Chemical Engineering and Processing 95 (2015) 353–361

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

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

Effects of solvent addition and ultrasound waves on viscosity reduction of residue fuel oil

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ARTICLE INFO

Article history:
Received 4 March 2015
Received in revised form 29 June 2015
Accepted 14 July 2015
Available online 23 July 2015

Keywords:
Residue fuel oil
Ultrasonic irradiation
Kinematic viscosity
API gravity
Artificial neural network

ABSTRACT

In this work, the influence of temperature, solvent concentration and ultrasonic irradiation time on viscosity reduction of residue fuel oil (RFO) are studied. The main feature of this research is using ultrasonic irradiation at low frequency of 24 kHz and power of 280 W, for viscosity reduction and quality enhancement of RFO. Kinematic viscosity of RFO was found to decrease from 4940 cSt to 2679 cSt due to application of ultrasonic irradiation for 5 min at initial temperature of 20 °C. Results showed that combination of ultrasonic irradiation with solvent led to intensified decrease of viscosity and API gravity promotion. The maximum reduction of viscosity (at 133 cSt) occurred in ultrasonic irradiation time of 5 min, temperature of 50 °C and acetonitrile loading of 5% by volume. API gravity, distillation and FT-IR analyses revealed that ultrasonic waves have an effective role in cracking and lightening of the examined heavy fuel oil. The measured results including 336 data points of eighty-four samples were analyzed by the feed-forward back propagation of artificial neural network (ANN). The relative importance percent of input variables was calculated and it was found that ultrasonic irradiation time and acetonitrile concentration has maximum and minimum relative importance in viscosity reduction, respectively.

1. Introduction

Residue fuel oil (RFO) is the heaviest fraction of crude oil obtained from an atmospheric distillation column. The composition of residues from conventional crude oils depends on both the original oil and the subsequent processing. Moreover, refinery processing can produce RFOs with different properties. The complexity of residue fractions drives from the combination of simple groups to give complex molecules and countless isomers. Fuel oils are usually classified based on boiling point, carbon chain length and viscosity. Kinematic viscosity is the most important characteristics in fuel oils transportation [1–3]. The RFO burns in furnaces, boilers, engines for heat generation or power. Therefore, it is important to find some methods to handle fuel oil by reducing its viscosity.

There are different methods for fuel oils treatment. These methods can be classified into some main categories including; thermal cracking [4–6], chemical [3,7,8], electromagnetic heating [9], acoustical method [10,11] and so on.

The need for easy transportation of residue fuel oil with high viscosity needs novel treatment methods. In recent years, among the above-mentioned methods, it has been found that the effects of ultrasonic waves are significant. The cavitation bubbles can produce by ultrasonic waves at different frequencies. Temperature and pressure variation by ultrasound propagation give birth to microscopic bubbles, which expand extremely and creating millions of shock waves. The temperature and pressure rise due to bubble collapse. Cavitation phenomenon increases the mass and heat transfer and is effective on flow rheology [9–11]. Shedid [12] introduced an ultrasonic irradiation technique for treatment of asphaltene deposition. The author investigated the influences of using ultrasonic irradiation on asphaltene behavior in the UAE crude oil, with consideration of solvent and temperature effects. Their results revealed that ultrasonic irradiation decreases the size of asphaltene clusters of UAE crude oil. A critical review was carried out by Gogate [13] about cavitational reactors for process intensification of chemical processing applications. In this work, a design of a pilot scale sonochemical reactor was presented and investigated. Sutkar and Gogate [14] had a study on design aspects of sonochemical reactors. They introduced techniques for understanding cavitational activity distribution and the effect of operating parameters in these reactors. In another research undertaken by Gogate et al. [15], design and scale up of

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http://dx.doi.org/10.1016/j.cep.2015.07.014
0255-2701/

Nomenclature

ACT-N solvent volumetric concentration (vol%)
ANN artificial neural network
API American Petroleum Institute
ASTM American Society for Testing Materials
d^{20} density at 20 °C (g/cm^3)
FT-IR Fourier transform infra-red
RFO residue fuel oil
Sp. Gr Specific gravity
T temperature (°C)
UAE United Arab Emirates
UST ultrasonic irradiation time (min)

Greek letter
ν kinematic viscosity (cSt or mm^2/s)

Subscripts
i data point/input layer
j hidden layer
k output layer
t transfer function
th transfer function of hidden layer
to transfer function of output layer

sonochemical reactors were applied with emphasis on heterogeneous systems. In addition, mixing, hydrodynamic characteristics and quantification of attenuation of the incident sound energy were discussed in solid/gas phases in a liquid medium. As shown in study done by Mohod and Gogate [16], it can be found that ultrasonic technology for degradation of polymers, carboxymethyl cellulose (CMC) and polyvinyl alcohol (PVA) is effective. Their experimental results demonstrated that ultrasonic irradiation had a significant role in viscosity reduction of the polymers. There are also other studies in literature those focused on using ultrasonic technology for different purposes [17–20]. On the other hand, some research were undertaken to use Artificial Neural Networks (ANN) in oil industries [21–22]

The main aim of this work is combination use of ultrasonic waves and solvent to obtain an appropriate RFO viscosity in optimum conditions (cost, energy, time and safety) for its easy transportation and quality promotion. For this purpose, a set of experiments were carried out at various acetonitrile concentration, in presence and without ultrasonication. The effects of using this solvent and ultrasonication on fuel oil viscosity reduction and API gravity promotion have been reported. For decreasing the number of experiments in prediction of the RFO kinematic viscosity, artificial neural network technique was employed.

2. Experimental

2.1. Experimental setup

Experimental setup used in this study is shown in Fig. 1. In this work, a sample from high viscosity RFO of Kermanshah Oil Refinery, Iran was prepared. The cylindrical beaker with a volume of 300 ml, which contains 100 ml of RFO, was used as a container. The top of the beaker was closed and a cold bath at 16 ± 1 °C surrounded it.

In the experiments, an ultrasonic apparatus (UP400s, Hielscher Co., Germany) with a constant frequency of 24 kHz and with a variable power in range of 0–400 W was used. Furthermore, cycle and amplitude was set and a probe with a diameter of 20 mm and a height of 30 cm was used in the experiments. Based on laboratory results and optimization method, a power of 280 W, a cycle of 0.5 and an amplitude percent of 70 were selected. Finally, in order to improve the RFO viscosity reduction, various concentrations of solvent were injected into beaker.

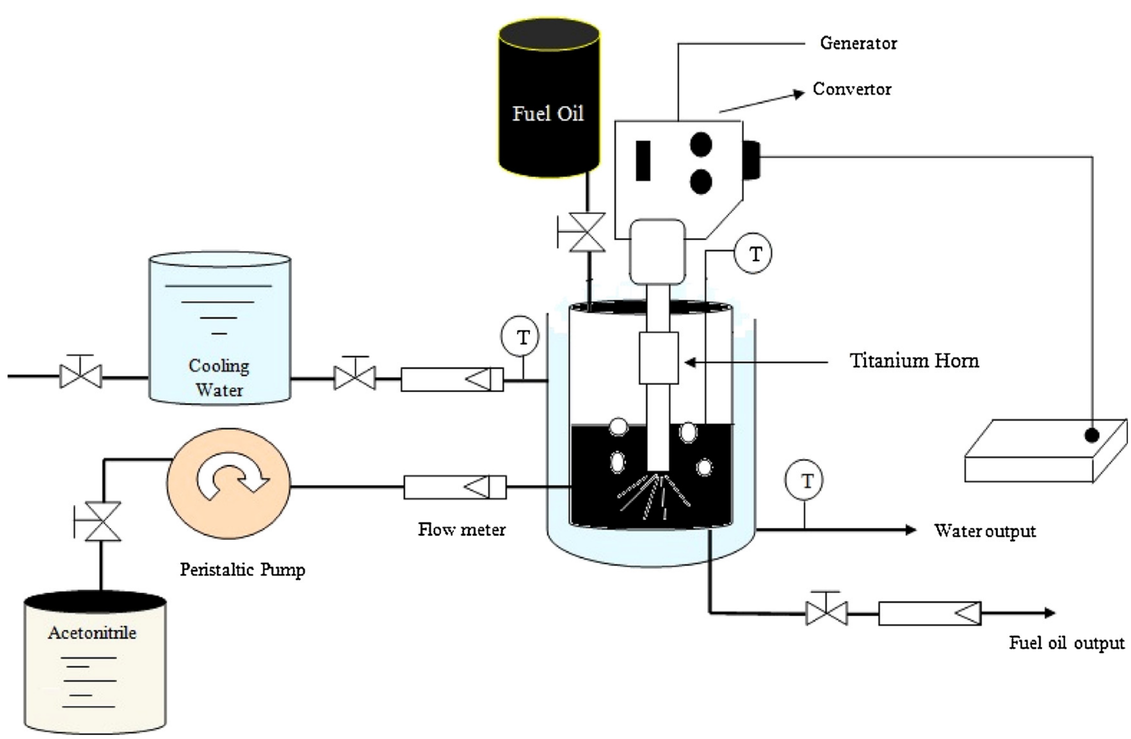

Fig. 1. Schematic view of experimental setup.