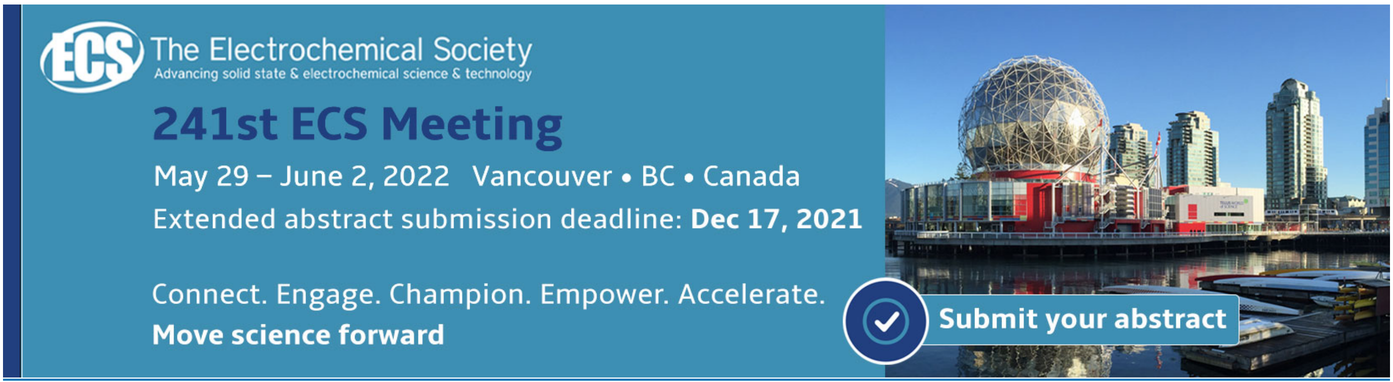
IOP Conference Series: Earth and Environmental Science

Screening of waterflooding, hot waterflooding and steam injection for extra heavy crude oil production from Tatarstan oilfield

To cite this article: A Pituganova *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **931** 012002



Screening of waterflooding, hot waterflooding and steam injection for extra heavy crude oil production from Tatarstan oilfield

A Pituganova, I Minkhanov, A Bolotov and M Varfolomeev

Department of Petroleum Engineering, Kazan Federal University, Kremlevskaya str. 18, 420008, Kazan, Russian Federation

Corresponding author's e-mail: pituganovaa@gmail.com

Abstract. Thermal enhanced oil recovery techniques, especially steam injection, are the most successful techniques for extra heavy crude oil reservoirs. Steam injection and its variations are based on the decrease in oil viscosity with increasing temperature. The main objective of this study is the development of advanced methods for the production of extra heavy crude oil in the oilfield of the Republic of Tatarstan. The filtration experiment was carried out on a bulk model of non-extracted core under reservoir conditions. The experiment involves the injection of slugs of fresh water, hot water and steam. At the stage of water injection, no oil production was observed while during steam injection recovery factor (RF) achieved 13.4 % indicating that fraction of immobile oil and non-vaporizing residual components is high and needed to be recovered by steam assisted EORs.

1. Introduction

Extra heavy crude oils (EHCO) are characterized by high density and viscosity. The world reserves of EHCO are estimated at more than 800 billion tons. In Russia, the proven oil reserves today amount to 18 billion tons from which more than 12 billion tons of extra-viscous oils reserves and 71.3% of the total volume are located in the West Siberian and Volga-Ural oil and gas regions. At the same time, the Ural and Volga regions contain 60.6% of the total Russian reserves of EHCO and 70.6% of viscous oils. EHCO deposits have been found in Tatarstan, Udmurtia, Bashkiria, Samara and Perm regions. Today, the share of extra heavy crude oil accounts for 23% of the total oil production in the Russian Federation. Serious reserves of EHCO are located in Tatarstan, they amount, according to various estimates, from 1.5 to 7 billion tons [1].

For the stability of energy sector, the world scientific community considers extra heavy oil as the main raw material [2]. The industrial development of this EHCO is proceeding at a slow pace due to the low profitability (or unprofitability) of their development [3].

Initially, for the development of heavy oil and bitumen deposits, the oil industry relied on cold production methods, mainly open-pit and mine development methods [4]. Thermal methods were later developed. The mechanism for extracting oil from a formation when a hot working agent is injected into it is based on changes in the properties of oil contained in the formation as a result of an increase in temperature. With an increase in temperature, the viscosity of oil, its density decreases, which favorably affects oil recovery [5]. Thermal enhanced oil recovery techniques, especially steam injection, are the most successful techniques for EHCO reservoirs.

2. Lab Experiment

2.1. Core preparation

For the experiments used grounded unextracted core (Figure 1). The ground rock was thoroughly mixed and pressed into the core holder by plunger (Table 1). The initial oil saturation *S*oi determined using core extraction was 77.24%.

Table 1. The core characteristics

Core lithology	Ground fraction, mm
Sandstone is brown uniform, fine-grained, poorly cemented, intensely oil-saturated with pyrite (diameter 0.5-1 cm) nodules	0.1÷1

(a) (b)

Figure 1. (a) initial full-size core, (b) grounded core to a fraction of 0.1 ÷ 1 mm

2.2. The set-up

The main objective of this study is to establish advanced recovery methods of extra heavy crude oil in the oilfield of the Republic of Tatarstan.

Filtration experiment were carried out on a bulk model of non-extracted core under reservoir conditions (P_{res}=0.5 MPa) in different injection modes. The experiment involves the injection sequence of water, hot water and steam.

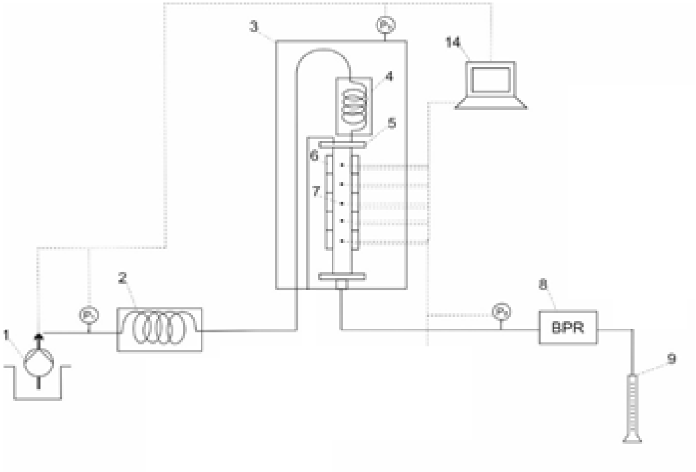


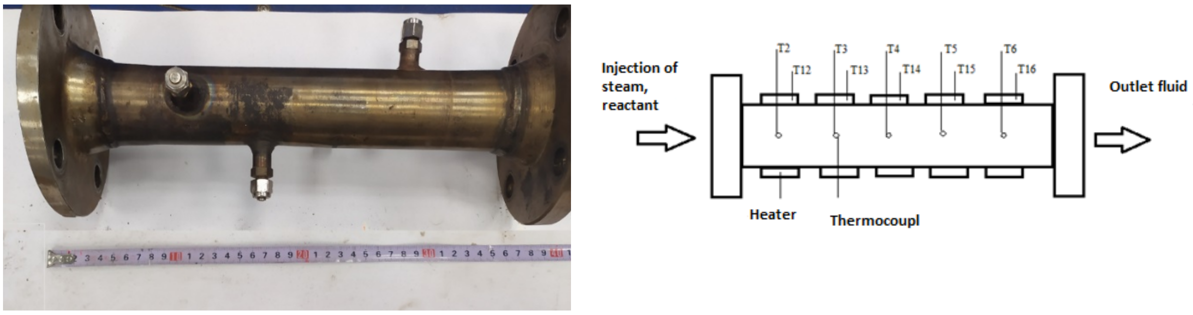
Figure 2. Scheme of the filtration equipment

The system consists of a precision high-pressure two plunger pump (1), dosing water at a constant rate to the input of an external steam generator (2), tubes connecting of external (2) and internal steam generators (4), core holder (5). The high-pressure chamber (3) includes an internal steam generator (4), core holder (5) with packed core material, ceramic electric heaters (6) and thermocouples (7) (Figure 2).

The fluid collection system consists of a back pressure regulator (8), which provides reservoir pressure maintenance in the model and fluid output to the separation burette, where separation occurs under standard conditions for liquid and gas.

Precision pressure sensors are installed at the inlet and outlet of the model and reflect the pressure change in real time. Thermocouples (7) are mounted on the core holder every 5 cm in the model and record the movement of the heat front in real time. Ceramic ring heaters for adiabatic maintenance are installed along the core holder (5) to prevent heat loss during the experiment. The control system for electric heaters (6) is configured to turn them on when the temperature inside the core holder model drops, and the heater turns off when the temperature inside the ring heater rises 5°C from the core model temperature. Each heater corresponds to a thermocouple installed in this heater. Thermocouples recorded the movement of the heat front in real time. Before the experiment, thermocouples were calibrated.

Thermocouples are assembled in accordance with the diagram in figure 3. The main axial thermocouples T2 – T6 are located in the center of the core. Thermocouples T12 – T16 are located under the heaters for temperature control during adiabatic heating of the core holder.



(a) (b)

Figure 3. (a) photo of core holder, (b) scheme of thermocouples positioning

After assembly the core holder was pressurized with a pressure about 4 MPa to check for leaks. To avoid sand grains entering the outlet tubes filter was installed. A high-pressure tube (with a core holder) was placed vertically to minimize gravitational effects.

2.3. Design of experiments

The experiment was carried out in 3 stages with different durations (Table 2).

Table 2. Experiment design

№	Injection stages	Duration, PV	Note
1	Water	2	Not effect
2	Hot water	3	Not effect
3	Steam	5	Until the oil supply is shut off

3. Results and Discussion

Figure 4 presents the temperature trend of the experiment. Water was injected at room temperature (T=23^{0}C). Hot water was injected at a temperature of 100^{0}C and steam was injected at a temperature of 200^{0}C.

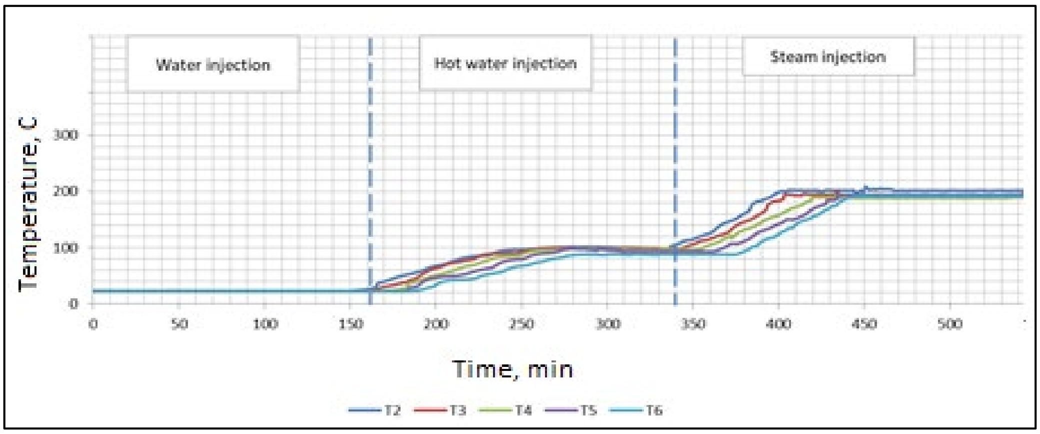


Figure 4. Temperature trend of the experiment

Figure 5 presents the pressure drop trend of the experiment. During the experiment, the pressure drop did not exceed 0.11 MPa.

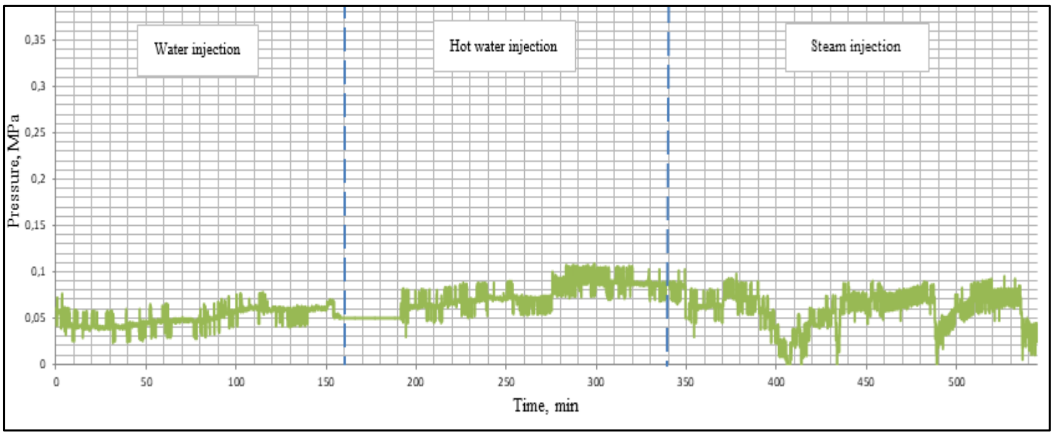


Figure 5. Pressure drop dynamic

Before and after experiment the permeability of model was determined by nitrogen injection. Permeability after the experiment improved by 14.7%. After steam injection density decreased by 14%, viscosity decreased 20603 times.

Table 3. Recovery factor after the experiment

№	Injected agent	RF, %
1	Water	0
2	Hot water	0
3	Steam	13.4

At the stage of water injection, no oil effluent was received while during steam injection RF achieved 13.4 % (Table 3).

Table 4. SARA analysis of initial and recovered oil (% mass)

Group	Initial oil*	Recovered at steam injection oil
Saturates (S)	29.4	72.7
Aromatics (Ar)	17.6	16.9
Resins (R)	32	4.6
Asphaltenes (A)	21	5.8

* Initial oil is characterized by a high resin and asphaltene content (32 and 21 % accordingly). The criterion of potential "Incompatibility" of initial oil can be used the numerical fraction of the ratio of the concentrations of asphaltenes (A) and resins (R) is used: A/R = 0.66 Value A / R > 0.35 is considered to indicate incompatibility at mixing with lights components. Also commonly used criterion Fouling Index (FI) [8,9] which is calculated as FI = Ar/A. For the original oil FI = 0.84 that means it is "Incompatible" due to sedimentation of asphaltenes (for stable oils FI <15 ÷ 17).

According to SARA analysis of produced oil by steam injection (Table 4) it contains much more light fractions than the initial oil in place. It means that steam injection stimulate distillation of light components leaving behind the heavies fraction (resins and asphaltenes). It should be noted a significant effect of core model preparation on EHCO recovery at steam injection. According to literature data [11,12] recovery factor due to steam injection on EHCO disintegrated extracted and then oil-saturated core model achieves up to 40÷70% that deviates from recovery 13.4 % for unextracted core model in which fraction of immobile oil and non-vaporizing residual components is higher.

4. Conclusion

Fresh water and hot water flooding is ineffective for the studied nonextracted core model due to zero oil production. Experiments on unextracted core shows recovery at steam injection lower in comparison with literature data. After steam injection fouling by immobile and non-vaporizing residual components crude oil needs to be recovered by additional EOR that is the subject of further work of our study.

Acknowledgments

This work was funded by the subsidy allocated to Kazan Federal University for state assignment in the sphere of scientific activities (Project № 0671-2020-0048 of State Assignment № 075-00216-20-05 of 04.06.2020 (Part II Section 1))

References

[1] Danilova Ye A 2008 Heavy Oil in Russia *The Chemical Journal* vol 12 p 34- 37
[2] Muslimov R K 2010 Non-traditional and alternative energy sources: prospects development *Rational development of mineral resources* vol 1 p 46-52
[3] Makarevich V N Iskritskaya N I Bogoslovsky S A 2010 Resource potential of heavy of oils of the Russian Federation: development prospects *Oil and gas geology Theory and Practice* vol 5 chapter 2 p 6-6
[4] Musin M M Lipaev A A Khisamov R S 2019 Development of oil fields (Moscow, Vologda: Infra-Engineering) p 328
[5] Muslimov R X 2005 Unconventional oil deposits - a significant potential for the further development of old oil-producing regions *Georesources* vol 1 chapter 16 p 2-8
[6] Serfass J P Joly A Samanos J 1992 SBS-Modified Asphalts for Surface Dressing—A Comparison Between Hot-Applied and Emulsified Binders *Polymer Modified Asphalt Binders* ASTM International p 281-308
[7] Parker R J and Rahimi P 2001 Stability of heavy crude oil blends after partial upgrading by visbreaking (Canada)
[8] US Patent 4762797 1988 “Method for determining the fouling tendency of hydrocarbons” Inventor: G B Dickakian
[9] US Patent 4853337 1989 “Blending of hydrocarbon liquids” Inventor: G B Dickakian

[10] Hiraiwa T Suzuki K 2007 New Method of Incorporating Immobile and Non-vaporizing Residual Oil Saturation Into Compositional Reservoir Simulation of Gasflooding. *SPE Reservoir Evaluation & Engineering* vol 10 p 60-65
[11] Yongbin W U Xueqi L I U Xuan D U Xiaoyi Z H O U Li W A N G Jun L I Yang L I 2020 Scaled physical experiments on drainage mechanisms of solvent-expanded SAGD in super-heavy oil reservoirs *Petroleum Exploration and Development* vol 47 chapter 4 p 820-826
[12] Yuan Z Liu P Zhang S Li X Shi L Jin R 2018 Experimental study and numerical simulation of nitrogen-assisted SAGD in developing heavy oil reservoirs *Journal of Petroleum Science and Engineering* vol 162 p 325-332