Fuel 188 (2017) 332–342

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Experimental work to determine the effect of load pressure on the gel pack permeability of strong and weak preformed particle gels

Mahmoud O. Elsharafi [a,*], Baojun Bai [b,c]

[a] McCoy School of Engineering, Midwestern State University, Wichita Falls, TX 76308, United States
[b] Department of Geological Sciences & Engineering, Missouri University of Science and Technology, Rolla, MO 65409, United States
[c] Chongqing University of Science and Technology, Chongqing, China

ARTICLE INFO

Article history:
Received 23 July 2016
Received in revised form 31 August 2016
Accepted 3 October 2016
Available online 13 October 2016

ABSTRACT

Preformed particle gels (PPGs) have been widely applied to reduce the permeability of super-high permeability streaks/fractures. PPGs have an ability to decrease water production and increase sweep efficiency in mature oilfields. Either the success or failure of a PPG treatment depends largely on whether or not PPGs can effectively reduce the permeability of the fluid channels to an anticipated level. This work sought to investigate the influence of several factors on PPG blocking efficiency. A filtration model was designed to determine the permeability of PPGs packed in channels/fractures. Two types of PPGs were used for these filtration experiments: Daqing (DQ) and LiquiBlock™ 40 K. Particle sizes fell between 30 and 120 meshes. Results indicate PPG permeability decreased as load pressure increased. Additionally, PPGs with a larger particle size exhibited higher PPG pack permeability than PPGs with a smaller particle size. The PPG permeability with a lower brine concentration was more than the PPG pack permeability with a higher brine concentration when the PPG pack was not compressed by a piston. However, PPG pack permeability was less when using a lower brine concentration whether the PPG pack was compressed because the PPGs with higher brine concentration loss more water than the PPGs with the lower brine concentrations. According to our paper results the optimum gel pack with a preferred permeability can be designed by the right selection of the gel strength and correct particle size at reservoir pressure.

1. Introduction

The production of hydrocarbons is typically accompanied by the production of water. This water consists of formation water, and water that has been injected into the formation. Water production increases over the life of a reservoir. Water produced from oil reservoirs is not economical for the follows reasons: 1. Unwanted water production damages surface equipment and causes casings leak. 2. Excess water increases costs related to disposal, scale, corrosion, water/oil separation, and more [16]. 3. Additionally, excess water reduces hydrocarbon production, even in formation zones, that still carry a considerable volume of hydrocarbons [40]. Oil companies must, therefore, find ways to handle relatively large amounts of water, in an environmentally acceptable manner, and reduce the operation cost. Water is the most abundant fluid in an oil field [27]. Oil field operators have conducted numerous studies to evaluate the drawbacks of water production.

Globally, an average of three barrels of water are produced with each barrel of oil [7]. The situation is even worse in the US, where more than ten barrels of water are produced with each barrel of oil [32,33,38]. The annual cost of both treating and removing water is estimated to be 40 billion USD [7].

Reservoir heterogeneity severely affects the flow of gas, oil, and water in a reservoir. It can also affect the choice of production strategies, reservoir management, and ultimate oil recovery. Reservoir heterogeneity is the single most important reason for both low oil recovery and early excess water production [4,6]. Many reservoirs have been hydraulically-fractured (either intentionally or unintentionally), or developed large channels due to both mineral dissolution and production during water flooding [31].

Conformance control treatments are typically more economical than other EOR (enhanced oil recovery) techniques. They can both increase oil production and decrease water production by treating only small swept zones/areas [10]. Gel treatment is the most efficient, cost-effective means for both decreasing water production and improving reservoir homogeneity in mature oil fields [39].

Traditionally, in-situ gels have been widely used to control conformance. A mixture of polymer and crosslinker, called gelant, is injected into a target formation. It reacts to form a gel that either fully or partially seals the formation at reservoir temperature. As a result, the gelation occurs under reservoir conditions. A new

* Corresponding author.

http://dx.doi.org/10.1016/j.fuel.2016.10.001
0016-2361/

Nomenclature

A	cross section area inside the round tube in (cm^2)
C_{gel}	compressibility of the gel in (psi^{-1})
d	inside diameter of the round tube in (cm)
h	height of the PPG sample in (cm)
K_{gel}	PPG pack permeability in (md)
KG_{BP}	PPG pack permeability before using a piston in (md)
KG_{AB}	PPG pack permeability after using a piston in (md)
K_R	reduction of the PPG pack permeability after compressed using a piston in (%)
V	volume of the fully swollen gel before compression in (cm^3)
μ	viscosity of the brine in (cp)
Q	flow rate in (cm^3/s)
ΔP_{gel}	drop pressure across the gel in (psi)
ΔV	difference between volume of compressed gel and non-compressed gel in (cm^3)

gel treatment method uses preformed particle gels (PPGs) to overcome the limitations of in-stiu gels [5]. PPGs are formed at surface facilities before injection. As a result, no gelation is present in the reservoirs. PPGs require less equipment for surface preparation. Gel particles vary in diameter from nanometers to a few millimeters [4,6].

Additional techniques were established during research laboratory investigations, including: using microgels for both relative permeability modification and in-depth division [11,24,25,34]; applying a pH sensitive polymer for novel conformance control [1,8,15]; employing colloidal dispersion gels for both conformance and mobility control [3,9,12,35,30,41].

Many researchers have been focused on both the transport and the plugging efficiency of PPGs in both fractures and super-high permeable formations [4,6,42–43]. Zhang and Bai found a millimeter-sized PPG forms a gel pack in open fractures. Gel pack permeability thus depends on both particle size and brine concentration [43]. No quantitative analysis was provided. Elsharafi and Bai determined the effect of both weak and strong preformed particle gels on the damage of the low permeability formations [17–19]. Elsharafi reported the effect of back pressure on the PPG pack permeability. In his study, he used different particle sizes and brine concentrations [20].

The selection of an appropriate gel and the design of an optimal treatment process depend on an understanding of gel behavior as it passes through high-permeability, fractures, and channels. [37] studied both the propagation and the dehydration of a preformed bulk gel through open fractures. Al-Anazi et al. studied the propagation of a pH-sensitive polymer solution through Berea cores, finding the solution penetrated easily through 6 in. cores [2]. They found that the pH-sensitive polymer reduced the permeability of the cores. The permeability reduction occurred because the pH-sensitive polymer formed a rigid gel inside the pores after both shut-in period for 24 h and increased pH value above 6. Rousseau et al. determined that microgels have outstanding mechanical, chemical, and thermal stability as they propagate through porous media [36]. This work ⁎⁎(Rousseau et al., 2005) used models of packed silicon carbide (SiC) particles and sandstone cores to evaluate both the in-depth propagation and the adsorption of their microgels [36]. Frampton et al. found that Bright WaterR could be injected into either packs or cores with a permeability between 124 and 3400 mD. In addition, Bright WaterR can reduce the permeability of the cores [25]. Bai et al. conducted core flooding tests using a sandpack core to understand PPG transport through high-permeability porous media [4]. Three types of flow patterns were identified in their work: pass, broken and pass, and plug. They also observed the particle performance of PPG in the porous media through visual micromodels. Bai et al. found that PPG propagation shows six patterns of behavior: direct pass, adsorption, deform and pass, snap-off and pass, shrink and pass, and trap [4]. Challa used a screen model comprised of a long acrylic tube, connected to an Isco pump to study the flow behavior of PPG through screens [13]. A piston was inserted into the acrylic tube. Screens of various mesh placed at the bottom of the tube represented permeable formations. Pressure from the pumped brine pushed the piston, forcing the PPG to pass through the screen. Challa found that the particles were permanently deformed after passing through the screen [13]. Zhang and Bai used a transparent fracture model to understand PPG propagation through open fractures and to study water flow through the PPG-placed fractures [43]. This model allowed Zhang and Bai both to study the effect of particle strength and size on gel injectivity as well as to observe particle movement in a fracture. They found that PPG can significantly reduce the permeability of fractures but cannot completely block fractures. Their research proposed the use of a gel pack, the permeability of which is affected by particle strength, particle size, and brine concentration [43].

Imqam et al. reported the resistance of the preformed particle gel to the water flow during conformance control treatments [28]. Imqam et al. determined that the fracture widths affect the propagation of the preformed particle gels and the water flow in opening fractures [29]. Goudarzi et al. used a five spot transparent fracture model to determine the propagation of the microgels through the reservoir porous media [26]. They reported the most important factors which can affect the design of the preformed particle gels for conformance control treatments. Those factors are the fluid viscosity, resistance factor (RF), and residual resistance factor (RRF). Chancellor et al. determined the effect the temperature on the swelling and the deswelling of preformed particle gel with a various particle sizes and various brine concentrations [14]. Elsharafi and Bai reported the effect of both weak and strong gels on the formation damage of several types of reservoir rocks [21–23]. They also reported that the weak gels are better than strong gels from the point of blocking efficiency. However, they reported that from the point of formation damage, the strong gels are better than weak gel because strong gels will not damage the low permeable formation. Elsharafi and Bai reported the effect of back pressure on the PPG pack Permeability in mature reservoirs [23]. In their study, they determined the effect of back pressure on the PPG compressibility. They determined that the increase of the back pressure will increase the PPG compressibility. Elsharafi and Bai determine the threshold of both strong and weak gels in terms of brine concentrations, gel types, gel strengths, and particle sizes [22]. They determined that the weak gel damaged the low permeable formation more than strong gel. They reported that PPGs damage on the formation was influenced by particle sizes and brine concentrations; further damage happened with a small particle size and a low brine concentration.

This work used two PPG pack permeability models to determine which parameters affect PPG blocking efficiency and to what extent each parameter impacts the permeability of a gel pack.