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The Potential of Microwave Heating in Separating Water-in-Oil (w/o) Emulsions

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Abstract

With the increasing energy crisis and the drive to reduce CO_2 emissions, the mechanism of microwave heating is essentially that of dielectric heating. In this study, microwave demulsification method was investigated in a 50-50% and 20-80% water-in-oil emulsions with microwave exposure time varied from 20 seconds to 180 seconds. Transient temperature profiles of water-in-oil emulsions inside a cylindrical container were measured. The temperature rise at a given location was almost horizontal (linear). The rate of temperature increase of emulsions decreased at higher temperature due to decreasing dielectric loss of water. Results of this work shown that microwave radiation is a dielectric heating technique with the unique characteristic of penetration, fast, volumetric, and selective heating is appropriate and has the potential to be used as an alternative way in the demulsification process. Microwave demulsification of water-in-oil emulsions does not require chemical additions.

Keywords: *Demulsification, temperature profile, w/o emulsion. Microwave heating, stability*

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1. Introduction

A problem in mature oil fields is the sizeable amount of water accompanying the produced crude oil. Water is also injected into the crude in course of steam treatment of producing wells or during de-salting operations. Petroleum emulsions readily form from water/oil mixtures in turbulent flows or due to pressure gradients in reservoir pores, in the chokes at the wellheads and in various valves in piping used for oil production. These emulsions can increase pumping and transportation costs, facilitate the corrosion of producing and processing equipment, and the poisoning of refinery catalysts [1-3]; [4]. [5], mentioned that the emulsifying agent separates the dispersed droplets from the continuous phase. Many industrial processes of demulsification have been employed in one application or the other including chemical and electromagnetic processes [6]; [7]; [8]; and [9]. The first application of microwave irradiation as an emulsion separation technique was by the pioneering works of [10] and [11]. Since then, there have been a significant number of research interests in this technique [12]; [13]; [14]; [15]; [16]; and [17]. The effects of inorganic salts and inorganic acids in microwave demulsification of water-oil emulsions were investigated by [18]. According to the authors, the separation efficiency as well as the demulsification rate are enhanced with increasing concentration of inorganic acids and also with the inorganic salt (NaCl, KCl, $NaNO_3$, and Na_2SO_4) concentration in dilute range (<0.5 M). Using water-n-decane emulsion, [19] studied the role of asphaltenes and resins on the stability of emulsion during microwave demulsification process. [14] Depicted that the rate of temperature increase decreases the dielectric properties and volumetric heat generated. [16] Showed that emulsion stability was related to surfactant concentration, stirring time, temperature, the water-to-oil phase ratio and agitation speed. [17], performed comparative analyses of the demulsification of water-oil emulsion using microwave irradiation energy and conventional thermal heating by comparing the percentage of water separated, and droplets size distribution in each crude oil.

The objective of the current research was to investigate the potential of microwave heating technology on the separation of 50-50% and 20-80% water-in-oil (w/o) emulsions.

2. Materials and Methods

In this manuscript, Elba domestic microwave oven model: EMO 808SS, its rated power output is 900 watts and its operation frequency is 2450 MHz was modified and converted from batch process system into a continuous process and used as shown in Figure 1.

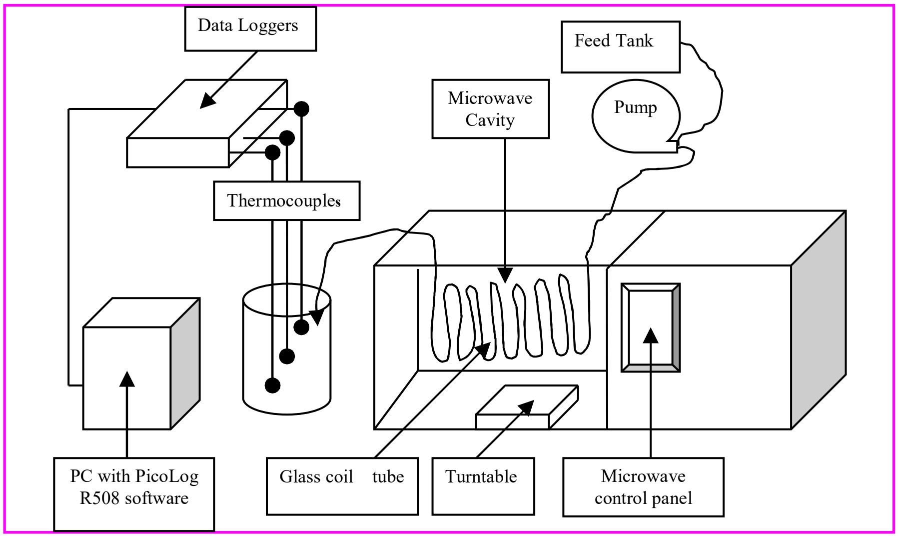

Figure 1: Continuous microwave processes

Three thermocouples type (K-IEC-584-3) were connected to Pico-TC-08 data loggers, and then the thermocouples connected to the settling tank. The data logger was connected to Pc; with Pico Log Rs.08.3 software. The thermocouples were inserted in the settling tank to different locations top, middle, and bottom of the emulsion sample to measure local temperatures. The rate of water separation in sedimentation depends on the settling velocity of water droplets in the emulsion. According to the force balance and Stoke's law, the settling velocity of water droplets through the oil is given by:

$$v_w = \frac{(\rho_w - \rho_o) g * D^2}{18 \mu_o} \tag{1}$$

Where: v_w= settling velocity of water; ρ_w = Density of water; ρ_o = Density of oil; μ_o = Viscosity of oil; g = gravity acceleration; D= diameter of droplets.

From above equation (1), the viscosity of oil (μ_o), is very sensitive to temperature. As temperature increases due to microwave radiation, viscosity decreases much faster than density difference $(\rho_w - \rho_o)$. Therefore, the heating, either by microwave or by conventional heat, increase the velocity of water, (v_w), and makes the separation of water-in-oil emulsion faster.

2.1 Sample Preparation and Procedures

A crude oil sample was collected from Malaka Refinery, Malaysia. At the laboratory, samples of 20-80% and 50-50 % water-in-oil emulsions were prepared using crude oil and tap water. Agent-in-oil method techniques followed for samples preparation. In this method, the emulsifying agent is dissolved in the oil phase. Then water has been added directly to the mixture and agitated vigorously with mixture for 10 minutes. The emulsifying agent used in this study is natural surfactant, NS-16-1 which is UMP product. The prepared samples were tested for w/o or o/w emulsions. All samples were w/o type. The glass container, containing 500 ml graduated beaker of emulsion sample was placed in the center of EMO 808SS microwave oven, and microwave radiation was applied at the highest power setting (900 watt). The radiation time varied from 1-10 minutes irradiation of microwave at 2450 MHz. After radiation, samples were taken out quickly from the oven and a calibrated glass thermometer was inserted in the sample in order to read the temperature at different locations. Table 1 shows experimental results of microwave heating.

Table 1: Experimental Results of Microwave Heating

Radiation Time t, sec	Temperature Increase, dTC°	Heating rate dT/dt, C/sec	Volume rate of heat generation q_{MW} cal/sec-cm^3
Water: 60	12.5	0.208	0.248
90	35.5	0.395	0.394
120	51.5	0.429	0.443
150	69.5	0.463	0.475
180	73.5	0.408	0.481
210	73.5	0.350	0.388
240	73.	0.306	0.345
270	73.5	0.272	0.271
300	73.5	0.245	0.245
Crude Oil: 60	6.5	0.108	0.192
90	14.5	0.161	0.253
120	36.5	0.304	0.343
150	50.5	0.337	0.366
180	59.5	0.331	0.281
210	68.5	0.326	0.277
240	74.5	0.311	0.264
270	83.5	0.309	0.263
300	89.5	0.298	0.272

Table 2 depicts experimental results of microwave heating.

Table 2: Experimental Results of Microwave Heating

Radiation Time t, sec	Temperature increased dT, C°	Heating rate dT/dt, C/sec	Volume of heat generation q_{MW} cal/sec-cm^3
50-50% w/o emulsion			
60	24.5	0.408	0.246
90	50.5	0.561	0.338
120	69.5	0.579	0.349
150	81.5	0.543	0.327
180	85.5	0.475	0.286
210	97.5	0.464	0.280
240	105.5	0.440	0.265
270	109.5	0.406	0.245
300	114.5	0.382	0.230
20-80% w/o emulsion			
60	29.5	0.492	0.301
90	54.5	0.606	0.373
120	77.5	0.646	0.402
150	89.5	0.597	0.387
180	94.5	0.525	0.392
210	108.5	0.517	0.386
240	114.5	0.477	0.381
270	122.5	0.454	0.374
300	127.5	0.425	0.364

3. Results and Discussion

The average temperature increasing rates for emulsion ratios of 50-50%, and 20-80% of water-in-oil emulsions were 0.473, and 0.527 respectively. It is observed that the rates of heating decreases with temperature increases, this might attributed due to decreasing of dielectric loss of water [14; 16; 17], Figure 2 shows the phenomena, while Figure 3 depicted the volume rates of heat generation versus the radiation time, it is clearly that the volume rates of heat generation increases in early stages of the microwave radiation, then it states decreases at microwave exposure time increases [18].

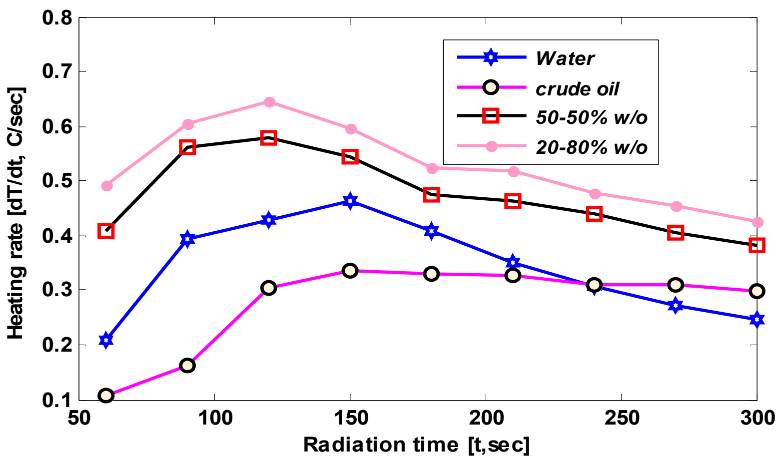

Figure 2: Heating rates vs. Radiation time

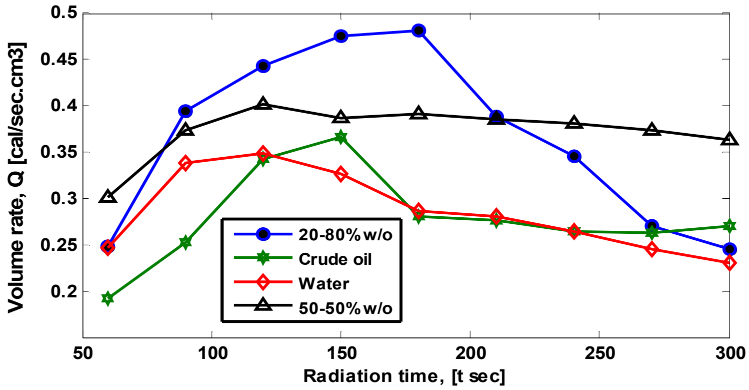

Figure 3: Volume rate of heat generation vs. Radiation time

Figures 4 and 5 have shown the separation of water from 50-50 % and 20-80 % water-in-oil emulsions respectively. All experimental tests have shown that microwave radiation is very effective in separation of water-in-oil emulsions, [14; 17]. Results of Figures 4 and 5 illustrate that microwave radiation can raise the temperature of emulsion, reduce viscosity and make separation is faster, as suggested by equation (1).

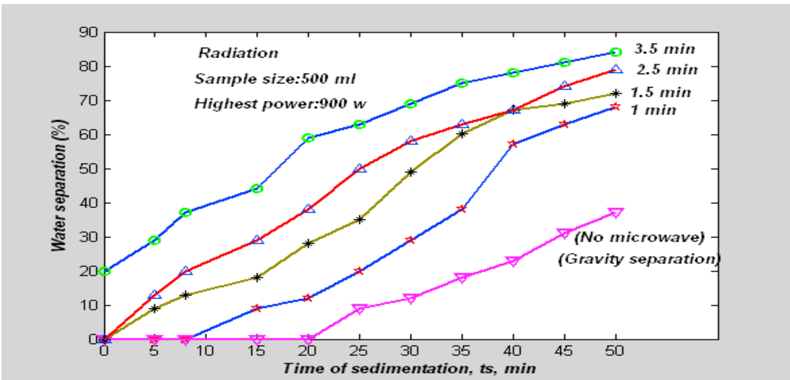

Figure 4: Separation of water from 50-50 % water-in-oil emulsion

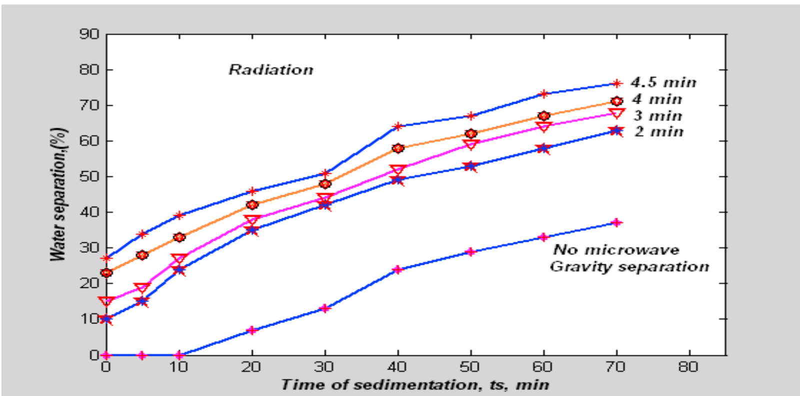

Figure 5: Separation of water from 20-80 % water-in-oil emulsion

Conclusions

Based on results of this manuscript, it can be concluded that microwave heating technology has been successfully applied for demulsification of 50-50% and 20-80% water-in-oil emulsions. Microwave radiation is very effective in separation of water-in-oil emulsions, in this regards the average temperature increasing rates for emulsion ratios of 50-50%, and 20-80% of water-in-oil emulsions were 0.473, and 0.527 respectively.
The results obtained in this study have exposed the capability of microwave heating technology in demulsification of water –in-crude oil emulsion. Further works are nevertheless required to provide deeper understanding of the mechanisms involved to facilitate the development of an optimum system applicable to the industry.

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