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Investigation of The Effect of Depth and Elasticity Modulus Difference between Reservoir Rock and the Surrounding Rock on Stress Arching

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Abstract

In this paper, the compression drive mechanism, which can be considered as the most related oil drive mechanism with the geomechanical properties of the reservoir, has been investigated. The constant total vertical stress on the reservoir and uniaxial reservoir compaction with zero lateral strain are two main assumptions in the conventional reservoir compaction modeling. These assumptions are not considering the stress arching which leads to a reduction in the total vertical stress. In this paper, due to the high capability of Abaqus software in numerical modeling of porous media, this software has been used to model the compaction of oil reservoirs with different elastic properties and located at different depths. Based on the obtained results, the difference in the elastic modulus of the reservoir with the surrounding rock and the ratio of depth to the dimensions of the reservoir are the most important parameters controlling the stress arching. Also, the study of the effect of stress arching on the compaction drive mechanism showed that the stress arching can reduce the compaction of reservoir pores by up to 50% and halve the oil production compared to its initial estimate by the compaction drive mechanism without considering the stress arching. Therefore, it is necessary to consider the effect of stress arching in estimating oil recovery due to compaction drive mechanism, especially in fields with a high depth to lateral expansion ratio and reservoir rocks with a lower modulus of elasticity than the surrounding rocks.

Key words: *stress arching, compaction drive, reservoir stress path, oil recovery, reservoir compaction*

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Extended Abstract:

1. Introduction

The compaction of reservoir rock is a known mechanism for the extraction of oil content of the rock pores. The state of stresses and its change during depletion of the reservoir have an important impact on oil recovery, directly through compaction drive and indirectly through permeability change (Holt et al. 2004). Conventionally, in reservoir compaction modeling, the vertical stress on the reservoir is assumed to be constant. With this assumption, the increase in effective stress on the reservoir rock is equal to the decrease in pore pressure multiplied in the Biot coefficient. However, a reduction in total stresses by reducing the pore pressure of the reservoir is indicated in periodic measurements of in situ stresses in different oil fields (Asaei, Moosavi, and Aghighi 2018). This decrease is due to stress arching, as a result of which a part of the vertical stress induced from the overburden weight is transmitted to the side burden of the reservoir (Sayers and Schutjens 2007, Gao and Gray 2020). Various driving mechanisms are responsible for oil production from reservoir rock, each of which in turn causes the extraction of a part of the in situ oil in the reservoir rock. The typical participations of each drive mechanism in oil production are shown in Table 1 (Sanni 2018).

Table 1. The participations of drive mechanisms in oil recovery (Sanni 2018)

Drive mechanism	Recovery of original oil (%)
Depletion drive	5-25
Segregated gas-cap drive	15-40
Compaction drive	2-5
Water drive	15-60

Among the mentioned drive mechanisms, compaction drive is in the field of geomechanics and is discussed in this paper. Although in most reservoirs rarely more than 5% of the total oil recovery are due to the reservoir compaction, in some reservoirs, this mechanism has a significant contribution in the oil recovery.

2. Materials and methods

In this paper, the effects of stress arching on the stress distribution and reservoir compaction are modeled using the ABAQUS software. Also, concerning the importance of compaction drive mechanism, the effect of stress alteration due to stress arching in different parts of the reservoir on the final oil recovery is investigated. For this purpose, a disk shape reservoir with a height of 200 meters and a redial of 1000 meters located in three different depths of 1000, 2000, 3000 meters were modeled. In addition to the depth of the reservoir, the ratio of Young's modulus of the reservoir rock (Er) to its surrounding rock (Es) was also considered as one of the variables in modeling, and models were repeated for three ratios of Es/Er =1, 5 and 10. In the first molding set, the Poisson’s ratio of the reservoir and its surrounding rock is considered to be the same and equal to 0.3, the porosity of the reservoir rock is 25%, and its Young modulus is equal to 5 GPa. Also, the initial reservoir pressure was assumed to be 25 MPa at the beginning of production, which reaches 5 MPa at the end of extraction.

3. Results and Conclusion

Figure 1 show the results of the reservoir model located at a depth of 2000 m with a ratio of Es/Er=5.

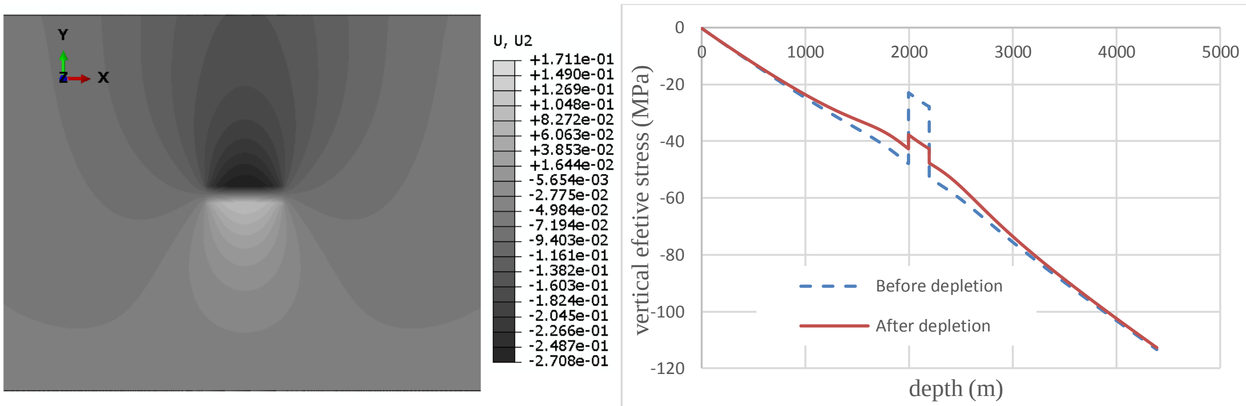

Fig. 1-a) The vertical displacement around the depleted reservoir and raising the lower part of the reservoir due to the vertical stress reduction,b) Effective vertical stress changes along the central axis of the reservoir

Figure 1a shows the vertical displacement that occurred in the reservoir and the surrounding rock due to the reservoir withdrawal. Based on the results presented in this Figure, the reservoir floor is displaced upwards by reducing the reservoir pore pressure, which indicates the stress arching occurrence in the reservoir overburden and reducing the total vertical stress applied to the reservoir floor. Figure 1b shows the total vertical stress changes along the central axis of the reservoir. In Figures 1b, the reduction of the vertical stress at the top and bottom of the reservoir due to its depletion can be seen. Figure 2a presents the results of the calculation of the vertical stress path for the 9 modeling statuses. Figure 2b shows volumes of the reservoir pores compaction that is equal to the amount of oil produced due to the compaction drive mechanism.

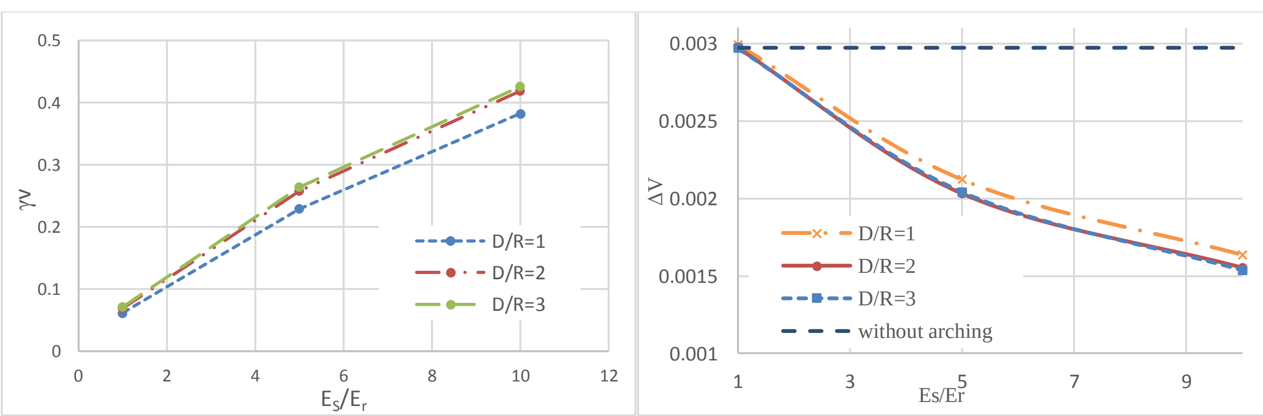

Fig. 2-a) The vertical stress path in different D/r and Es/Er ratios, b) The effect of stress arching on the oil recovery due to compression drive mechanism

As can be seen in Figure 2a, Young's modulus ratio of the reservoir and the surrounding environment has a significant effect on the arching coefficient, but the aspect ratio (D/r) has not such a tangible effect. As can be seen in Figure 2b, in all three D/r ratios when the elastic modulus of the reservoir and the surrounding rock are the same, the reservoir pore volume reductions obtained by numerical modeling and the amount calculated using pro_elastic reletion are almost identical. It should be mentioned, the pores compressibility (Cpp) of the modeled reservoirs, based on pro-elastic reletion will be equal to 0.59 GPa^{-1}. Also, change in the pore volume induced by pore pressure dropping of 20 MPa will be equal to 0.00297 m^3 per unit the volume ($1m^3$) of the reservoir rock.

4. Conclusion

The results of reservoir depletion modeling using ABAQUS software indicated that the stress path coefficients, which are key parameters in the reservoir compaction, are very different from the results obtained based on the pro-elastic relations and uniaxial compaction model. The modeling indicated Young's modulus contrast between the reservoir and the surrounding rock have the greatest impact on the reservoir compaction. Accordingly, the maximum reservoir compaction is obtained when the elastic modulus of the reservoir and the surrounding rock are the same, in this case the reservoir geometry does not affect its compaction volume, and the reservoir compaction will be equal to the calculated value based on the uniaxial compaction model. However, it should be noted that even in this case, the stress path coefficients are different from the values calculated based on the uniaxial compression model and the effect of stress arching on distribution of stresses and other parameters affected by it, such as reservoir permeability and compressibility cannot be neglected.

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