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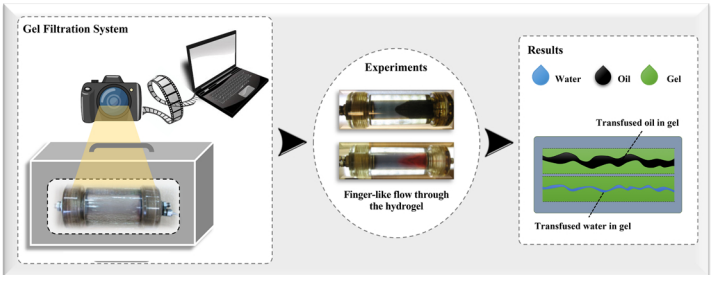
Examination of disproportionate permeability reduction mechanism on rupture of hydrogels performance

Mahsa Baghban Salehi[a,*], Mina Soleimanian[b], Asefe Mousavi Moghadam[a]

[a] Petroleum Engineering Department, Chemistry & Chemical Engineering Research Center of Iran, 14335-186, Tehran, Iran
[b] Faculty of Chemical Engineering, Tarbiat Modares University, 14115-143, Tehran, Iran

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, the overall performance of a disproportionate permeability reduction mechanism for a sulfonated polyacrylamide copolymer and the chromium triacetate crosslinker was investigated. A home-built gel filtration system was used for visual inspections and evaluations of the hydrogel performance. The experiments were conducted based on rheological test plans, energy-dispersive X-ray spectroscopy, and scanning electron microscope. Accordingly, quadratic equations based on the polymer and crosslinker concentrations were presented predicting the rupture pressure gradient of the hydrogel and the hydrogel output due to the oil and water injection through the hydrogel. It was indicated that the polymer concentration was the main effect on the rupture pressure gradient of the hydrogel and hydrogel output. Moreover, under constant concentration of crosslinker, increasing polymer concentration showed an increase in rupture pressure gradient and output of the hydrogel due to the increase of elastic modulus of hydrogel network and its strength as a viscoelastic material. As the hydrogel structure illustrated no rupture during the gel filtration experiments, a mechanism presented justifying the disproportionate permeability reduction phenomenon which in that under constant condition, the oil permeability through hydrogel was greater than the water permeability.

1. Introduction

One of the major challenges in petroleum engineering is excess water production from oil and gas wells [1,2]. There are various chemical and mechanical methods for water management operation [3]. A chemical method to control and reduce the water production is applying of polymeric hydrogel system [4]. Long lifetime, eco-friendly, economic efficiency, increasing ability of sweep efficiency, high comfort and handling of hydrogel injection operation, and successful outcomes of them in the world especially in the Middle East, amplified the use of hydrogels as a misleading or blocking agents in improving the oil and gas production [2,4–6]. Hydrogel system typically includes a

* Corresponding author at: Chemistry & Chemical Engineering Research Center of Iran, Tehran, Iran.
E-mail address: m.bsalehi@ccerci.ac.ir (M.B. Salehi).

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polymer solution and an aqueous solution of crosslinker. Crosslinkers connect the polymer chains. The compound of these two solutions is called gelant. Under a time and temperature defined specifically for each hydrogel system (gelation time) [7], gel structure is formed by chemical reactions [8]. When hydrogels injected into the well and after the gelation time gel forms, it turns to a semisolid material. Intelligently, hydrogels have the ability to significantly reduce water permeability, while their ability to reduce the oil permeability is not impressive compare to water permeability. These characters become famous as disproportionate permeability reduction (DPR) or relative permeability modifiers (RPM) [9,10]. In injection wells, gelant pervade and thereafter block the high permeable lines and fractures that have already been swept by the injected fluid. Accordingly, injected water or gas into the well pervade the low permeable zones and lead to increase the residual oil recovery [11,12]. In production wells, polymer gel systems are typically injected to reduce water production, to eliminate extra costs, and to improve pressure drop in high permeable lines and fractures [5]. Hydrogels after emplacement in porous media may affect under different pressure gradients due to the fluid injection or oil production of injection and production wells, subsequently. Pressure gradients cause hydrogel displacement, rupture, dehydration, or fluids permeate inside the hydrogel [13]. Based on the Seright research [14], fractures are main important reason in the water production, so they are most important places in hydrogel operation to control water production. That is the reason to attract many researchers to study the effect of pressure on the hydrogel placed inside the fracture [4,15]. Study the creation of rupture and its progress along the gel due to the injecting water and oil separately, indicated the different behavior of gels in facing of water and oil [1]. As Ganguly et al. [16] observed, water and oil pass through the gel by creating rupture in it. However, regardless of the type of the rupture creating fluid, the oil permeability was always reported higher than the water permeability. He explained this phenomenon because of the higher surface tension between oil and gel than water and gel. Moreover, adsorptive-retention of polymer gel is defined as DPR phenomenon [17,18]. Many studies have been fulfilled on DPR in porous media [1,16], while investigating the fluid pass through the gel structure is necessary.

Therefore, in this study, the performance of the gel structure against water and oil has been studied individually (outside of porous media), and then it was compared with the ability of water and oil in creating the rupture in the hydrogel network. Moreover, a polymer system containing PAM-NaAMPS and chromium acetate (III) was selected for this research because of its thermal stability suitable for Iranian reservoirs temperature [19,20], the structural strength against the ions of formation water [21], the successful field operation [19,22] the ability to disproportionate permeability reduction [1], and also environmental and economic beneficial [23]. Accordingly, as hydrogel network properties and its rheological behavior depend on polymer and crosslinker concentration [24], the effect of polymer and crosslinker concentration and their interaction on the rupture pressure gradient of the hydrogel, and also the removed gel as a result of water and oil injection were examined by using central composite design (CCD), to evaluate the dual behavior of gels against these two fluids. To simplify the process of this research experiments, the following block diagram was presented (Fig. 1).

2. Experimental methodology

2.1. Materials

A sulfonated copolymer of hydrolyzed polyacrylamide (Acrylamido propyl sulfonated acid) under the trade name of AN113, with an average molecular weight of 8 million Dalton, sulfonation degree of 13% and degree of hydrolysis of 10% was provided by SNF Co. (France). In this type of copolymer, replacement of sulfone with amide functional group (NH_2) leads to resistance increase of copolymer against temperature and divalent ions. The chromium triacetate (Cr $(CH_3COO)_3$) of Carlo Erba company as crosslinker and distilled water to provide the solutions was used.

2.2. Sample preparation

First, a homogeneous solution of polymer was prepared with the desired concentration. Then, the crosslinker was mixed with distilled water at room temperature using a magnetic stirrer (Stuart CB162, UK) for 5 min to prepare crosslinker solution. Finally, the copolymer and crosslinker solutions were mixed for 15 min to obtain the gelant solution while the oxygen was removed from the solution with nitrogen gas. In order to determine the gelation time, based on the designed concentration by using CCD, (Fig. 2), gelant was prepared and then was stored in an oven at a temperature of 70 °C evaluated at different time intervals. To determine the random error as well as validation of the results, 4 center points were considered. In CCD, star points and central points are added to the points of two levels. These points cause the level of each variable to be increased from 2 to 5. Meanwhile, in this method these points are distributed in a way that when the numbers of observations in terms of variables are drawn, a normal distribution can be obtained [25]. In this study, 70 ml volume bottles were used for the bottle tests. By inverting the bottle at the specific time and observing the gelant movement based on Sydansk code [25,26], the approximate

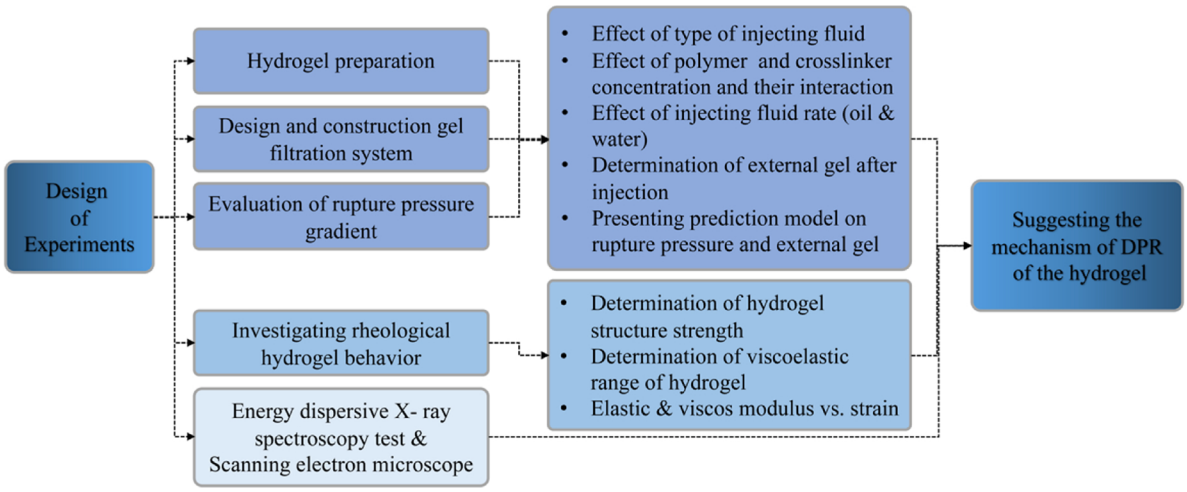

Fig. 1. Block diagram of the experimental steps.