INVESTIGATION OF RHEOLOGICAL PROPERTIES OF HEAVY OIL DEPOSITS

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ABSTRACT

High viscosity of heavy oils at reservoir conditions is one of the main causes of the low production rates of producing wells, and sometimes even their complete absence when trying to develop a field on a natural mode. The rheological properties of heavy oil deposits in a wide temperature range were studied in this work. Special attention was paid to the study of viscous and elastic components of oil viscosity as a function of temperature to justify the optimal conditions for the development of heavy oil fields. Heavy oil samples collected from Pechersky oil field (Russia) were used in this research. Dynamic viscosity tests were carried out on the heavy oil of this field. It was noticed that high values of viscous and elastic components of oil viscosity were observed over the entire temperature range. It has also been remarked that the values of oil viscosity components are inversely proportional to the temperature increase.

Keywords: High viscosity oil, Bitumen, Elastic viscosity component, Rheological properties, Oil deposits.

I. INTRODUCTION

Due to the steady depletion of reserves of light, low-viscosity oils in the oil industry, it is becoming increasingly important to launch onto the development of deposits of hard-to-recover reserves like high-viscosity oil and natural bitumen.

Most of the deposits of hard-to-recover reserves are located in Canada, Venezuela and Russia. In the Russian Federation, more than 70% of high-viscosity oils are confined to 5 regions: Perm region (more than 31%), Tatarstan (12.8%), Samara region (9.7%), Bashkortostan (8.6%) and Tyumen region (8.3%) [1].

Oil deposits of this type are usually characterized by small depths of oil-bearing beds and, often, low reservoir temperatures, while the oil or bitumens lying in them have Non-Newtonian properties [2, 3, 4]. Such properties are due to the high content of paraffin of asphaltenes and resins [5, 6, 7]. With a high content of heavy components in the oil, viscoelastic properties appear in the oil composition. These viscoelastic properties were first discovered in the 1970s. [8, 9, 10].

High viscosity values of such oils in reservoir conditions are the reason for low flow rates of producing wells, and sometimes their complete absence when trying to develop a field in the natural mode [11, 12, 13].

At the present time, the effect of using thermal methods or technologies on the productive formation is most widely used in the development of deposits of such hydrocarbons [14, 15, 16].

Among these technologies, we may cite the cyclic steam injection and the areal steam injection. These two technologies are the most common methods of extracting and intensifying the oil flow rate in Russia whereas the steam and gravity drainage (SAGD - steam assisted gravity drainage) is widely used abroad [17, 18].

To study the properties of high-viscosity oil, located in a complex carbonate reservoir, the Pechersky field, located on the bank of the Volga River, near the village of Pechersky was selected.

Earlier, rock (limestone and dolomite) saturated with heavy oil was mined at this field for subsequent extraction of raw material for the production of bitumen mastic.

II. EXPERIMENTAL STUDY

The author organized field visits to this field to collect information about the structure of the reservoir and to gather samples to study the rheological properties of oil and the void spaces of the reservoir.

In this work, we studied the effect of temperature on the rheological properties of oil. For this case, a modern high-precision rotational viscometer with air bearings was used [19, 20].

An experiment to study the dependence of the dynamic viscosity on temperature was carried out as follows: a drop of oil with a volume of 1 ml was placed on the heated to 70°C viscometer platform, then the drop was pressed by the rotor while the temperature increased to 110°C.

The angular velocity was set at 5 S⁻¹ on the viscometer, after which the temperature gradually dropped to 50 °C. This temperature was proposed as a limiting temperature to prevent excessive overload of the viscometer motor (see Fig. 1).

In this figure, it can be clearly observed that when the temperature increases the dynamic viscosity decreases. Which means, that the viscosity of oil as a liquid is related inversely proportional to the increasing temperature.

Figure 1: Dependence of dynamic viscosity of high-viscosity oil on temperature.

The figure shows that the dynamic viscosity of oil can be described by a power function of the form

$$y = 117732055169617 \times 10^4 X^{-7.24} \quad (1)$$

with a value of approximation reliability $R^2 = 0.99554$.

R-squared represents the determination coefficient and it is the fraction by which the variance of the errors is less than the variance of the dependent variable.

Oil in the entire range of temperatures presented is highly viscous (viscosity at 110 °C is 2003 mPa s, and at 50 °C it is 502343 mPa s).

At this stage of the test, it was not possible to measure the viscosity of the oil at a reservoir temperature of 20 °C due to the limited capabilities of the viscometer.

For a deeper study of the rheological properties of this oil, additional specialized dynamic tests were carried out to determine the elastic and viscous components of the oil viscosity. In the course of the experiments, the effect of decreasing temperature on the elastic component of viscosity (dynamic shear modulus, also called storage modulus) and viscous component of viscosity (flexibility or loss modulus) were studied [21 , 22 , 23]. The oil of the Pechersky field, used in this research, was cooled in a selected temperature range from 90oC to 50°C.

The experiment was carried out as follows: a drop of oil with a volume of 1 ml was placed on the heated to 70°C platform of the viscometer, then the drop was pressed by the rotor, and the temperature increased to 90°C, after which it gradually decreased to 50°C with data recording. The dynamic load was represented by the oscillatory motion of the rotor at a frequency of 1 Hz and a load of 100 Pa. The results are shown in Fig. 2.

Figure 2: Dependence of the elastic (storage modulus) and viscous (loss modulus) viscosity components of high-viscosity oil of the Perchersky Field on temperature.

The figure shows the dependency of both components (elastic and viscous) of oil viscosity of Perchesky field on temperature. It shows how both values of these components decreased with the increase of temperature. The figure shows that the elastic viscosity component of oil (storage modulus) can be described by a power function of the form

$$y = 130226893597931 \times 10^{10} x^{-10,723} \quad (2)$$

with a value of approximation reliability $R^2 = 0.99554$.

Figure 2 also shows that the viscous component of oil viscosity (loss modulus) can be described by a power function of the form

$$y = 52364875928,8 e^{-2448x} \quad (3)$$

with a value of approximation reliability $R^2 = 0.99554$.

III. DISCUSSION

Analyzing the presented dependences, Fig 2, it is quite possible to conclude that both viscous and elastic components of oil viscosity decrease with the increasing temperature and reach relatively small values at 80°C, which proves the need for the use of thermal energy in the development of this field. It is also noticeable that at the studied temperature range oil has elastic properties, which, although reduced with the increasing temperature, reach significant values: 23.54 Pa.

It is well known, that the fluid mobility represents the ratio of effective permeability to phase viscosity and the well productivity is directly proportional to the mobility product [24 , 25 , 26 , 27]. Therefore, the fluid viscosity represents a dominating factor affecting the mobility of any fluid. Therefore, any small reduction in oil viscosity will defiantly lead to a big increase in oil mobility which in its turn has a positive impact on the oil recovery. This will lead us to the fact that, the use of thermal treatment in the oil fields with heavy oils (high viscosities) will enhance the viscous characteristics of these oils and make them more mobile.

IV. CONCLUSION

Based on the results of the research, it is possible to draw the following conclusions:

1. High viscosity oil of the Pechersky field is characterized by an abnormally high viscosity; the measured dynamic viscosity at 50 ° C is 502343 mPa s.
2. Based on the fact that the oil viscosity decreases from 502343 mPa s to 2000 mPa s with the increasing temperature from 50 to 110 ° C, the thermal treatment is necessary to extract oil from the rock of this field.
3. The studied oil has complex rheological properties, probably due to the high content of asphaltenes and resins characteristic of the near-surface deposits of the Samara region. High values of viscous and elastic components of viscosity are observed over the entire temperature range at which the dynamic tests were carried out. These high values of the components will undoubtedly have a negative impact on the process of extracting oil from the reservoir.
4. Once the feasibility study of the development process for any oil field containing heavy oils is conducted, the use of thermal treatment is recommended to enhance the viscous characteristics of these oils and bring many of the abandoned producing wells back to life.
5. It is highly recommended for further tests aimed at substantiation of effective technologies of extraction of such anomalous oils from productive formations, for example, technologies with the use of complex effects of thermal agents and solvents.

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