priority to push more oil out and control water production. Excess water production through fractures and high permeability thief zones is a growing concern for sweep efficiency and oil production. Gel treatment has been applied widely to plug thief zones and reduce excess water production to improve macroscopic sweep efficiency. Field studies demonstrated that gel treatments can be applied successfully in mature and fractured reservoirs to reduce unwanted fluid production to lower the operating cost causing premature well abandonment.

The primary objectives of this work are to conduct laboratory work to understand the transport and propagation of microgel and develop a conformance control reservoir simulator to help screen oil reservoir targets for effective particle gel applications to improve sweep efficiency and reduce water production. These microgels can be injected as suspension in water into an injection well. Many experiments were performed to understand the transport mechanism of microgels through porous media and to identify the control variables. The lab data include oil recovery, water-cut, resistance factor, residual resistance factor, oil viscosities, gel concentrations, salinity, gel rheology, and gel strength. The success of gel treatment depends on the magnitude of permeability reduction and flow diversion.

We have developed correlations for resistance factor, residual resistance factor and apparent viscosity as a function of gel strength, gel concentration, rock permeability, salinity, and flow rate. The models are validated against lab measurements and implemented into a reservoir simulator called UTGEL. Gel properties such as rheology and adsorption are also investigated.

The mechanistic models and numerical tools developed will help select future conformance control candidates for a given field and optimize the gel chemistry and treatment.

1. Introduction

Excess water production is a critical problem in mature oil fields as the oil reservoir is subjected to long water flooding. Gel treatments, if applied correctly, can reduce excess water production and improve conformance by filling water channels and fractures.

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Nomenclature

a_{11}, a_{12}, b_1	resistance factor model parameters
a_{21}, a_{22}, b_2	residual resistance factor model parameters
$C_{ppg,1}$	PPG concentration in aqueous phase, ppm
C_{SEP}	effective salinity, meq/ml
d_p	average pore throat diameter, m
$\bar{k}$	average permeability, md
k	permeability, md
$k_{microgel}$	effective permeability during microgel injection, md
k_w	effective permeability during waterflood, md
k_x, k_y, k_z	directional permeabilities, md
$\Delta P_{microgel}$	microgel injection pressure drop, kPa
$\Delta P_{Base\ Water}$	initial water injection pressure drop, kPa
$\Delta P_{Post\ Water}$	post water injection pressure drop, kPa
q	flow rate, m^3/Day
RF	resistance factor
RRF	residual resistance factor
r_h	pore throat radius, m
S_ℓ	saturation of phase ℓ
u_1	aqueous phase flux
u_{x1}, u_{y1}, u_{z1}	components of Darcy flux for aqueous phase, m/Day
$\mu_{aqueous\ phase}$	aqueous solution containing gel viscosity, cp
$\mu_{microgel}$	microgel viscosity (cp)
μ_w	water viscosity, cp
ϕ	porosity

In principle it can be divided into in-situ gels and preformed gels. Traditionally in-situ gels were used for controlling water production where a mixture of polymer and crosslinker, which is called gelant, is injected into the formation to form gel at reservoir conditions for blocking the channels [28,22]. The disadvantages of this method are the effects of adsorption and formation water on the crosslinking reaction and possible damages on the low permeability unswept oil zone [4]. The new technology for gel treatment is to form the gel at surface conditions and inject the preformed gel into the reservoir. The process can overcome problems such as the lack of control on gelation time and uncertainties due to the effect of adsorption and shear degradation which usually occur in traditional in-situ gel.

Microgel is an applicable kind of gel and there are essentially four different types of microgels which can block the high permeability layers and divert the injected water into low permeability unswept oil zones (Fig. 1). The four different gels are Performed Particle Gel (PPG), Thermally Active Polymer (TAP), Colloidal Dispersion Gel (CDG), and pH-sensitive microgel. PPG can swell when dissolved in water and can be injected deep into the reservoir for blocking high permeability channels. Salinity, particle size, pore size distribution, and permeability contrast are the main factors controlling swelling capacity and blocking efficiency of PPGs. CDG, or size-controlled, soft particles can be injected into the reservoirs to block high permeability zones and divert water into low permeability unswept zones. TAP can be injected with water at low surface temperatures and activated to swell when temperatures exceed a critical value. This can block the flow in thief layers and divert flow to bypassed layers due to adsorption and permeability reduction. pH-sensitive microgels are un-hydrolyzed polymer solutions that are hydrolyzed and swell when pH increases due to in-situ precipitation/dissolution reactions. To conduct pH-sensitive conformance process in the field, an acid preflush is required to decrease reservoir pH as much as possible. This acid injection will be designed based on rock mineralogy, permeability, and salinity.

We present the results of laboratory Berea sandstone coreflood using micro-sized PPG. The measured data include oil recovery factor, water-cut, and gel swelling factor. The experimental results were history matched using an in-house research reservoir simulator, UTGEL. A very good agreement between model and lab data was achieved. A new model for resistance factor and residual resistance factor including the effect of salinity was introduced and the model was validated using measured data. Finally, we investigated the most influencing factors for design and optimization of field-scale gel projects in heterogeneous reservoirs.

2. Literature survey on various microgels

2.1. Preformed particle gels (PPG)

PPG is an improved super absorbent polymer (SAP) which can be used for either conformance control or water shutoff or both in some cases. There are different types of PPGs such as preformed bulk gels [26], partially preformed gels [29], millimeter-sized preformed particle gels [1], and pH sensitive crosslinked polymers [18]. In microscopic scale, PPG propagation through pore throats can be described by three patterns: pass, broken and pass, and plug [2]. Experimental results in micromodels showed that PPG can pass

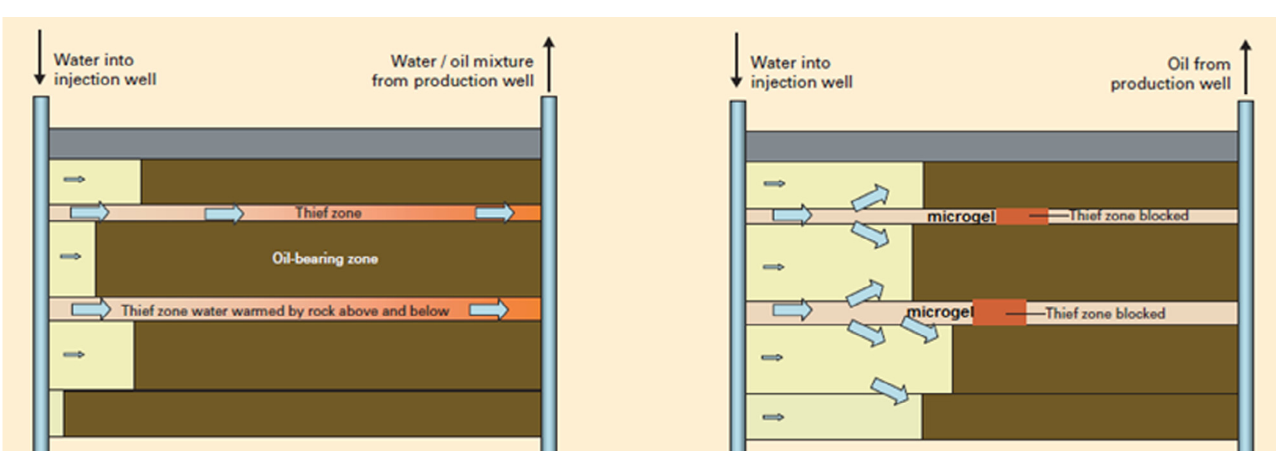

Fig. 1. Microgel is adsorbed and retained on the rock surface in thief zones and diverts the water into low permeability areas.