IOP Conf. Series: Earth and Environmental Science **155** (2018) 012020 doi:10.1088/1755-1315/155/1/012020

Laboratory Tests of Bitumen Samples Elasticity

E R Ziganshin [1], S A Usmanov[1], D I Khasanov [1], G S Khamidullina [1]

[1]Institute of Geology and Petroleum Technologies, Kazan Federal University, Kazan, Russia

E-mail: eduard-ziganshin@mail.ru, sausmanov@gmail.com

Abstract. This paper is devoted to the study of the elastic and acoustic properties of bitumen core samples. The travel velocities of the ultrasonic P- and S-waves were determined under in-situ simulation conditions. The resulting data were then used to calculate dynamic Young's modulus and Poisson's ratio. The authors studied the correlation between the elasticity and the permeability and porosity. In addition, the tests looked into how the acoustic properties had changed with temperature rise.

1. Introduction

Bitumen deposits are an essential type of hydrocarbon reservoirs that contribute significantly to the world reserves. Heavy oil reservoirs contain reserves of more than 6 tln. barrels which is three times the total world reserves of conventional oil and gas [5]. The capacity of this resource seems very attractive, but petrophysical characterization of these reservoirs requires deeper understanding for the effective development of them.

Unlike conventional hydrocarbons, bitumens are more viscous. This results in difficulties to apply traditional technologies to develop heavy oils [7]. For the enhancement of production, various techniques have been proposed to reduce the viscosity of bitumen, for example, by injecting chemical solvents or heating up the formation [6, 8]. There are a lot of challenges that are new or poorly understood to be solved at the stage of bitumen reservoir management. In particular, optimization of the well map for production and injection wells, control of coolant propagating within the reservoir. A lot of tests have been done to explore such deposits [1]. However, this scope of an inquiry is still burning and requires more tests.
This paper is designed to studying the acoustic and elastic geomechanical properties of bitumen sandstones under in-situ simulation conditions, as well as to understanding of how these parameters change as the temperature rises. In addition, the correlation between acoustic parameters and the permeability and porosity was studied. The tests can significantly improve the accuracy of the interpretation of shallow seismic survey data (updated velocity model). Correct setting of such correlations as input data will make it possible to identify subtle field changes based on surface tests, which will ensure an increase in the resolution of seismic surveys to monitor the development of shallow reservoirs of heavy oils.

2. Methodology

The paper describes experimental testing on core samples aimed at measuring their acoustic properties and elastic dynamic parameters. The experiments were performed on the PIK-UZ-UEP test set-up (Figure 1).

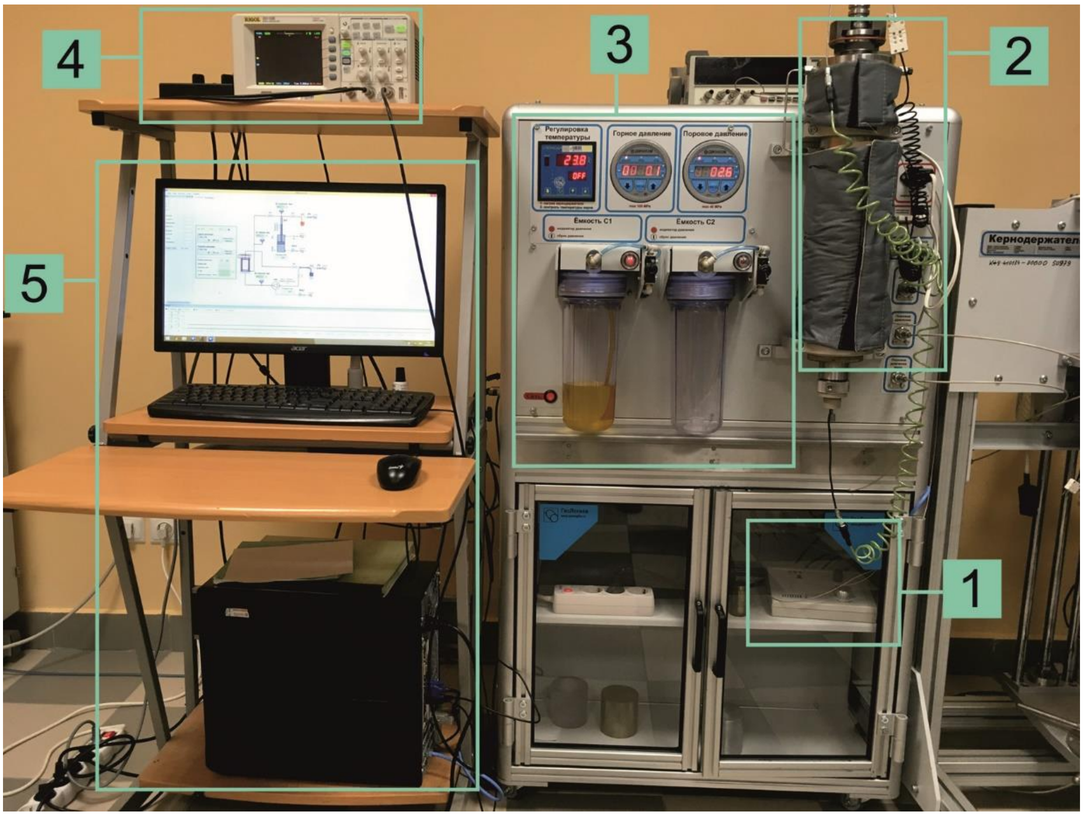

Figure 1. The PIK-UZ-UEP test unit for measuring the elasticity under in-situ simulation conditions: 1 – signal source; 2 – core holder; 3 – control unit for creating reservoir conditions; 4 – the Rigol 1102E oscilloscope; 5 – personal computer with software.

The test unit consists of two ultrasonic sensors, a signal source, an oscilloscope, an RLC meter and relays. The source generates 1 MHz signal. The signal goes to one of the sensors, which excites the pulses of S- and P-waves. The waves pass through a core sample held by a core holder and are detected by the second ultrasonic sensor. Then the received signal goes to the oscilloscope. The oscilloscope is connected to the PC for analysis and recording of the received signal. The source gives three output signals: S-wave, P-wave, and a signal of source synchronization with oscilloscope. When measuring the elasticity of core samples, it is possible to graphically display the S- and P-waves, measure the wave travel time, and capture wave travel velocities, as well as to acquire Young's modulus and Poisson's ratio using the software to control the operation of the test unit. This requires knowing, among others, the length, the diameter, mass and density of the sample. A cylindrical core sample 30 mm in diameter and 30 mm in length is placed in a rubber cup in the core holder, where reservoir conditions are reproduced (squeezing pressure similar to the rock pressure, pore pressure similar to the reservoir pressure, as well as the temperature similar to the reservoir pressure).

Acoustic properties are measured in the following sequence:

1. The sample is inserted into the core holder and clamped by two clamping plungers;
2. The sample squeezing pressure is raised to 5 MPa and the temperature goes up to 25 $^{\circ}$C inside the core holder; in the case of poor visibility of the first arrivals, the pressure can rise to 15 MPa;

IOP Conf. Series: Earth and Environmental Science **155** (2018) 012020 doi:10.1088/1755-1315/155/1/012020

3. The oscilloscope connection is done, and the settings of the signal amplifiers are picked to better determine the first arrivals;
4. The operator selects the time of the first arrival and enters its value into the program to calculate the P- and S-wave velocities, Young's modulus and Poisson's ratio;
5. The heating of the sample goes on, and measurements take place every 10 degrees, starting at 30 $^{\circ}$C and ending at 90 $^{\circ}$C.

3. Results and Discussions

The lab test results of open porosity and density by the sinker method were used to compare the resulting data with the porosity and permeability.

28 samples of the rocks of the sand formation taken from the Ufimian Sheshma horizon, which is the main oil bearing stratum within the Lower Karmalka superviscous oil reservoir of the Cheremshanskoye field, were tested. The lithological analysis identifies 4 types of samples (Table 1):

a) Gray calcareous clay with a shell-like fracture. Non-bitumen samples;
b) Hard gray medium-grained sandstone. Non-bitumen samples;
c) Brown calcareous fine-grained, moderately cemented, uniformly bitumen-saturated sandstone;
d) Clayed gray flag-like limestone with multiple brachiopod shell fragments. Non-bitumen samples.

Table 1. Types of rock core samples by lithological description.

a)	b)	c)	d)
			

The laboratory tests under reservoir conditions resulted in correlations obtained and studied that allowed to estimate the interrelation between the porosity and permeability and the elasticity of rocks. When comparing the P-wave velocity with the open porosity, it was established that a good correlation is observed in samples of group C (bitumen sandstone) and D (non-bitumen limestone). The ultrasonic P-wave velocity versus porosity correlation shown in Figure 2 can be described by a linear function with a high degree of reliability (R^2 = 0.8282):

$$V_p = -82.805 \times \varphi + 5514.2, \qquad (1)$$

where φ = porosity, %; Vp = P-wave velocity, m/s.

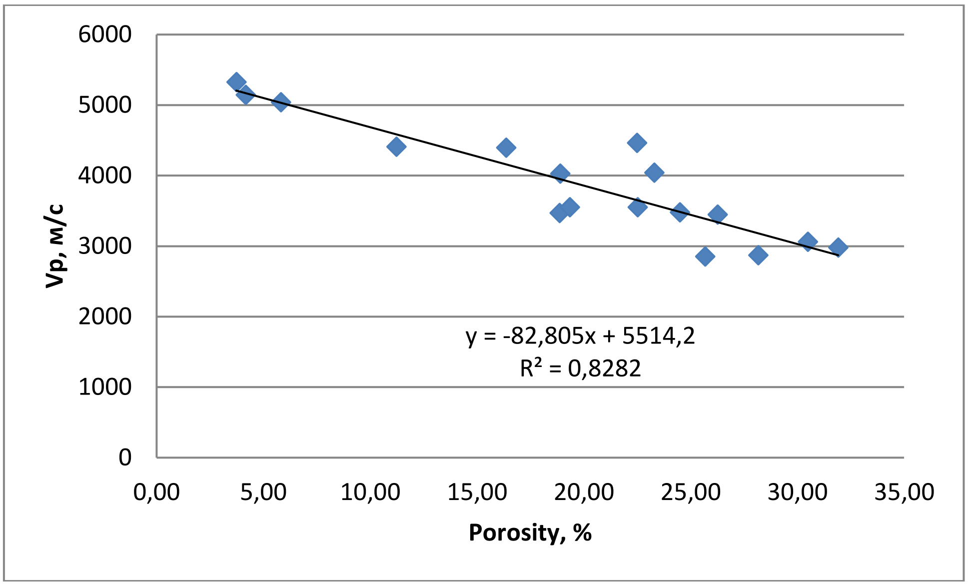

Figure 2. P-wave velocity vs. porosity.

This laboratory method of study acoustic properties can be recommended as an express method for estimating open porosity. Determination of the ultrasonic wave travel velocity under reservoir conditions should not take more than 10 minute for one sample.

These velocities and elastic moduli were calculated for a sample that was heated from 25 to 90 degrees. The measurements were taken every 10 degrees. The resulting figures were then used to look into the dependence of the P- and S-wave velocities, Young's modulus and Poisson's ratio on the temperature. For most of the samples, the velocities and elastic moduli decreased uniformly. In samples containing bitumen (type C, Table 1), a greater decrease in velocity was observed unlike the non-bitumen samples (type A, B, D, Table 1). In bitumen-saturated samples, the P-wave velocity decreased by an average of 6.4 %, and in non-bitumen samples by 4.9 %. For S-wave velocities, in bitumen-saturated samples – 6.9 %, in non-bitumen samples – 4.8%. The same is true for Young's modulus: 12.5 % and 8.4 %, respectively, for bitumen-saturated and non-bitumen samples.

The acoustic properties of samples as the temperature rises can be described by a linear equation of the form Vp = A*T+B, where Vp and T are the P-wave velocity and the temperature, respectively; the factor A describes the rate of change of the acoustic properties. Figure 3 shows the correlation of the factor A (rate of change of acoustic properties) and the porosity. This correlation is described by the linear equation:

$$A = 0.0616 \times \varphi - 5.6118 \quad (2),$$

where A is the factor characterizing the rate of change of temperature, φ is the open porosity, %. The degree of reliability is rather high (R2 = 0.8612); therefore, this correlation can also be used to estimate open porosity.

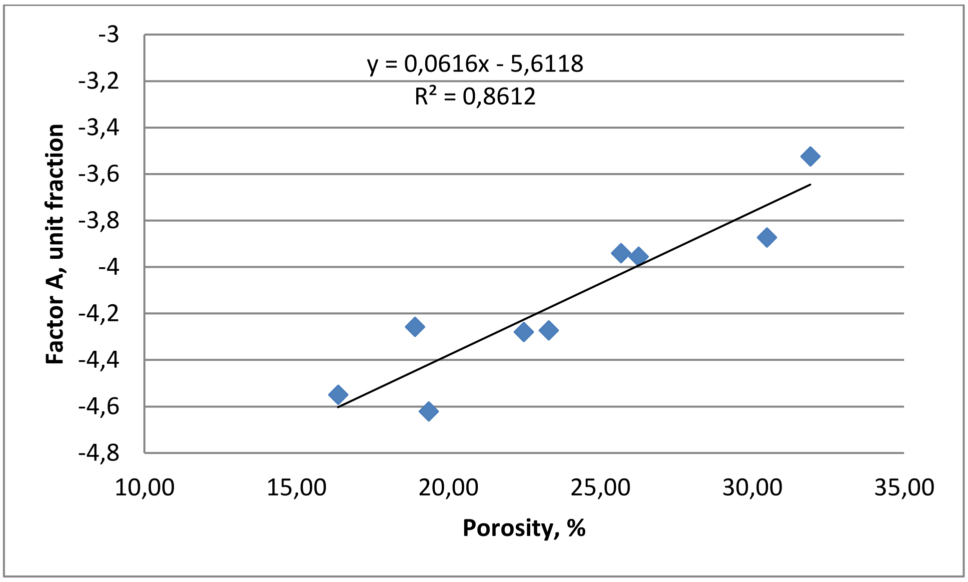

Figure 3. Factor A vs. porosity.

The fact that the samples behave differently when heated arouses much interest. Moreover, the groups identified by the change in velocity are not compared with the groups determined from the point of lithology. A possible explanation may be the pattern of how the bitumen situated in the rock.

According to the previous survey [3], the distribution of bitumen in the rock at low temperatures can be divided into three main types:

1.The sandstone is saturated with water, and the bitumen is sealed off from the pore walls, so the bitumen becomes part of the saturating liquid. Should this happen, the bitumen can mainly change the pore pressure, or its effect on acoustic velocities is similar to that of liquid.

2.The rock is heavily saturated with bitumen, and the bitumen forms a matrix to which sandstone grains are attached without interacting with each other.

3.The rock is less saturated with bitumen, and therefore bitumen accumulates only on grain contacts. Sands are cemented with bitumen, which can significantly increase the through-sample wave velocity.

The type of bitumen sandstone determines the pattern of the ultrasonic wave velocity [2]. The velocity is assumed to decrease linearly for sandstones as the bitumen of type (1) propagates across the rock. Samples behave non-linearly that are most likely related to the propagation type of bitumen (2) and (3). Also, the velocity jump can be caused by the specific dependence of fluid compressibility on temperature. According to Avchyan, "the presence of liquid in pores can cause a total effect of increasing velocity as the temperature rises" if the medium is poorly cemented and saturated with fluid at a small pore pressure [4]. The tests show that there is a need for a more detailed studying the pores of bitumen samples. The next test stage will be computer tomography of these samples to determine the propagation of bitumen and pore space.

4. Conclusions

The laboratory tests of bitumen sandstones reveal the following results:

- The P- and S-wave velocities, as well as the porosity and permeability of bitumen sandstones samples were acquired;
- The correlation of the ultrasonic P-wave velocity and the open porosity was analyzed to an acoustic study practice as an express method for estimating the porosity factor;

- The behavior of the P-wave velocity with increasing temperature was studied, four groups were distinguished according to the change in the velocity values;
- A linear function between the rate of change in acoustic properties and the values of open porosity were determined;
- An attempt was made to explain the pattern of velocity-temperature curves.

References

[1] Eastwood J 1993 *Temperature-dependent propagation of P- and S-waves in Cold Lake oil sands: comparison of theory and experiment Geophysics 58 (6)* pp. 863–872

[2] Han D-H, Liu J and Batzle M 2006 *Acoustic property of heavy oil-measured data: 76th Annual International Meeting, SEG, Expanded Abstracts* pp. 1903–1907

[3] Han X and Junxin G 2016 *Rock physics modeling of acoustic velocities for heavy oil sand. Journal of Petroleum Science and Engineering Vol 145 September 2016* pp. 436-443

[4] Avchyan G M, Matveenko A A and Stefankevich Z B Petrophysics of sedimentary rocks under deep conditions M: Nedra 1979 p. 224

[5] Muslimov R H, Vojtovich E D, Badamshin Je Z, Lebedev N P, Smelkov V M, Uspenskij B V Accommodation and development of natural resources of Tatarstan Geology of oil and gas №2 1995 P. 7-9

[6] Hisamov R S, Gatijatullin N S, Shargorodskij I E, Vojtovich E D, Vojtovich S E Geology and development of natural bitumen deposits of the Republic of Tatarstan p. 295

[7] Hisamov R S, Sultanov A S, Abdulmazitov R G and Zaripov A T Geological and technological features of the development of deposits of high viscosity and super viscous oil 2010 p. 335

[8] Sudakov V, Nurgaliev D, Khasanov D, Stepanov A, Khamidullina G, Kosarev V, Galukhin A, Usmanov S, Zaripov A and Amerkhanov M *Technology of Integrated Monitoring of Steam Chamber Evolution During the Oil Production from the Shallow Deposits of Super-Viscous Oil* Paper SPE-182000-MS presented at the SPE Russian Petroleum Technology Conference and Exhibition 2016 Moscow Russia pp 24-26