PIPELINE FLOW OF WATER-OIL MIXTURES

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Transporting a mixture of water and heavy oil along a pipeline is a complicated task. The flow characteristics of any heavy-oil emulsion are unknown, so the carrying capacity of the pipeline for oil cannot be established with the required accuracy on the basis simply of theoretical expressions. Experiments have therefore been performed to determine the behavior of such a mixture under laminar flow conditions.

Here we report experiments designed to give the characteristics of water-oil mixtures having varying water contents \( B \) in \( \% \) and various temperatures \( t \).

We have performed visual observations on the flow and have measured the temperatures and pressure differences by the use of thermocouples and sensitive pressure detectors. We found that there are no signs of emulsification for \( B > 30\% \), and instead the flow separates into oil and water layers moving respectively in the upper and lower parts of the pipe.

It is very difficult to pump the heavy crude oil such as that from the Mukhaizna deposit in South Oman directly from the borehole because of the high viscosity. Dilution with water is the most economical of the methods of improving the fluidity of crude oil.

The results from researches, mainly experimental ones, on various water-oil mixtures are conflicting, so one cannot generalize from the characteristics or extend them to other mixtures. The discrepancies may arise because the viscosity is largely dependent on \( B \), temperature \( t \), and shear rate \( \dot{\gamma} \).

Our purpose has been to obtain additional experimental evidence on water-oil mixtures that could be used in the form of an empirical equation relating the viscosity to temperature, water content, and shear rate.

Newtonian and non-Newtonian flow states have been reported in the literature for water-oil mixtures traveling as emulsions in pipelines, with the non-Newtonian state considered as pseudoplastic. The flow on the whole is complicated and is determined by \( \dot{\gamma}, t, \) and \( B \). It has also been observed that the mixing rate is the most significant parameter in emulsions that are readily formed. On the other hand, it is difficult to suppose that this parameter is important for unstable mixtures.

At present, we do not have adequate data on the behavior of emulsified heavy oil such as the oil from the Muzhaizna deposit, particularly data on the viscosity of the water-oil mixtures, which is a parameter difficult to predict with reasonable accuracy, although the literature contains some general information [1-3]. However, we have not been able to locate any tests that could be used in order to calculate pipeline carrying capacity with adequate accuracy. One therefore needs careful laboratory tests before starting to perform calculations on actual pipelines.

We now consider the experiments on the laminar flow of water-oil mixtures in a closed hydraulic system. The experiments were performed under controlled laboratory conditions and involved visualizing flow structure and measurement of the pressure differences for various \( \dot{\gamma}, t, \) and \( B \).

Figure 1 shows schematically the hydraulic system, in which the water-oil mixture is in two interconnected vessels on a platform at a height of 1 m above the floor. The mixture was pumped into the pipeline by a Bornemann spiral rotary pump (type EL375), which was capable of producing pressures up to 0.7 MPa and which was fitted with a variable-speed drive to regulate the flow. A pump of that type has certain advantages over a gear or piston one, as it produces a flow almost entirely free from pulsations and has no effect on the rheological parameters.

Before entry into the pipe of diameter 4" and length 25.1 m, which is the main element, the mixture passes through a constriction designed to flatten the velocity profile. The main part of the pipeline consists of steel sections and a bend. At a distance of six times the diameter from the inlet, there was a transparent plexiglass part of length 1 m, which was used for visual

Fig. 1. Hydraulic scheme: 1) vessels; 2) pump; 3) pipe sections, diameter 4", length 1 m; 4) transparent parts of pipeline; 5) pipe, diameter 4"; 6) pipeline constriction; 7) computer; p and t points of pressure and temperature measurement, s sampling point.

Fig. 2. Flow in inlet transparent section (B = 70%, flow from left to right).

observation. A second transparent part for the same purpose was mounted at the end of the pipe. The entire pipe was slightly tilted (1:250) towards the outlet to provide complete drainage. The second part of the system included a sampler designed to provide information on the concentrations and distributions of the oil and water across the pipe.

The system was designed to operate with liquid temperatures up to 40 °C. The mixture was heated by two heaters having power of 2 and 2.4 kW immersed in one of the vessels and fitted with regulators for automatic disconnection when the set temperature was reached. Rapid cooling was provided by a spiral inserted in the vessel in direct contact with the liquid. The entire system, including the vessels, was thermally insulated with polyethylene during the experiments to reduce the consumption in the heating and maintaining the temperature. The laboratory building had a ventilation system to eliminate the vapor released on heating the oil above 30 °C.

The flow rate in the pipe was determined by calibrating the pump on operation with water. We found that the deviation in flow rate with oil from that obtained with water was not more than 1%.

The pressures were measured with precision calibrated sensors. To obtain the best data throughout the pressure range, we used two sets of sensors having measurement ranges of 0–0.1 and 0–1 MPa. The electrical analog output from the pressure sensors (voltage range 0–100 mV) was connected to the computer through an interface.

The temperatures at the pipe inlet and output were determined with insulated thermocouples type K, whose outputs were amplified by a factor of 1000. The thermocouples were calibrated with thermometers.