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Research paper

# Emulsification of heavy crude oil in water for pipeline transportation

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ABSTRACT

The stability and viscosity of W/O emulsions and their application for heavy oil pipeline transportation were investigated using two Iranian crude oil samples. An Iranian heavy crude oil sample named West Paydar and a blend of diesel and bitumen were used to produce heavy crude oil emulsions in water. The diverse factors affecting the properties and stability of emulsions were investigated. There was a restricted limit of 60 vol.% for crude oil content in the emulsions, beyond that limit the emulsions were inverted to water-in-oil emulsions. Different crude oil-in-water emulsions were prepared through addition of Triton X-100 surfactant. According to performed investigations, emulsification reduces the viscosity of the crude oil samples. However the viscosity of the emulsions increased by increasing the oil content of the emulsion, surfactant concentration, speed and time of mixing, salt concentration, and pH of the aqueous phase, while temperature of homogenization process substantially reduced the viscosity of the prepared emulsion. The stability of crude oil-in-water emulsions decreased by increasing the oil content while increasing the surfactant concentration, time and speed of mixing, pH of the aqueous phase and temperature enhanced the emulsion stability. The stability of crude oil emulsions was also increased by increasing the salt concentration. The main applicable observation of this research is that heavy crude oil-in-water emulsions can be highly stabilized simply by increasing the pH of the aqueous phase to basic values.



## 1. Introduction

Hydrocarbon resources are very important regarding the fact that they include about 65% of the world's overall energy resources (Langevin et al., 2004). Nowadays crude oil is the most important hydrocarbon resource of the world and heavy crudes account for a large fraction of the world's potentially recoverable oil reserves (Chilingar and Yen, 1980; Langevin et al., 2004). However, the heavy crude oils have a little portion in the world's oil production due to their high viscosities which cause problems in their pipeline transportation (Plegue et al., 1989). Production of heavy crudes is expected to increase significantly in the near future as low viscosity crudes are depleted (Plegue et al., 1989). Several alternative transportation methods for heavy crudes have been proposed and employed, including preheating of the crude oil with subsequent heating of the pipeline (Layrisse, 1998; Saniere et al., 2004), dilution with lighter crude oils (Iona, 1978), partial upgrading (MacWilliams and Eadie, 1993), and injection of a water sheath around the viscous crude. All the above-mentioned methods experience logistic, technical, or economic disadvantages, however.

One of the newest pipeline techniques is the transport of viscous crudes as oil-in-water (O/W) emulsions (Lappin and Saur, 1989; Gregoli et al., 2006). In this method, by the aid of suitable surfactants, the oil phase becomes dispersed in the water phase and stable oil-in-water emulsions are formed. The result causes a significant reduction in the oil viscosity, i.e. the produced emulsion has a viscosity in a range about 50–200 cP, and therefore in the transportation costs and problems. This method can be very effective in the transportation of crude oils with viscosities higher than 1000 cP especially in cold regions. Besides, since water is the continuous phase, crude oil has no contact with the pipe wall and this reduces the pipe corrosion (e.g. in the crudes with high sulfur content) and prevents forming of sediments in pipes (e.g. in the crudes with high asphaltene content) (Poynter and Tigrina, 1970).

To transport the crude oil using emulsion systems three steps are performed, including producing the oil-in-water emulsions, transportation of produced emulsions to the desired destination, and finally separation of oil and water phases (Poynter and Tigrina, 1970). To form the emulsions, the common method of homogenization is used, however, the new methods of emulsification by membranes and ultrasonic waves are being studied recently (Lidietta et al., 2003; Lin and Chen 2006). After transformation of crude oil is accomplished several different methods can be applied to separate the oil and water phases. Some of the important methods are thermal demulsification, electro-demulsification, chemical demulsification, freeze–thaw method, and demulsification by membranes (Yan and Masliyah, 1998; Srijaroonrat et al., 1999).

Different oil-in-water emulsions have been made by different crude oil samples. The use of surfactants and water to form stable O/W

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emulsions with crude oils is the subject of a series of patents (Titus, 1973; Ahmed et al., 1999). The technical viability of this method has been demonstrated in an Indonesian pipeline in 1963 and in a 13 mile long, 8 inch diameter, pipeline in California (Ahmed et al., 1999).

The purpose of the current research is to investigate the various factors affecting the preparation of a stable crude O/W emulsion for two Iranian oil samples, namely, West Paydar crude oil, and a blend of diesel and bitumen. The study investigates the influence of oil content of the emulsion, type and concentration of the surfactant, speed and duration of mixing, salt concentration and pH of the aqueous phase, and the temperature of homogenization on the stability and viscosity of the emulsion.

## 2. Materials and methods

### 2.1. Materials

All chemicals used were analytical grade reagents from Merck. Aqueous solutions were made using tap water. Triton X-100 (polyethylene glycol octylphenol ether) with chemical formulation of $C_{33}H_{60}O_{10}$ was used as surfactant. This surfactant is a nonionic hydrophilic surfactant which is suitable to form O/W emulsions. Hydrochloric acid and sodium hydroxide were employed to adjust the pH of the aqueous phase. Sodium chloride was used to adjust the water phase salinity. The homogenization method was used to perform the emulsification process and a laboratory scale Polytron hemogenizer, PT-1200C model; with maximum rotation speed of 22,000 rpm from Kinematica AG (Switzerland) was employed. An electric adjustable heater was used whenever heating was required. A Precisa pH900 pH meter was used to adjust and measure the pH of aqueous solution. A polyvisc viscometer, Viscostar model from Kinematica (Switzerland) was employed for viscosity measurements.

### 2.2. Specifications of Iranian oil samples

As mentioned above, an Iranian oil sample of West Paydar crude oil and a blend of diesel and bitumen were employed to perform the experiments. The characteristics of these samples are given in this section.

#### 2.2.1. West Paydar crude oil

West Paydar crude oil was employed to perform the first series of experiments. This sample was supplied by the National Iranian Oil Company. The specification of this sample is illustrated in Table 1. According to the observed characteristics, West Paydar crude oil belongs to the heavy crude oils with high tenacity category. The viscosity of this sample equals 198 cP at 25 °C (77 °F). The West Paydar crude oil pipeline is closed at the cold winters because of high viscosity and adhesiveness of it (NIOC-RIPI PVT department report, 2005).

#### 2.2.2. The blend of diesel and bitumen

The blend of diesel and bitumen was used to perform the second series of experiments. To simulate an extra-heavy oil sample, diesel and bitumen were blended to produce a synthetic crude oil with a viscosity equal to those of extra-heavy crude oils. The specifications of the 85/100 bitumen employed for this purpose are shown in Table 2 (Iranian Institute of Standards and Industrial Research, 2008). Diesel was mechanically mixed with the bitumen at the temperature of 50 °C until a homogeneous solution was formed. The viscosity of the obtained solution was adjusted by adding various amounts of diesel to bitumen. The effect of diesel quantity on the obtained viscosity of the blend is shown in Table 3.

### 2.3. Experimental procedure

Two series of experiments were performed using two different samples of crude oils. In both series, the influence of operating parameters including oil content of the emulsion (40–80 wt.%), surfactant concentration (0.5–4 wt.%), speed of mixing (1000–15,000 rpm), duration of mixing (5–40 min) salt concentration, pH of the aqueous phase (5–9), and temperature of homogenization (25–65 °C) on the stability and viscosity of the emulsion was investigated.

In each series of experiments, oil-in-water emulsions were prepared using various amounts of particular oil samples while other parameters were fixed at desirable values. Therefore, the maximum limit of oil content for each sample was revealed. Beyond that limit, phase inversion would occur. The produced emulsions were classified in two parts, one part for the viscosity and another part for the stability measurements. After finding the maximum limit of oil content for each sample, further investigations were carried out at the obtained maximum limit.

### 2.4. Stability of the prepared emulsions

The emulsion stability was measured based on the amount of separated water from the prepared emulsions after 24 h. O/W emulsions prepared at different conditions were tested for their stability by transferring the emulsions into laboratory graduated tubes; the latter were left at room temperature to rest for a while. The volume of separated water was recorded after 24 h since the time homogenization was performed. By dividing the amount of water separated from the emulsion to the initial amount of water in the emulsion, the percentage of separated water from the prepared emulsions was achieved.

## 3. Results and discussion

### 3.1. Effect of oil content

To prepare the O/W emulsions, the concentration of Triton X-100 surfactant in water was kept constant, namely 2 wt.% at the temperature of 25 °C and pH of 7, while speed and duration of mixing were 6000 rpm and 20 min, respectively. For each particular type of the crude oils, the oil content of the emulsion was varied from 40 to 80 vol.% with respect to the total volume of the emulsion. Fig. 1 demonstrates the effect of oil content on the viscosity and stability of the emulsions.

By increasing the oil content up to 60 vol.%, the viscosity of the emulsions slightly decreases. However, beyond this limit the viscosity increases significantly due to the occurrence of phase inversion. The

**Table 1**
Specifications of West Paydar crude oil (NIOC-RIPI PVT department report, 2005).

| Characteristics | Unit | Amount | Experimental method |
|---|---|---|---|
| Saturated | wt.% | 34.22 | SARA |
| Aromatics | wt.% | 38.82 | SARA |
| Resins | wt.% | 19.96 | SARA |
| Asphaltenes | wt.% | 6.58 | SARA |
| Wax appearance temperature | °F | 122 | Viscosity |
| Wax | wt.% | 3.56 | BP-237 |

**Table 2**
Specification of bitumen used in blend production (Iranian Institute of Standards and Industrial Research, 2008).

| 85/100 bitumen specification | Amount | Experimental method |
|---|---|---|
| Density at 25 °C (g/cm$^3$) | 1–1.05 | D-70 |
| Penetration at 25 °C | 85/100 | D-5 |
| Softening point (°C) | 45–52 | D-36 |
| Weight reduction caused by heating (wt.%) | 0.05 | D-6 |
| Penetration reduction (%) | 20 | D-6, D-5 |
| Fire point (°C) | 225 | D-92 |
| Solubility in carbon sulfide (wt.%) | 99.5 | D-4 |
| Spot test | Negative | A.A.S.H.O.T.102 |