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Pulsed ultrasound assisted dehydration of waste oil

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ABSTRACT

A method to aid the separation of the oil phase from waste oil emulsion of refineries had been developed by using a pulsed ultrasonic irradiation technology. Compared with conventional continuous ultrasonic irradiation, it is found that pulsed ultrasonic irradiation is much better to make water drop coalescence and hence dehydration of waste oil. The effects of ultrasonic irradiation parameters on waste oil dehydration are further discussed. The orthogonal experiment is also designed to investigate the degrees of influence of ultrasonic parameters and the optimal technological conditions. Under the optimal experimental conditions, the water content of waste oil is decreased from 65% to 8%, which thereby satisfies the requirements of refineries on the water content of waste oil after treatment (<10%).

1. Introduction

Separation and recovery of the oil phase from waste oil emulsions has a powerful influence on environmental protection and economic benefits to refiners. A common waste oil treatment method in a refinery is to collect waste oil into a tank farm for thermal precipitation, and then sent for recycling by removal of a majority of impurity and water content. However, this method has some drawbacks. In particular, given that precipitation in a tank farm is time consuming, the production cycle usually takes several days, thus affecting the production efficiency. Besides, the tracing steam consumption in the settlement process is relatively large. Researches on chemical demulsification of waste oil have also been further developed in recent years [1]. However, the dehydration process is not ideal yet. In addition, chemical demulsifiers have poor adaptability and may cause environmental pollution in the progress of water treatment.

As an easier, simpler and more efficient method, ultrasonic technology has recently been applied to water–oil emulsion separation on the laboratory scale in many literatures [2–11]. Experimental results in these literatures suggest that the separation is enhanced under ultrasonic irradiation. And then, many kinds of sonochemical reactors [12,13] and ultrasonic dehydration apparatus [14–16] on the large scale have been designed successfully, which makes scale up of ultrasound-assisted dehydration become possible. Mechanism of ultrasonic separation is ascribed to a force on the drops in the emulsion under ultrasound irradiation, which includes the primary acoustic force and the secondary acoustic force because the density and compressibility are different between the dispersed phase and the continuous phase [17–23]. Pangu [4] divided the trajectory model of the agglomeration of droplets into two regimes. (a) Droplets are driven to equilibrium positions near the pressure node (or antinodes) by the primary acoustic force. (b) The droplets subsequently approach collision slowly because of the combination of the secondary acoustic forces and van der Waals forces. It indicates that ultrasonic irradiation can help small water droplets coalesce and become bigger, which is favorable to water droplet settling down caused by an external force such as gravity. After the irradiated emulsion settles down for a reasonable period, water content of the emulsion should decrease.

However, few research is carried out on the ultrasound-assisted dehydration of waste oil. It probably attributes to the fact that the composition of waste oil (i.e., high contents of colloid, asphaltene and solid particles) is very complicated, which increases the stability of emulsion [24,25]. In addition, in order to obtain the best dehydration result, an optimal ultrasonic frequency should be inversely proportional to the squares of water droplet volume [26] in the process of dehydration with continuous ultrasound. The waste oil comes from multiple processing procedures in refinery, which results in quite different volumes of water droplets in waste oil emulsion. Thus, some small water droplets may not match the optimal frequency, which adds the difficulty of dehydration with conventional continuous ultrasound. On the other hand, Tuziuti et al. [27] found that the small degassing bubbles were ineffective for sonochemical reaction under continuous ultrasound irradiation due to the small volumetric oscillation. Moreover, the

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small degassing bubbles prevent the propagation of sound by absorption and scattering of the sound, and hence the reduction of the sound pressure amplitude. However, the pulsed ultrasound technique can implement coalescence of small degassing bubbles more effectively and promote the high amplitude of sound propagation, which leads to an increased number of bubbles that are effective for sonochemical reaction.

In this paper, we have investigated the effects of pulsed ultrasonic irradiation on improving the efficiency of waste oil dehydration. In the process of ultrasonic demulsification, even if both the properties of waste oil and ultrasonic radiation parameters influence the demulsification results, this study is mainly focused on investigating the effects of pulsed ultrasonic radiation parameters on demulsification, which should provide a guide for setting condition for the dehydration of waste oil.

2. Material and methods

The experiments were conducted in a rectangular constant-temperature chamber from Wuxi Ultrasonic Electronic Company. Fig. 1 shows the schematic of the chamber, which consists of a PZT transducer (a rectangular flat), an ultrasound generator (10/20/40/80 kHz), a hydrophone, and an osciliograph. The PZT transducer was fixed on top of the chamber and a screw bolt was used to adjust the distance between the transducer surfaces. When the distance was kept as a constant of an odd number of the half a wavelength:$h = n\lambda/2$, which was detected by hydrophone that wave nodes and antinodes appear alternately on a osciliograph, the chamber could be considered at a standing wave field condition. However, when the distance was not an odd number of the half a wavelength, it was found that distribution of wave nodes and antinodes on the osciliograph was not regular. At this time, the chamber could be considered at a reverberant wave field condition. The ultrasonic field was produced by energizing the transducer at various frequencies (10/20/40/80 kHz). Temperature of waste oil in the chamber was adjusted by electrical heating equipment in the jacket of the chamber. Besides, a temperature control system was used to keep the chamber at a constant temperature.

The chamber was filled with emulsions (i.e., 10.5 L) prepared from a waste oil provided by Sinopec Yangzi Petrochemical Company. Characteristics of waste oil are showed inTable 1. It can be seen that the composition of the waste oil is complicated (i.e., high contents of colloid, asphaltene and solid particles). Those natural emulsifier in waste oil are adsorbed on the oil–water interface, forming a viscoelastic membrane with high strength. It is a kinetic barrier to droplet aggregation, thereby ensuring the stability of waste oil emulsion and hindering the oil–water separation.

A series of experiments were run to investigate the effects of ultrasonic irradiation factors on waste oil demulsification. Table 2 displays experiments conducted throughout the study. The number and size of the water droplets before and after ultrasonification were observed and recorded using an optical microscope fitted with a high-performance computer-controlled digital camera. After the emulsion was irradiated at 30 °C by ultrasound and then gravity settled for 3 h at 30 °C, 100-ml emulsion at the location of 3 cm from the oil surface in the upper layer was removed with a pipette, and then the water content of this emulsion was analyzed by the method of distillation (GB/T8929-1998 measurement of water content in crude oil). To get reproducibility, we repeated every experiment 4 times and the final experimental data was a mean of 3 results, whose errors were not more than 5%.

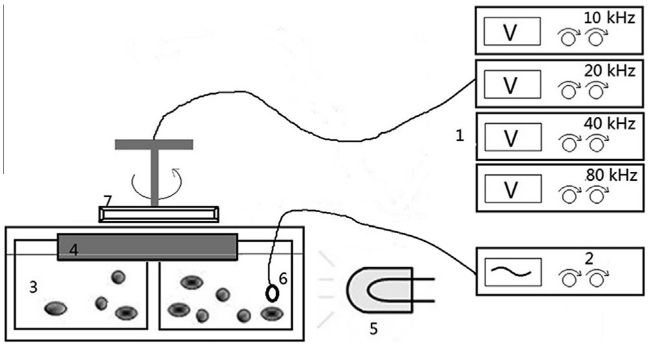

Fig. 1. Experimental device of ultrasonic dehydration: 1, ultrasonic generator; 2, osciliograph; 3, acoustic chamber; 4, ultrasound transducer; 5, light; 6, hydrophone; 7, screw bolt.

Table 1
Characteristics of waste oil for experiments.

Species	Value	Species	Value
Density (g/cm^3) (20 °C)	0.92	Solid particles (mg/L)	361
Interfacial tension (dynes/cm)	36.3	Water content (v.%)	65
Viscosity (mPa s) (20 °C)	1440	Asphaltene content (wt.%)	12.4

3. Results and discussion

3.1. Effects of ultrasonic parameters on dehydration with ultrasound

3.1.1. Comparison of the effects of different ultrasonic irradiation types on waste oil dehydration

Fig. 2 demonstrates the confocal images of waste oil sample before and after the ultrasonic irradiation. It can be seen that the size of water droplets in the emulsion significantly increases and the number of small water droplets decreases after the ultrasonic irradiation. In addition, relative to continuous ultrasonication, coalescence of water droplets after pulsed ultrasonic radiation is more obvious, and the number of water droplets in the emulsion is smaller after 3-h thermal precipitation. The result indicates that ultrasonic radiation can promote coalescence of water drops in waste oil emulsion.

As shown in Fig. 3, the water content of waste oil after the 3-h thermal precipitation (without ultrasonic radiation) is 56%. The water content of waste oil is decreased to 21% after continuous ultrasonic radiation for 4 min and thermal precipitation for 3 h. Moreover, after a pulsed ultrasonic radiation for 6 min and thermal precipitation for the same time, the water content of waste oil emulsion can be decreased to 8%, which satisfies the requirement in terms of water content of waste oil after treatment (i.e., <10%). In the process of dehydration with continuous ultrasound, in order to obtain the best dehydration result, an optimal ultrasonic frequency should be inversely proportional to the squares of water droplet volume [26]. However, the waste oil comes from multiple processing procedures in refinery, which results in quite different volumes of water droplets in waste oil emulsion. Some small water droplets are not match the optimal frequency of continuous ultrasound, and then coalescence of these droplets becomes difficult. Moreover, these small water droplets prevent the propagation of sound by absorption and scattering of the sound, which leads to a decrease in the sound pressure amplitude. Therefore, waste oil dehydration is limited with conventional continuous ultrasound irradiation. However, an appropriate pulse-off time that is specific to the ultrasound pulsing operation can implement coalescence of the small water droplets more effectively [27], and thereby promote a high amplitude of sound propagation and improve the efficiency of waste oil dehydration.

Besides, with the help of the pulsed ultrasonic irradiation, the time of waste oil dehydration decreases to about 3 h from several days, indicating that the dehydration progress becomes more