J. Appl. Environ. Biol. Sci., 7(4S)1-8, 2017

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

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Effect of Flow Pulsation on Oil Blob Trapped in a Capillary Tube Constriction

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Received: April 9, 2017
Accepted: June 16,2017

ABSTRACT

In this study, the effect of flow pulsation on oil blob trapped in a capillary tube constriction was studied numerically. Instantaneous flow images were used to understand the flow evolution process. Results from the study shows that flow pulsation effectively aided to squeeze out oil blob trapped in a capillary tube constriction. When the flow was excited by 20 Hz sinusoidal pulsation with peak amplitude about 75% of the mean flow, the blob breaks into smaller droplets and pass through the constriction with shorter period of time compared to the unexcited uniform injection flow. When the flow was not pulsed, the first droplet passed through the constriction 0.012 s after the beginning of the injection. When the injection was pulsed, the first droplet passed through the construction within the first period of the pulsation after 0.004 s of the injection. In addition, the droplet that crossed the constriction is bigger in size when the flow was pulsed. The first droplet crossed the length of the capillary in 0.058 s when the flow is pulsed compared to 0.077 s when the flow was uniform. Overall, within the same period of time, droplet recovery is higher when the flow is pulsed. Apparently, such observation shows that flow pulsation has good potential to recover oil blob trapped by capillary action. The method may be extended to recover residual oil trapped by capillary force in pore spaces of reservoir rocks.

KEYWORDS: Jet Pulsation, Capillary Tube Flow, Flow Excitation.

INTRODUCTION

Flow of immiscible fluid through a constriction has several applications in many engineering field. Of particular interest is flow of oil through a reservoir. Oil and gas flows through a porous media where viscous, gravity and capillary forces are in competition. At the end of secondary recovery, the typical oil recovery factor from mature fields around the world is only between 20% and 40% [1]. Some of the remaining hydrocarbon can be recovered with the application of enhanced oil recovery (EOR) techniques developed over the last few decades [2-4]. In most cases, the conventional EOR techniques, which involve gas injection, steam flooding and chemical injection, suffer from certain limitations. In light of this, many researchers are working on improving various aspects of EOR methods such as screening techniques [5, 6], improving sweep efficiency [7] and exploring alternative techniques, such as electromagnetic heating and seismic excitation [8-11]. In an effort to maximize recovery factor, new techniques commonly known as unconventional EOR are being investigated [12-15]. One of these techniques is based on elastic vibration stimulation

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which has been reviewed by [16]. Increase in oil production due to seismic activity was first observed in Russia [16]. Some of the change in production was associated with large-scale structural displacement. However, it was observed that far away from the epicenter where the reservoir is subjected to low frequency and low amplitude mechanical vibration, increase in production was observed. Inspired by such natural phenomenon, many researchers investigated the application of mechanical vibration as a tool for EOR application. Although the technology showed potential for practical applications, tests in some fields show mixed or inconclusive results [10, 17]. Several mechanisms have been proposed to explain how this technique results in improved recovery. Droplet percolation, viscosity reduction and unilateral movement due to low frequency perturbation are some of the mechanisms proposed in literatures. In addition, several theories related to effects of gravitational force and capillary pressure such as change in wettability, alteration in relative permeability, coalescence and dispersion of the oil phase and reduction in viscosity were proposed. However, there is no general agreement between the theories that explain the effect of seismic excitation on fluid flow in a reservoir. As such, the key mechanism for increased production is not yet known. Apparently, clear understanding of the seismic wave stimulation mechanism is work in progress. The lack of full understanding of the physics of the technique hinders full practical application and makes performance prediction and project design very difficult and unreliable. At present, however, researchers focus on understanding the fundamentals of the technique to exploit full potential of the technology.

In this paper, our objective is to study flow characteristics of continuous and pulsed injections to squeeze oil droplet placed in a converging-diverging capillary tube model. The study was conducted numerically using a commercial software. Even though our main goal is to investigate effect of elastic wave excitation on flow behaviours through a porous media, the simplified model we used in this study represents a single pore throat of a porous media. Apparently, it is difficult to build all aspects of flow through a reservoir into such simplified model. However, the result obtained should be able to highlight basic flow characteristics in order to understand the underlying flow interactions.

METHODOLOGY

Numerical Model

The numerical study was conducted using FLUENT software. The volume of fluid multiphase model was used in order to investigate the flow behaviour. The 2D axisymmetric capillary model shown in Figure 1 has a length of 5 mm and inlet width of 0.5 mm. The centre of the constriction with radius 0.186 mm is at 1.5 mm from the inlet. A circular oil droplet with radius 0.23 mm is manually placed 1 mm from the inlet. This location is in the full developed flow zone and will be discussed later in the results section.

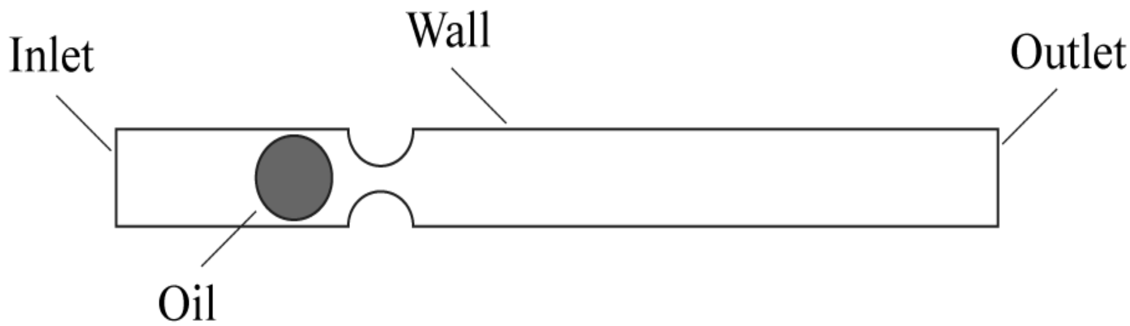

Figure 1: Geometry of the 2D axisymmetric converging-diverging capillary tube model

Water is injected at the inlet. The geometry is meshed in ANSYS workbench. To capture the large velocity gradient near the wall, inflation layer meshing is applied. To reduce the number computations, the tube is modelled in 2D axisymmetric geometry. The mesh was imported to Fluent to do the calculations and post processing. The boundary conditions are velocity inlet, pressure outlet and wall. To capture wettability effect, the contact angle was 173, i.e. the wall is water wet. The density of water and oil are 1000 kg/m^3 and 720 kg/m^3 respectively. Water and oil viscosities are 0.001 kg/ms and 0.00054 kg/ms respectively. Water is primary phase and oil is secondary phase. In the phase interaction, wall adhesion was selected and the surface tension between water and oil was set to 27 dyn/cm. Fractional steps were used for pressure-velocity coupling. For pressure PRESTO, for momentum QUICK and for volume fraction geo-reconstruct schemes were used. To keep the global courant number small, 1e-6 s time step was used. Also, to make sure results are independent of mesh and time steps, grid convergence and time step convergence tests were done. The simulations were run in first order implicit and non-iterative time advancement schemes.

Simulation Cases

In order to investigate the flow characteristics of uniform injection and pulsed injection, two different cases were simulated. In both cases, the outlet boundary was set to pressure outlet with 0 gauge pressure. In the case of the uniform injection, water was injected at 5 mm/s uniform velocity at the entrance. In the pulsed injection case, water was injected with a velocity that varies sinusoidal with amplitude ±0.75 the mean flow and frequency 20 Hz. In both cases, the mass flow rate is the same.

RESULTSAND DISCUSSION

In order to place the oil droplet in the fully developed flow regime, we studied how velocity varies from the entrance along the axis of the capillary. The x-axis is aligned with the capillary tube centerline and the transverse axis is r. Figure 2 shows the entrance velocity profile along the centerline of the capillary tube. At the entrance, the velocity profile is uniform with 5 mm/s magnitude. The velocity boundary layer develops and eventually the profile becomes parabolic. The point where the velocity gradient along the x-axis is zero marks the entrance length. In this case, the entrance length is 0.48 mm and the maximum velocity is 9.96 mm/s. The oil droplet is placed 1 mm from the entrance and it is in the fully developed flow zone.

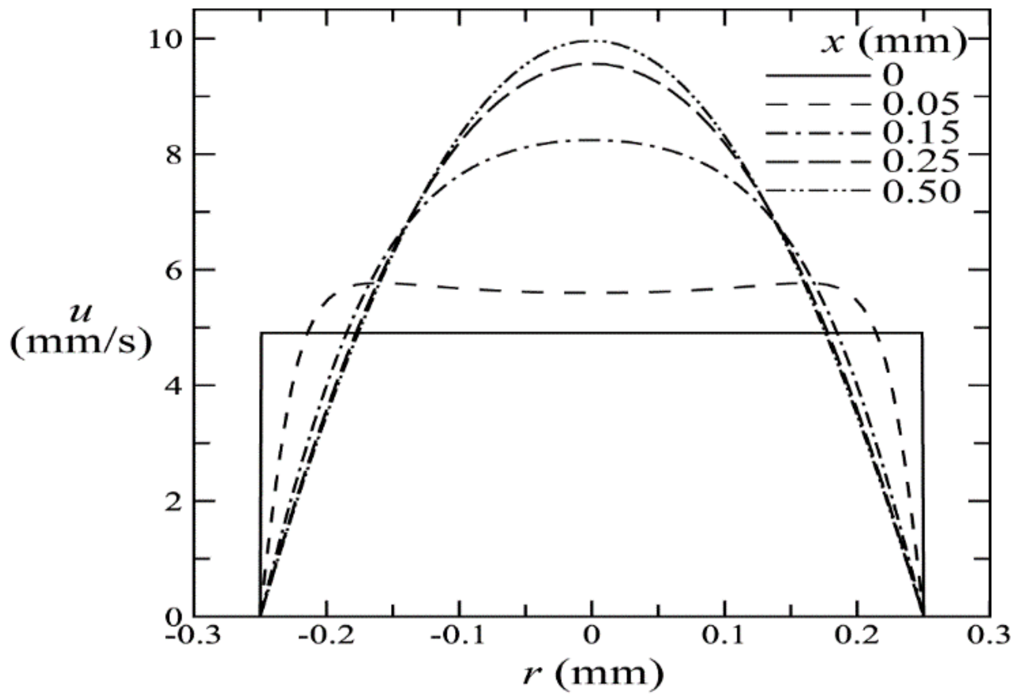

Figure 2: Velocity profile along the centerline of the capillary tube

Figure 3 shows volume fraction of the water and oil during continuous injection. In the phase volume fraction, blue colour is 100% oil and red colour is 100% water. It is the flow evolution during the first 0.090 s. Figure 3a is shows the beginning of the injection. At t = 0.0035 s, small oil droplet breaks off from the main droplet arrived at the constriction. The small droplet sits at the narrowest point of the constriction until more droplets joined. Finally, the first droplet crossed the constriction around 0.012 s. After the first small droplet crossed, lump of oil shown in Figure 3c blocked the constriction and small droplets snap off from the trailing edge and moved towards the inlet due to reverse flow as a result of the blockage. The injected water flows around the lump of oil and become a continuous phase again. At the same time, small droplets came off the leading edge of the oil blob and more oil crossed the constriction. The blockage, reverse flow and snap off at the trailing edge continued for many cycles as shown in Figure 3c and more droplets coalesce and result in larger droplet around the inlet as shown in Figure 3d and Figure 3e. Careful observation of the animation we recorded shows that when the injected water impinge with the trailing edge of the oil droplet, it creates a recirculating vortex and the fluid that comes out of the recirculation flows back in the opposite direction of the injection. The recirculating water at the trailing edge causes low pressure zone which snaps off droplets from the oil blob and the droplets also move in the opposite direction to the injection due to the reverse flow described above. In addition, the injected water that crosses through the constriction creates a recirculation region immediately after the constriction and creates a slightly high pressure region. Basically, the constriction sits between two high pressure regions. As such, it is difficult for the whole oil blob to cross through that region as a continuous phase. As a result, the original oil droplet breaks apart and coalesces continuous for several times before it gets a chance to pass through the narrow constriction. Based on this observation, we investigated the pulsed injection scenario in order to periodically ease off the amount of injected fluid to allow more oil droplets cross through the constriction as discussed below. The first small droplet shown in Figure 3d crossed the length of the capillary in 0.077 s.

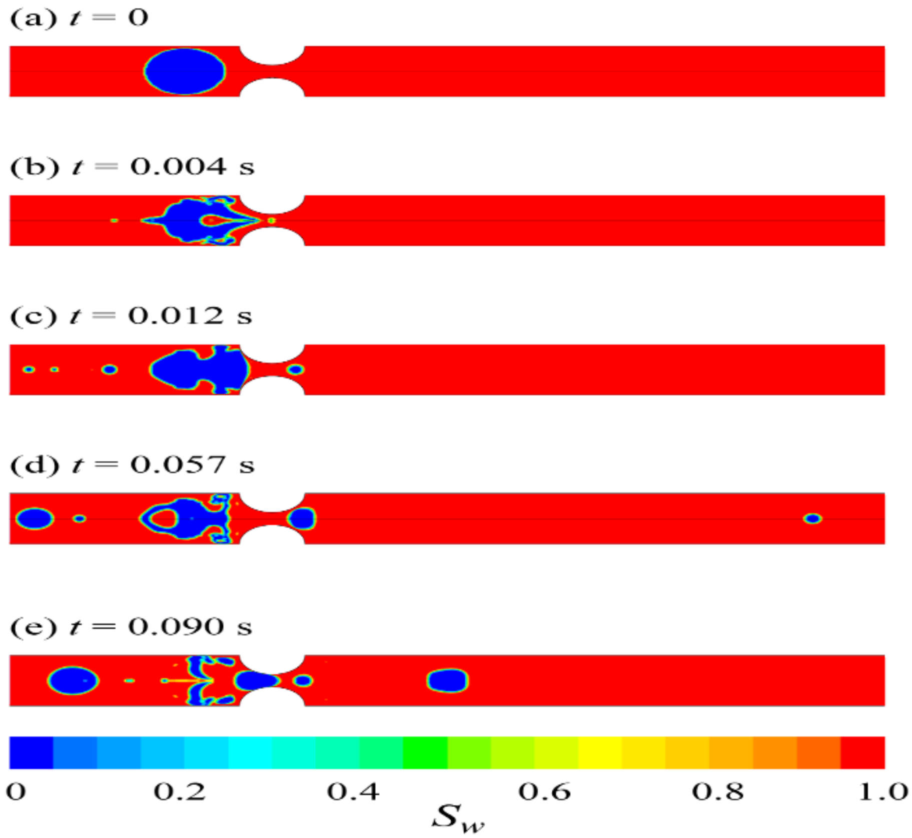

Figure 3: Flow evolution during the continuous injection presented by volume fraction of water and oil phases during the first 0.090 s

Figure 4 shows the flow evolution process during the pulsed injection. As discussed in the numerical model section, the mean flow is sinusoidal pulsed at 20 Hz frequency and velocity amplitude of 75% of the mean flow. It should be emphasized that the mass flow rate of the injected water duration full cycles of the pulsation is the same as the continuous injection case. Even though similar flow dynamics discussed in the continuous injection case is seen during the pulsed injection, the strength of the reverse flow from the trailing edge of the oil blob is reduced. In addition, the two high pressure zones immediately downstream and upstream the constriction disappears periodically following the pulsation cycle. That facilitated more droplets to cross through the constriction. The first droplet crossed through the constriction at about 0.004 s and crossed the length of the capillary tube at about 0.058 s. Comparison of the continuous injection and the pulsed injection during the same time frame reveals how pulsation altered the flow characteristics significantly. Even though the reverse flow still present during the pulsed injection as manifested by Figure 4c and Figure 4d, the high pressure regions periodically cycle between low and high following the pulsation. Figure 3e and Figure 4e shows the continuous injection and the pulsed injection at t = 0.090 s respectively. During continuous injection, large volume of oil was pushed by the reverse flow towards the inlet and was trapped near the entrance. However, when the flow is pulsed, significant volume of oil passed through the constriction and there was no oil trapped by the reverse flow near the entrance as shown in Figure 4e. This observation is apparent in the animation we recorded.

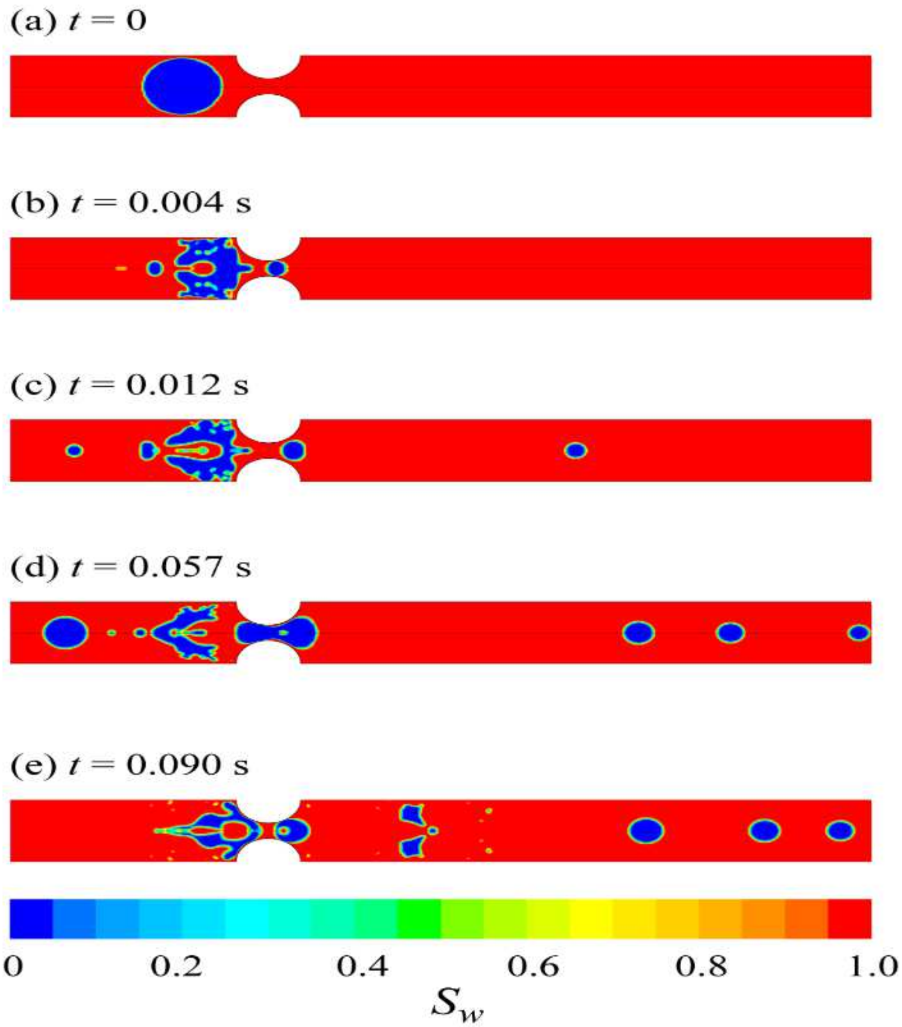

Figure 4: Flow evolution during the pulsed injection presented by volume fraction of water and oil phases during the first 0.090 s

The main idea of the present study is to demonstrate how flow pulsation affects the characteristics multiphase flow through narrow constriction. The main interest is multiphase flow through a porous media. Apparently, a simplified capillary tube model shown here cannot capture the flow dynamics through a porous media. However, once the process is clearly understood from simplified models such as the one presented here, it can be extended to complex flows. Effect of frequency, amplitude, waveform, fluid properties and wettability need to be studied in detail. Then, the technique can be tailored for specific application.

CONCLUSION

The numerically study shows flow characteristics through a converging diverging capillary tube during continuous injection and pulsed injection. The mass flow rate in both cases is the same. However, the flow characteristics is completely different. Pulsation helped more volume of oil to pass through the constriction within the same amount of time. The amount of trapped oil due to the reverse flow was also significantly reduced when the flow was pulsed. Even though detailed understanding is required to extend this result to flow through porous media, which is our main interest, the result found here clearly demonstrates the benefit of flow pulsation to squeeze oil droplet through narrow constrictions. Apparently, before flow through real porous media is studied, the technique should be investigated in detail using simplified model such as the one used in the present study. Once the flow behaviour is understood in detail and effects of excitation parameters such as frequency, amplitude, waveform, duty cycle etc. are understood well with respect to fluid properties and surface wettability, the method can be extended to porous median to tailor for specific application.

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