IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Thermal Treatment of Reservoir as One of the Powerful Method of Shale Formation Development in Russia

To cite this article: A M Gorshkov and I S Khomyakov 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 032004

View the article online for updates and enhancements.

This content was downloaded from IP address 115.171.85.171 on 08/10/2019 at 22:46

IOP Conf. Series: Earth and Environmental Science **272** (2019) 032004 doi:10.1088/1755-1315/272/3/032004

Thermal Treatment of Reservoir as One of the Powerful Method of Shale Formation Development in Russia

A M Gorshkov[1], I S Khomyakov[2]

[1]Petroleum Geology Laboratory, National Research Tomsk Polytechnic University, Russia
[2]Division for Oil and Gas Engineering, National Research Tomsk Polytechnic University, Russia

E-mail: gorshkovam89@mail.ru

Abstract. World interest in shale oil has provoked high attention to Russian unconventional resources, to which, the Bazhenov Formation (Western Siberia) primarily belongs. Depletion drive type development of the Bazhenov Formation allows producing only 3% of geological reserves. One of the potential method for increasing oil recovery in the Bazhenov Formation is the thermal treatment, which, according to experts, allows rising oil recovery factor to 30-40%. Laboratory tests are needed to successfully introduce new thermal methods for development shale reservoirs in Russia. These tests would allow scientifically and technically substantiating technological parameters of in-situ pyrolysis. This work is concerned with investigation of high temperatures effects on reservoir properties of Bazhenov Formation rocks. Reservoir properties of the Bazhenov Formation were determined on crushed core by the GRI method. It is shown that, the open porosity and matrix permeability are increased in several times with rising temperature.

1. Introduction

Estimation of unconventional reservoirs resources indicates the significant potential of these projects for oil and gas development in the world. In Russia, the greatest interest among unconventional resources is manifested in shale oil, concentrated in the Domanic deposits of the Volga-Ural oil and gas province and the Bazhenov Formation of the West Siberian oil and gas province. Oil reservoirs in Bazhenov Formation are considered as one of the most important objects for replenishment of hydrocarbon resources in Russia. Estimation of the unconventional reservoir resources varies from 600 million to 30 billion tons [1, 2].

However, despite high potential of Bazhenov Formation rocks, complex geological structure of the reservoir keeps under its resources development. Complex geological structure is due to heterogeneity of the strata material composition. Heterogeneity of material composition is associated with a change in content of clay, siliceous, carbonate and organic (up to 10-25%) matter due to sedimentation characteristics [3].

Hydrocarbons in Bazhenov Formation rocks are in liquid and solid state. Light oil, concentrated in macro-fractures of fissured-cavernous reservoirs, is drained through these reservoirs. Also light oil is in micro-fractures of porous-fractured reservoirs. These reservoirs are matrix of the Bazhenov Formation, according to which liquid hydrocarbons are practically not drained under reservoir

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

conditions [4-6]. Kerogen is potential hydrocarbons in a solid state. This is organic rock forming matter that can transform into liquid and gaseous hydrocarbons, depending on its origin, at high temperatures. Thus, Bazhenov Formation rocks are a source of both existing and potential oil, which indubitably should be taken into account during the selection of oil production technologies for them.

Accumulated long-term field experience of oil production indicates inefficiency of the depletion drive type development of Bazhenov Formation deposits. The recovery factor of oil is about 3% [5, 6]. The water flooding type development of Bazhenov Formation deposits is also not effective, since an impact does not involve development of either light oil reserves in micro-fractured rocks or hydrocarbon potential of kerogen [7].

The use of multi-stage fracturing on horizontal wells became the main method of shale oil production in the United States. But the method for deposits of the Bazhenov Formation allow to reach the recovery factor of oil about 5% by additional migration of light oil from micro-fractures of matrix, however, the kerogen potential is also not involved in development.

Innovative technologies of oil production are actively used in foreign countries to develop deposits of kerogen-bearing rocks. These technologies are based on in-situ pyrolysis of kerogen by combustion, or by heating with help of heat transfer medium (gas, steam, etc.). So at the moment, innovative technologies, developed by Exxon Mobil «*ExxonMobil Electrofrac*», Shell «*Shell ICP*», Chevron «*Chevron in-situ process*», AMSO «*AMSO EGL Technology*» and other, are being approbated to reach more than 90% of converted oil [8].

OAO «RITEK» has achieved greatest progress in the evolution and implementation of thermal treatment methods on rocks of the Bazhenov Formation. The company carries out pilot projects of thermal gas treatment at the Galyanovskoe and Sredne-Nazymskoe fields [7, 9-13]. The thermal gas treatment method is based on integration of thermal and gas methods of oil recovery (a kind of in-situ burning). The method is involved air and water injection into reservoir. As a result of thermal gas treatment on rocks of the Bazhenov Formation, it is possible to rise the oil recovery factor from drainable zones to 30-40% due to formation of micro and macro fracturing in reservoir under heat influence and additional oil and gas recovery as a result of pyrolysis and cracking of kerogen.

The thermal method of shale formation treatment is quite «junior» in Russia and subsoil users are beginning to master it in oil fields. Careful laboratory tests are necessary to mass introduction of methods of oil-bearing rocks (the Bazhenov Formation) thermal treatment. These studies would allow doing an objective estimation of the efficiency of thermal impact on reservoir properties of shale, on depth of process penetration, and on amount and composition of hydrocarbons that formed as a result of pyrolysis.

At the moment the influence of high temperatures and exposure duration of pyrolysis on amount and composition of hydrocarbons has investigated well [14]. However, there are practically no experimental data of high temperatures effect on reservoir properties of shale formation. Accordingly, the aim of this work was to study the influence of high temperatures on reservoir properties of Bazhenov Formation deposits.

2. Experimental procedure

2.1. Materials

The Bazhenov Formation cored from exploratory wells of the Yuzhnoe and Yuzhno-Kinyaminskoe oil fields (Tyumen region) was object of study. The core samples are represented by siliceous-argillaceous rocks with a high content of kerogen. Also core samples are characterized by a low thermal maturity (T_{max} < 429 ºC) and low reservoir properties.

2.2. Method and equipment

Essence of laboratory experiments in modeling of shale formations thermal treatment was stepwise heating of crushed core in the muffle furnace from ambient temperature to 350 °C. At the same time, core samples were held in muffle furnace for 10 hours at each temperature step. It should be noted that, investigated samples were cooled to ambient temperature after each stage of heating and their petrophysical properties such as bulk and grain density, open porosity and matrix permeability were determined.

The petrophysical properties of Bazhenov Formation deposits were determined on cores with natural saturation the SMP-200 shale permeameter (Core Lab Instruments, USA). Before the start of the experiments, whole core was crushed and sieved through five- and two-millimeter cells to obtain a fraction of a homogeneous size. The mass of one weighed portion amounted about 30 grams.

The bulk and grain density were determined by the gas expansion method in the sample chamber the SMP-200 permeameter (figure 1).

a) **b)**

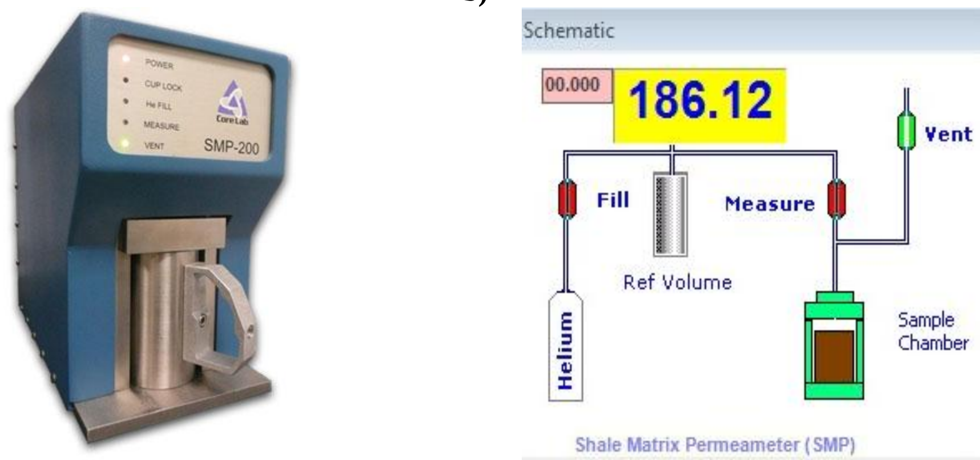

Figure 1. The SMP-200 shale permeameter: a) – the appearance of the device; b) the device schematic diagram.

The device works based on the Boyle's law whereby calibration of the reference and dead volume (figure 1b) before each series of experiments and determination of the sample volume during the experiments are carried out with high accuracy. The experiment on determining bulk and grain density consisted in calculating a bulk volume of sample at the baseline (before helium penetration into pores) and a volume of matrix material at the end of the experiment (after sample saturation with helium) correspondingly for the pressure decay curve [15]. The bulk and grain density was calculated by dividing the mass of crushed sample with natural saturation by the bulk volume of sample and the volume of matrix materials, correspondingly.

The open porosity coefficient was calculated on the basis of bulk and grain density values [15, 16].

The matrix permeability of Bazhenov Formation samples was determined on crushed core by the Gas Research Institute (GRI) method [17-21]. This method allows to significantly reduce the duration of permeability determination, as well as to exclude the influence of the natural fracturing of shale formation rocks on permeability values. The method consists in the approximation of the theoretical curve of experimental data on a pressure drop that occurs due to helium penetration into the micropores of separate particles in crushed core, as well as the subsequent calculation of matrix permeability values on the basis of the obtained curve parameters [16-21].

The insignificant pressure change during the experiments (0.1-0.5% of the absolute value) imposes heightened requirements to device calibration, the absence of leaks and thermal stabilization during the process of determining petrophysical properties [16].

3. Results of study

Investigation results of the heating temperature influence on the reservoir properties of shale's are presented in figure 2.

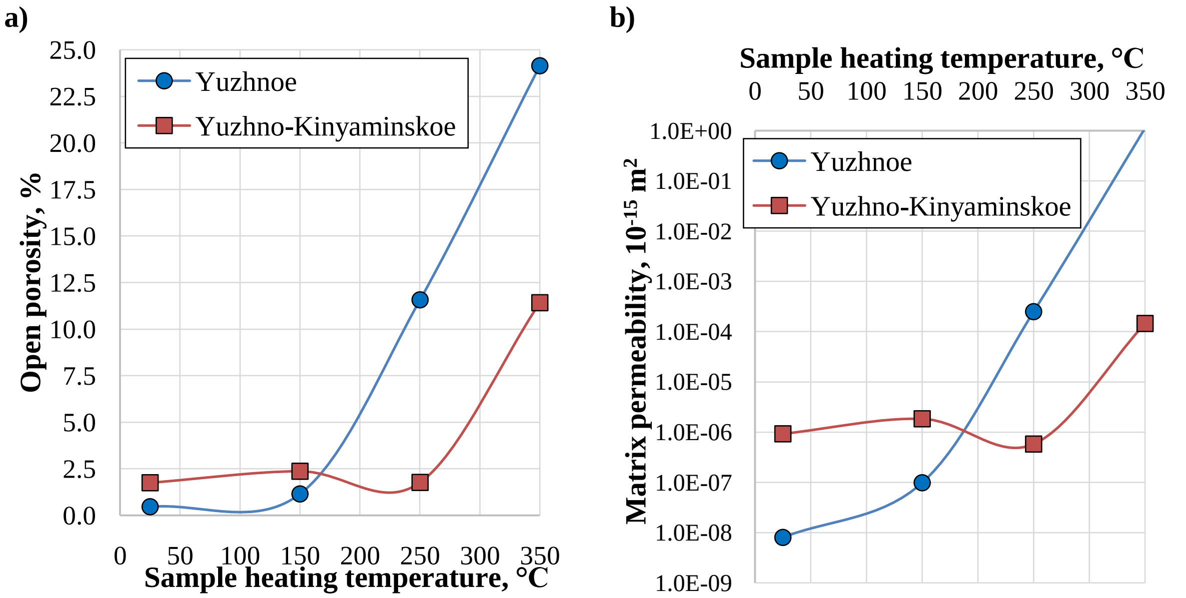

Figure 2. Influence of the heating temperature on the reservoir properties of samples: a) – influence of the heating temperature on the open porosity; b) – influence of the heating temperature on the matrix permeability of oil shale.

It should be noted, that the bulk density value, obtained for the initial (without thermal treatment) sample, was used to calculate the open porosity. Bulk density of the initial core sample of the Yuzhnoe field was 2.057 g/cm^3; bulk density of the initial sample of the Yuzhno-Kinyaminskoe field was 2.223 g/cm^3.

By increasing the heating temperature of samples, the grain density increases. It ultimately leads to an upward trend in reservoir properties of investigated shales (figure 2). Therefore, the open porosity of the Yuzhnoe field sample significantly grows with a rise in the heating temperature above 150 °C and reaches a maximum value (about 24%) at the heating temperature of 350 °C. At the same time, the matrix permeability value is increased by eight orders of magnitude. The similar behavior is demonstrated by the Yuzhno-Kinyaminskoe field sample. The open porosity significantly growth when the sample is heated temperature above 250 °C and reaches a maximum value (about 11%) at the heating temperature of 350 °C. At the same time, there is not such a sharply increase in permeability as for the Yuzhnoe field sample. Permeability of the sample is increased by only two orders of magnitude. This phenomenon most probably due to the formation of different pore channels with sample heating. The rapid pressure stabilization for several seconds is observed for the Yuzhnoe field sample with heating to temperature of 350 °C. Then the slight increase in pressure occurs due to the adiabatic expansion of helium in the sample chamber of permeameter (figure 3). This curve behavior of the pressure with time corresponds to the upper limit of permeability measurement on the SMP-200. Thus, large pore channels for gas filtration are formed with the sample heating.

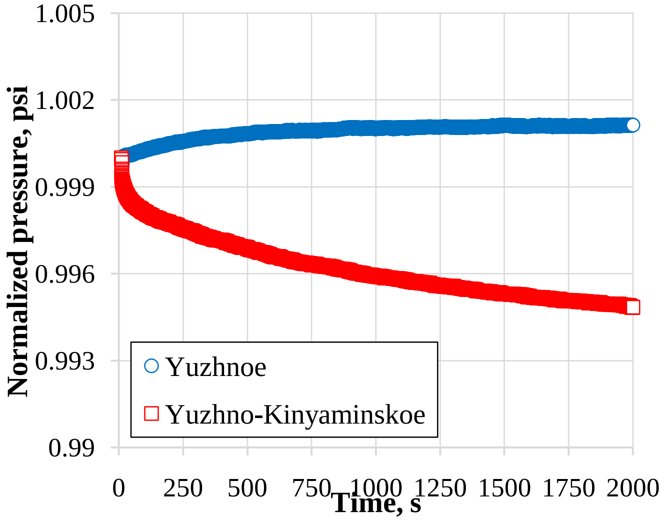

Figure 3. Change in the normalized pressure with time for samples, heated to a temperature of 350 °C.

When the Yuzhno-Kinyaminskoe field core sample is heated to temperature of 350 °C, the pressure slowly decreases with time throughout the experiment. It corresponds to the lower limit of permeability measurement on the device (figure 3). This behavior of pressure dependence on time is characteristic for the sample with narrow pore channels, through which the filtration of liquid hydrocarbons will be difficult.

4. Conclusion

According to results of experimental data of the heating temperature influence on the reservoir properties of Bazhenov Formation samples, the following conclusions are made:

- An increase in the temperature of oil shale thermal treatment allow to substantially rise the open porosity of Bazhenov Formation samples;
- An growth in the temperature of oil shale thermal treatment leads to an increase in matrix permeability of Bazhenov Formation samples;
- As a result of thermal treatment of samples with high temperature, it is possible to form both larger pore channels and smaller ones in comparison with the initial (without thermal treatment) samples. This fact should be taken into account when methods of thermal treatment of Bazhenov Formation rocks are projected.

5. References

[1] Afanasjev I S, Gavrilova E V, Birun E M, Kalmykov G A and Balushkina N S 2010 Bazhenov Formation. Overview, problems *Scientific and Technical Journal OJSC «Rosneft»* **4** 20–25
[2] Lobusev A V, Lobusev M A, Vertievec Iu A and Kulik L S 2011 Bazhenov Formation – supplementary source of hydrocarbons materials in West Siberian *Territory of Neftegaz* **3** 28–31
[3] Pavlova M A, Suhorukova C V, Glinskih V N and Kazanenkov V A 2012 Log data interpretation of the Bazhenov Formation producing interval: lithotypes and their physical parameters *Interexpo Geo Siberia* **2** 127–131
[4] Boxerman A A, Graifer V I, Kokorev V I and Churbanov O V 2008 Thermal gas treatment method of enhanced oil recovery *Interval* **7** 26–33
[5] Sonich V P, Baturin Ju E, Malyshev A G, Zaripov O G and Shemitillo V G 2001 Problems and perspective of Bazhenov group development *Oil Industry* **9** 32–36
[6] Slavkin V S, Alekseev A D and Koloskov V N 2007 Some aspects of a geological structure and prospects of oil-bearing capacity of Bazhenovskaya Suite in the West of Latitudinal Priobye *Oil Industry* **8** 100–104

[7] Kokorev V I, Vlasov S A, Sudobin N G and Polischuk A M 2010 Studies of thermal impact on samples of Bazhenovsky series rocks *Petroleum Engineering* **3** 12–19

[8] Grushevenko D A and Grushevenko E V 2012 *Oil of shale plays – a new challenge to energy market? Data analytics review* ed. A A Makarov and *et al* (Moscow: ERI RAS) p 50

[9] Kokorev V I 2010 On the appropriateness of thermo-gas method application for developing of hydrocarbon accumulations, confined to deposits of the Bazhenovskaya Suite in West Siberia *Oil Industry* **7** 88–91

[10] Kokorev V I 2010 Basic aspects of controlling of thermal gas impact on rocks of Bazhenov Formation as to geological conditions of Sredne-Nazymsky and Galyanovsky fields (part 1) *Petroleum Engineering* **6** 29–31

[11] Shchekoldin K A 2012 Investigation of possibilities of regulation of thermal gas treatment on deposits of the Bazhenov Formation *Territory of Neftegaz* **9** 53–57

[12] Kokorev V I, Darischev V I, Akhmadeishin I A, Schekoldin K A and Bokserman A A 2014 Field test results and prospects of thermal gas treatment technologies for the Bazhenov Formation development in OJSC «RITEK» *Drilling and Crude Oil* **11** 26–28

[13] Alekseev Yu V, Erofeev A A, Pachezhertsev A A, Meretin A S and Nikitin R N 2015 Prospects for use of thermochemical recovery methods for development of the Bazhenov Formation *Oil Industry* **10** 93–97

[14] Maaten B, Loo L, Konist A, Nesumajev D, Pihu T and Kulaots I 2016 Decomposition Kinetics of American, Chinese and Estonian Oil Shales Kerogen *Oil Shale* **33** 167–183

[15] Gorshkov A M 2017 Effective porosity determination by laboratory methods, adapted to ultralow permeability rocks of the Bazhenov Formation *The book of science papers of International scientific and practical conference of TIU EAGE Student Chapter «Natural processes in oil and gas field. Geonature 2017»* ed. I I Nesterov (Tyumen: TIU) pp 31–36

[16] Gorshkov A M, Kudryashova L K and Lee-Van-Khe O S 2016 Petrophysical rock properties of the Bazhenov Formation of the South-Eastern part of Kaymysovsky Vault (Tomsk Region) *IOP Conf. Ser.: Earth Environ. Sci.* **43** 012010

[17] Guidry K, Luffel D and Curtis J 1995 *Development of Laboratory and Petrophysical Techniques for Evaluating Shale Reservoirs*. *Gas Research Institute Final report. GRI-95/0496* (Des Plaines) p 49

[18] Luffel D L and Hopkins C W 1993 Matrix Permeability Measurement of Gas Productive Shales *SPE Annual Technical Conference and Exhibition (3–6 October, Houston, Texas, USA)* SPE 26633-MS

[19] Bustin A M, Cui X and Bustin R M 2009 Measurements of Gas Permeability and Diffusivity of Tight Reservoir Rocks: Different Approaches and Their Applications *Geofluids* **9** 208–223

[20] Tinni A, Fathi E, Agarwal R, Sondergeld C, Akkutlu Y and Rai C 2012 Shale Permeability Measurements on Plugs and Crushed Samples *SPE Canadian Unconventional Resources Conference (30 October – 1 November, Calgary, Alberta, Canada)* SPE 162235-MS

[21] Sinha S, Braun E M, Passey Q R, Leonardi S A, Wood A C, Zirkle T, Boros J A and Kudva R A 2012 Advanced in Measurement Standards and Flow Properties Measurements for Tight Rocks such as Shales *SPE/EAGE European Unconventional Resources Conference and Exhibition (20–22 March, Vienna, Austria)* SPE 152257-MS