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An Experimental Investigation on Foam Injection in a Fractured Matrix: Effect of Viscous Cross flow

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INTRODUCTION

During most EOR processes, injectant flows through some paths which may not be in contact with oil; as a result, reservoir oil may be bypassed. This could happen in microscopic or macroscopic dimensions that include not only rock heterogeneities but also fluid difference in terms of viscosity and density. The bypassed oil can be recovered by mechanisms molecular diffusion and crossflows (viscous, capillary or gravity) [1]. Since large portions of bypassed oil are located in the fractured reservoirs, reinforcing viscous cross flow as a driving force for production can enhance the recovery factor of these reservoirs. Therefore, foam injection can enhance oil recovery as one of the effective methods in the fractured reservoirs.

Foam cross flow in heterogeneous radial model by transmissibility control for the first time was investigated by Bertin et al [2]. Sweep efficiency of foam and gas flow in an oil-free fractured micromodel was compared by Ma et al. Their results indicated that foam with higher quality was able to block the high permeable media and divert the flow to low permeable media [3]. Oil recovery by using foam flooding in a heterogeneous porous microfluidic system with permeability contrast has been studied by Conn et al [4]. In addition, it has been shown that foam can cause local pressure gradients that results in diverting foam flow from high permeable region into the low permeable one.

The goal of recent studies in the area of foam flow in porous media, was diversion of foam flow from high permeability layer to low permeability layer. In this study, viscous cross flow has been investigated during foam injection in a 2D microfluidic device. Two sets of experiments with varying parameters of injection rate and foam quality has been designed and viscous cross flow has been observed in a fractured system directly.

EXPERIMENTAL PROCEDURE

The fluids used in this study were n-decane as the model oil with purity of 99.95%, distilled water, and nitrogen gas with purity of 99.95%. Oil and distilled water were dyed red and blue using sudan red and methylene blue respectively, to provide direct observations of distinguishable phases in the foam displacement. Alpha olefin sulfonate was selected as foaming agent.

The effect of foam quality and injection rate on apparent foam viscosity has been investigated in recent studies [5,6]. In order to consider the effect of oleic phase on viscous cross flow, experiments were performed in two different saturation media. Hence, in the first set, the effect of injection rate on fluid flow has been studied in a water-saturated micromodel. Then, the optimum value of injection rate was used in the second set of experiments with different foam quality. Moreover, the second set of experiments were conducted in an oil-saturated micromodel.

In both sets of experiments, first, the saturation fluid was injected by positive displacement pump at specified pressure. Then, the injection of pre-generated foam was started at a constant rate in the fracture. The experiments were monitored by a digital camrecorder.

RESULTS AND DISCUSSION

By flowing a viscous fluid like foam through a permeable region like fracture, which lies beside a low permeability matrix, pressure drop across the fracture causes the foam to invade the matrix region and moves through the yellow arrows which are shown in Fig. 1.

Viscous cross flow and emulsion are two main mechanisms for mobilization of trapped oil. During foam injection in water-saturated micromodel, viscous cross flow was also observed. According to Fig. 1, there are two regions due to the saturation of foam inside the matrix. In first Region, the dynamic behaviour of the foam triggers a flow toward the fracture and the foam's forehead is arc-like, and mobility of fluids at this region is high. Furthermore, the saturation of foam is low and participation of surfactant saturation is higher than gas phase in dynamic region. Behind this region, there is a static zone, in which foam saturation is high, and foam is generated within the porous medium. In addition, fluids mobility in this region is lower than dynamic region. Some portion of bypassed oil was recovered by emulsion. Consequently, the oil droplets (oil in water emulsion) flow through the arc-like aqueous phase path and accumulated near the downstream (dash-line number 2 in Fig. 1). Most of these oil droplets were transported to the fracture and produced.

CONCLUSIONS

In this study, bypassed oil and water were recovered by foam injection into the fracture. According to visual data, viscous cross flow was observed in both saturated media. Hence, oleic phase has no effect on viscous cross flow behavior of foam and this mechanism is the main driving force in both sets of experiments. In addition, pressure drop in the mainstream is the driving force during foam displacement. This pressure drop is constant and strengths the fluids flow up to a certain level in foam front.

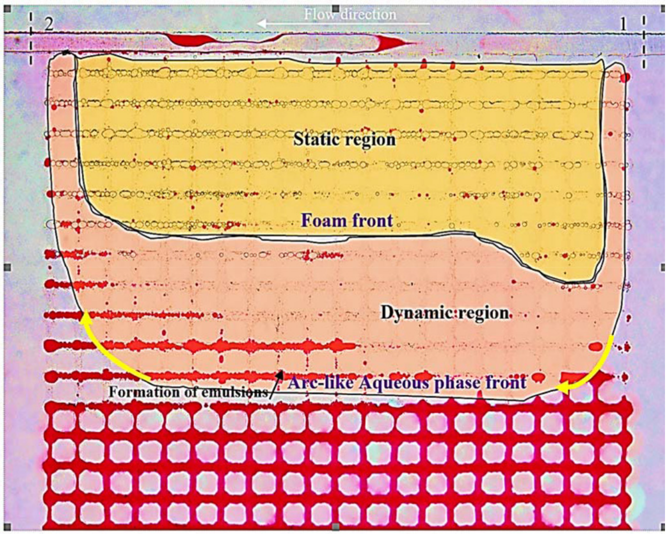

Figure 1: Characterization of two regions that was observed in oil displacement by foam flooding in a fractured porous media.

Therefore, each pressure drop in the mainstream is proportional to an individual recovery factor.

As injection rate increases, recovery factor decreases in the water saturated micromodel due to the shear thinning behavior of foam which leads to a decrease in apparent foam viscosity in low quality regime, and consequently lower pressure drop. Whereas, as foam quality increases, apparent viscosity increases, which this occurrence results in higher pressure drop in the mainstream and higher recovery.

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