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Flow characteristics of surfactant stabilized water-in-oil emulsions

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ABSTRACT

In this paper, an investigation was carried out to study the effect of water fraction and flow conditions on the flow characteristics of surfactant stabilized water-in-oil emulsion. Pressure drop measurements were conducted in 2.54-cm and 1.27-cm horizontal pipes. The influence of water fraction and the flow conditions on emulsion stability, type, conductivity, droplet size distribution, viscosity and pressure drop were reported. The results showed a significant increase in the emulsion stability, viscosity and pressure drop with increasing water fraction up to 70%. In addition, shear thinning behavior was observed for the emulsions especially at high water fractions. Furthermore, pressure drop measurements of high concentrated emulsions showed pipe diameter dependency especially at high Reynolds (*Re*) numbers. Moreover, drag reduction was observed with decreasing water fraction. The viscosity of surfactant-stabilized water-in-oil emulsions was modeled with a modified fluidity-additivity model.

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Keywords: Water-in-oil emulsion; Shear thinning; Pressure drop; Stable emulsion; Water fraction; Surfactant

1. Introduction

One of the common occurrences in the petroleum industry during transportation and production is oil–water flow in pipes. Moreover, two-phase liquid–liquid flow is common in the process and petrochemical industries. Although the accurate prediction of oil–water flow is essential, oil–water flow in pipes has not been explored as much as gas–liquid flow. The majority of studies reported in literature, have mainly focused on oil–water segregated flow patterns (annular and stratified flow). The pipeline flow behavior of water-in-oil and/or oil-in-water emulsions has received less attention.

Emulsion technology has been utilized in the acid treatment of reservoir rocks in the region near well bore. Sometimes, the pore structure near the well bore is plugged either by particulates from drilling process or by production precipitation deposits caused by pressure or temperature changes. As a result, permeability is reduced as well as the well productivity. To remove these unwanted deposits, acid stimulation is used. The carbonate matrix acidizing process consists of injecting hydrochloric acid into the formation pore space. The acid reacts with and dissolves portions of rock matrix and hence permeability is increased. The effectiveness of the treatment depends on the penetration depth of the acid into the formation.

Acid is consumed very quickly and it causes corrosion in the metal tubular goods. Therefore, deep penetration of the acid as well as corrosion rate reduction is the target. One method to achieve such retardation and to avoid corrosion is the use of the emulsified acid where the hydrochloric acid is injected as a water-in-oil emulsion. To maintain hydrochloric acid as the dispersed phase, it is necessary to use a composition that sits near the oil apex of the pseudo ternary diagram as reported by Hoefner and Fogler (1985) to form stable emulsion.

Generally, water-in-oil or oil-in-water emulsions are unstable thermodynamically. As the water/oil droplets are hydrophilic/hydrophobic they tend to separate from the oil/water continuous phase. In order to form a stable emulsion, a surfactant (emulsifier) must be used to reduce the interfacial tension and promote the formation of smaller droplets.

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Table 1 – Properties of the oil phase.

Product name	SAFRA D60
Flash point	67 °C
Density	780 kg/m^3
Viscosity	1.57 cp at 25 °C
Interfacial tension oil–water	0.017 N/m at 20 °C

Table 2 – Properties of the emulsifying agent.

Commercial name	ARMAC T
Common Name	Tallowalkylamine acetates
Appearance at 25 °C	Solid
Hydrophile–lipophile balance (HLB)	6.8

High pressure drop, caused by friction losses, can be a problem while pumping emulsified acid. As a result, emulsified acid is pumped at low flowrates and thus limited job efficiency is achieved. Consequently, methods of pressure drop reduction are highly desired.

Laminar and turbulent flow behaviors of unstable oil-in-water and water-in-oil emulsions in pipes have received a considerable attention (Baron et al., 1953; Cengel et al., 1962; Pal, 1987, 1993, 2007; Angeli and Hewitt, 1998; Masalova et al., 2003; Al-Yaari et al., 2009; Omer and Pal, 2010). The emulsion effective viscosities were calculated form single phase Hagen–Poiseuille equation and Blasius equation for laminar and turbulent flow, respectively. It was reported that since emulsion effective viscosity calculated for turbulent flow is lower than that for laminar flow or since the measured turbulent pressure drop is lower than that calculated from Blasius equation, drag reduction was claimed (Cengel et al., 1962; Pal, 1987, 1993; Omer and Pal, 2010). In addition, it was reported that such drag reduction increases with the increase in the volume fraction of the dispersed phase (Pal, 1987, 1993), the decrease in pipe diameter (Pal, 1993; Masalova et al., 2003) and the decrease in the viscosity of oil continuum (Omer and Pal, 2010). Moreover, drag reduction is a function of emulsion type (Pal, 1993) and pipe material (Angeli and Hewitt, 1998). Droplets stretching and elongation, in turbulent regime, is proposed as a mechanism of the reported drag reduction of studied unstable emulsions (Pal, 2007). Furthermore, phase inversion of unstable emulsions was also reported (Pal, 1993; Al-Yaari et al., 2009).

However, pipeline flow behaviors of stable oil-in-water and water-in-oil emulsions have received less attention. While drag reduction was reported for surfactant stabilized oil-in-water emulsions (Rose and Marsden, 1970; Zakin et al., 1979), little or no drag reduction was addressed for surfactant stabilized water-in-oil emulsions (Pal, 1993; Omer and Pal, 2010). In addition, with increased dispersed phase volume fraction, phase inversion and increased emulsion effective viscosities, calculated from the single phase equations, were reported (Pal, 1993; Omer and Pal, 2010).

This paper aims at studying the flow characteristics of surfactant stabilized water-in-oil emulsions. The influence of water (dispersed phase) fraction on emulsion stability, droplet size, viscosity and pressure drop is investigated. Also, it aims to examine a possible friction reduction through the control of water fraction. In addition, stable water-in-oil emulsions dependency on pipe diameter is studied.

2. Experimental setup and procedure

Surfactant stabilized water-in-oil emulsions were prepared using brine (with 50 kppm NaCl) as the aqueous phase and a type of kerosene, known as SAFRA D60 produced in Saudi Arabia, as the oil phase. Some physical properties of the oil are presented in Table 1. The emulsifying agent is ARMAC T from Akzo Nobel (Tallowalkylamine acetates), was used as the surfactant (emulsifier) and its physical properties are tabulated in Table 2.

Schematic layout of the flow loop is shown in Fig. 1. The flow loop consists of two small tanks (1 and 2), made from PVC, with a volume of 70 L each. Two centrifugal pumps (3 and 4) are used for low and high pumping rates. Test sections are two horizontal pipes with inside diameter of 2.54-cm and

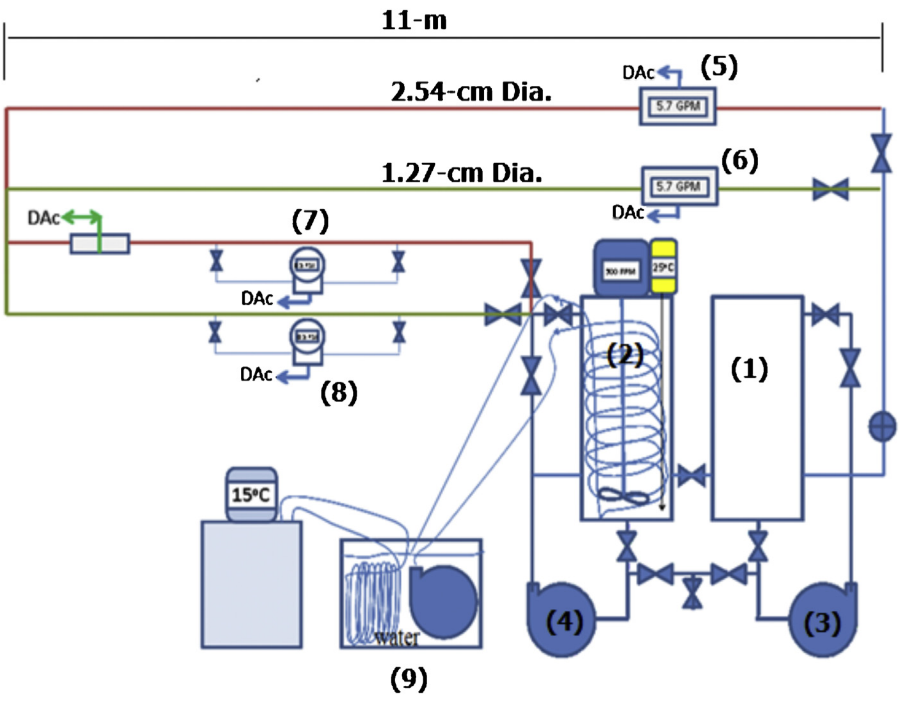

Fig. 1 – A schematic layout of the flowloop.

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