Journal of Petroleum Science and Engineering 128 (2015) 145–149

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Effect of water salinity on flow pattern and pressure drop in oil–water flow

A. Mukhaimer [b], A. Al-Sarkhi [a,*], M. El Nakla [a], W.H. Ahmed [c], L. Al-Hadhrami [a]

[a] Department of Mechanical Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[b] Center of Research Excellence in Renewable Energy, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[c] School of Engineering, University of Guelph, Guelph, Ontario, Canada N1G 2W1

ARTICLE INFO

Article history:
Received 15 March 2014
Accepted 5 February 2015
Available online 14 February 2015

Keywords:
flow pattern
pressure drop
salinity
oil–water flow

ABSTRACT

The effect of water salinity on flow pattern and pressure drop in oil–water flow was investigated experimentally in an acrylic 2.25-cm diameter horizontal pipe. The used oil has 781 kg/m^3 density and 1.85 cP viscosity at 25 °C. Water salinity was increased to 75‰ by mixing food salt with an amount of 9% of water weight to the water tank. The addition of salt changed the density of the water from 999 kg/m^3 to 1065 kg/m^3, and the viscosity from 0.985 cP to 1.246 cP at 23.5 °C. This caused the oil–water density ratio to change from 0.78 to 0.732 and the viscosity ratio to change from 1.94 to 1.536. The results showed that salinity delayed the transition from dispersion of oil in water over a water layer flow pattern to the dispersion of water in oil and oil in water flow pattern. It was also noticed that the waves in the stratified with mixture at the interface flow pattern in saline water had less amplitudes than that in tap water. Results for the pressure drop showed that inversion point location was noticed to start earlier in saline water than in tap water, and the decrease rate in pressure drop as the oil fraction approaches the inversion point was reduced in saline water. This means that inversion effect was reduced. However, since saline water density is greater, higher pressure drop was produced.

1. Introduction

The oil production process from wells always contains some amount of water which depends on wells' location and reservoir pressure. In some cases, water is deliberately injected into certain wells to stabilize the reservoir pressure. Under certain conditions, the injection of water into a crude oil pipeline results in a significant reduction of pressure loss, therefore facilitating oil transportation. Hence, oil–water flow in pipelines has attracted the interest of many researchers (e.g., Hasson et al., 1970; Oglesby, 1979; Arirachakaran et al., 1989a, 1989b; Beretta et al, 1997a, 1997b; Angeli and Hewitt, 2000; Soleimani et al., 2000). In a real case of crude oil–water flow, the injected water or the produced water in the flow is mainly saline with, in some cases, very high salinity. However, the majority of studies reported in the literature, is mainly performed with the use of either tap water or distilled water. The pipeline flow behavior of saline water and oil has received very much less attention.

There are different parameters that affect flow pattern transition, pressure drop, and inversion point in oil–water flow. These parameters include pipe diameter, inclination, interfacial tension, fluids densities and viscosities, etc. Numerous amount of studies on these effects were made, especially on pipe inclination as in Alkaya et al. (2000), Lum et al. (2006), Rodriguez and Oliemans (2006), Atmaca et al. (2009); oil viscosity as in Russell et al. (1959), Charles et al. (1961), Arirachakaran et al. (1989), Nädler and Mewes (1997a, 1997b); pipe material and diameter as in Beretta et al. (1997), Ioannou et al. (2005); and interfacial tension as in Ngan et al. (2011).

The effect of changing oil physical properties on flow pattern and pressure drop was investigated in many studies. This can be achieved by using different kinds of oil with different physical properties. However, the effect of changing water physical properties was not previously investigated. Moreover, used water in the previous experimental works has almost the same properties, where its density ranges from 997 to 1030 kg/m^3. This study aims on showing the effect of changing water density and viscosity on flow pattern and pressure drop of oil–water flow.

The effect of changing fluid densities might be strongly observed in the transition from stratified to stratified with mixture at the interface. When the density ratio increases, the stratified region increases with decreasing the stratified with mixture at the interface region. This effect can be seen in Brauner and Moalem Maron (1992a, 1992b) model of flow pattern transition. In the transition to dispersed flow, fluid densities seem to have an insignificant effect

* Corresponding author. Tel.: +966 3 8607725; fax: +966 3 9602949.
E-mail address: alsarkhi@kfupm.edu.sa (A. Al-Sarkhi).

http://dx.doi.org/10.1016/j.petrol.2015.02.012
0920-4105/

on the transition boundaries as could be seen using dispersed flow models such as Trallero and Tulsa (1995) or Brauner (2001). These models take into account the fluids densities, but their effect on the transition boundaries is slight.

2. Experimental setup and procedure

A schematic diagram of the experimental facility is shown in Fig. 1. It consists of two tanks for oil and water, two pumps for each fluid, test section, two separation tanks that are attached at the end of the test section, and a return pump close to the separation tanks to return the separated phases back to their original tanks (most of the time the water is drained and fresh water is replaced). The pumps can deliver oil or water with a maximum velocity of 3 m/s. Also, they can deliver oil and water together with a 3 m/s mixture velocity. A *Y*-shaped mixing section joins the oil and water pipes to the test section which has a 2.25 cm diameter. The pipes are made of PVC. The last section of the pipe was made of a transparent Plexiglas for visual observation. The velocity range of the conducted experiments was from 0.05 m/s to 3 m/s. The experiments were conducted indoor at 25 °C and regular check for the density was made and showed consistence results with no doubt about evaporation effect increasing brine salinity.

The test section pipe is made of PVC with ASTM D-1785 standard number. The pipe was installed horizontally. The first part of the test section is used for pressure readings. The other transparent part is used for visual observation to determine flow patterns. The total length of the test section is 8 m. Six pressure tabs (P1–P6) are distributed along the pipe as shown in Fig. 1 where the manometers are attached. Pressure drop was taken between P4 and P5 using a water manometer (mm of water) and a Rosemount differential pressure transducer. The pipe length to diameter ratio at P5 is 232. This ratio is taken from the start of the test section center of pressure tab P5. The water manometer error in reading is 0.5 mm of water. The flow meters used are variable area flow meters type from "king instrument co." and have an error of ±4% of full scale, with a range of 5–40 gpm. Other flow meters used for small flow rates (up to 1.5 m/s) have an error of ±1% of full scale where they range from 1 to 10 gpm. The density and the salinity of the saline and tap water were measured using an ATAGO S/Mill-E instrument. The uncertainty in the density measurement is ±0.001 kg/m^3, while the uncertainty in the salinity is ±1%.

The flow loop is a closed loop. However, a line to drain the loop is installed. Set of ball valves are installed to allow directing the flow either back to the main tank or to the drain. For each batch (oil fraction from 0 to 1), the oil and water mixture is collected in a large separation vertical tank which is opened to the atmosphere at the end of the loop. Once the oil and water completely separated in the separation tank the oil is returned to the main oil tank by using the return pump and the water is drained and new fresh water/brine will be used.

The operational procedure of the experiment starts by going from 100% water cut to other water cut ratios by pumping oil to achieve the required water cut. Two types of pressure drop profiles were taken, one with constant mixture velocity, and the other with fixing oil or water superficial velocity and increasing the other phase velocity. Each run continues for 2 min to achieve stable flow before taking data. After that, readings for pressure drop and pictures of the flow patterns are taken. The mixture then goes to the separation tank to separate oil from water.

Flow pattern is taken using visual observation only. The flow pattern map was taken at a superficial velocity range of oil and water from 0.05 m/s to 3 m/s. Oil and tap water properties are presented in Table 1. The used oil was Safrasol 80 which is a one type of Kerosene produced in Saudi Arabia.

3. Results and discussion

The classification of Trallero et al. (1997) and Nadler and Mews (1997a) for horizontal oil–water flow patterns were used. Seven flow patterns were identified. The seven flow patterns are: stratified (ST), stratified with mixing at interface (ST–MI), water-in-oil emulsion (W/O), oil-in-water emulsion (O/W), dispersion of oil in water over a water layer (DO/W&W), dispersion of water in oil under an oil layer (DW/O&O), the dispersion of oil in water and the dispersion of water in oil (DO/W&DW/O).

The effect of salt on the flow pattern is shown by providing pictures of the flow patterns for saline and tap water at the same oil–water flow rates. Several pictures were taken at different flow rates. The noticeable differences are shown in Fig. 2.

In Fig. 2(a) and (b), the flow pattern for tap and saline water is dispersion of oil in water over a water layer. It can be seen from the figures that for tap water, the oil flows in slugs or in separated masses while in saline water, a continuous layer of oil–water mixture is present at the upper part of the pipe.

In Fig. 2(c) and (d), the flow pattern in tap water is more as dispersion of water in oil and oil in water. However for saline

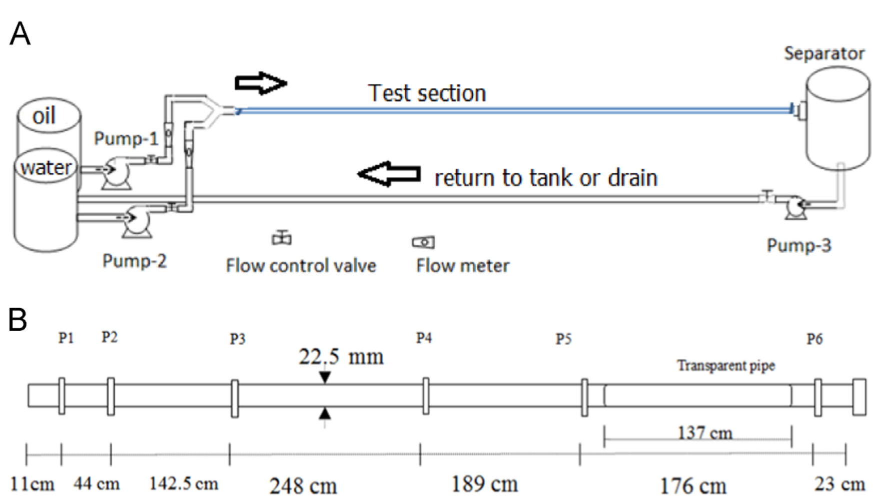

Fig. 1. (A) The experimental setup and (B) the test section.