An estimation of Ufimian terrigenous reservoir lithology influence on oil recovery factor by steam stimulation basing on tube experiments

To cite this article: A. Rojas *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **282** 012028

An estimation of Ufimian terrigenous reservoir lithology influence on oil recovery factor by steam stimulation basing on tube experiments

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Abstract. The settings, scale and geometry of lab facilities to simulate enhanced recovery methods play a significant role in the approximation of underground conditions of oil fields. The reliability more or less of the best replication of these conditions is a question of the reservoir engineer when forecasts are made for cases when enhanced recovery methods are applied. This paper presents the results of two experiments carried on in a steam flooding tube facility adding clay in one of them to assess the influence in temperature growth and production rates and onset times of a highly viscous oil field of the Tatarstan Republic. The results of the runs show that 4% (by weight) of clay content in the porous media has a strong effect on the overall oil recovery, reducing the temperature growth rate in average 73% when steam stimulation methods are used.

1. Introduction

The steam stimulation process at certain physical and chemical conditions leads to aquathermolysis. It is considered a catalytic process where different reactions take place and consequently upgrading oil fractions [1]. In the reservoir rock of the Ufimian horizon the main lithologies are found dispersed clay sand deposition and clay micro interlayering [2]. The effect of clay minerals contained within the reservoir rock has been tested and found that in dependence on the mineral content, oil production might be affected by nanoparticles migration and consequently throat blockage and modification of relative permeability curves [3,4]. Another study [5] found that the sensitivity on relative permeability curves has a dependence on the type of clay and salinity content of water. These were tested in absence of heat induction. Clay minerals in the reservoir rock is thought to play a role in the overall production reduction effect due to differences in heat capacities. On the other hand, depending on the natural state of reservoir rock, clay minerals or metals might produce a catalytic upgrading effect on high molecular hydrocarbon chains simplifying them into lighter ones at certain physical conditions while steam is reacting with oil [6-8] and therefore relatively improving recovery; however, the latest is not the focus of this paper and any possible catalytic effect will be neglected. The purpose of this research is to assess the degree of influence of the reservoir lithology of the mentioned horizon not on the oil's composition modification but on the total recovery factor under steam stimulation conditions in lab scale, using core steam flooding, as a preliminary stage for the planned future aquathermolysis studies in our research center. Additionally, to provide an overview of our experience on the settings of the facility to simulate steam stimulation methods.

2. Experimental

IOP Conf. Series: Earth and Environmental Science **282** (2019) 012028 doi:10.1088/1755-1315/282/1/012028

After having been assessed geological data from cores and well logs it was identified the lithological units and obtained a geological model [2], a cross section is shown in figure 1. The experiment's preparation involves the use of a methodology protocol created in our "Unconventional Reservoirs Modeling Center" and adapted to core rock measurements and fluid samples' analysis. To measure the porosity a total of 8 loose sand samples underwent through a process of bitumen extraction and found an average representation of 30% for the reservoir rock of the Ufimian horizon. It was observed macroscopically the presence of clay minerals in the sand samples and of our interest to investigate the effect in the recovery factor, therefore x-ray analysis for identification and quantification of mineral content was made for several samples of the pay formation.. Oil samples underwent analysis of viscosity with temperature dependence. The oil used for the experiments corresponds to produced oil using thermal recovery with steam injection and after being produced having density of 960 kg/m3 and 8700 cP of viscosity at 8^0 C. The purpose of the experiments carried on do not involve a comprehensive study of the oil fractions' change nor oil catalysis due to aquathermolysis and mineralogy, therefore oil data of the shallow highly viscous oil reservoir of the Ufimian horizon of the Tatarstan Republic will be skipped.
The assemblage of the core into the reactor pipe was made for two experiments: sand + crude oil (case 1) and sand + clay + crude oil (case 2). This was done by previously mixing dry sand with crude oil and stirred at a constant rate for about 5 minutes or until homogeneity is reached by using a sand blender. For the second experiment (with addition of clay), it was mixed before adding crude oil with 4% clay (weight %) to simulate a clay dispersed system. The amount of sand, clay and oil in mixture was weighted and recorded as shown in (table 1). Oil saturation was planned to be 100%, meaning no water was added to the system. Later, the prepared core was added to the flooding facility in three batches, pressurizing to reservoir conditions (4.5 T) each time until the desired pressure stabilizes.

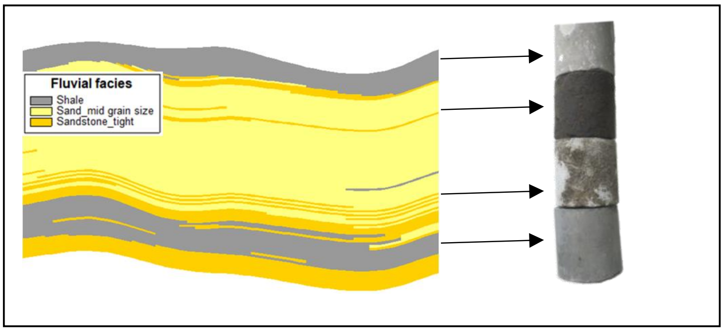


Figure 1. Cross section of field of study with core samples of lithotypes

Case #	Sand mass (%)	Oil mass (%)	Shale mass (%)
1	90.31	9.69	
2	82.67	13.35	3.98

Table 1. Core masses percentages for cases 1 and 2 of experiments under steam stimulation

In order to isolate the core, an epoxy solution at both edges of the pipe was poured and a special temperature resistant silicon-like material was placed in between of the epoxy and the pipe's wall to plug off from leaking fluids. Two wells were set, an injector and a producer. The wells are approximately 5cm long, 6mm external diameter and 3mm internal diameter. Temperature sensors placed all along at the top of the pipe to measure temperature development and steam chamber growth. Within the geometry of the reactor was used a cylindrical pipe with a pair of wells to simulate steam flooding technology as an EOR method. The flooding facility is a cylinder shaped with 40cm long and 10cm diameter. The facility operates under pressures of up to 50 bars and the steam generator heats with temperatures of up to around 400°C. The reservoir's initial temperature is 8°C, however both experiments were run initially at room temperature (25°C). Distillated water was used for the steam injection. An average of 17 kg of water were used per experiment to be injected. Every run was set to inject steam constantly under the same conditions (T:205°C, P:18 bars). The temperature of the reactor was controlled by a temperature controller. Pressure was regulated to keep constant temperature of 205 °C as in figure 9, therefore injection rates might be sensitive to these changes. Injection rate was set constant: 0.6 L/h of steam (distillated water equivalent). The pipe was thermally isolated to prevent heat losses with the environment. Also production line was isolated to reduce the impact of reduction of oil viscosity due to the cooling and be efficiently recovered into the sampling jar. For the dimensions of the pipe was determined an effective run time of average 30 hours when dismissible oil production was observed into the collection jars. In addition a back-pressure valve was installed next to the production line. Due to the characteristics of the facility, of the injector and producer it is considered a steam flooding setting. After the experiment the collected samples were submitted to centrifugation and separated into three phases: oil, water and sand and so determine the recovery factor. Consequently, viscosity of the oil samples were measured.

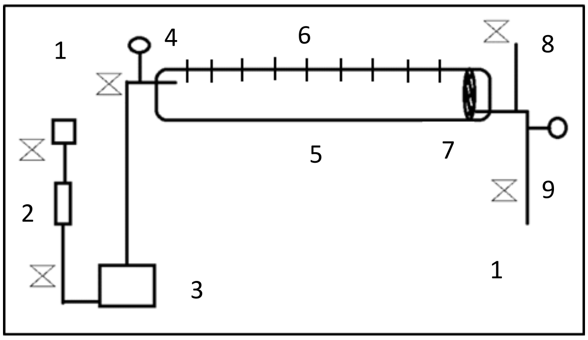
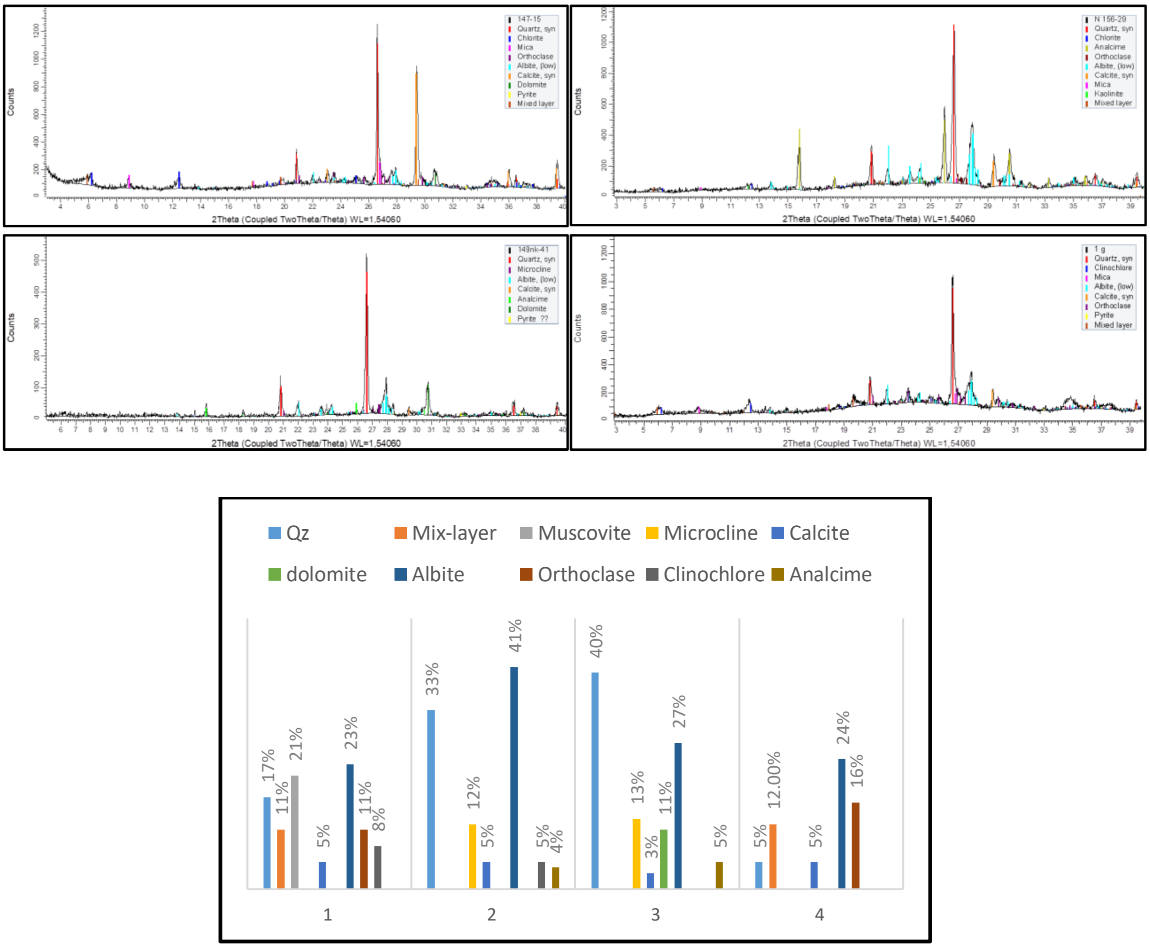


Figure 2. Scheme of steam flooding facility used in the Unconventional Reservoirs Modeling Center. 1) Water cylinder input. 2) Displacement cylinder pressurized with nitrogen. 3) Steam generator. 4) Pressure manometer at the injector well head. 5) Pipe reactor. 6) Thermocouples. 7) Metallic grid filter 8) Back pressure valve. 9) Pressure manometer at the producer well. 10) Sampling point.

3. Results and discussion

3.1. Reservoir parameters

Figures 3- 7. summarize the measurements and analysis of rock samples after bitumen extraction which showed that the mineral with higher abundance is Albite having 41% of its content. It was found that due to mineralogical analysis, the clay embedded in the interlayering of the reservoir sand of the Ufimian horizon, has a weak difference with the one on the top of the reservoir rock "Lingula clay"; however, it shows a fare resemblance to that at the bottom. Moreover, the overall content of clays in the rock samples studied, correspond to 4%. It is worth noting that the reservoir owes carbonate-cemented sandstones distributed in some parts of it and the influence on the overall recovery was not studied in this paper since it was addressed to only loose sand.



Figures 3-7. X-ray diffraction analysis for determination of mineralogical content in a bitumen-extracted loose sand sample of the Ufimian horizon.

3.2. Material balance

After the experiments were finished, the collected samples were centrifuged and the material balance was obtained. Within the results it was observed almost similar dynamics on the instantaneous oil production and with a few hours delay in the case 2 experiment which is agreed due to the higher heat capacity in comparison with that of sand; however it showed different dynamics on the rates response and on the total recovery factor, and so, being that 81,92 % without addition of clay (case 1) and 50.26 % adding 4% clay (case 2), suggesting that the clay has a strong influence in the overall recovery although it is a small percentage of 4 % as in figures 8. Absorption and adsorption studies of the oil into the clay were not carried on. The total Steam-Oil-Ratio was determined for case 2 being higher than case 2, as expected, due to the presence of clay as in figure 8b. An average of 17 steam pore volumes were injected during both experiments of steam stimulation with the prepared terrigenous core of the Ufimian horizon shown in figure 8a. In figure 8.b, in the fifth hour a peak of SOR in case 2 as a consequence of dismissible oil production in that time step, as in case 1 in time step 2 taking into account that it is an hourly time step basis. It is evident in figure 8.b, how the SOR gives a clue of how the steam injection becomes less economical after 12 hours (7 pore volumes) for case 1. Case 2 shows a delay in the plateau zone which is approximately at the hour 17 (10 pore volumes) which is in agreement with the 5 hours delay of the initial production time step in comparison with case 1.

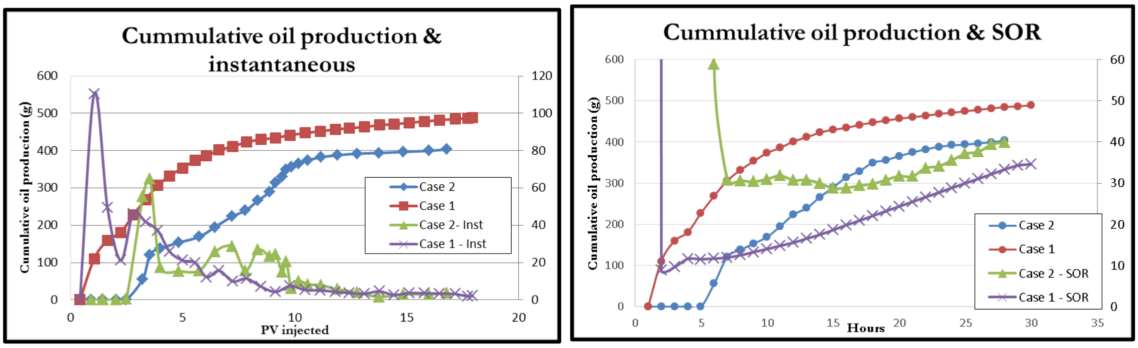


Figure 8. Oil production results comparisons of cases 1 and 2. a) cumulative and instantaneous oil, b) cumulative and SOR.

3.3 Temperature profile analysis

As shown in figure 2, thermocouples were placed along the tube to monitor temperature development during the steam displacement experiments. Case 1 and case 2 show quite different profiles (figures 9 and 10); even though both experiments were set to inject steam under 205° C. As in figure 10 during the first half of the run, temperature was increased slightly and progressively up to 215° C due to no response in oil production within the same period in which case 1 produced (hour 2). Temperature profile of case 2 shows a lean on of the curves. It shows two stages and it is hypnotized that: the first (up to 400 min) the delay is thought to be as a result of clay swelling and change in relative permeability curves. The second stage (400 – 1000 min), as a result of the higher heat capacity of swollen clay.

It is evident from figures 9 and 10 that the required amount of time for the last thermocouple to start temperature increase is by a factor of two, for case 2. For the oil tested it is a highlight to notice that the apparent mobility onset is around 40° C; however, at different operation times in dependence on clay concentration (case 1: 100 min, case 2: 400 min). Additionally, the oil production rate drastically decreases after temperature is normalized to 205° C (case 1: 400 min, case 2: 1000 min) (figures. 8 - 10). It can be said it represents the state of irreducible oil saturation; however, higher temperatures were not tested to prove this wrong. The temperature growth rate can be expressed as:

$$T\ (rate) = \frac{\Delta T}{\Delta time} \qquad (1)$$

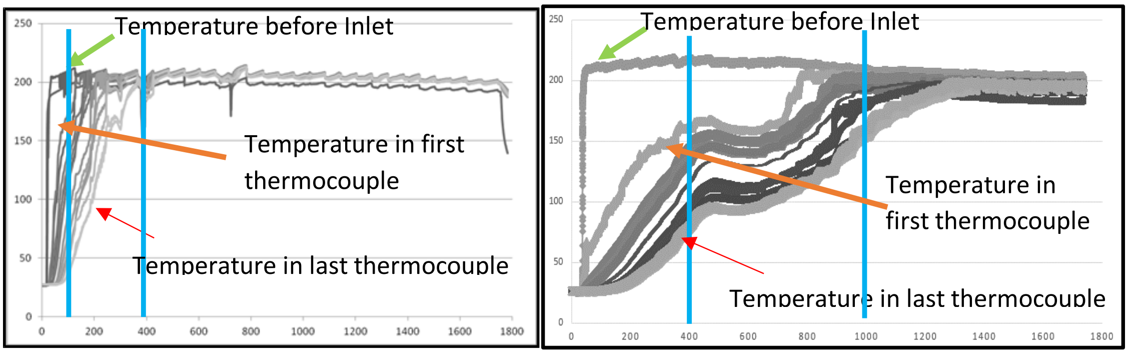
Where:

T(rate) – Temperature growth rate (°C/min)

ΔT – Temperature increment (°C)

Δtime – Time from start of temperature increment until 205 °C are reached for last thermocouple (min)

From (1) it can be obtained that T (rate) is 0.56 °C/min and 0.15 °C/min for case 1 and case 2, respectively. It is worth mentioning that these observations were performed for a tube steam displacement facility where thermodynamic conditions are considered isobaric and confined to a volume of 0.00314m^3.



Figures 9 and 10. Temperature profile of experiment for case 1. X-axis: time in minutes, Y-axis: temperature in ^{0}C. Left – case 1. Right – case 2

4. Conclusions

X-ray analysis found that the reservoir clay does not show any determinant difference to those at the top and the bottom; therefore, heat capacities can be assumed to be also closely similar. Two cores were elaborated and mounted on a steam flooding tube facility. Two experiments were launched and run successfully. One of the experiments required the addition of clay (4% by mass) to measure the influence on the overall oil recovery. As expected the cumulative oil production for case 2 was lower than that of the case 1. It was correlated from the temperature profiles of the tests run that the oil's apparent mobility onset is around 40° C. Also temperature growth rate was estimated to be 0.56 °C/min for case 1 and 0.15 °C/min for case 2. Additionally, SOR is shown higher for case 2 all over the experiment. It can be concluded that the presence of clay has a strong influence on the reduction of the overall recovery factor and delay on the production times. Moreover, the contact time of reservoir with steam from the results obtained in the experiments performed could be used as an approach for prediction of production times and scheduling when interpolations of the clay index distribution in the reservoir could be done. Furthermore, for a more efficient timing forecast to applying hybrid enhanced oil recovery methods in the terrigenous reservoir rock of the Ufimian horizon since the highest SOR's were observed after approximately 17 hours (10 pore volumes) for both cases, under the conditions of the reported experiments here, where it shows itself to be non-economical. It is worth mentioning that there is a need for repeatability of the carried on experiments and also to trial the effect on different clay deposition patterns.

Acknowledgements

The work was supported by the Ministry of Education and Science of the Russian Federation (project No. 02.G25.31.0170) and by the subsidy allocated to Kazan Federal University as part of the state program for increasing its competitiveness among the world's leading centers of science and education.

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