Journal of Petroleum Exploration and Production Technology (2019) 9:2145–2147
https://doi.org/10.1007/s13202-019-0615-z

SHORT COMMUNICATION – PRODUCTION ENGINEERING

Slight insights and perspectives of future heavy oil recovery

Fengrui Sun[1,2,3] · **Yuedong Yao**[1,2,3] · **Guozhen Li**[3]

Received: 20 November 2018 / Accepted: 11 January 2019 / Published online: 21 January 2019

Abstract

In this paper, we put forward critical future prospects based on the paper that was published on International Journal of Heat and Mass Transfer. At present, engineers are familiar with the advantages and disadvantages of different working fluids in thermal recovery of heavy oil. For all the oil displacement mechanism, they can be summarized into only three aspects: (a) physical heat conduction, (b) chemical reactions, and (c) the differences in hydrodynamic properties between fluids. This is already well known in the existing body of knowledge. However, how much will each of these three mechanisms contribute to the total oil recovery efficiency is quite interesting and important to the industry. Based on the commented paper and some related references, we pointed out the future research directions in this area.

Keywords Heavy oil · Different working fluids · Three main displacement mechanisms · Contribution degree · Quantitative characterization

Insights and perspectives

The paper entitled "Experimental study on the mechanism of enhanced oil recovery by multi-thermal fluid in offshore heavy oil" published on International Journal of Heat and Mass Transfer presented important additives to the existing knowledge on the oil displacement mechanisms under different thermal fluid flooding condition. At present, the study on heavy oil displacement mechanisms can be divided into three branches: (a) the physical heating mechanism (Sun et al. 2018a, b, c; Zhao et al. 2018), (b) the chemical reaction mechanism (Tiyao et al. 2010; Huang et al. 2018; Xu et al. 2013), and (c) the hydrodynamic mechanism (Bao et al. 2016; Wu et al. 2018).

For the first mechanism, the heavy oil will be heated to a higher temperature under thermal fluid injection, and the corresponding oil viscosity will be reduced. As a result, the mobility of heavy oil is increased. This oil displacement mechanism is caused by heat conduction. It has been pointed out that the contribution of heat conduction on oil recovery efficiency increases rapidly with the increase of steam quality, and the effect of steam temperature on physical heat conduction can be neglected when it is superheated steam (Sun et al. 2018b). This study revealed that physical heating is not the dominant factor in controlling oil recovery efficiency when it is superheated steam. However, it has been reported that the oil recovery efficiency is greatly increased when saturated steam is replaced with superheated steam (Xu et al. 2013). This finding showed that either chemical reactions or the hydrodynamic mechanism is the dominant controlling factor in increasing heavy oil displacement efficiency.

For the second mechanism, the components in heavy oil or compositions from rock mineral react with water under high-temperature condition (Xu et al. 2013). The heavy components in heavy oil can be reduced to lighter ones after hydrothermal pyrolysis reactions between oil components and water, and the permeability of rock matrix can be increased due to high-temperature steam flooding (Xu et al. 2013). One may find that the above-mentioned two

✉ Fengrui Sun
13126682711@163.com

✉ Yuedong Yao
1181890005@qq.com

✉ Guozhen Li
1174107928@qq.com

1 State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum-Beijing, Beijing 102249, People's Republic of China

2 College of Petroleum Engineering, China University of Petroleum-Beijing, Beijing 102249, People's Republic of China

3 China University of Petroleum-Beijing, Beijing 102249, People's Republic of China

mechanisms can be achieved under static conditions. Note that the physical heating and chemical reactions are the basics of all mechanisms. This is because the decrease in oil viscosity and increase in rock permeability must be the fundamental objectives to achieve if the heavy oil displacement efficiency is wanted to be increased.

For the third mechanism, the fluid mobility varies according to relative permeability of fluid phase. The heated radius will be larger if the thermal fluid is injected to a farther place in reservoir, so that physical heating and chemical reactions can take place in a farther place. Consequently, the oil displacement efficiency is increased.

The results from the commented paper are well known before reading. As a result, quantitative characterization of contribution degree of the mentioned three mechanisms can have practical value. We expect the authors to conduct CMG simulations to find out the contribution degree of physical heating, chemical reaction and hydrodynamics on heavy oil recovery efficiency under different working fluids, so that engineers are able to quantitatively master different recovery mechanisms in practice.

The authors have conducted a series of studies on thermal recovery of heavy oil, geothermal energy recovery and shale oil and gas development (Sun et al. 2017a b, c, d, e, f, g; Sun et al. 2018d, e, f, g, h, i j, k, l, m, n, o, p, q), and the further readings of these articles are listed below and recommended (Sun et al. 2017h, 2018r, s, t, u, v, w, x, y, z, aa, ab, 2019a, b; Yu et al. 2019).

Acknowledgements The research was supported by National Science and Technology Major Projects of China (Nos. 2016ZX05042, 2017ZX05039 and 2016ZX05039) and the National Natural Science Foundation Projects of China (Nos. 51504269, 51490654 and 40974055). The authors also acknowledge Science Foundation of China University of Petroleum, Beijing (No. C201605), the National Basic Research Program of China (2015CB250900), the Program for New Century Excellent Talents in University (Grant no. NCET-13-1030) to support part of this work.

References

Bao Y, Wang J, Gates ID (2016) On the physics of cyclic steam stimulation. Energy 115:969–985

Huang S, Cao M, Cheng L (2018) Experimental study on the mechanism of enhanced oil recovery by multi-thermal fluid in offshore heavy oil. Int J Heat Mass Transf 122:1074–1084

Sun F, Yao Y, Li X, Yu P, Ding G, Zou M (2017a) The flow and heat transfer characteristics of superheated steam in offshore wells and analysis of superheated steam performance. Comput Chem Eng 100:80–93

Sun F, Yao Y, Chen M, Li X, Zhao L, Meng Y, Sun Z, Zhang T, Feng D (2017b) Performance analysis of superheated steam injection for heavy oil recovery and modeling of wellbore heat efficiency. Energy 125:795–804

Sun F, Yao Y, Li X, Yu P, Zhao L, Zhang Y (2017c) A numerical approach for obtaining type curves of superheated multi-component thermal fluid flow in concentric dual-tubing wells. Int J Heat Mass Transf 111:41–53

Sun F, Yao Y, Li X, Zhao L (2017d) Type curve analysis of superheated steam flow in offshore horizontal wells. Int J Heat Mass Transf 113:850–860

Sun F, Yao Y, Li X, Zhao L, Ding G, Zhang X (2017e) The mass and heat transfer characteristics of superheated steam coupled with non-condensing gases in perforated horizontal wellbores. J Pet Sci Eng 156:460–467

Sun F, Yao Y, Li X, Tian J, Zhu G, Chen Z (2017f) The flow and heat transfer characteristics of superheated steam in concentric dual-tubing wells. Int J Heat Mass Transf 115:1099–1108

Sun F, Yao Y, Li X, He Li, Chen G, Sun Z (2017g) A numerical study on the non-isothermal flow characteristics of superheated steam in ground pipelines and vertical wellbores. J Pet Sci Eng 159:68–75

Sun F, Yao Y, Li X (2017h) Effect of gaseous CO_2 on superheated steam flow in wells. Eng Sci Technol Int J 20(6):1579–1585

Sun F, Yao Y, Li G, Li X (2018a) Effect of physical heating on productivity of cyclic superheated steam stimulation wells. J Pet Explor Prod Technol. https://doi.org/10.1007/s13202-018-0527-3

Sun F, Yao Y, Li G, Li X, Sun J (2018) Comparison of steam front shape during steam flooding process under varying steam state condition: numerical analysis. In: Abu Dhabi International Petroleum Exhibition and Conference, SPE-192996-MS, 12–15 November, 2018, Abu Dhabi, UAE. https://doi.org/10.2118/192996-MS

Sun F, Yao Y, Li G, Qu S, Zhang S, Shi Y, Xu Z, Li X (2018) Effect of pressure and temperature of steam in parallel vertical injection wells on productivity of a horizontal well during the SAGD process: a numerical case study. In: SPE International Heavy Oil Conference & Exhibition, SPE-193659-MS, 10–12 December 2018 in Kuwait City, Kuwait. https://doi.org/10.2118/193659-MS

Sun F, Yao Y, Li X (2018d) The heat and mass transfer characteristics of superheated steam coupled with non-condensing gases in horizontal wells with multi-point injection technique. Energy 143:995–1005

Sun F, Yao Y, Li X, Li G, Chen Z, Chang Y, Cao M, Han S, Chaohui L, Feng D, Sun Z (2018e) Effect of flowing seawater on supercritical CO_2—superheated water mixture flow in an offshore oil well considering the distribution of heat generated by the work of friction. J Pet Sci Eng 162:460–468

Sun F, Yao Y, Li X, Li G, Miao Y, Han S, Chen Z (2018f) Flow simulation of the mixture system of supercritical CO_2 & superheated steam in toe-point injection horizontal wellbores. J Pet Sci Eng 163:199–210

Sun F, Yao Y, Li X, Li G, Sun Z (2018g) A numerical model for predicting distributions of pressure and temperature of superheated steam in multi-point injection horizontal wells. Int J Heat Mass Transf 121:282–289

Sun F, Yao Y, Li X, Li G, Huang L, Liu H, Chen Z, Liu Q, Liu W, Cao M, Han S (2018h) Exploitation of heavy oil by supercritical CO_2: effect analysis of supercritical CO_2 on H_2O at superheated state in integral joint tubing and annuli. Greenh Gases Sci Technol 8(3):557–569

Sun F, Yao Y, Li X, Li G, Liu Q, Han S, Zhou Y (2018i) Effect of friction work on key parameters of steam at different state in toe-point injection horizontal wellbores. J Pet Sci Eng 164:655–662

Sun F, Yao Y, Li X, Li G, Han S, Liu Q, Liu W (2018j) Type curve analysis of multi-phase flow of multi-component thermal fluid in toe-point injection horizontal wells considering phase change. J Pet Sci Eng 165:557–566

Sun F, Yao Y, Li X, Li G, Chen M, Chen G, Zhang T (2018k) Analysis of superheated steam performance in offshore concentric dual-tubing wells. J Pet Sci Eng 166:984–999

Sun F, Yao Y, Li G, Li X (2018l) Numerical simulation of supercritical-water flow in concentric-dual-tubing wells. SPE J 23(6):2188–2201

Sun F, Yao Y, Li G, Li X, Lu C, Chen Z (2018m) A model for predicting thermophysical properties of water at supercritical state in offshore CDTW. Measurement 124:241–251

Sun F, Yao Y, Li G, Li X, Zhang T, Lu C, Liu W (2018n) An improved two-phase model for saturated steam flow in multi-point injection horizontal wells under steady-state injection condition. J Pet Sci Eng 167:844–856

Sun F, Yao Y, Li G, Li X (2018o) Geothermal energy extraction in CO_2 rich basin using abandoned horizontal wells. Energy 158:760–773

Sun F, Yao Y, Li G, Li X, Li Q, Yang J, Wu J (2018p) A coupled model for CO_2 & superheated steam flow in full-length concentric dual-tube horizontal wells to predict the thermophysical properties of CO_2 & superheated steam mixture considering condensation. J Pet Sci Eng 170:151–165

Sun F, Yao Y, Li G, Li X (2018q) Performance of geothermal energy extraction in a horizontal well by using CO_2 as the working fluid. Energy Convers Manag 171:1529–1539

Sun F, Yao Y, Li G, Li X (2018r) Geothermal energy development by circulating CO_2 in a U-shaped closed loop geothermal system. Energy Convers Manag 174:971–982

Sun F, Yao Y, Li G (2018s) Comments on: the flow and heat transfer characteristics of compressed air in high-pressure air injection wells [Arabian Journal of Geosciences (2018) 11: 519]. Arab J Geosci 11(20):631

Sun F, Yao Y, Li X (2018t) Numerical simulation of superheated steam flow in dual-tubing wells. J Pet Explor Prod Technol 8(3):925–937

Sun F, Yao Y, Li X (2018u) The heat and mass transfer characteristics of superheated steam in horizontal wells with toe-point injection technique. J Pet Explor Prod Technol 8(4):1295–1302

Sun F, Yao Y, Li X (2018v) Effect analysis of non-condensable gases on superheated steam flow in vertical single-tubing steam injection pipes based on the real gas equation of state and the transient heat transfer model in formation. J Pet Explor Prod Technol 8(4):1325–1330

Sun F, Yao Y, Li X, Li G (2018w) A brief communication on the effect of seawater on water flow in offshore wells at supercritical state. J Pet Explor Prod Technol 8(4):1587–1596

Sun F, Yao Y, Li G, Zhao L, Liu H, Li X (2018) Water Performance in Toe-point Injection wellbores at Supercritical State. In: SPE Trinidad and Tobago Section Energy Resources Conference, SPE-191151-MS, 25–26 June 2018 in Port of Spain, Trinidad and Tobago

Sun F, Yao Y, Li G, Mingda D (2018y) Transport behaviors of real gas mixture through nanopores of shale reservoir. J Pet Sci Eng. https://doi.org/10.1016/j.petrol.2018.12.058

Sun F, Yao Y, Li X, Li G (2018{) An Analytical equation for oil transport in nanopores of oil shale considering viscosity distribution. J Pet Explor Prod Technol. https://doi.org/10.1007/s13202-018-0486-8

Sun F, Yao Y, Li G (2018z) New analytical equations for productivity estimation of the cyclic CO_2-assisted steam stimulation process considering the non-Newtonian percolation characteristics. J Pet Explor Prod Technol. https://doi.org/10.1007/s13202-018-0518-4

Sun F, Yao Y, Li G, Li X (2018|) Effect of critical thickness on nanoconfined water fluidity: review, communication, and inspiration. J Pet Explor Prod Technol. https://doi.org/10.1007/s13202-018-0540-6

Sun F, Yao Y, Li G, Zhang S, Xu Z, Shi Y, Li X (2019a) A slip-flow model for oil transport in organic nanopores. J Pet Sci Eng 172:139–148

Sun F, Yao Y, Li G (2019b) Comments on Heat and mass transfer characteristics of steam in a horizontal wellbore with multi-point injection technique considering wellbore stock liquid [International Journal of Heat and Mass Transfer 127 (2018) 949–958]. Int J Heat Mass Transf 132:1319–1321

Tiyao Z, Linsong C, Chunbai H, Zhanxi P, Fengjun Z (2010) Calculation model of on-way parameters and heating radius in a superheated steam injection wellbore. Pet Explor Dev 37(1):83–88

Wu Z, Liu H, Zhang Z, Wang X (2018) A novel model and sensitive analysis for productivity estimate of nitrogen assisted cyclic steam stimulation in a vertical well. Int J Heat Mass Transf 126:391–400

Xu A, Mu L, Fan Z, Wu X et al (2013) Mechanism of heavy oil recovery by cyclic superheated steam stimulation. J Pet Sci Eng 111:197–207

Yu H, Li Q, Sun F (2019) Numerical simulation of CO_2 circulating in a retrofitted geothermal well. J Pet Sci Eng 172:217–227

Zhao L, Jiang H, Sun F, Li J (2018). Effect of steam state on the productivity of a horizontal well pair during the steam-assisted-gravity-drainage process: physical aspect analysis. In: spe trinidad and tobago section energy resources conference, SPE-191173-MS, 25–26 June 2018 in Port of Spain, Trinidad and Tobago. https://doi.org/10.2118/191173-MS