J Biochem Tech (2019) Special Issue (2): 59-69
ISSN: 0974-2328

# Experimental and Simulation Study of Gravity Drainage Mechanism in Relation to Chemical Enhanced Oil Recovery Operation in One of the Iranian Fractured Reservoirs

**Shahryar Abdollahi*, Saeed Jafari, Saeed Norouzi, Mahin Schaffie**

Received: 20 September 2018 / Received in revised form: 10 March 2019, Accepted: 21 March 2019, Published online: 25 April 2019


## Abstract

Enhanced oil recovery methods cause more ultimate oil recovery from reservoirs. One of which is solvent injection that is known as a proper method for chemical enhanced oil recovery from reservoirs. Solvent injection affects mass transfer mechanism at system and many factors affects reservoir ultimate oil recovery in this mechanism. For examples: permeability of reservoir rock, Density difference between oil and solvent, viscosities and etc. In this study, the effect of these factors on ultimate oil recovery were investigated. Some experiments were done for investigating mass transfer rate between matrix and fracture. In soak and saturation experiment, a porous medium that consists of oil, was submerged in bottle which contains solvent and at this way matrix network and fracture simulated. In experiments, the weight of core that is submerged versus time was recorded and oil recovery from core was calculated. Experimental data were compared with simulated model built with the software and good matching was observed. Influence of different parameters related to rock and fluid properties on the amount of oil recovery were studied and it was concluded that the rate of mass transfer depends on permeability of rock and oil and solvent densities. With increasing density difference between oil and solvent, oil recovery from core increased and with increasing permeability of core, the rate of mass transfer and so oil recovery from core were enhanced and with changing the solvent type, according to oil properties, more and faster oil recovery can be achieved.

**Key words:** Fractured Reservoir, Enhanced Oil Recovery, Solvent Injection, Gravity Drainage, Simulation.

## Introduction

Fractured reservoirs account for about 20 percent of the total oil reservoirs (Firoozabadi, 2000). Compared to non-fractured normal reservoirs, the recovery from these reservoirs is usually less because of the permeability difference between the fracture and the matrix network, and the higher flow rate in the fractures than the flow in the matrix network (Zitha, 2005). In the absence of effective transmission between the matrix network and the fracture, the injected fluids will not have much impact on the recovery of oil from the system. In other words, economic recovery requires effective transmission from the matrix network to the fracture. When the matrix network is water-wet and have a low permeability (in md), the water injection that leads to water Imbibition of the system can be an effective method (Firoozabadi, 2000).

Many of the fractured reservoirs are oil-wet, and the opposite imbibition of capillary forces and therefore water injection may not be effective. In other words, the water is not imbibed to the matrix and will flow through the fracture network, for example, the Ghaba North Field in Oman is an oil-wet carbonate reservoir, which only showed 20% recovery after 20 years of production (Al-Hadhrami and Blunt, 2000). In such cases, gas injection may be a good alternative because the high difference in the density between the oil inside the matrix block and the gas injected compared with the density difference between water and oil make the gravity force be more than the capillary force that holds the oil in place, and results in oil production from the matrix. Such a process is called gas oil gravity drainage (Gallo et al., 1997).

The gravity drainage is suitable for matrix blocks with a large vertical length, high permeability of the matrix blocks and low surface tension. When the gas is injected under miscible conditions, the negative effect of capillary pressure can be prevented. In the absence of capillary pressure, there is no surface between miscible fluids with different compounds (Farzaneh, Kharrat and Ghazanfari, 2010). Therefore, oil recovery in fractured reservoirs can be improved by increasing the pressure or the injection of suitable (miscible or almost miscible) fluids, which reduce the capillary pressure and interfacial tension (Dindoruk and Firoozabadi, 1997; Karimaie and Torsater,

**Shahryar Abdollahi*, Saeed Jafari, Saeed Norouzi, Mahin Schaffie**

Department of Petroleum Engineering, Shahid Bahonar University of Kerman, Kerman, Iran.

* P.O.B. 123456789 Kerman, Iran
***Email:** Shahryarabdollahi1990@gmail.com

2010). Injection of miscible gas will improve the final recovery, because the miscibility will have the advantage of single-phase flow and eliminate surface Tension. In the single-dimensional flow, recovery is observed to be close to 100% for completely miscible fluids (Ameri et al., 2015). In addition, this is the main reason that the miscible process is favorable as enhanced oil recovery method.

In most of the actual operations aimed at enhancing the recovery of oil through gravity drainage, the gas is produced, recovered, compressed, and re-injected into the reservoir. When the reservoir is deep and oil generally contains heavy compounds, the cost of gas condensation will be very high. For example, nitrogen gas or carbon dioxide, which are currently used for enhanced recovery purposes, can only be used in a limited range because their phase behavior is complex, and full miscibility is limited to light oil occurring at a very high pressure (Berg et al., 2010).

The amount of oil recovery by solvent injection generally depends on the mass transfer rate between the solvent in the fracture network and the oil in the matrix network. Initially, the solvent in the fractures diffuses to the matrix network and mixes with the oil in the matrix block. The mixing of solvent and oil affects oil properties. For example, it reduces oil viscosity and changes the oil volume depending on the type of solvent used, which leads to an increase or decrease in oil density (Sherratt, Sharifi Haddad and Rafati, 2018). The natural convection current accelerates the solvent movement within the matrix grid and improves the mixing process, which can result in a rapid recovery of oil from the matrix block. If the mass transfer for the solvent is controlled only by diffusion, the time needed to produce the same amount of oil will be much higher and it will generally be impossible from the operational point of view (Kahrobaei, Bonnieu and Farajzadeh, 2017).

A review of the mechanisms involved in transferring the mass between the solvent in the fracture and the oil in the network has been done in many studies. An overview of these studies has been presented in the review and analysis section. In summary, we can say that there are limitations in empirical methods that examine the mass transfer process and analyze existing mechanisms; there is insufficient empirical data for simulation studies.

In this research, the data obtained from the laboratory review was used to match the simulation model so that a simulation model could be obtained from the mechanism. These results and the obtained model can be useful in simulating the mechanism of mass transfer in fractured reservoirs. In this regard, the experiment has been first described and explained, and then the simulations carried out to examine this mechanism have been discussed. The current study aimed at investigating the interaction between solvent in the fracture and oil in the matrix network, the effects of different parameters such as density, viscosity of the fluids, and permeability of the rock, and having more information of the process of increasing the chemical EOR.

## Methodology

In order to investigate the effect of solvent injection on oil recovery from reservoirs, soak experiments were carried out. The simulation and fabrication of the process model were performed using COMSOL software.

*Laboratory method*

In this study, for soak experiments, heptane was used as oil and toluene was used as solvent. The specifications of the fluids have been provided in Table 1. Heptane-toluene are completely miscible at ambient temperature (24 ° C) (Ameri et al., 2015).

Table 1. Oil specifications and solvents used in the research [1]

| Material | Chemical formula | Type | Density $\frac{g}{cm^3}$ | Viscosity (cP) at 24 ° C |
|---|---|---|---|---|
| Heptane | $C_7H_{16}$ | Oil | 0.66 | 0.393 |
| Toluene | $C_5H_{12}$ | Solvent | 0.84 | 0.566 [2] |

Samples of the cores used in this research included two examples of reservoir cores related to one of the southwestern fractured carbonate reservoirs of Iran, whose petrophysical characteristics and their dimensions have been described in Table 2.

Table 2. Specimen of core samples used in research[3]

| Core number | Length (mm) | Diameter (mm) | Permeability (md) | Porosity (%) | Density $\frac{g}{cm^3}$ |
|---|---|---|---|---|---|
| 1 | 50.66 | 37.54 | 5.362 | 18.2 | 2.71 |
| 2 | 50.63 | 37.53 | 3.943 | 20.9 | 2.71 |

[1] webbook.nist.gov/ 2018
[2] wiki.anton-paar.com / 2018
[3] Petro Vision Pasargad/ 2018

In order to measure the submersed cores' weight in a solvent, a digital balance was used with a precision of one hundredth degree. Iso glass container, a vacuum pump, and a titration vessel were used to saturate the cores from the fluids.

The immersion test was used to examine the mass transfer mechanism between the fracture and the matrix grid. In this experiment, a core was suspended in a glass filled with solvent, the core was completely saturated with oil, so the concentration or saturation of the solvent inside the core and also the concentration of oil in the solvent were zero. The distance between the core and the vessel wall was considered as a fracture and this fracture was filled with solvent. Matrix network included oil that was recovered. After starting experiment, with the penetration of the solvent into the core, the submersed core mass in the solvent was changed and the core weight was recorded at each instant. Using the results of this measurement, oil recovery could be concluded from the core at any moment. Experiments were repeated three times. Figure 1 shows the depositions of the core, oil and solvent in the immersion test. The test was conducted in such a way that the solvent was injected into a beaker with a volume of 400 ml. The core was placed in the solvent connected by a hook linked to a wrap around the cores, vertically and centered with a cylinder, so that the core was completely cylindrical in the center of beaker; The distance of the end of the core from the bottom of the container, the height of the oil located above the core, and the distance of the outer radius of the core from the wall of the container have been shown in Fig. 1. Due to the solvent volatility, it was used on a container using cellophane foam.

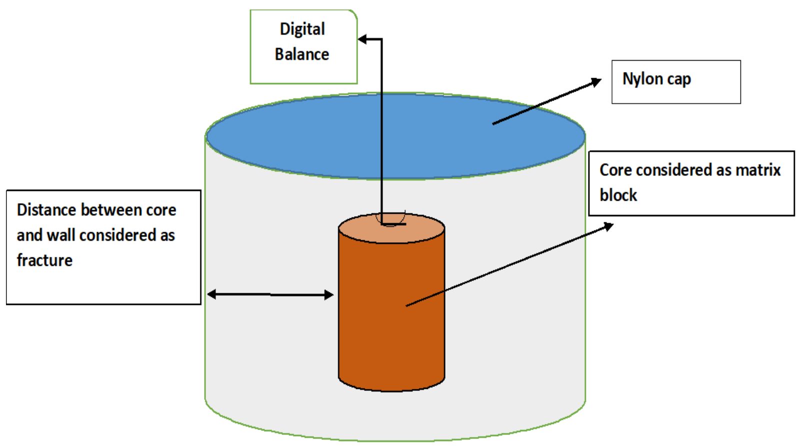


**Figure 1.** A plot of soak experiment (Digital scale, cap made with cellophane, glass container having solvent, whose core has been conditional, drowned core In the solvent, as a matrix, which have been placed at the center of solvent containing cylinder, 7.3cm, 7.4 cm, the distance between core and the wall of the container as the fracture (3.1 cm))

The experiments were conducted at atmospheric pressure and ambient temperature. The porosity and permeability of the core were assumed constant during the experiment and equal to the initial value. The presence of capillary forces in the miscible displacement was neglected.

First, the cylindrical core was dried; lacking any water and other fluids, and was weighed. Dry specimen weight was 88.33 grams. Then the core was saturated with the oil used, i.e., normal heptane. The saturation method was done by placing the sample in an Iso glass and turning the vacuum pump on and reducing the relative pressure inside the container to -0.74 MPa, 750 ml of oil (heptane) -through the valve of the container connected to the hopper containing oil-, under vacuum, was poured onto the sample and after a sufficient amount of time and observing the absence of bubbles indicating vacuum conditions and a complete saturation of the sample, the pump was turned off. In this experiment, at first, 15 minutes were spent to ensure that there was no leakage and a sufficient vacuum. Then the oil was spilled onto the core, the relative pressure inside the container was at -0.068-Mpa at the time of saturation. After half an hour and after the saturation of the core with oil, the sample was reweighed, the weight of the sample was 131.01 grams. Table 3 describes the weight conditions of the core and the environment of the test.

Table 3. Environmental conditions and cores` weight in different modes

| | |
|---|---|
| Dry sample's weight | 123.88 |
| Sample weight after saturating with heptane | 131.01 |
| Sample weight after saturating with toluene | 133.27 |
| The difference between the weight of the core saturated with solvent and the core saturated with oil | 2.26 |
| Acceptable amount of pressure inside the container due to vacuum pump's operation | -0.068 |
| Environmental pressure during testing | 0.101 |
| Ambient temperature during testing | 24° C |

*Simulation method*

Simulation of the test and modeling conditions were done using COMSOL 5.3. In this study, a fluid module was used. As it was mentioned, recovery of oil from a core immersed into the solvent occurring in two stages. 1- Penetration of the solvent into the core. 2- Flow induced by gravity to remove the moving oil out of the matrix grid. These two mechanisms were considered in the simulation, and in the end, different states were simulated.

The physical conditions of the tested data were entered into the simulator in accordance with Table 1 and 2 and Figure 1. At the external boundary of the system, the velocity of the fluid in the wall of the system was zero. The solvent concentration was considered one in the entire range, defined for the solvent at the initial time, and it was considered zero for the core. COMSOL software is a software based on the finite element solving method, so a variety of networking can be used for the model. After Analyzing type and size of grid blocks, triangular grid block for domain around the core and rectangular grid block for core domain were considered.

In this research, the oil-heptane and solvent-toluene systems were used for the first and second cores and heptane-oil and decalin solvent were used for the first core to extract the simulator, and the geometry of the problem was two-dimensional symmetric, the networking of which has been specified in pictures 2 and 3.

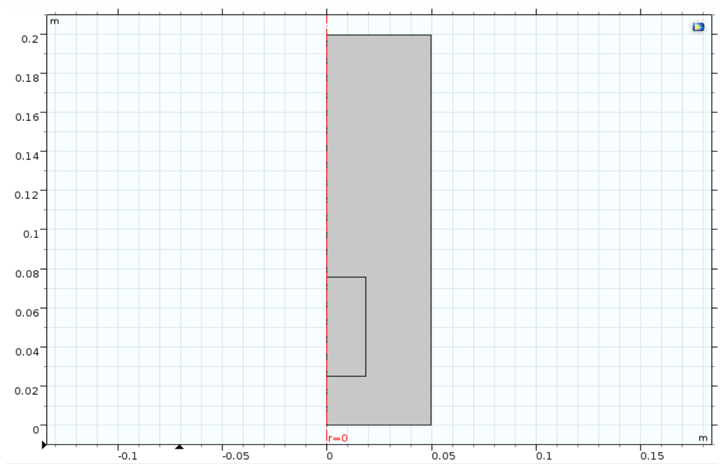


**Figure 2.** Two-dimensional geometry of the problem

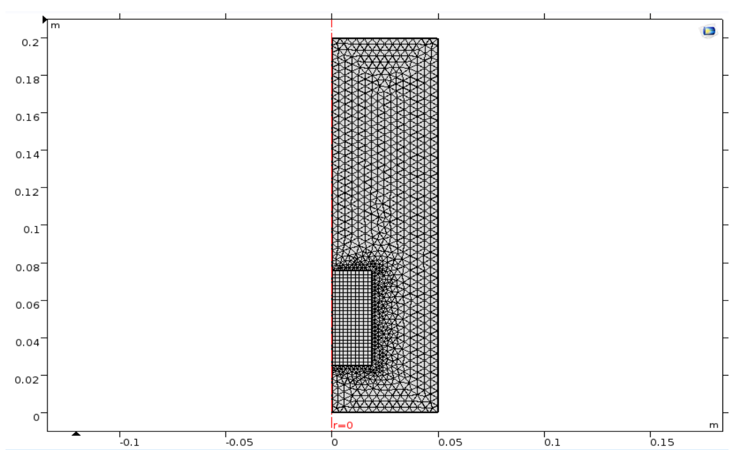


**Figure 3.** Gridding Considered in Simulation

## Presentation and analysis of results

*Experimental results*

The results of the experiments were carried out to determine the rate of oil recovery from number one core and the core Submersed in the solvent of the heptane-oil and toluene-solvent systems have been presented in Figures 4 and 5.

In Figure 1-5, the results of the test are shown in terms of core weight change over time. At the start of the test, the weight of the core was increasing due to the solvent and oil type, and the rapid penetration of the solvent into the core. However, this increase was fast at the beginning of the experiment, up to 500 minutes, then increased slowly and stayed constant for about 1000 minutes. After 1000 minutes, the slope of the core weight changes reached zero and no weight change was observed.

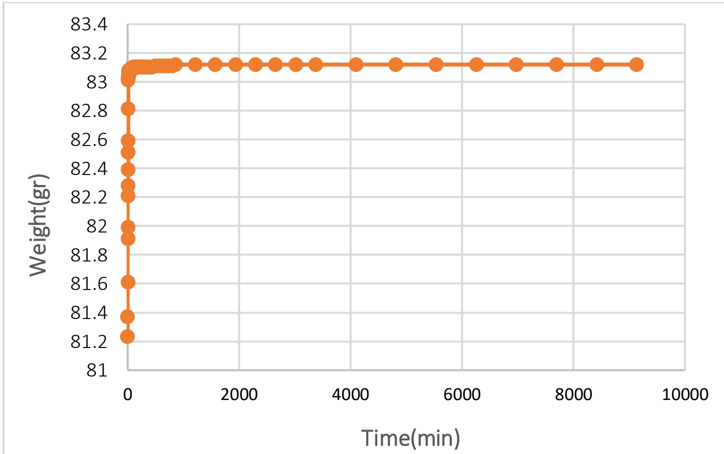


**Figure 4:** Changing the weight of the immersed sample in the solvent obtained from the heptane-toluene immersion test considering the passing of time at 24 ° C and atmospheric pressure

As we can see, the extreme changes in weight occurred at the initial test times, as shown in Fig. 2-2, between zero and 100 minutes, with varying variations in the graph. In accordance with the expected solvent penetration into the core, the concentration of oil in the core decreased and, therefore, the weight of the immersed core sample in the solvent increased with the passing of time.

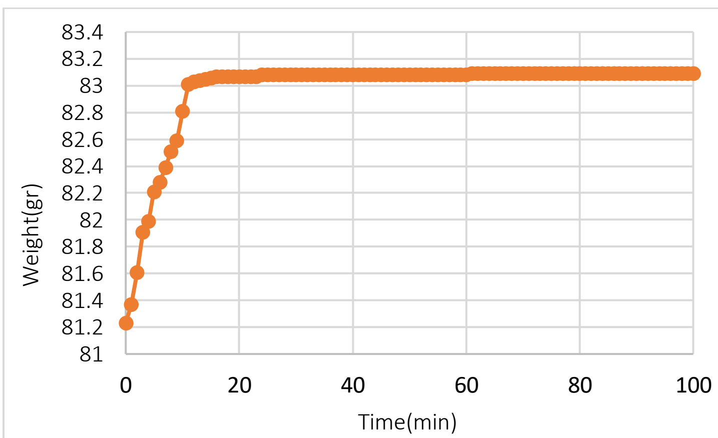


**Figure 5:** Changing the weight of the immersed sample in the solvent obtained from the heptane-toluene immersion test considering the passing of time at 24 ° C and atmospheric pressure in the range of 0 to 100 minutes

The recovery was calculated by having the initial weight of the saturation sample of the oil immersed in the solvent and the weight of the immersed sample in the solvent at any moment, also by having the difference of the completely saturated sample and the completely saturated sample of solvent. The absolute value of the difference in the weight of the sample immersed in the solvent at each instant and the initial weight of the sample were divided by the difference in the weight of the total saturated oil sample and the total saturation of the solvent, had multiplied by 100, in order to obtain the recovery of the core at any given time. Table 4 shows the values obtained during the experiment to calculate the recovery rate.

Table 4. The values obtained during the experiment to calculate the recovery rate and the oil recovery formula

| | |
|---|---|
| The weight of completely saturated core with oil (heptane) in grams | 131.01 |
| The weight of completely saturated core with the solvent (toluene) in grams | 133.27 |
| The weight difference between the completely saturated core with the solvent and completely saturated core with oil (heptane) in grams | 2.26 |

| | |
|---|---|
| The initial weight of the completely saturated core with oil (heptane) and immersed in solvent in grams | 81.23 |

Figure 6 shows the amount of oil recovery from the core over time. Immediately after the start of the experiment, the weight of the immersed sample increased, and in the initial periods of the experiment, this change occurred quickly so that the oil recovery from the core samples after 495 minutes reached to 83.2% and until 855 minutes, the recovery rate of the sample reached to 6.83%, since then recovery has remained constant. Therefore, the final recovery of the core was 6.83%. It is carefully observed that after a certain time, the changes were slower, and then the graph could be considered constant. As time passed and the amount of residual oil in the core changed, the recovery rate of oil should have been increased to reach the final recovery level at the end of the test.

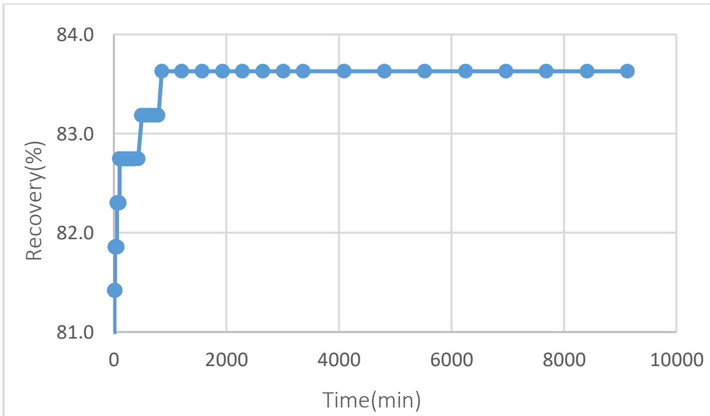


**Figure 6.** Graph of oil recovery from an immersed sample in a solvent obtained from a heptane-toluene immersion test over time at 24 ° C and atmospheric pressure

Therefore, it is seen that in this system, with the penetration of solvent into the core containing oil, the viscosity of the oil inside the core changes, and due to the fact that the density of oil was less than the solvent, the gravity drainage caused the oil to be displaced by the solvent of the core. The immersion test with the mentioned system was performed with three times iteration and the same results were obtained.

*Simulation results*

In this section, simulation results have been presented for both cores. Initially, the core No. 1 was simulated with the information contained in Table 2; its results have been depicted. Figure 7 shows the concentration of oil in the core at the beginning of the simulation. As it was said, at the beginning of the work, the core was completely saturated with oil (heptane), and the concentration of oil at the initial time in the core was equal to one and in the part containing the solvent was equal to zero, 5-4.

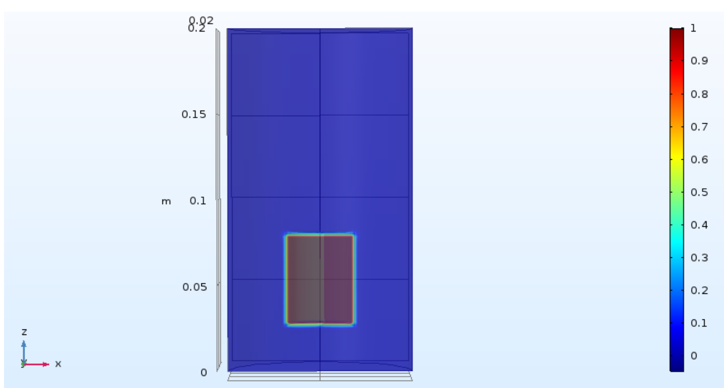


**Figure 7:** Concentration of oil (heptane) and solvent (toluene) at 0 min related to the simulation of the first cores

It was further observed that the concentration of oil inside the core decreased with the penetration of the solvent into the core. In Figure 8, the process of penetrating the solvent into the matrix block was considered, which was the core. It was observed that, in the end, the concentration of oil reached a constant level, which determined the final recovery rate from the core.

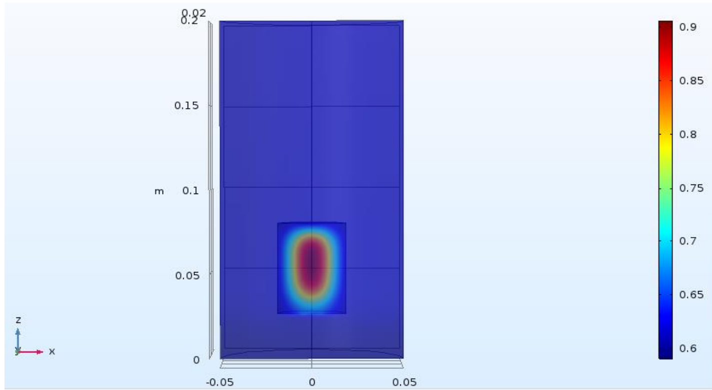


**Figure 8:** The concentration of oil (heptane) and solvent (toluene) in 1000 minutes related to the simulation of the first cores

By dissolving the oil within the solvent, the fluid properties of the mixture (including solvent and oil) have changed, which would cause a density difference in the different parts of the container containing the core. This difference creates a vortex current inside the container, which plays a major role in the transfer of mass from the core to the solvent. This vortex flow is well visible in simulation results (figure 10).

The profiles of the fluid flow generated around the core are shown in Figures 9 to 10. At first, the velocity at all points was equal to zero, given that the fluid in the core and the solvent were still standing. With the onset of the process, a slow motion from the solvent was created around the core, which in turn increased the convective mass transfer coefficient around the core and improved the mass transfer. The value of this speed was 0.01 m / s.

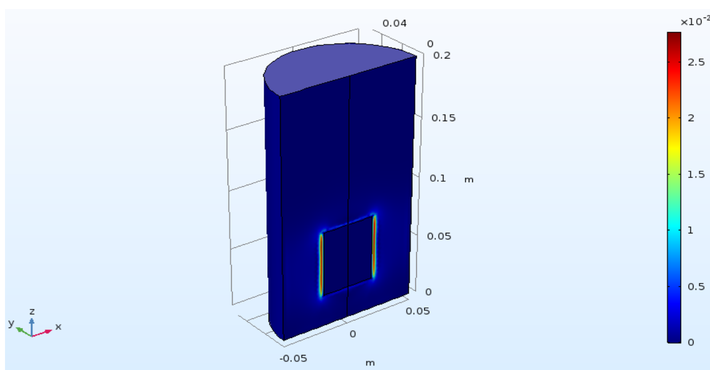


**Figure 9:** Flow velocity contour at zero min for simulating rock and fluid conditions of the first cores and heptane (oil) - toluene (solvent)

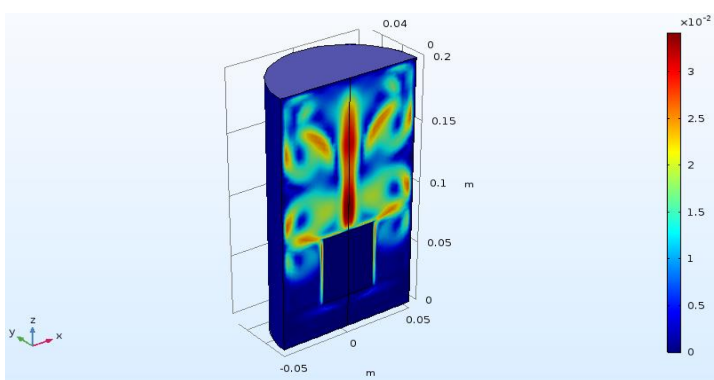


**Figure 10.** The flow velocity contour at 30 minutes for the simulation of rock and core conditions and heptane (oil) - toluene (solvent)

As shown in Figures 11 and 12, it was observed that, initially, a vortex flow was created around the core, the vortex current generated around the core was depicted in a more regular form; this turmoil decreased with a more uniform concentration distribution within the solvent. It was observed that due to the higher solvent's density compared to oil, the entrance of the solvent to the core was greater than the bottom of the core and the outflow of oil was from the upper part of the core.

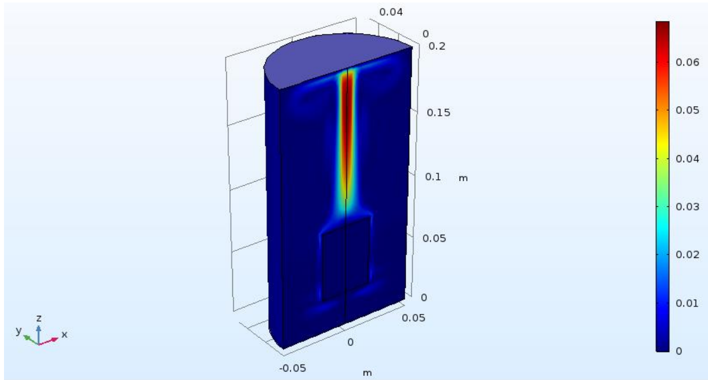


**Figure 11.** The flow velocity at 60 minutes related to the simulation of rock and core conditions and heptane (oil) - toluene (solvent)

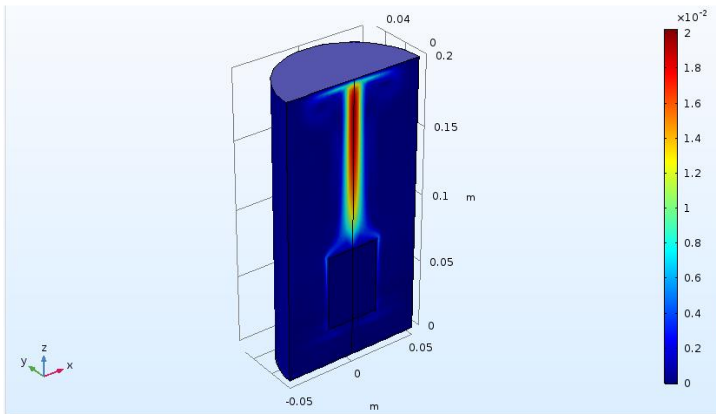


**Figure 12.** The flow velocity at 1000 minutes related to the simulation of rock and core conditions and heptane (oil) - toluene (solvent)

It was observed that after about 1000 minutes, the fluid velocity changes almost reached zero, indicating the end of the process of oil recovery from the core. . Due to the type of solvent that was heavier than oil and the higher viscosity of oil compared to solvent, both mechanisms of penetration and convection have been effective and resulted in such recovery from the core.

Table 5. Comparison of the simulation results with experimental results in heptane-toluene system

| Absolute value of the difference of simulation results from Experimental results (%) | Recovery by simulation results (%) | Recovery by Experimental results (%) | Time (minute) |
|---|---|---|---|
| 1.49 | 82.61 | 81.4 | 30 |
| 1.00 | 82.72 | 81.9 | 52 |
| 0.70 | 82.88 | 82.3 | 100 |
| 0.20 | 83.37 | 83.2 | 555 |
| 0.19 | 83.44 | 83.6 | 855 |
| 0.19 | 83.44 | 83.6 | 2655 |
| 0.19 | 83.44 | 83.6 | 7695 |

According to Table 5 and the error rate obtained from the comparison of simulation results with laboratory results, it is observed that the error rate in most times was less than 5% and therefore it can be said that the simulated model was properly constructed. Therefore, it is possible to base this model on different conditions of rock and fluid, and then examine the results to obtain the best solvent for a real stone rock to achieve maximum recovery in the shortest possible time.

Therefore, using the model to simulate the gravity drainage process through the solvent's intrusion to the matrix, the next simulation was conducted by the second core at the fluid conditions of the heptane (oil) - toluene (solvent); the results are shown in Figures 13 to 14. It was observed that core properties played a significant role in the rate of recovery and extraction from the core. By increasing the permeability of the core and its porosity, the flow of fluid would penetrate more easily into the core and would penetrate the core into higher recovery. According to the previous state, at the initial time, the core was completely saturated with oil and the concentration of oil around the core was zero. With the passage of time and the penetration of solvent into the core, the concentration of oil inside the core decreased. These mechanisms are shown in Figures 13 to 14.

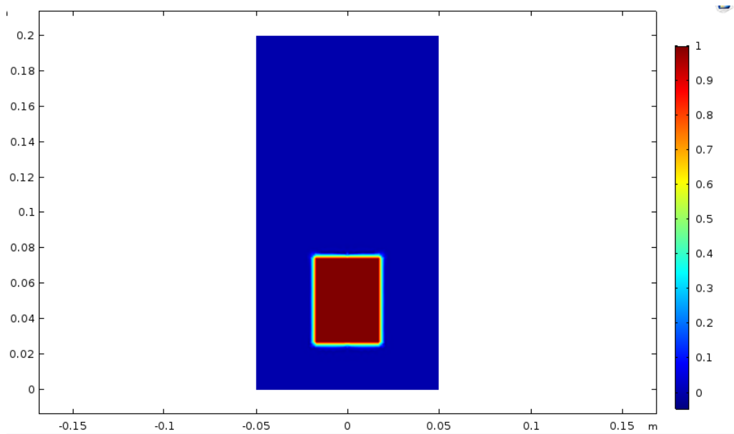

**Figure 13:** The concentration of oil (heptane) and solvent (toluene) at 0 min for the second core's simulation

The simulation results showed that, over time, the amount of recovery reached an almost constant level and slight changes were observed in the output value. Figure 14 shows that after 800 minutes, much of the oil has been recovered inside the core, but was less than the amount of recovery in the first core.

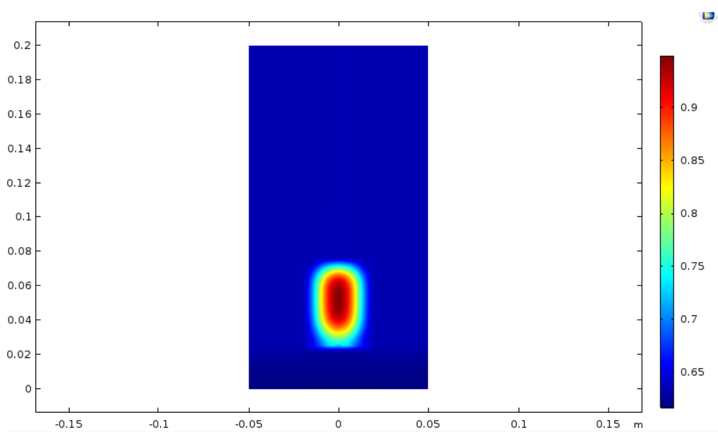

**Figure 14:** The concentration of oil (heptane) and solvent (toluene) at 800 min for the second core's simulation

As before, in the early stages of the process, the concentration was high, with the solvent concentration in the core reaching a maximum, the oil recovery process was stopped from the core and the final recovery was achieved. Results are shown in Figures 15 to 18 to change the fluid flow rate inside the system. At the beginning of the process, due to the static state of fluid, the velocity of the whole system was equal to zero. This is illustrated in Figure 15.

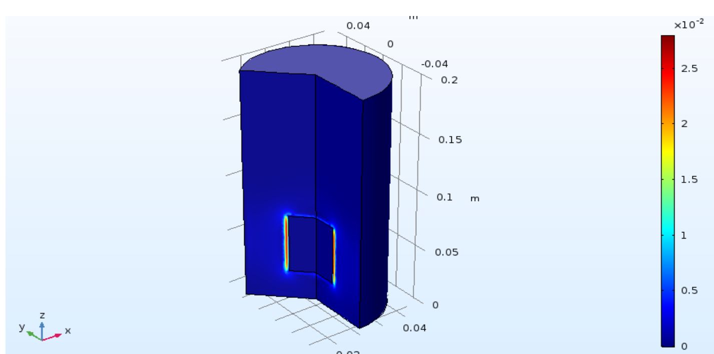

**Figure 15.** The velocity at zero minutes for the simulation of rock and fluid conditions of the second core and the heptane (petroleum) - toluene (solvent)

At the time of 200 minutes after the start of the process, with the penetration of solvent into the core, the velocity of the fluid in the system was changed and according to the properties of the rock and the fluids in the system, these changes were accentuated more. In Figure 16, fluid velocity contour at this time was displayed in the system. It was observed that due to the high solvent content in comparison with oil, the penetration of solvent into the core was from the bottom of the core, and the outlet oil from the top of the core caused a difference in fluid velocity in the system.

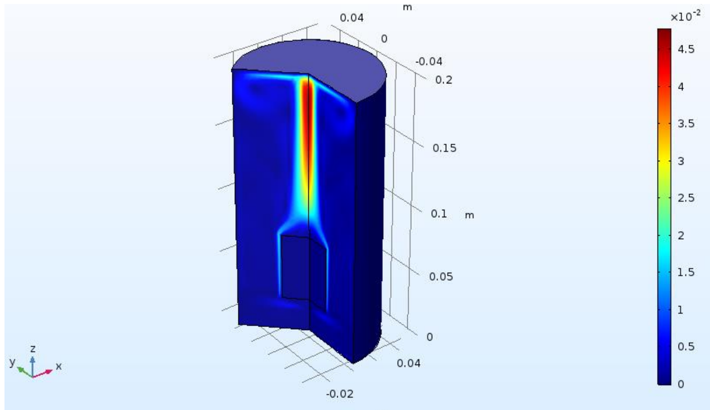


**Figure 16:** Flow velocity contour at 200 minutes for simulating rock and fluid conditions of the second core and heptane (petroleum) - toluene (solvent) system

Figure 17 shows the flow velocity contour at 800 minutes, which over time would change the speed pattern throughout the system, and the continued penetration of the solvent into the matrix would continue due to the difference in density with the oil contained therein. In the upper part of the core, due to the large amount of density difference, the velocity would change more than the other points, and the speed variations could be visible in this section.

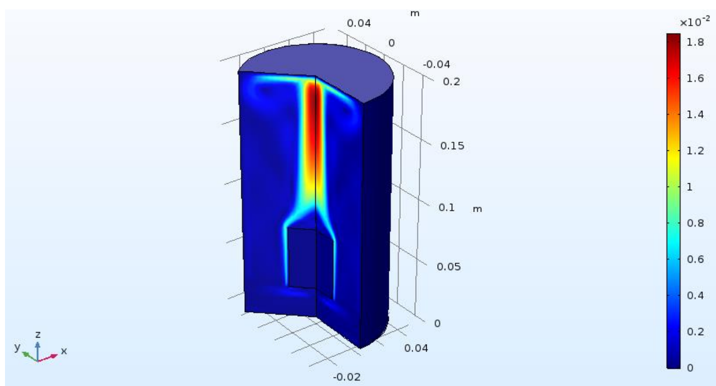


**Figure 17:** Flow velocity contour at 800 minutes for simulating rock conditions and second core fluid and heptane (petroleum) - toluene (solvent) system

The recovery rate obtained from the system with the rock conditions and the second core fluid and the heptane (petroleum) -toluene (solvent) system are shown in Fig. 18, which had some changes compared to the first core. Since the two cores had different permeability and porosity, it was found that at the core No. 1, which had a greater permeability, the final recovery rate was a bit higher than the second core, which could be due to the greater permeability of the first system than the second state, the path to fluid movement was higher and the core had a better fluid flow. So the oil was recovered faster and was more than the core. Therefore, changing the properties of the porous medium led to a change in the rate of oil recovery from the core. The final recovery rate of oil from the core in the simulation was 76.18%.

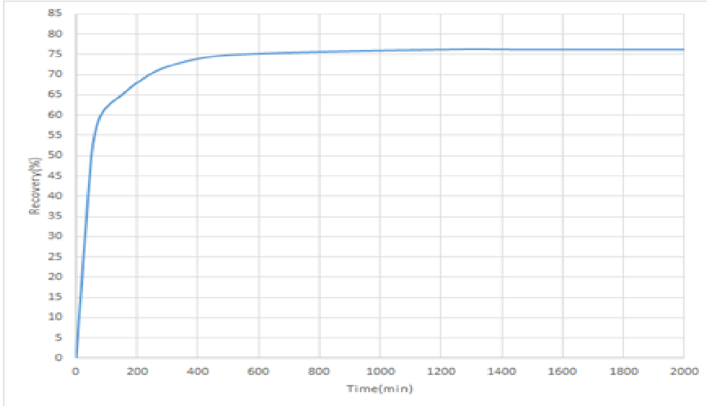


**Figure 18.** Oil recovery from the core for simulating the rock and fluid conditions of the second core and heptane (oil) - toluene (solvent) system

## Conclusion

According to the experimental and simulation results, in the absence of capillary forces, solvent injection can be considered as an effective way to increase the recovery of oil from the core.

- Mass transfer between the fracture and matrix networks was investigated through immersion experiments in the model of heptane and solvent-toluene oil system, and 83.6% of the recovered oil was obtained from the core. Therefore,
- By changing the properties and reducing the core permeation from 362.5 Millidarcy to 943.3 Millidarcy, the final recovery rate from cores decreased from 83.4 percent to 76.16 percent, and the time to reach the final recovery reached to 1080 minutes from 850 minutes, so other parameters affecting the amount and time of recovering included the properties of the rock, which was improved by increasing permeability and porosity, faster and more recovery.
- Experimental observations and simulation showed that over time, the amount of recovery increased to a maximum value, and since then, recovery did not occur. This point was considered as the final recovery from the core.

## References

Al-Hadhrami H.S, Blunt M.J, Thermally induced wettability alteration to improve oil recovery in fractured reservoirs, in: SPE/DOE Improv. Oil Recover. Symp, Society of Petroleum Engineers, (2000).

Ameri A, Farajzadeh R, Suicmez V.S, Verlaan M, Bruining J, Dynamic Interactions between Matrix and Fracture during Miscible Gravity Drainage in Naturally Fractured Reservoirs, Ind. Eng. Chem. Res. 54 (2015) 5356–5371.

Berg S, Oedai S, Landman A.J, Brussee N, Boele M, Valdez R, van Gelder K, Miscible displacement of oils by carbon disulfide in porous media: Experiments and analysis, Phys. Fluids. 22 (2010) 113102.

Dindoruk B, Firoozabadi A, Crossflow in Fractured/Layered Media Incorporating Gravity, Viscous, and Phase Behavior Effects: Part I-Formulation and Features in Layered Media, SPE J. 2 (1997) 120–135.

Farzaneh S.A, Kharrat R, Ghazanfari M.H, Experimental study of solvent flooding to heavy oil in fractured five-spot micro-models: the role of fracture geometrical characteristics, J. Can. Pet. Technol. 49 (2010) 36–43.

Firoozabadi A, Recovery mechanisms in fractured reservoirs and field performance, J. Can. Pet. Technol. 39(2000).

Gallo Y, Le Romancer J.F, Bourbiaux B, Fernandes G, Mass transfer in fractured reservoirs during gas injection: experimental and numerical modeling, in: SPE Annu. Tech. Conf. Exhib., Society of Petroleum Engineers, (1997).

Kahrobaei S, Li K, Bonnieu S.V, Farajzadeh R, Effects of compositional variations on CO2 foam under miscible conditions, in: IOR 2017-19th Eur. Symp. Improv. Oil Recovery, (2017).

Karimaie H, Torsater O, Low IFT gas–oil gravity drainage in fractured carbonate porous media, J. Pet. Sci. Eng. 70 (2010) 67–73.

Sherratt J, Sharifi Haddad A, Rafati R, Hot Solvent-Assisted Gravity Drainage in Naturally Fractured Heavy Oil Reservoirs: A New Model and Approach to Determine Optimal Solvent Injection Temperature, Ind. Eng. Chem. Res. 57 (2018) 3043–3058.

Zitha P.L.J, Uijttenhout M, Carbon dioxide foam rheology in porous media: a ct scan study, in: SPE Int. Improv. Oil Recover. Conf. Asia Pacific, Society of Petroleum Engineers, (2005).