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Optimizing the strength and size of preformed particle gels for better conformance control treatment

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HIGHLIGHTS

- Permeable gel-pack was formed in the large fluid channels by gel particles.
- A better gel blocking efficiency gained by optimizing gel strength and particle size.
- Gel pack permeability was a few hundred millidarcies before the load pressure.
- PPG is compressible and its compressibility was between 0.0003 psi^{-1} and 0.003 psi^{-1}.
- PPG formed internal channels when subjected to a continuous load pressure.

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ABSTRACT

A newer trend in gel treatments is using preformed particle gel (PPG) to reduce fluid channels through super-high permeability streaks/fractures and thus to decrease water production and increase sweep efficiency for mature oilfields. The success of a PPG treatment mainly depends on whether or not the PPG can effectively reduce the permeability of the channels to an appropriate level. This work sought to determine what factors significantly influence the blocking efficiency of PPG in fluid channels. A transparent filtration model was designed to observe the compression of gel particles in fluid channels at several differential pressures and to study the effect of various parameters, such as brine concentrations and particle sizes, on PPG blocking efficiency. The results suggested that rather than fully blocking the channel, a permeable gel pack was formed in the fluid channel by gel particles, and its permeability was dependent on the gel strength, particle size, and load pressure. The gel pack permeability decreased as the gel strength, particle size, and load pressure increased. Thus, the blocking efficiency of the particle gel on a channel is increased if large sizes or/and strong particles are used. The gel pack permeability was a few hundred millidarcies before the load pressure was applied; it decreased to less than 10 md when the load pressure rose. The results also indicated that the PPG pack was compressible and its compressibility decreased as the load pressure increased. These results can be effectively used to optimize a PPG design. A gel pack that has a desired permeability can be devised by selecting the proper gel strength and particle size corresponding to the reservoir pressure. This is essential for a successful gel treatment so as to reduce the permeability to a manageable preplanned degree.

1. Introduction

Water production from hydrocarbon reservoirs causes major problems worldwide as more reservoirs become mature. Excess water production triggers a higher level of corrosion and scales, an increased load on fluid handling facilities, additional environmental concerns, and the shorter economic life of a well. Various materials have been proposed to reduce both water channeling and high water cuts to enhance the oil recovery of mature oilfields. Gel treatment has been widely applied as a cost-effective method to reduce excess water production; it can improve the macroscopic sweep efficiency by plugging high permeability zones during hydrocarbon production. Different gel types have been used to control water production through either high permeability channels or fractures without damaging highly oil-saturated unswept zones. Traditionally, in situ bulk gels are used for conformance control. They consist of a mixture of polymer and crosslinker (gallant) injected either together or separately with a slug. A crosslinking reaction then occurs by using a specific trigger to generate

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gels in situ at reservoir temperature to either fully or partially plug the formation. This technology, however, has several disadvantages that restrict its applications for conventional reservoirs, such as a lack of gelation time control, gelling uncertainty due to shear degradation, chromatographic separation between polymer and crosslinker, and dilution by the formation of water and minerals [5,6,7,8,2,3]. In recent years, newer gel systems have been developed to overcome these drawbacks. These newer gels have a better performance because they are formed at surface facilities and then injected into target zones with no need for gelation to occur under reservoir conditions. These gels have different commercial product names, and they include PPGs, microgels, temperature sensitive polymer microgels, and pH sensitive polymer microgels. *PPGs* are superabsorbent crosslinking polymers that can swell up to 200 times their original size in brine. A PPG is a millimeter-size particle formed at the surface. It is then dried and crushed into small particles to inject into a reservoir [8,2,3]. *Microgels* are injected into a reservoir as fully water soluble, nontoxic, soft, stable, and size-controlled. They have particle sizes between 10 and 1000 nm [5,6,7,16,19]. *Temperature sensitive polymer microgels* (*BrightWater*®) are submicron gel particles. They are injected into the reservoir with cooler injection water relative to the reservoir temperature. As the polymer passes through the reservoir, it gradually picks up heat from the surrounding warmer reservoir rocks. As it heats up, the polymer begins to expand to many times its original size, blocking pore throats and diverting water behind it [15,9,14,17,10]. A *pH sensitive polymer microgel* uses the change in pH as an activation trigger. With increases in pH, the gel begins to adsorb water, swelling up to 1000 times its initial volume [1,12,4]. The primary differences between all of the current commercially preformed gels are the particle sizes, swelling ratios, and swelling times.

The millimeter-size particles of PPGs make them not only more distinguishable but also more reliable than other types of preformed gels for plugging large channeled features [13]. The success of gel treatments depends heavily on the gel's ability to reduce conductivity of these large channel features. Thus, understanding both the mechanism and the factors affecting the gel's ability to resist water flow through these channels are the main keys to achieving a successful conformance control treatment.

Much research has been conducted to study the rheology and factors affecting gel resistance to water flow. Grattoni et al. [11] conducted a series of experimental work to link polymer gel properties (such as gel strength and polymer concentrations) to flow behavior. They found that permeability was a function of both water flow rate and polymer concentration. Yang et al. [18] developed a mathematical model for the flow of water through channels impregnated with a polymer gel. Their results indicated that gels' intrinsic properties (e.g., gel reference permeability and elasticity index) controlled water flow behavior.

Previous experiments conducted by Zhang and Bai [20] showed that millimeter-size particles formed a permeable gel pack in opening fractures rather than create full blocking. This paper will addresses the effect of brine concentration, particle size, and load pressure on the permeability of the PPG pack inside large channeled features. In addition, it will evaluate the ability of PPGs to reduce channel conductivity when the gel is subjected to the load pressure.

2. Gel pack descriptions

Previous fracture transparent model (Fig. 1) indicates that the PPG propagated like a piston along the fracture, and gravity did not change the shape of the front of the PPG if the particle size was larger than or close to the fracture width. The fracture transparent model was constructed of two acrylic plates with a rubber O-ring between them. Bolts and nuts were used to fix the two plates and control the fracture width. On one side of the plate, a hole functioned as an inlet for the injection of the brine and PPG; on the other side, another hole provided an outlet to discharge the brine and PPG. The model was transparent so that the movement of the PPG and brine would be clearly visible. In the case of the large channeling features, such as conduits, wormholes, and caves, understanding the gel pack permeability mechanism and determining which factors have a significant effect on the strength of the gel pack permeability is also needed to have a better PPG treatment design through these large feature systems. This paper describes factors that affect the gel pack permeability inside large channels and evaluates the gel pack compressibility in the presence of load pressure. The load pressure in this study refers to the pressure developed by a piston movement to compress the gel particles inside a transparent channel model.

2.1. Gel pack permeability

The PPG pack permeability was determined by measuring the differential pressures and flow rates while injecting brine through the gel pack-filled channel tube. The gel pack permeability was fitted according to the power law as follows:

$$K_{PPG} = k_o v^n \quad (1)$$

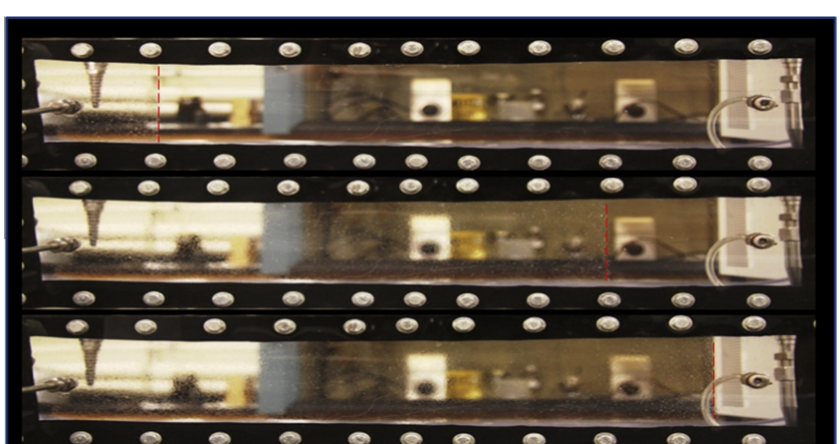

Fig. 1. PPG propagates like a piston [20].