ARTICLE IN PRESS

Journal of Analytical and Applied Pyrolysis xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Analytical and Applied Pyrolysis

journal homepage: www.elsevier.com/locate/jaap

The experimental study of effect of microwave heating time on the heavy oil properties: Prospects for heavy oil upgrading

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ARTICLE INFO

Keywords:
Heavy crude oil
Microwave
Sulfur
Asphaltene
Upgrading

ABSTRACT

A heavy crude oil sample from an oil field in southwest Iran was placed in a Fischer assay and heated by microwave for two-minute time steps until 14 min total heating time had elapsed. Unlike conventional heating technique (CHT), which caused light carbonic components to escape and raised C_{20+} components in oil samples, the value of light carbonic components increased under microwave heating technique (MHT) up to 6 min. These materials cannot escape the oil sample in MHT because the cracked components approach a superheated state, and in this study a large portion of them remained at 6 min. Moreover, in contrast to the CHT results, the C_1–C_{20} components increased to 13.5 wt% in the analysis of cracked gases during MHT. In MHT, light components increased with heating time, and C_{7+} components fell. This is indicative of light components escaping after 6 min. Some components escaped as condensate. In CHT, the escape of only small amounts of condensates was observed at 12 and 14 min, while under MHT, this phenomenon started at 8 min and contained larger amounts. This phenomenon is due to secondary cracking in oil, which is created by an abrupt increase in the temperature of some components that have more capacity to absorb microwaves. The sulfur content of heavy oil in MHT tended to decrease over time, approaching 34 wt% at 14 min; in contrast, in CHT it remained constant. Sulfur was removed from the oil sample as H_2S and SO_2, predominantly in a gas state, but also as condensate, in increasing amounts over time. Sulfur removal from the heavy crude oil sample is highly important in the upgrading process because of its high coefficient of microwave absorption. H_2S is produced from the start of MHT, but SO_2 is observed only after 6 min, and then only in the produced gas. Saturation, Aromatic, Resin and Asphaltene (SARA) components analysis showed changes in the resin and asphaltene components. The amount of asphaltene components began to decline starting early in the heating process, and approached its lowest amount at 4 min (3.21 wt%). Reduction of resin components in MHT began at 8 min and reached 55% at 14 min. Asphaltenes have a high capability to absorb microwaves due to having SNO (Sulfur, Nitrogen and Oxygen) components that create hot zones in heavy oil; these hot zones enhance cracking and upgrading. Scanning electron microscopy images of asphaltene particles showed that microwaves caused some changes in the structure of these particles. Energy-dispersive spectroscopy analysis of these particles showed that SNO components under MHT declined over heating time. The results also suggest that after sulfur, nitrogen and oxygen have the highest potential to absorb microwaves.

1. Introduction

In recent years the development of heavy-oil upgrading has assumed great importance. Various techniques are used to produce high-quality oil from heavy and ultra-heavy oils; these techniques are being enhanced to recover more product with less cost. The objectives of these enhancements are to decrease time treatment, increase energy efficiency, better manage the fluid flow, reduce waste and waste materials, increase safety by using less equipment, and allow the use of equipment that is more easily controlled.

Microwaves can assist in the separation of oil and water in stable oil-water emulsions, and enhances the effect of demulsifiers [1]. Hascakir et al. [2] showed that microwave raises production by heating specific components and reducing viscosity. Ranji [3] investigated the mechanism of MW effectiveness and stated that the existence of some heavy elements in oil with different absorption coefficients for MW creates hot zones. Jackson [4] incorporated some additives with a high capability to absorb microwaves into heavy oil, finding that this

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http://dx.doi.org/10.1016/j.jaap.2017.10.012
Received 21 July 2017; Received in revised form 13 October 2017; Accepted 14 October 2017

improves the upgrading process. Hence, extensive research in the field of heavy/ultra-heavy oil using more-efficient processes needs to be conducted.

Microwaves are electromagnetic waves with a frequency range of 300 MHz to 300 GHz, corresponding to wavelengths of 1 mm to 1 m. Current estimates indicate that microwave technology in various industries can result in considerable savings in energy consumption and processing time. Moreover, microwaves create a uniform and homogeneous heating in substances. Microwaves affect some materials profoundly and others weakly [5]. Energy absorption varies depending on microwave frequency and power, sample composition and dielectric properties, and temperature. The dielectric properties of a substance and the result of applying electromagnetic waves on that substance can be studied. To optimize electromagnetic heating, these properties should be examined, as they have different values at different frequencies of electromagnetic waves. This interaction can be used to selectively heat specific sites in a sample [6,7]. In selective heating, only a selected volume of the target material is exposed to microwave radiation.

The most difficult obstacle to increasing the efficiency of production from heavy-oil reservoirs is that a large amount of energy is required in the process of heat injection. The usual method of transferring energy from the source to the sample takes advantage of the benefits of electromagnetic radiation over conventional thermal processing. MHT delivers energy directly, and offers a long thermal gradient, high penetrating capacity, and volumetric heating [8]. The chemical reactions that occur when microwaves are used to heat the oil are still largely unknown [9]. Much attention is focused on the microwave enhancement of changes and cracking of oil components because microwave irradiation has been shown to accelerate these processes. The effect of factors such as temperature, heating rate, and type of heating must be investigated. Moreover, understanding the kinetics of oil is also significant. Changes in the properties of heavy oil under various heating conditions have not been extensively studied. Because the quality of oil recovered from a heating process (conventional or microwave) is a light crude oil, additional upgrading processes are required [10]. The results reported in this paper can somewhat reduce the ambiguities in the use of microwave technology in the oil industry, particularly with respect to enhancing production from heavy- and ultra-heavy-oil reservoirs, and can suggest additional ways to apply microwaves in oil reservoirs in the future.

2. Materials and Methods

A 150 ml sample of Sarvak oil (Viscosity: 943.66, API: 15) from an oil field in the southwest of Iran was subjected to MHT in a Fischer assay apparatus (Fig. 1). MHT was performed at a frequency of 2450 MHz and a power of 400 W and 900 W. All parts of the device were first filled with helium so that heating could take place without the presence of oxygen and other reactive gases; this was because the volume and components of outlet gas would be measured when heating the oil sample. The sample was subjected to heating in the Fischer assay at time intervals of 2, 4, 6, 8, 10, 12, and 14 min. The gas extracted by heating the oil sample was stored in a gas meter (VINCI-Numero serie N*200). Gas composition was determined using gas chromatography (GC). The outlet condensate from the crude sample was gathered in a receiving flask using a condenser. The condensate components were determined by GC (ASTM D6729), and its sulfur content was also measured using a Vario Max-CHNS elementar (Carbon, Hydrogen, Nitrogen and Sulfur) (ASTM D4294). The heated crude sample was stabilized in a cold environment for one day. Carbon and CHNS components were measured using gas chromatographic simulated distillation (GC-Sim Dis) and the Vario Max-CHNS elementar, respectively (ASTM D5291, ASTM D4294). Saturations, aromatics, resins (ASTM D-4124), and asphaltenes (IP-143) were determined using SARA analysis. Scanning electron microscopy (SEM) images of asphaltene particles under MHT were taken to observe changes in their structure. The asphaltene particles under MHT were examined using electron-dispersive spectroscopy (EDS) to determine amounts of CSNO (Carbon, Sulfur, Nitrogen and Oxygen), V (Vanadium), and Ni (Nickel) components. All tests were also conducted using CHT for comparison. After each heating period, we immediately measured the temperature with a thermometer. Because the thermometer had a metal wire, we could not put it inside the microwave. Therefore, after the heating time was completed, we immediately measured the temperature. In CHT, we adjusted the oven based on the heating time. For example, if the temperature in the microwave oven reaches 44 °C at 4 min, the typical oven temperature is set to 44 °C at 4 min. In some cases, it was not possible to reach expected temperature at a given time interval. In these circumstances, we changed the temperature rate of the oven to reach the desired temperature. The temperature of the crude oil sample at different time durations is displayed in Fig. 2 (2450 MHz and 400 W). The reason for choosing time intervals of 2 minutes is that we did not observe a significant change between different steps at intervals of 1 minute. A total heating time of 14 minutes was selected because after 10 minutes the rate of the changes had nearly approached zero. Microwave irradiation imparts energy directly to the oil sample by the interaction between an electric field and the electric charges of molecules, or molecular interaction within the generated electromagnetic field [11]. Therefore, the components of the material can be heated individually and instantaneously by applying energy as high-frequency electromagnetic waves, overcoming limits imposed by the material's heat-transfer characteristics. MHT to 10 minutes considerably increased the samples' temperature (84 °C), after which their capacity to absorb microwaves decreased.

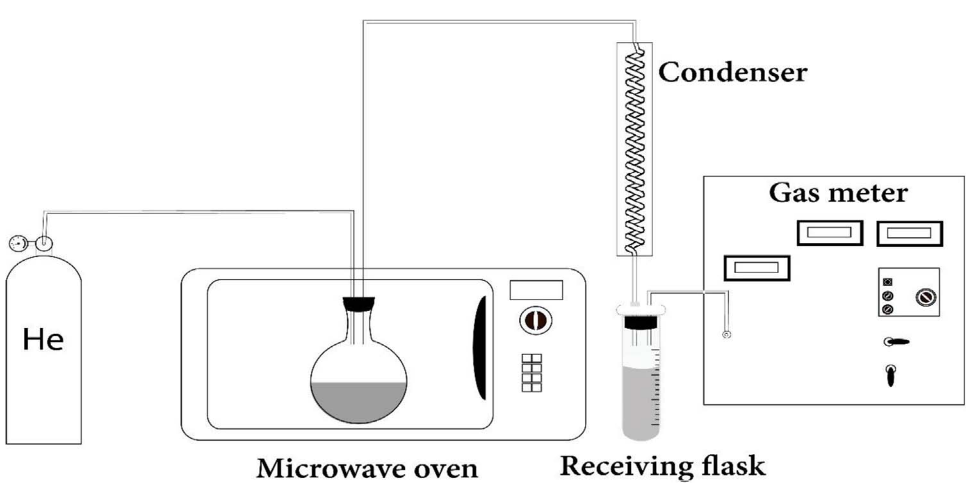

Fig. 1. Schematic of microwave Fischer oven.