Design and Implementation of the Frequency Control in an Ultrasonic Break Water-in-Oil Emulsion Chamber

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Abstract

Water-in-oil emulsions present high stability and its separation is commonly accelerated by addition of chemical demulsifiers or using electrostatic techniques. An alternative to reduce the amount of demulsifiers is the use of ultrasonic standing waves. In this work, the design and implementation of an ultrasonic demulsifier system operating in the 1 MHz range is presented. The design includes the ultrasonic resonant chamber, the power electronics to drive the piezoelectric transducers and the control system. The control must track the operating frequency, compensating the changes due to temperature variation. The system was evaluated in a laboratory pipeline showing that the use of ultrasound reduces the final water content in all cases.

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Keywords: Frequency control; emulsion break; ultrasound; resonating chamber; temperature effects; water-in-oil emulsion

1. Introduction

In petroleum extraction industry, it is often required the reduction of the water content mixed with oil (Kokal, 2005). Before sending the extracted oil to the refinery, it should meet certain specifications for the maximum amount of water (typically less than 1%). Emulsion separation is commonly accelerated by the addition of chemical
demulsifiers or with electrostatic techniques (Eow et al., 2001). An alternative to reduce the amount of chemical demulsifiers is the use of a standing wave ultrasonic system. When small water droplets mixed in oil are placed on a standing wave, the acoustic radiation force pushes the water droplets to the pressure nodes, inducing its coalescence (Pangu and Feke, 2004). Figure 1 presents an illustration of the separation of water-in-oil emulsion by an acoustic standing wave. It should be noted that coalescence occurs only when the cavity is in resonance. Important studies about this ultrasonic application can be found in the literature, such as the ultrasonic separation of suspended particulates (Benes et al., 2001) and the kinetic study of the coalescence of water in oil emulsions (Pangu and Feke, 2009).

This paper presents the design of an ultrasonic chamber to be applied in the water/oil separation. The ultrasonic standing wave is produced by two piezoelectric transducers which are electrically excited independently by two power amplifiers with a resonance tracking system.

![Fig. 1. Ultrasound application technique scheme in emulsions coalescence. (a) Emulsion subjected to a standing wave acoustic field, (b) aggregation of water droplets at the pressure nodes, (c) coalescence and sedimentation of water droplets, and (d) final separation due to gravity and density difference.](image)

2. Coalescing chamber

The design of the resonating chamber is a key point in the implementation of the demulsifier system. It basically consists of a resonant cavity with attached piezoelectric transducers. The cavity resonant frequency depends on the speed of sound of the liquid sample, which in turn depends on the temperature. If a temperature gradient occurs, different sections of the chamber have different resonant frequencies, limiting the system efficiency. The use of the same frequency in the entire chamber produces coalescence only in places where the resonance occurs. The rest of the system is only giving power to increment the temperature and then reducing the global efficiency. A solution is to excite each piezoelectric transducer independently (see Fig. 2), with the right frequency correspondent to the resonance for this particular position. However, it was verified that the main temperature gradient occurs in the flow direction, and then the emitters are divided in two sets named as Transducer 1 and Transducer 2 in Fig. 2. This approach is applied in order to reduce the influence of the temperature gradient between the inlet and the outlet.

![Fig. 2. Ultrasonic break water-in-oil emulsion chamber.](image)

A typical 4 layers resonator (Groschl, 1998b) was designed with a PZT4 piezoceramic layer (2.02 mm), an aluminum coupling layer (5.6 mm), a liquid (water-in-oil emulsion) layer (20 mm), and an aluminum reflector layer
The piezoceramic layer is composed by two transducers which are independently electrically excited. Each transducer is composed by three piezoelectric square (160 mm$^2$) plates, as shown in Fig 2(a). The chamber volume is approximately 200 ml. Figure 2(b) shows the coalescence chamber assembled in a laboratory processing plant.

3. Frequency tracking control

Due to temperature variation during the chamber operation a frequency tracking system is required to maintain the resonance in the liquid inside the chamber. Figure 3(a) shows the transducer conductance as a function of frequency. The conductance is proportional to the power supplied by the electronic system that derives the transducers (Mortimer et al., 2001 and Ramos-Fernandez et al., 1985). Figure 3(a) shows two curves, one with the cavity filled with oil and the other filled with air. One can observe a sequence of small peaks due to the resonances inside the chamber in the case of the chamber filled with oil. Tuning the driving frequency in one of these resonances and make the tracking when the temperature changes, are the main objectives of the control system. The controller adjusts the frequency to follow a chamber resonance peak in a given frequency interval (1.1-1.15 MHz), avoiding the resonance of the transducers.

The frequency tracking control follows the power peak shifts due to temperature variations using a conventional hill-climbing algorithm. Two additional problems must be solved. First, the driving frequency must belong to a safe operating band, avoiding the resonance of the transducer. This band is highlighted in red in Fig. 3(a). If the frequency goes below the left limit, the setpoint is increased in $\Delta f$. Note that the jump between two consecutive peaks depends on the chamber length and the speed of sound in the liquid. In our example this value is around 35 kHz. The second problem occurs when the cell is operated using high power and the temperature gradients reduce the resonant peaks. To avoid local maxima out of the resonance frequency, two different sweep ranges are used. For example, the control makes a normal sweep of 700 Hz and after a configured number of sweep cycles makes a 20 kHz sweep to ensure that it is at maximum. Figure 4 shows the evolution of the power supplied by the source and the frequency selected by the control. Initial setpoint is selected by sweeping the frequency in the operating frequency band.
4. Experimental results

The acoustic separation of water in oil emulsions by the ultrasonic chamber was evaluated. Four working regimes were used to evaluate the efficiency of separation with and without the use of the ultrasound in the coalescing chamber. During the tests the temperature at the inlet and the static pressure were maintained constant at 70 °C and 517 kPa, respectively. Tests were performed by varying the amount of demulsifier and the initial water content. In all the tests, the electric power supplied to the ultrasonic chamber and the flow rate were kept constant at 80 W and 1.66 ml/s, respectively. The final water content, measured at the chamber outlet, is presented in Table 1. The results of Table 1 show that the ultrasonic application improved the separation of water in oil emulsion in all the tested conditions.

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5. Conclusions

An ultrasonic standing wave system for the oil-water emulsion break was presented. The main improvement in the system is the physical design of the resonant chamber. The ultrasonic standing wave is produced by two independent piezoelectric transducers, reducing the influence of temperature gradients between the inlet and the outlet. Each transducer must be drive by dedicated electronics that generates the sinusoidal excitation. In order to implement the frequency control, the electronics measures the instantaneous power supplied. Additionally the power level can be controlled by changing the amplitude of the sine wave. Two independent hill-climbing controls were implemented to assure the resonant regime. From experimental results, it was found that the use of standing waves can be applied to enhance the water-in-oil emulsion breaking technique in a laboratory processing plant.

Acknowledgements

We thank the support received from Petrobras/ANP and FAPESP.

References