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Oily water treatment using a new steady-state fiber-bed coalescer

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ABSTRACT

This study was concerned with the possibility of oil separation from two heavily polluted wastewater types: formation water and wastewater from hardening shop, using bed a newly developed coalescer. Experiments were carried out using original wastewaters and an artificial model wastewater. Results obtained for seven samples of formation water of very different quality showed that the water properties had no significant effect on bed coalescence efficiency. In contrast to this, crude oil properties strongly influenced steady-state bed coalescence. In the treatment of hardening oily wastewater in situ during a 4-month period oil concentration in the effluent was less than 20 mg/l in all experiments. It appeared that oil concentration and water quality had no effect on bed separation efficiency. Special design of the coalescer and use of two filter materials ensured its good performance. Namely, the pipe-in-pipe construction provided the water orientation change several times while passing through the unit, making inertia one of dominant separation mechanisms.

1. Introduction

Oily waters may contain lubricants, cutting liquids, heavy hydrocarbons such as tars, grease, crude oils, diesel oil, and light hydrocarbons such as kerosene, jet fuel and gasoline, as well as fats, vegetable oils or fatty acids [1]. Several separation setups have been used for oily water treatment: settlers, deep bed filters, bed coalescers, centrifuges, adsorbers, membranes, and others [2–5]. However, very often, the selected separation technique does not meet the desired requirements in real situations.

Selection of separation technique depends on several factors, the most important being oil solubility in water. Namely, part of the oil is always soluble while the other part is dispersed in water. Adsorption is an effective and economically reasonable solution only for soluble oil. In case of dispersed oil, it is important to know its pour point. When the working temperature is higher than oil pour point, the dispersion contains two immiscible liquids, so that we deal with a liquid–liquid system. In the case when this temperature is below the pour point there exists a liquid–solid dispersion. Settlers, deep bed filters, centrifuges and membranes are useful and effective for both types of oil dispersions [6], while bed coalescers are suitable only for liquid–liquid dispersions, emulsions.

For oil separation from wastewater the most important data are water quantity, phase ratio, and emulsion stability.

Steady-state bed coalescers are very comfortable solution for the separation of unstable emulsions, regardless of their quantity and phase ratio. The use of fiber-bed coalescers is getting increasingly attractive in the industry due to their high efficiency and simple construction. However, their design is still based on experimental data and experience [7–9].

In the present literature, it is still not clearly explained that bed coalescers can operate in two regimes: unsteady-state and steady state. In an unsteady-state regime, drops collect in the bed and pressure drop increases with time [10,11]. This operation is similar or equal to deep bed filtration, where operation is discontinuous and filter needs washing. During the washing step, a new quantity of oily water is generated.

In the steady-state regime, pressure drop is constant with time, and fluid velocity determines its value. In these circumstances, saturated oil exists inside the bed. Small inlet droplets coalesce on the surface of saturated liquid inside pores, and larger drops (globules) detach from the surface and settle behind the bed [10,11]. This operation could work continuously for a long time, especially if the content of suspended solid in the wastewater is not extremely high. One of the advantages of these units is the possibility to automatize the process.

Bed coalescers consist of two sections: bed and settling section [8,9,12–14]. Separated oil, with low concentration of water, collects on the top of the settling section and is discharged discontinuously.

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The objective of this work was to develop a new bed coalescer with high separation efficiency, which could treat heavily polluted oil wastewaters. The tests were carried out in the Central Laboratory of Oil Company of Serbia and the Kikinda Foundry. Some of commercial separators that have been used there appeared to be unsuitable for these applications.

2. Materials and methods

2.1. Experimental fiber-bed coalescer

The bed coalescer is schematically presented in Fig. 1. The coalescer body is a vertical pipe-in-pipe system. The coalescer pipes are filled in with different polymer materials: granular expanded polystyrene (EPS) (pipe 1), and polyurethane (PU) fibers (pipe 2). Wastewater enters at the bottom of Section 4, passes vertical up through the EPS bed, changes its orientation to vertical down on the top of the unit, and then is passing through the PU bed. The waste oil collects at the top of unit 5, and is discharged discontinuously through valve 3. The tested coalescer was of two sizes: a small laboratory setup with the capacity of 0.025 m^3/h, and a pilot unit with the capacity of 1 m^3/h.

2.2. Operating conditions

In all experiments, the steady-state regime was achieved by pre-oiling the PU fibers. Therefore, a steady state was established from the very beginning of the experiment, which was confirmed by a constant pressure drop.

In all experiments fluid velocity was 7 m/h. Temperature was determined for each set of experiments. Oil concentration in water was determined by IR spectrometry using a carbon tetrachloride extract. Oily water samples were conserved by adding HCl to pH 2.0.

2.3. Formation water

Formation water treatment was carried out in the Central Laboratory of Oil Company of Serbia. Two sets of experiments were performed; one involving real formation water (samples marked from DA to DG) and the other involving model formation water (marked from DMA to DMG). Wastewater was mixed in the inlet tank to obtain oil drops of the mean drop size of 20 μm. Wastewater temperature was kept constant at 35 °C.

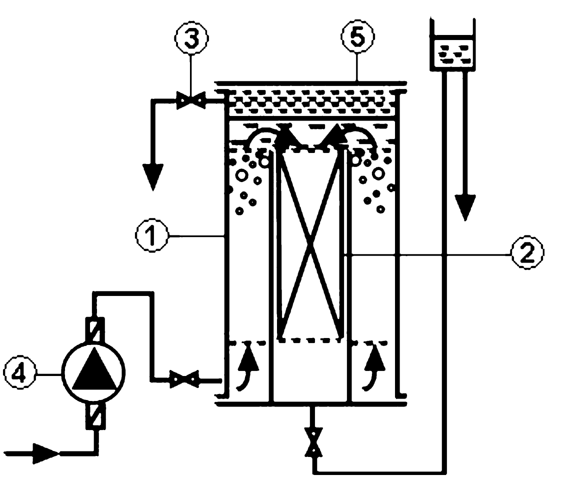

Fig. 1. Schematic of the coalescer.

Seven samples of formation water of very diverse composition were selected, special care being paid to those which have low separation efficiency by gravity. Main characteristics of the wastewaters and crude oils (A–G samples) are given in Tables 1 and 2.

Model formation water was treated under similar conditions. In this case, the continuous water phase was prepared by adding 13.5 g/l NaCl and 1.5 g/l $CaCl_2$ to tap water to obtain a salinity of 15 g/l. The discontinuous oil phase consisted of those crude oils that existed in the real formation water. The influent oil concentration was constant, 500 mg/l.

For each sample tests were run for 15 h in continuity. Oil concentration in the effluent was determined every 2 h in composite samples, collected at the outlet of the unit during the last 15 min at 5-min interval.

2.4. Hardening shop wastewater

In case of hardening shop wastewater, two discontinuous tests were performed in situ on real hardening wastewater and in laboratory on a model wastewater. The pilot coalescer was located in the hardening shop of the Kikinda Foundry after the equalization tank, and testing lasted 4 months. Oil concentration in the effluent was determined in the composite samples for every work shift, in 2 h interval.

Characteristics of the hardening wastewater determined during the test period are given in Table 3. Main properties of the hardening mineral oil at 20 °C were: density 885 kg/m^3, viscosity 147.60 mP s, and refraction index 1.49.

The model water, with constant inlet oil concentration of 130 mg/l was prepared by mixing tap water and waste hardening mineral oil. Oil concentration in the effluent was determined in composite samples for every work shift.

3. Results and discussion

3.1. Crude oil separation from formation water

Crude oil production is always accompanied by remarkable quantities of formation water, which represents a very complex dispersion, with high concentration of suspended solid, high salinity, crude oil, phenols, ammonium, inorganic ions (calcium, magnesium, sodium, lithium, barium, strontium, chlorides, sulfates, nitrates, etc.). This water represents a very big environmental problem. The best way to solve this problem is to inject formation water back into oil well. Before injection, some treatment of formation water has to be done. Crude oil separation is necessary because the big oil droplets could block pores inside earth layers. The separated crude oil is of economic value as a by-product, important for sustainable development.

Formation waters from Vojvodina oil fields contain very different crude oils, their main characteristics being given in Tables 1 and 2. The range of suspended solids in the investigated samples was from 31 to 335 mg/l; ammonia was from 5 to 125 mg/l, and salinity from 2 to 27 g/l. The density of crude oils was from 850 to 920 kg/m^3; viscosity was from 7 to 1132 mP s; pour point was from −30 to 30 °C, and mean molecular weight was from 200 to 500 kg/kmol.

It is well known from the literature that emulsion characteristics are determined by the nature of both constitutive liquids. Interdependences between them are specified by their properties such as double layer, zeta potential, van der Waals forces, interfacial tension, etc.

The coalescer showed high separation efficiency for these complex oil–water dispersions. Effluent oil concentrations during 15-h