Contribution ID: **384** Type: **Poster**

Simulation of spontaneous imbibition in tight oil reservoir with complex hydraulic fracture network

Thursday 17 May 2018 13:30 (15 minutes)

Tight oil reservoirs are widely distributed around the world and playing an important role in the energy industry. Multistage hydraulic fracture technology has shown a great success in tapping these reservoirs because it improves fracture conductivity and brings higher oil yields. Nevertheless, enhanced oil production from stimulated tight reservoirs is challenging because of the complex fracture distribution and matrix with ultra-low permeability. Recent studies suggested that water huff-n-puff, which was proposed to take the full advantage of spontaneous countercurrent imbibition, can be a significant and effective technology for the improvement of tight oil recovery. Therefore, understanding the imbibition mechanism and its effect on the production performance of tight oil are essential.

On the reservoir scale, we developed a multi-component model to simulate the spontaneous imbibition of water into tight formations. The reservoir mainly includes three zones, i.e., hydraulic fractures, matrix, and stimulated area characterized through dual-porosity model. The relative permeability and capillary pressure hysteresis curves were measured experimentally and utilized. We also validated the efficiency of our model using physical experiments and explored the impact of several factors, e.g., wettability, relative permeability, capillary pressure, etc., on the imbibition oil recovery. It was confirmed that our model could reveal the difference of imbibition rate among different crude oil components. The most sensitive parameters are the capillary pressure, crude oil viscosity, and residual oil saturation. We suggested that the correlation between water-oil interfacial tension (IFT) and oil recovery is not monotonous; that is, with the increase of IFT, the recovery increases first and then decreases. At different IFTs, the gravity and capillary force exert distinct effects and the underlying mechanisms were probed. We also found that an optimal injection rate is required to maximize the oil recovery, and it can be optimized with fracture network characteristic and oil production rate.

We demonstrated that water huff-n-puff is an effective enhanced oil recovery (EOR) technique suitable for a stimulated reservoir having complicated fracture network. The networks having more complex fracture distributions and larger stimulated areas are beneficial for the oil exchange from matrix to fractures, but the imbibition occurred mainly in the near wellbore region. As the number of huff-puff cycle increases, the exchange efficiency and incremental oil volume decreases. We put forward the optimal water huff-n-puff development strategy, including injection pressure, injected volume, cycles, and soaking time. Research results show that exchange rate and quantity of fluid between fracture and matrix has changed significantly in fracture network systems and the oil recovery enhanced by imbibition can be up to 3%. Water huff-n-puff has been changed from a supplementary method to a new economical and effective development method for tight oil. Owing to its low cost and high investment benefit, it could be a potential EOR technology in tight oil reservoirs.

Key words: imbibition; fracture network; tight porous media; numerical simulation

References

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Session Classification: Poster 4

Track Classification: MS 1.23: Challenges in porous media characterization and modelling of multi-phase flow with capillarity