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Investigation on effectiveness of analytical models to describe steam chamber growth during steam-assisted gravity drainage

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Abstract

The analysis of analytical approaches to steam chamber growth during crude oil recovery by steam assisted gravity drainage method has been represented. The numerical model which takes into account most of the assumptions applied to analytical approaches has been developed and used for the effectiveness assessment. The model includes the mass balance equations for water, steam and oil saturations, the energy conservation law with latent heat of vaporization/condensation of water as well as Darcy's law of filtration. Computer implementation of the model is based on numerical solution to the developed system of equations by finite-element method with respect to the saturation and pressure variables. The results of numerical simulation have shown a quasi-stationary regime of the steam chamber growth in horizontal and vertical directions caused by convective flux of cold water to the interface. However, the considered analytical solutions predict a linear (or close to it) rise of the steam chamber during the whole process of heating. This can lead to the incorrect values of oil production rates on the initial stage of recovery. At the stage of vertical growth a formula which takes into account non-stationary heat flux through the steam chamber boundary gives the best qualitative agreement with numerical solution. Meanwhile a qualitative and quantitative agreement between the most considered models and numerical results has been observed when the steam chamber approached to the top of oil horizon. The analytical evaluations of its width after reaching the top have a qualitative disagreement with the results of the proposed model which predicts substantially non-linearity of the steam chamber evolution.

Keywords

crude oil, steam-assisted gravity drainage, multiphase flow, multiphysics modelling, analytical models

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References

1. Коноплев Ю.П. *Научно-методические основы проектирования и анализа термошахтной разработки нефтяных месторождений*: дис. … д-ра техн. наук / Всерос. нефтегазовый НИИ им. акад. А.П. Крылова. М., 2004. 253 с.
2. Костина А.А., Желнин М.С., Плехов О.А. Исследование особенностей движения нефти в пористой среде в процессе парогравитационного дренажа // *Вестник Пермского научного центра*. 2018. № 3. С. 6–16. doi:10.7242/1998-2097/2018.3.1
3. *Справочник химика. Т. I. Общие сведения, строение вещества, свойства важнейших веществ, лабораторная техника* / под ред. Б.П. Никольского. М.: Химия, 1966. 1072 с.
4. Хисамов Р.С., Морозов П.Е., Хайруллин М.Х., Шамсиев М.Н., Абдуллин А.И. Моделирование процесса парогравитационного дренирования с учетом предельного градиента давления // *Нефтяное хозяйство*. 2018. № 8. С. 48–51. doi:10.24887/0028-2448-2018-8-48-51
5. Akin S. Mathematical modeling of steam-assisted gravity drainage // *Computers & Geosciences*. 2006. Vol. 32. P. 240–246. doi:10.1016/j.cageo.2005.06.007
6. Bogdanov I.I., Ganaoui K.El, Kamp A.M. COMSOL 2D simulation of heavy oil recovery by steam assisted gravity drainage // *Proceedings of the European COMSOL Conference 2007, 23–24 October, 2007, Grenoble, France.* Grenoble: COMSOL France, 2007.
7. Butler R.M. *Thermal recovery of oil and bitumen*. New Jersey; Englewood Cliffs: Prentice-Hall Inc., 1991. 528 p.
8. Butler R.M., Stephens D.J. The gravity drainage of steam-heated heavy oil to parallel horizontal wells // *J. of Canadian Petroleum Technology*. 1981. Vol. 20(2). P. 90–96.
9. Butler R.M., McNab G.S., Lo H.Y. Theoretical studies on the gravity drainage of heavy oil during in-situ steam heating // *Canadian J. of Chemical Engineering.* 1981. Vol. 59, N 4. P. 455–460.
10. Chang J., Ivory J., Tunney C. Numerical simulation of steam-assisted gravity drainage with vertical slimholes // *Society of Petroleum Engineers SPE Canadian Unconventional Resources Conf., 15–17 November 2011, Calgary, Alberta, Canada.* Richardson: Soc. Petroleum Engineers, 2012. Article N SPE-148803-PA. https://doi.org/10.2118/148803-PA
11. Keshavaraz M., Harding T.G., Chen Z.J. Modification of Butler's unsteady-state SAGD theory to include vertical growth of steam chamber // *Society of Petroleum Engineers SPE Canada Heavy Oil Technical Conf.,*
7–9 June 2016, Calgary, Alberta, Canada. Richardson: Soc. Petroleum Engineers, 2016. Article N SPE-180733-MS. https://doi.org/10.2118/180733
12. Lake L.W. *Enhanced Oil Recovery*. Englewood Cliffs: Prentice-Hall Inc., 1989. 550 p.
13. Lee H., Kharangate C., Mascarenhas N., Park I., Mudawar I. Experimental and computational investigation of vertical downflow condensation // *International J. of Heat and Mass Transfer*. 2015. Vol. 85. P. 865–879. doi:10.1016/j.ijheatmasstransfer.2015.02.037
14. Liu H., Cheng L., Huang S., Jia P., Chen M. Evolution characteristics of SAGD steam chamber and its impacts on heavy oil production and heat consumption // *International J. of Heat and Mass Transfer.* 2018. Vol. 121. P. 579–596. doi:10.1016/j.ijheatmasstransfer.2018.01.038
15. Reiss J.C. A steam – assisted gravity drainage model for tar sands: linear geometry // *J. of Canadian Petroleum Technology*. 1992. Vol. 10, N 1. P. 14–20. https://doi.org/10.2118/92-10-01
16. Shafiei A., Dusseault M.B. Geomechanics of thermal viscous oil production in sandstones // *J. of Petroleum Science and Engineering.* 2013. Vol. 103. P. 121–139. doi:10.1016/j.petrol.2013.02.001
17. Shaolei W., Linsong C., Wenjun H., Shijun H., Shuai L. Prediction for steam chamber development and production performance in SAGD process // *J. of Natural Gas Science and Engineering*. 2014. Vol. 19. P. 303–310. https://doi.org/10.1016/j.jngse.2014.05.021
18. Shi X., Okuno R. Analytical solution for steam-assisted gravity drainage with consideration of temperature variation along the edge of a steam chamber // *Fuel*. 2018. Vol. 217. P. 262–274. https://doi.org/10.1016/j.jngse.2014.05.021
19. Yin Y., Liu Y. FEM analysis of fluid-structure interaction in thermal heavy oil recovery operations // *Sustainability*. 2015. Vol. 7. P. 4035–4048. doi:10.3390/su7044035
20. Zargar S.M., Farouq A. Analytical modelling of steam chamber rise stage of Steam-Assisted Gravity Drainage (SAGD) process // *Fuel*. 2018. Vol. 233. P. 732–742. doi:10.1016/j.fuel.2018.06.106