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Numerical investigation of air injection in a multilayer heavy oil reservoir

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Summary

Steam injection is widely used to recover the heavy oil resources. However, the performance and economics of steam injection is significantly affected by the reservoir heterogeneity, especially in the multilayer reservoirs. Air injection is recommended as a follow up process because of its low operating cost and high energy efficiency. In this study, air injection is applied in a multilayer heavy oil reservoir following the steam injection. Numerical simulation is performed to investigate the main mechanisms of air injection in a multilayer heavy oil reservoir. Geological properties from a real oilfield is obtained to develop the geomodel of a multilayer reservoir. A comprehensive reaction kinetics model, ranging from low temperature to high temperature oxidation reactions, is incorporated into the numerical model to represent the complex chemical reactions between heavy oil and oxygen. Moreover, local grid refinement is designed to capture the thin combustion front. Sensitivity analysis is subsequently carried out. It is found the permeability and oil saturation in each layer are the dominant parameters controlling the combustion front velocity. The combustion front propagates faster in the high permeability layer because more air is injected in that layer. It seems that combustion front moves faster in low oil saturation layer. This is due to the fact that less fuel is deposited in low oil saturation zone. Based on the well logging interpretation results, it is suggested that layers with similar properties are developed with the same time. In this way, the early combustion front breakthrough can be effective avoided and vertical sweep efficiency is greatly improved. Preliminary simulation results indicate that the oil recovery is increased by four times through proper injection scheme and vertical sweep efficiency is significantly enhanced.

Theory / Method / Workflow

A multilayer reservoir model is developed. A total of 15 layer are included in the model. The geological properties, including layer thickness, porosity, permeability, and oil saturation, are obtained from well logging interpretation as shown in Table 1. For the other interlayers, the permeability is set as 1 md because the high content of shales. Vertical wells are used in the oilfield and distance between injector and producer is about 100 m. The grid size is 10 m by 10 m and is refined as 1 m in the direction of combustion front propagation. The simulation model of a multilayer reservoir is displayed in Figure 1. A comprehensive reaction kinetics model is incorporated in the model (Yang et al., 2017). In the production, safety limits are set to monitor the oxygen production. The relative permeability curves are used as those presented in the literature (Wang et al., 2019).

Table 1 reservoir properties in each layer

Layer No.	Thickness, m	Porosity, %	Permeability, mD	Oil saturation, %
1	5.2	20.0	547.2	16.7
3	0.5	24.8	839.7	25.6
5	1.6	24.2	775.8	39.0
7	3.9	33.6	3269.3	63.7
9	1.7	32.5	2726.4	68.9
11	1.6	34.2	3443.8	66.9
13	1.9	26.8	1317.5	33.1
15	1.8	31.6	2685.9	54.0

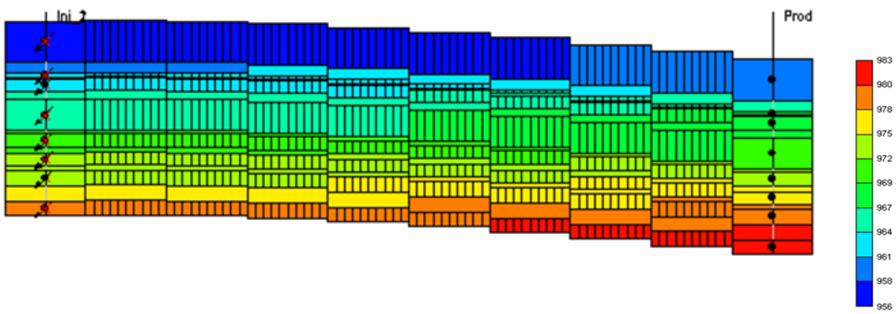


Figure 1 The simulation model of a multilayer heavy oil reservoir (grid top)

Results, Observations, Conclusions

Sensitivity analysis is carried out to investigate the effect of different properties on combustion front propagation. In this work, temperature is as indicator as the combustion front location. Based on previous experimental results in the literature (Moore et al., 1999a; 1999b), the high temperature oxidation reaction is activated when the temperature is higher than 350 ^{o}C. The effect of permeability and oil saturation is investigated, respectively.

Figure 2 presents the effect of permeability on combustion front propagation. Three representative layer are included in the model, namely, 2000 mD, 1000 mD, and 500 mD. The combustion front propagates faster in the high permeability layer. This is mainly because more air or oxygen is introduced in the high permeability layer.

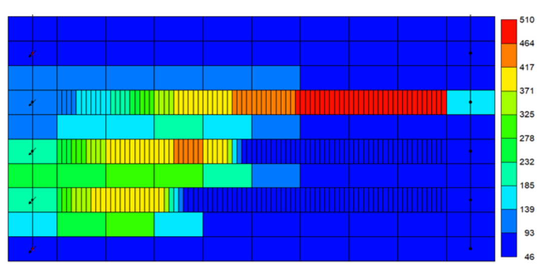


Figure 2 Effect of permeability in each layer on combustion front velocity

Figure 3 presents the effect oil saturation on combustion front propagation. Three representative layer are included in the model, namely 0.8, 0.6, and 0.4. The simulation results indicate that the combustion front propagates faster in the low oil saturation layer. This is mainly due to the fact that less fuel is deposited in the low oil saturation layer. In addition, the effect of layer thickness is also investigated and results indicate layer thickness has little effects on combustion front velocity.

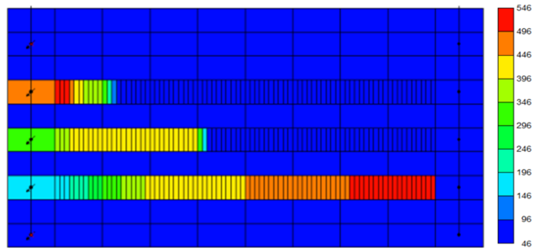
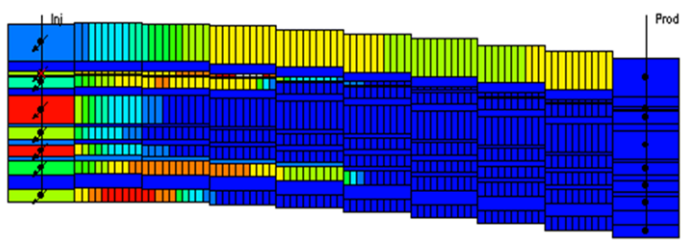
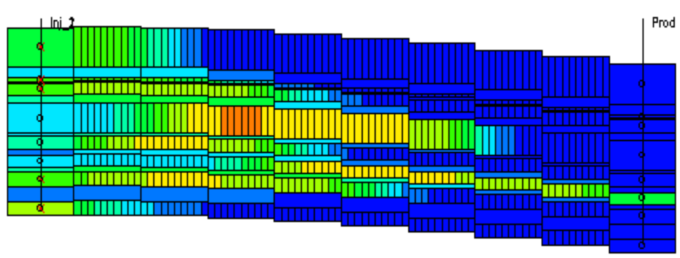


Figure 3 Effect of oil saturation in each layer on combustion front velocity

In order to improve the oil recovery in the multilayer reservoir, the air is injected separately in different layers. Based on the geological properties in the Table 1. It is recommended layer #7, #9, and #13 can be developed at the same time, followed by layer #15. Layer #3, #5, and #13 can be operated at the same time. In this way, the early combustion front breakthrough can be effective avoided and vertical sweep efficiency is greatly improved. Figure 4 presents the performance between two operation schemes. When the air injection is designed based on the various properties of layers, the combustion front sweep efficiency can be significantly improved.



(a)



(b)

Figure 4 Comparison of air injection performance between two injection schemes

Novel/Additive Information

The workflow proposed in this work provides technical guide for development of multilayer reservoirs using air injection. Through properly designed injection strategies, air injection performance and combustion front sweep efficiency in the multilayer reservoir can be significantly improved.

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