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Energy efficiency challenge of waxy oil production by electric submersible pumps

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ABSTRACT

In this paper the solid wax formation in two live oils of the Samara region fields on five operating pressures with different contents of high molecular substances were examined. For both oil samples a linear relation between wax appearance temperature and pressure was obtained. The study showed the inevitable transition of wax from the liquid phase to solid in the examined live oils under downhole conditions. This fact indicates a high probability of complications during well operations of these oilfields. If measures are not put in place to prevent the deposit formation in wells, there is a chance of complete blockage of tubing and flowlines by wax. These problems will lead to decrease in well flowrates to their shutdown, thereby increasing the operation costs to remove deposits and capital expenditures of oil production. Evaluation of the conditions for the wax precipitation in oil wells will allow to develop technology of prevention and remediation of previously formed organic deposits. The potential solid wax formation depth of both wells for minimum well flowrate of 20 m^3 per day are calculated. The technology of continuous injection wax inhibitor in designed depth where formation of solid wax has not been observed yet is proposed.

1. Introduction

Active agents which are used for tertiary recovery change the properties of the original oil in place (change viscosity, stabilize water-in-oil emulsions etc.). Furthermore, these surfactants can lead to both decreasing and increasing sizes of formed solid organic particles in oil [1–3]. Producing of changed oil is generally related to complications. The operator company in the field assesses the most possible production risks and develops methods for their prevention and remediation. Oil production from a majority of Russian oil fields is complicated by the organic scale formation in oil wells as a result of the thermodynamic disequilibrium in the oil dispersion system [4–7]. Identification and detailed study of factors that affect flow assurance is necessary for reliable oil production, technology development and validation of measures for the prevention of problems associated with the wax deposition in wells and porous media. Research aimed at the study of the equilibrium state of oil with dissolved high molecular weight components and adjustment of the wax precipitation process plays an important part in the energy-efficient petroleum exploitation.

Wax appearance temperature (WAT) is the temperature at which the first wax crystals appear in oil [8]. Upon further cooling, a spatial structure is formed by wax in oil, leading to considerable increase in its viscosity. Deposition of solid organic particles on the internal surface of tubings and pipelines creates additional local resistance to the moving stream (pressure loses), leads to decrease in effective area of internal section of tubings, to increase in pumping pressure [9–11]. Brown [12] showed that increase in oil viscosity considerably reduces capacity, head and efficiency of electric submersible pump (ESP). This causes additional energy consumption for pumping oil through the tubing and flowlines. Because of high oil viscosity the actual production is located on the left side of the down thrust condition of ESP. It results in an overheat of the downhole motor and pump wear [13], so that downhole equipment had to be replaced, which increases capital expenditures of oil production. There are many ways to slow the wax accumulation process in well and remove previously formed deposits, the most popular of which is the chemical method due to its high technological effectiveness [8,14–18].

WAT depends on many parameters of the studied system, basic of which include oil composition, gas saturation and pressure

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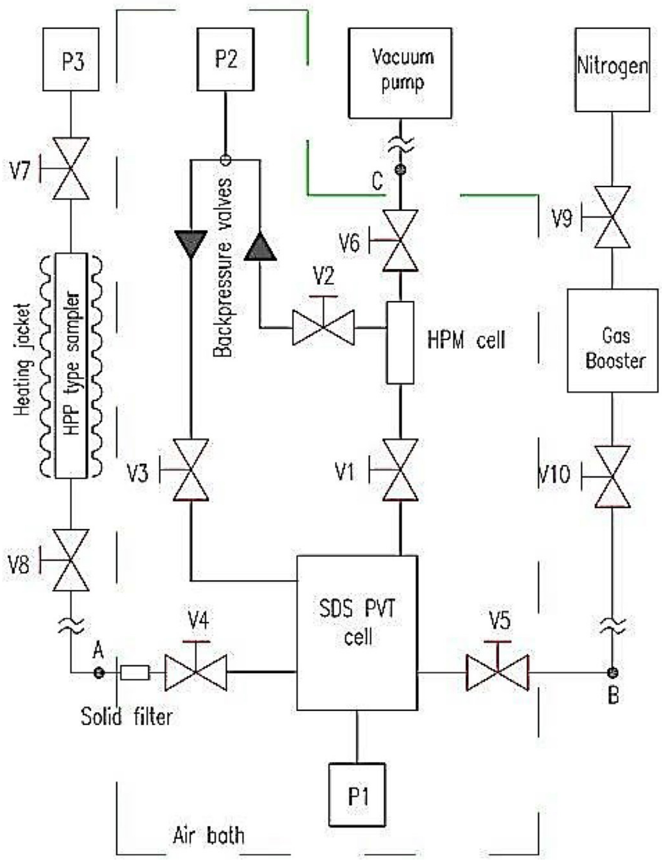

Fig. 1. Schematic diagram of the laboratory unit. P – pump; V – valve; A, B, C – connection points of the external equipment.

[19–21]. This study presents the comparison of wax precipitation conditions in two live oil samples of various compositions from two oil fields of the Samara region. Effect of high-molecular organic content (resins, asphaltenes and wax) and gas presence on the wax precipitation process in oil was evaluated. The objective of this research is to contribute results that lead to better understanding of the phenomenon in order to recommend appropriate preventive measures for organic deposition in oil wells.

2. Apparatus, fluid sample and experimental procedure

2.1. Apparatus

Study apparatus used for the experiments in this paper consist of an SDS PVT cell (solid detection system pressure-volume-temperature cell) of solid detection system [22,23] in which the energy of the transmitted light through an oil sample is measured - the main pump is set in this cell (P1 in Fig. 1) which supports a set pressure in the system; HPM cell (high pressure microscope cell) with in-built high pressure microscope [24] for taking micrographs of the oil sample under given conditions of temperature and pressure; a recirculation pump (P2 in Fig. 1), which agitates the analyzed fluid, homogenizing it; pipes and valves (V in Fig. 1). All system components are installed in the air bath, with operating temperature range set from 293 to 473 K with 0.1 K error.

Fig. 1 shows the connection diagram of elements of the research system.

2.2. Samples properties

Two live oil samples (sample A_1 and A_2) were collected from wells (A_1 and A_2) of two oil fields of the Samara region. Both wells are equipped with ESP. A_1 oil field was found in 1945 and has been exploiting since 1946. A_2 oil field was found in 1977 by exploratory well with the current depth of 1916 m and started producing in 2016 due to field infrastructure development. Wells are currently producing from oil-bearing formation with an API (American Petroleum Institute) gravity of 39.4 and 38.2, respectively. The producing formations are represented by sandstone with thickness of 20–40 m with interbeds of shale structure with thickness of 2–8 m. The production mechanism for these reservoirs is a water drive. Problems with the pumping equipment (cable burning, pumps wear) have been taking place in well A_1 during the last 10 years. Moreover, most of oil wells were shut in for workover on the average twice a year in order to remove the organic scale formation in the downhole equipment by hot oil flushing, solvent treatment or pigging operation. Well flow rate decreases lower than 100 m^3/d and water cut increases up to 90% during the workover period.

Table 1
Properties of the live oil samples.

Oil sample	A_1	A_2
Reservoir temperature (K)	321.3	320.5
Reservoir pressure (MPa)	26.2	18.4
Gas/oil ratio (m^3/m^3)	45.6	38.7
Bubble point pressure (MPa)	6.6	3.9

The oil samples were delivered to the laboratory at controlled reservoir pressure and temperature. Live oil from field A_1 (sample A_1) has a resin content of 3.0 wt%, asphaltenes of 0.1 wt% and wax of 6.3 wt%. Live oil from field A_2 (sample A_2) has a resin content of 4.7 wt%, asphaltenes of 1.5 wt% and wax of 4.9 wt%. These oil fields are complicated by the organic scale formation in the downhole equipment.

The main properties of these oils are shown in Table 1.

2.3. Measurement procedures

The oil sample was heated to 358 K in the sampler and then homogenized at reservoir pressure for 12 h. Then the laboratory facility was heated to 358 K, all lines of the system were vacuumized and then nitrogen was pumped into the system, creating reservoir pressure using a gas booster. 50 ml of oil from the sampler was transferred to the unit at reservoir pressure using pumps P1 and P3 (Fig. 1). Then nitrogen and 10 ml of oil were bled slowly through the upper point of the system (point C in Fig. 1), after which only 40 ml of the live oil sample remained in the installation for experiments. Finally, the recirculation pump was put on and the oil was homogenized for 12 h. Laboratory studying of wax crystallization process in oil was performed on a mode of isobaric temperature depletion step by step. For both reservoir oils temperature decrease was conducted from reservoir temperature approximately to temperature on 10 K below the wax appearance temperature on five operating pressures. Before each experiment the oil sample was heated up to 358 K by way of paraffin melting-down and maintained at this temperature and operating pressure till thermodynamic equilibrium was reached. In all experiments, temperature was reduced at a rate of 1 K per h. Each experiment was carried out three times. The error of results did not exceed 3%.

3. Results and discussion

As a result of laboratory experiments with the two live oil samples from different oil fields, the following data, presented in Figs. 2 and 3, were obtained.

In Fig. 2 the data of particles grain size distribution which precipitated out of the live oil sample at step by step temperature