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Gas-oil gravity drainage in fractured porous media

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ABSTRACT

Gas-oil gravity drainage is considered to be one of the most dependable recovery mechanisms in naturally fractured reservoirs. The production mechanism is as a result of the density difference between the phases and capillary contrast between the matrixes and the fractures. This mechanism is contingent upon certain factors such as capillary threshold height and capillary discontinuity, among others. To assess the efficiency and contributions of these factors, a simulation study was carried out on a modeled fractured porous system using ECLIPSE-100 simulator. The results obtained show that oil recovery from a single matrix block (RUN1) was higher than matrix blocks with two, three and five stacks with capillary continuity (RUNS 2, 3 and 4 respectively). Additionally, with capillary discontinuity (RUNS 5, 6 and 7), the results depicted an increase in oil recovery compared to the cases of capillary continuity. However, varying the degree of capillary discontinuity with the respective matrix block stacks in the fractured model yielded no significant increase in oil recovery. Thus, the results show that while both capillary threshold height and capillary discontinuity remain significant factors in gas-oil gravity drainage, capillary continuity and varying the degree of discontinuity between the matrixes degree has little or no effect on this recovery mechanism in fractured porous media.

Keywords: Gas-oil gravity drainage, Oil recovery, Capillary threshold height, Capillary discontinuity, Fractured porous media.

1. INTRODUCTION

The use of gas injection as an oil recovery technique in fractured reservoirs has long been established both as secondary and tertiary oil recovery methods. In fractured reservoirs, gas-oil gravity drainage is a very efficient oil recovery technique used to recover oil from the oil saturated matrix in the reservoir. In this recovery method, the injected gas displaces oil in the matrix by gravity drainage as a result of the density difference between the two phases (oil and gas), which results in downward movement of oil in the matrix. In addition, oil-gas gravity drainage production mechanism involves drainage of oil by gravity from an oil saturated reservoir matrix, which is surrounded by a gas saturated fracture system. Thus, when the matrix block is surrounded by gas, the gravitational forces around the matrix block exceed the capillary forces inside the block for the oil to be displaced from the matrix block. The displaced oil flows to the fracture and is recovered as in the case of a fractured system. Worthy of mention is that, in gravity drainage the predominant force is the gravity forces as compared to capillary and viscous forces in the system. Oil recovery by gravity drainage mechanism is contingent upon three factors, namely: the shape of the oil relative permeability curve, the magnitude of gravitational forces relative to viscous forces, and the reservoir geometry and heterogeneity. The key factors that control the recovery rate and ultimate recovery in a single block are the connate water saturation, oil relative permeability and matrix capillary pressure (Jafari et al. 2008). In addition, the matrix block height is of utmost importance in gas-oil gravity drainage, and the matrix block height must be smaller than the capillary threshold height for the oil in the matrix block to be produced by gravity drainage mechanism. Firoozabadi (2000) maintains that two mechanisms, namely, reinfiltration and capillary continuity affect the efficiency of gas-oil gravity drainage in fractured reservoirs. This paper examines the effect of capillary continuity and discontinuity in fractured porous media using ECLIPSE-100 Simulator to simulate oil recovery from the system. The contribution of reinfiltration and gas diffusion in gas-oil gravity drainage are not considered.

2. MATERIALS AND METHODS

The reservoir description/model in this study is an extension of an earlier work of Udoh and Okon (2012) except that modifications are made in terms of the grid size and number of grid blocks. The grid model comprised of two matrix blocks with forty (40) grid blocks surrounded by fractures as depicted in Figure 1. In the model, gas is injected at the top of the matrix block while oil is produced at the bottom of the matrix block. Figures 2 & 3 present the relative permeability (K_r) curve of the different phases and the capillary pressure (P_c) curve respectively in the matrix. The relative permeability (K_r) in the fracture is assumed to be a linear function of phase saturation. Thus, expanded mathematically as:

$$K_{rg} = S_g \qquad (1)$$

$$K_{ro} = 1 - S_g \qquad (2)$$

Where:
K_{rg} = Gas relative permeability

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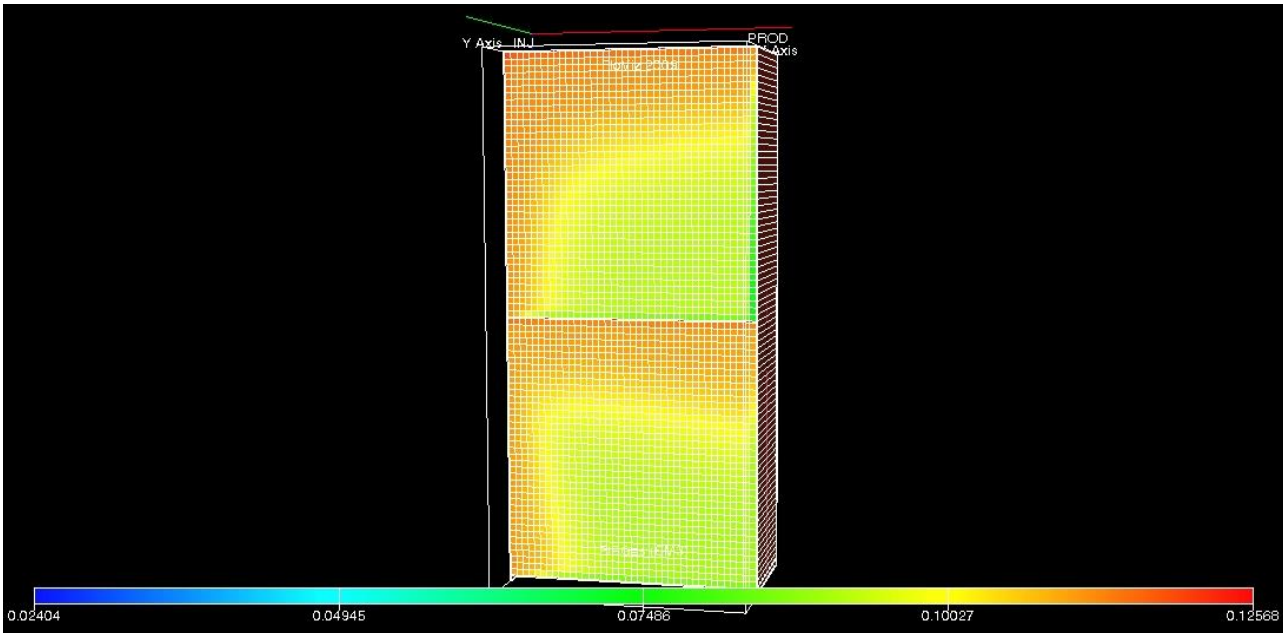

Figure 1
Grid Model

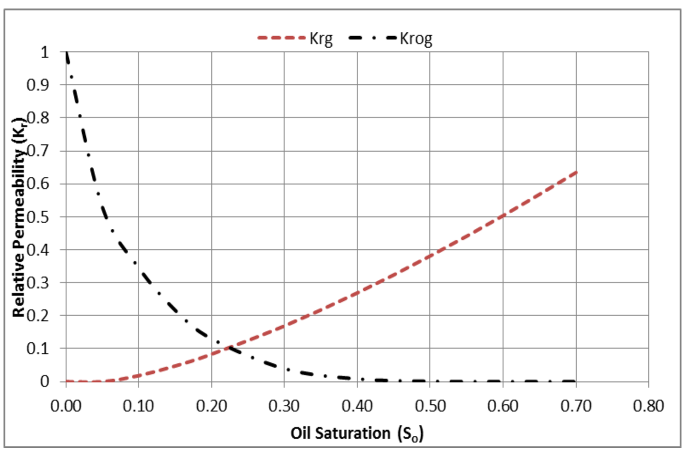

Figure 2
Relative Permeability curve (K_r)

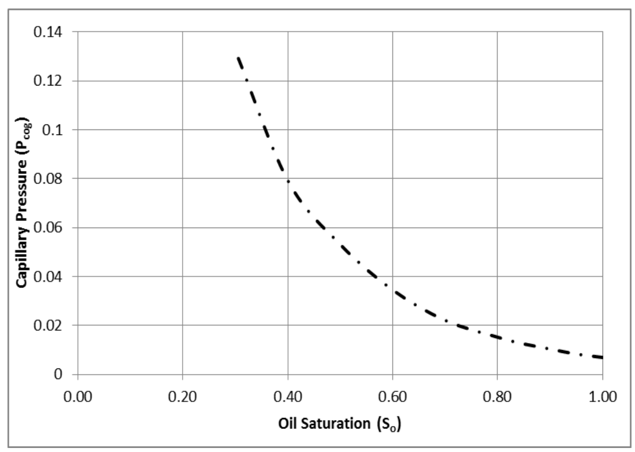

Figure 3
Capillary Pressure curve (P_c)

Table 1 Reservoir Description

Description	Value
Matrix Compressibility (c_m)	5.29×10^{-5} Pa^{-1}
Matrix Porosity (φ_m)	0.30
Matrix Permeability (k_m)	1.0mD
Matrix Block	0.05m
Fracture Width (b)	0.01m
Fractured Porosity (φ_f)	1.0
Fractured Permeability (k_f)	30mD
Oil Viscosity (μ_o)	0.190cP
Gas Viscosity (μ_g)	0.023cP
Oil Density (ρ_o)	850kg/m^3
Gas Density (ρ_g)	0.83kg/m^3
Oil Formation Volume Factor (B_o)	1.50
Gas Formation Volume Factor (B_g)	0.0042
Reference Pressure (P_{ref})	350Bar
Injection Pressure	370Bar

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Table 2 Capillary continuity between matrix block

Simulation Runs	Number of stacks	Recovery Factor
RUN1	1	0.5998
RUN2	2	0.5862
RUN3	3	0.5715
RUN4	5	0.5486

Table 3 Capillary discontinuity between matrix block

Simulation Runs	Number of stacks	Recovery Factor
RUN5	2	0.5894
RUN6	3	0.5754
RUN7	5	0.5511

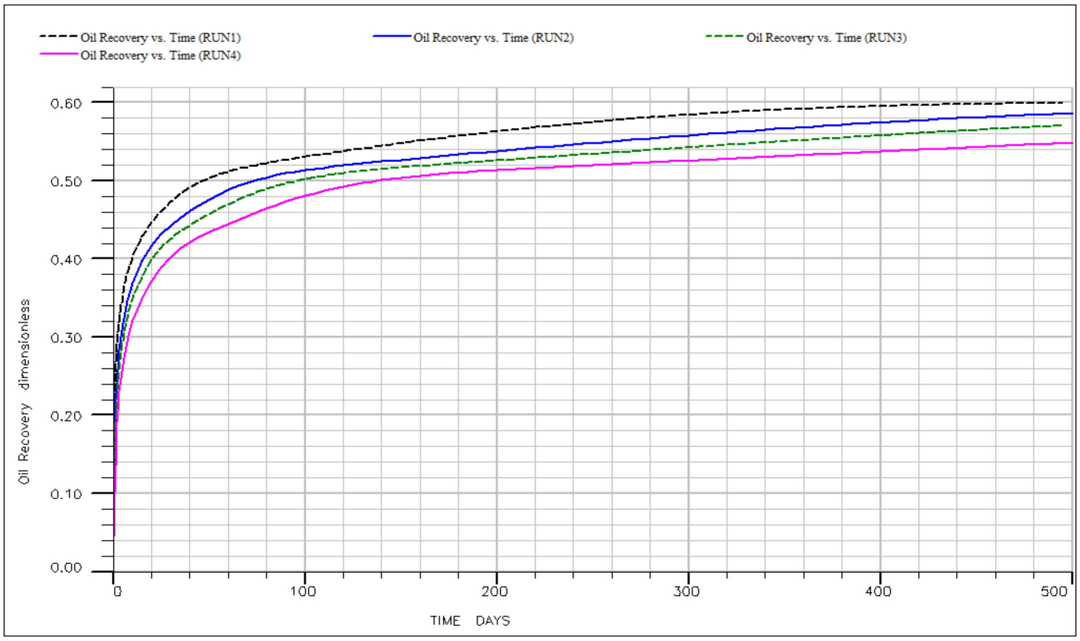

Figure 4
Oil Recovery vs Time (Capillary continuity)

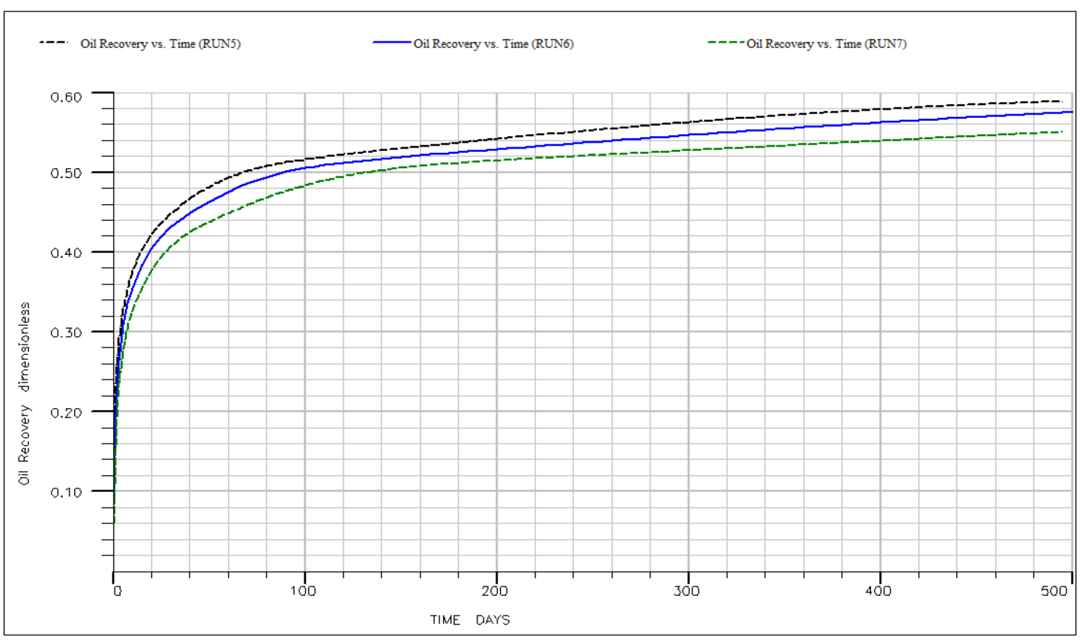

Figure 5
Oil Recovery vs Time (Capillary discontinuity)

K_{ro} = Oil relative permeability
S_g = Gas saturation

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Equations 1 and 2 indicate that there is no irreducible or residual phase saturation in the fracture. The assumption of relative permeability (K_r) linearity with phase saturation in the fracture is based on the high fracture permeability (K_f). Since the multiphase flow in the fracture is controlled mainly by gravitational forces, the gravity equilibrium essentially reduces the relative permeability curve to two straight lines (Torsæter, 2011). Thus, the capillary pressure (P_c) in the fracture is assumed to be zero. Table 1 shows the modeled reservoir parameters incorporated in ECLIPSE-100 input file for the simulation runs in this study. To evaluate gas-oil gravity drainage in fractured porous media, different configurations of matrix block stacks with capillary continuity and capillary discontinuity between matrix blocks were studied. Additionally, the fracture width in the case of capillary discontinuity was varied to assess its contribution to gas-oil gravity drainage in fractured porous media. Tables 2-4 present the simulation runs for the different scenarios in this study.

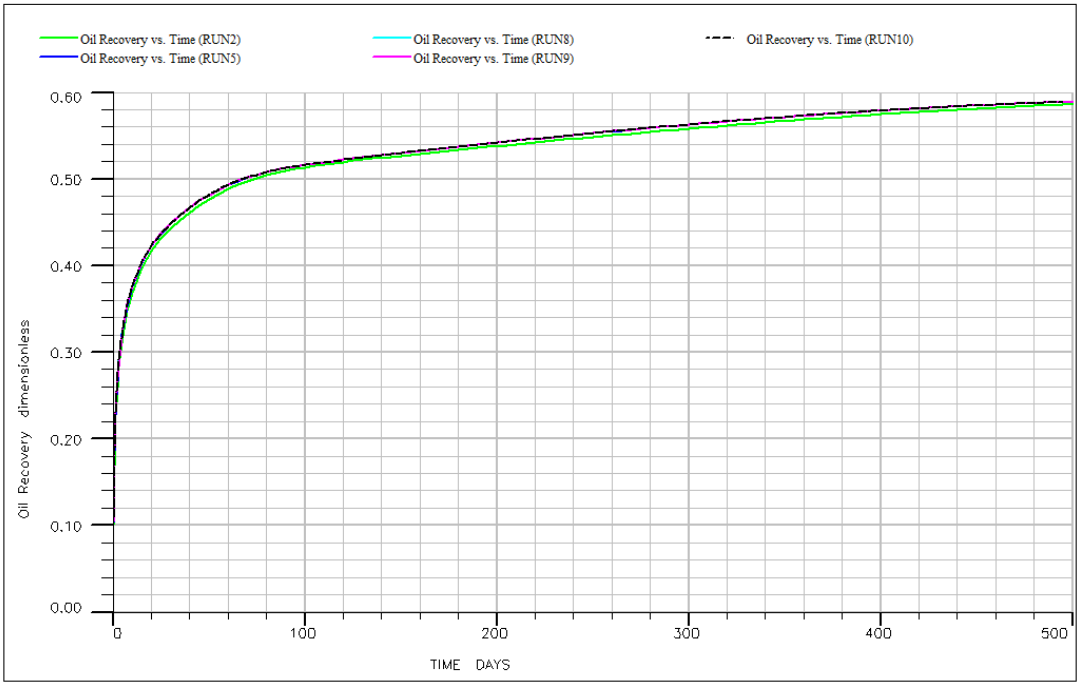

Figure 6

Oil Recovery from different fracture width (two stacks)

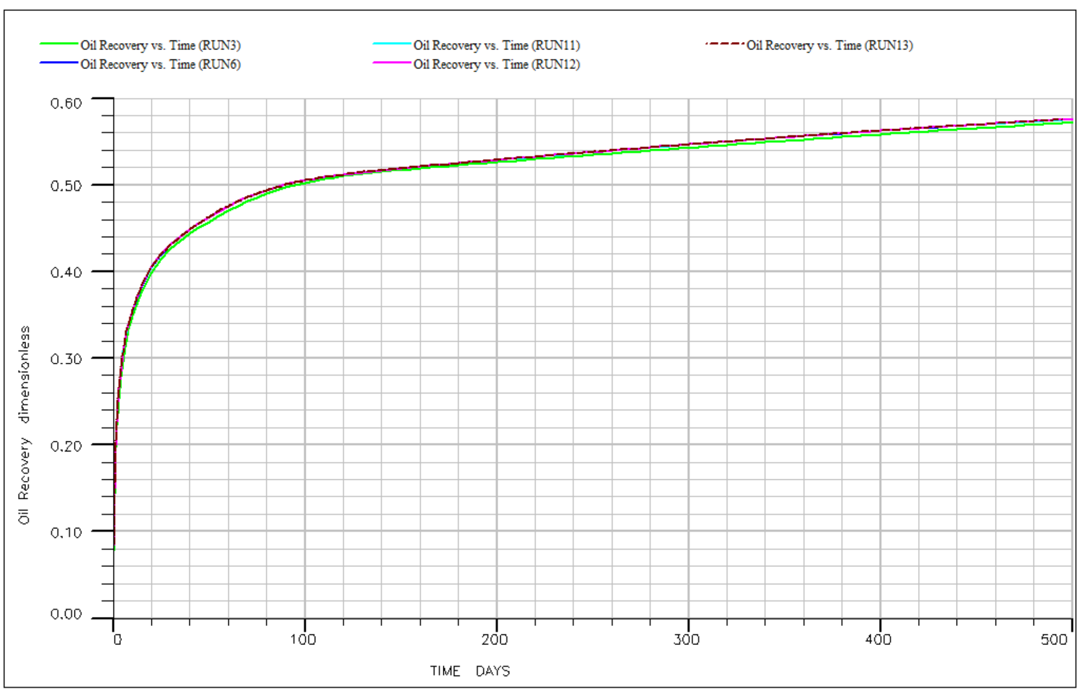

Figure 7

Oil Recovery from different fracture width (three stacks)

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3. RESULTS AND DISCUSSION

Figures 4-8 depict the results obtained from the various scenarios in the simulation study. Figure 4 and Table 2 present the oil recovery and recovery factor respectively from different number of matrix block stacks (i.e., RUN1 through RUN4) with capillary continuity. The results indicate that the oil recovery from a single block with a recovery factor of 0.5998 was higher when compared with other modeled matrix blocks in the simulation study. In addition, the results further show that the oil recovery and the recovery factor obtained from the study decreased as the matrix blocks (number of block stacks) increased. This observation in the oil recovery and recovery factor are governed by the fact that in gas-oil gravity drainage, the gravity forces dominate the flow in the oil saturated matrix. Thus, suggesting that the oil in the saturated matrix was displaced as the gravity forces exceeded capillary forces in the matrix. In the single block model, the capillary force in the oil saturated matrix depended on the block's height which was exceeded by the gravity force. This resulted in the high oil recovery as well as recovery factor compared with other modeled matrix blocks, as there was no holding back of oil in the single matrix block by capillarity. The dependency of capillary force in the oil saturated matrix on matrix blocks' (stack) height was observed as the matrix blocks (stack) were increased in the simulation study. These account for the less oil recovery and recovery factor obtained from the increased matrix blocks' height (number of blocks stack), since there was capillarity holding back of oil in the matrixes.

Figure 5 and Table 3 present the oil recovery and recovery factor from matrix blocks with stacks of 2, 3 and 5 blocks (i.e., RUN5, RUN6 and RUN7 respectively) with capillary discontinuity. The results depict a decrease in oil recovery as well as recovery factor as the matrix block height (number of stacks) increased. The reason for this is attributed to the increased capillarity in the oil saturated matrix block as the matrix block's height increased. The increased capillarity in the matrix block as the number of matrix block stacks increased resulted in the withholding of some of the recoverable oil in the matrix. This in turn resulted in less oil recovery and recovery factor in RUNS 6 and 7 (i.e., 3 and 5 block stacks respectively) compared to RUN5 (i.e., 2 block stacks). In addition, further comparison of the corresponding matrix block stacks between capillary continuity and discontinuity depict that there was a slight increase in the oil recovery and recovery factor from capillary discontinuity compared to capillary continuity as presented in Tables 2 and 3. This is due to the presence of fractures between matrix blocks which increased the gravity forces around the matrix block while reducing the capillary forces in the oil saturated matrix. On the other hand, capillary continuity with the absence of fractures between matrix blocks yielded low oil recovery and recovery factor. Therefore, capillary discontinuity in fractured porous media will result in increased oil recovery from gas-oil gravity drainage.

Figures 6-8 depict the oil recovery from the different modeled matrix blocks with various degree of capillary discontinuity. Figure 6 shows the oil recovery obtained from two matrix block stacks. The result indicates that there was no significant difference from the oil recovery obtained from varying the degree of capillary discontinuity in the matrix block. These observed results are due to the fact that in fractured porous media, the fractures are passive channels with no oil saturation and storativity. In addition, the injected gas around the matrix that displaces the oil is dependent on the matrix height not the fracture width (b). Thus, in gas-oil gravity drainage, the injected gas surround the oil saturated matrix through the fractures and reduces the capillary contrast between the matrix and the fracture thereby displacing the oil from the matrix block. Also, varying the degree of capillary discontinuity as a result of increased fracture width (b) has little or no effect on oil recovery from gas-oil gravity drainage in fractured porous media. Figures 7 & 8 depict the oil recovery obtained from three and five matrix block stacks respectively. Apparently, the results indicate no significant difference as was observed in Figure 6 with two matrix block stacks. Thus, it is evidenced from the foregoing discussion that the degree of capillary discontinuity (increased fracture width) in oil recovery from gas-oil gravity drainage is inconsequential. Rather, the presence of capillary discontinuity resulted in increased oil recovery and recovery factor as compared to capillary continuity from gas-oil gravity drainage.

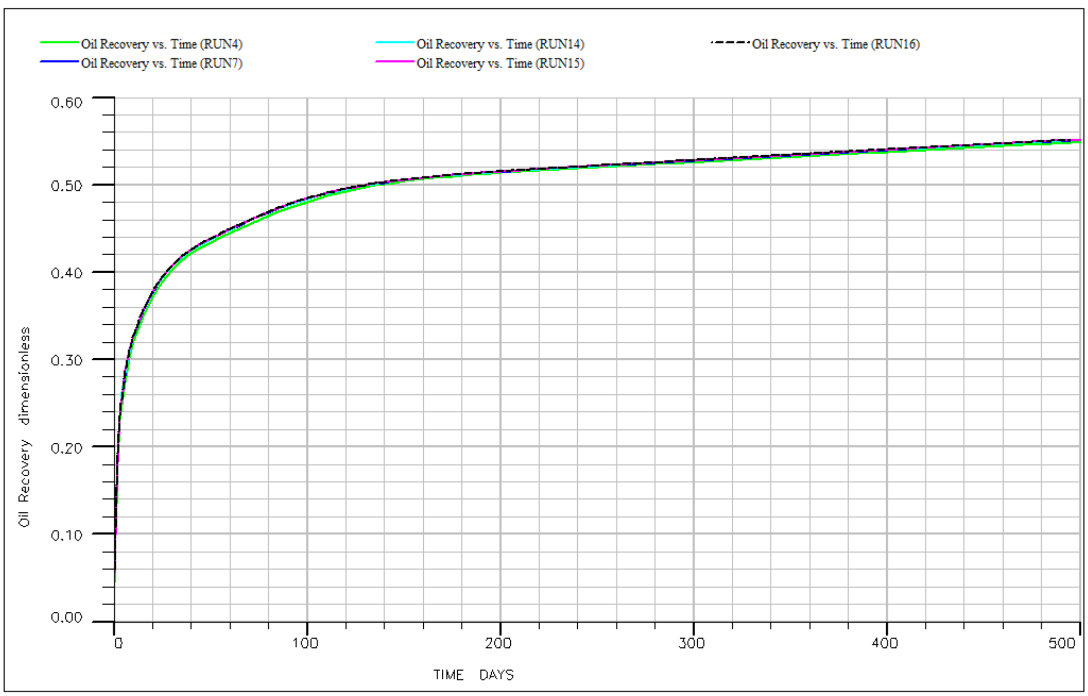

Figure 8

Oil Recovery from different fracture width (five stacks)

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4. CONCLUSION

In both homogeneous and heterogeneous oil reservoirs, gravity drainage has been the most prolific recovery mechanism compared to other recovery mechanisms. Gas-oil gravity drainage contributes substantially to the recovery process in fractured reservoirs as a result of capillary contrast between the matrixes and the fractures in the reservoir. In the course of this simulation assessment of gas-oil gravity drainage in fractured porous media, reservoirs with capillary continuity and discontinuity were modeled. Based on the results obtained, the following conclusions are drawn:

1. The matrix block height is very significant in oil recovery from gas-oil gravity drainage. Higher recovery was obtained in a single block with less capillary threshold height compared to increased matrix block stacks.
2. Capillary continuity between the matrix blocks reduced the efficiency of oil recovery from gas-oil gravity drainage as a result of the capillarity holding back oil in the saturated matrix.

The presence of capillary discontinuity between the matrixes enhanced oil recovery from the matrix block. In addition, varying the degree of capillary discontinuity between the matrixes had no effect on oil recovery from gas-oil gravity drainage in fractured porous media.

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