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Separation of water-in-heavy oil emulsions using porous particles in a coalescence column

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ABSTRACT

In this study, the principle of capillarity and the mechanism of a wetting film in porous media are applied in designing coalescence media. Water-wet porous particles are used for the first time in a coalescing column to enhance the separation of water from water-in-heavy oil emulsions. Experimental results show that this type of particles can remain water-wet in an oil environment and can significantly enhance the coalescence of water droplets in water-in-heavy oil emulsions. The coalescing column test results show that the flow of the emulsion through the 10 cm coalescing column reduced water content from 44.37% to 21.54% at 80 °C, without using a demulsifier. The coalescing column can further reduce the water content beyond what was reached in gravity separation using a high dosage of demulsifier. At a fixed temperature of 80 °C, when the dosage of the selected demulsifier changed from 50 to 100 to 150 ppm, water content was reduced to 10.49%, 1.32%, and 0.64%, respectively, with the use of a 10 cm coalescing column. These results indicate that the effect of adding a coalescing column to water separation from water-in-heavy oil emulsions is significant, as compared to using only a demulsifier in gravity separation. More importantly, flow through the coalescing column could reduce the water content in the heavy oil to a very low level (<1.0%) and, at the same time, reduce the consumption of demulsifier.

1. Introduction

Crude oil is generally produced with water in the form of emulsions—dispersions of water droplets in oil. Emulsions are difficult to treat and cause a number of operational problems, such as the surging in separation equipment in gas-oil separating plants, the production of off-spec crude oil, and the creation of high pressure drops in flow lines. Emulsions have to be treated to remove the dispersed water and associated inorganic salts [1].

The water-in-crude-oil emulsion of heavy oil is generally a thermodynamically unstable system; however, additives can be used to provide the necessary kinetic stability. The stability of water-in-crude-oil emulsions depends, in part, on the irreversible adsorption of asphaltenes, which are naphthenic acid and clays at the oil-water interface [2,3].

Substantial treatments are required to break water-in-oil emulsions and to accelerate water separation. Along with gravity separation, heating, and centrifuge and hydro cyclone separation, chemical treatment with demulsifiers remains the most common process for breaking emulsions, although this technique is not always competitively effective [4–6]. Furthermore, there has been much research discussing how to apply a coalescer to bring together dispersed droplets in oil-in-water emulsions [7,8].

Coalescence is an effective process used to reduce high levels of oil and grease in an appropriate particle size range in oil-in-water (O/W) emulsion separation. The efficiency of oil removal from water largely depends on the properties of the filter medium, so the filter medium is the key criterion in a coalescence process for oily wastewater treatment [9–11]. Many types of packing materials have been tested. These fall into the categories of fixed media, granular packing, and fibre packing. The materials range from high-tech oleophilic plastic fibres to such exotic packing materials as granulated black walnut shells. Some of the more common packing materials tested include glass, fibreglass, peat, coal, sand, and polyethylene fibres [12].

Although hundreds of papers have been published regarding the use of porous media to coalesce dispersed droplets of oil-in-water emulsions, very few appear to be applicable to real-world problems. A significant portion of the literature deals with oil-in-water emulsions and, typically, with dilute oil concentrations. Many studies on water-in-oil emulsions employed synthetic

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emulsions, and often use simple oils such as kerosene, diesel, or mineral oils, rather than actual crude oils. The few studies that have examined resolving oilfield-derived emulsions include very early studies on light crude oil emulsions [13]. Madia et al. [14] concluded that oleophilic packing best coalesces oil droplets. Other studies have shown that neutral wettability packings yield the greatest success [15]. Still others claim that packings composed of "mixed media"—oleophilic and hydrophilic materials in the same bed—have a symbiotically enhanced success [16,17]. These studies over the course of a decade showed that the packing should have the same wettability as the dispersed phase. Of the materials tested—red rock from three different locations, fibreglass, polypropylene, coal, sand, lava rock, carbon granules, zorball (a commercial oil-absorbing mineral), and crusher dust—the most effective was a certain red rock which can maintain its water-wet character [13].

The primary objective of this research is to use porous particles in the coalescence column for separating water from water-in-heavy oil emulsions. A series of experiments have been conducted to demonstrate that the dispersed phase can coalesce on the same wetting material. The key point is to determine the long term effect of a coalescence material on breaking the emulsions by employing a new coalescer column design to remove water and basic sediment from produced heavy oil emulsions at a laboratory scale.

2. Experimental

2.1. Materials

In this research, Daqing heavy oil (Daqing, China) was used in all separation tests. Table 1 provides the properties of the heavy oil. The density of this crude oil is 920.8 kg/m^3 at 20 °C and is 900.6 kg/m^3 at 50 °C it. On the matter of density, the greater the density of the crude oil, the smaller the density differences between the oil and water, which causes difficulties in the gravitational settlement of heavy oil dehydration. When the temperature is at 50 °C, the viscosity of the crude oil is 235.6 mPa s. The materials used for coalescer packing are obtained by rubblizing tiles made of clay to a size range of 4–10 mesh. The demulsifier, DMO 8601, is a commercial product provided by the Baker Hughes Company. It is a synergistic blend of oxyalkylated phenolic resins, alkylphenols and sulfonates in a mixture of solvents of aromatics and alcohols.

The coalescing material plays a key role in enhancing the separation of water drops from W/O emulsions. After considering numerous materials (hard, soft, and porous, etc.), the particles of porous materials were obtained by rubblizing tiles made of clay. The pore size range is between 2 and 100 μm with the mean pore diameter of 26 μm. The selected porous particles can satisfy the porosity and the wettability requirements for the packing material of the coalescence column. These particles were highly porous, with fine pores connected and open to the surfaces of the particles. The procedures to treat the coalescing porous particles are as follows:

(1) Crush the tiles made of clay to obtain 4–10 mesh (diameter: 2–5 mm) packing particles.
(2) Rinse the particles by using water to remove fines on the surface of the particles.
(3) Dry the porous materials by putting them in an oven at 100 °C for 24 h.
(4) Immerse the particles in pure water for 24 h to make sure the particles are fully saturated with water.

Table 1
Properties of Daqing heavy oil sample.

Density @ 20 °C, kg/m^3	Density @ 50 °C, kg/m^3	Viscosity @ 50 °C, mPa s	Wax content, %	Colloid, %	Asphaltene content, %
920.8	900.6	235.6	29.7	28.70	0.24

2.2. Coalescence flow tests

The experimental set-up for separating water-in-heavy oil emulsions is shown in Fig. 1A. The set-up consists mainly of an oilfield emulsion tank, a coalescence column, a pump, a settling tank, and a water bath. Fig. 1B shows the processing of a water-in-oil emulsion through the coalescing and settling units. The photo and schematic of the coalescing column are presented in Fig. 1C. The pre-saturated porous particles are tightly packed in the holder to form the coalescing column. Two distributors are used at inlet and outlet ends of column to ensure a uniform flow of the emulsion through the porous particle bed. The emulsion is injected into the coalescence column from its bottom as shown in Fig. 1C. The water droplets of the emulsion coalesce to form larger droplets when the emulsion flows through the bed. After the mixture of the oil and water is transferred to the settling unit, oil and water then separate by gravity.

The procedure of the coalescence flow test includes the following steps:

(1) Pack the coalescence column by adding water saturated porous particles into the bed holder, which is filled with water.
(2) Connect the pump, emulsion tank, coalescence column, and settling unit.
(3) Set the temperature of the water bath to warm up the emulsion, coalescence column, and settling unit to a desired test temperature.
(4) Pump 500 mL of the emulsion, at 1.0 cm^3/min, to flow through the coalescence column.
(5) Keep the collected oil and water in the settling unit, at the same temperature, for 4 h to allow water droplets to settle by gravity.
(6) Take an oil sample from the oil layer in the settling unit for determining water content of the oil.

2.3. Water content analysis

The water content in the oil after separation was analyzed using the Dean-Stark method [18]. In the Dean-Stark analysis for determining water content in oil, the oil sample was mixed with the solvent (toluene) in the flask. The mixture was heated to vaporize the solvent and water. The vaporized solvent and water condensed in the condenser and were collected in the burette. From the water volume collected in the graduated tube (at the bottom) and the initial oil sample volume and the known densities, the water content in the oil was determined.

3. Results and discussion

3.1. Wettability of the coalescing material

When the dried particles of the materials were immersed in pure water, the immersed materials yielded fine bubbles and the bubbling persisted for a long time. Fig. 2A and B shows the bubbling phenomenon of the immersed materials and the dry particles. It was also observed that the surfaces of the pores of the materials were strongly water-wet. When the particles were immersed in water, water could therefore spontaneously imbibe into the pores and push air out. In addition, the materials were subsequently further tested for the ability of remaining strongly water-wet after being in contact with heavy oil.