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Online droplet diameter measurements to improve the crude oil dehydration process

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ABSTRACT

Emulsion droplet size is information of paramount importance in the design and evaluation of oil–water separators. This paper describes the application of a technique for *in situ* determination of water droplet diameter distribution (DDD) in actual production scenarios. We discuss the DDD and water content measurements in emulsions obtained during normal operation and plant upsets including variations of the demulsifier chemical dosage or tripping of the electrostatic coalescer grids inside a large dehydrator vessel operated on a crude oil production field in Saudi Arabia. It is demonstrated that DDD data can provide a detailed understanding of the oil–water separation phenomena occurring inside the dehydrator vessel, which helped in planning process recovery strategies in the event of a plant upset.

Keywords: Droplet; Diameter; Distribution; Crude oil; Emulsion; Separation

1. Introduction

Particle size measurement is of great interest in the oil industry. Attempts have been made since the 1980s to obtain representative size distributions to characterize the behavior of the oilfield emulsions encountered during treatment and production and to improve separation efficiency (Flanigan et al., 1988).

The droplet diameter (d) is the most important parameter impacting water–oil gravity driven segregation since it is squared in Stokes' law which, assuming dispersed water droplets with no surface active components present, can be written as follows (Arntzen and Andersen, 2001):

$$v_{\mathrm{St,visc}} = \left(\frac{\Delta\rho g d^2}{18\eta_c}\right)\left[\frac{\eta_c + \eta_d}{{}^2\!/\!{}_3\eta_c + \eta_d}\right] \quad (1)$$

In Eq. (1), the first factor between brackets is the traditional Stoke's law. The second factor can be interpreted as a correction coefficient which varies between 1 (in the case of viscous liquid drops suspended in a gas) and 3/2 (for a high degree of circulation inside the droplets). Stokes' law suggests that any separation process should promote the coalescence of droplets to maximize its efficiency. When sizing water-in-oil emulsion treating equipment, it is necessary to predict the droplet diameter which must be separated from oil to meet the desired BS&W specifications. In other words, a relationship exists between the design BS&W of the treated oil and the droplet size range that must be removed for a set drop size distribution (Stewart and Arnold, 2009). *In situ* DDD measurements in dark crude oil emulsions are challenging (Sparks and Dobbs, 1993).

A measurement campaign to acquire DDDs in a dehydrator vessel operated in a gas–oil separation plant (GOSP) was completed successfully. The problems associated with the equipment installation are discussed. Actual field-test results in normal operation and during controlled process upsets involving the variation of demulsifier injection rates and the tripping of the electrostatic coalescer grids will be presented and discussed with the aim to better understand the oil dehydration process.

2. Experimental methods

2.1. *Droplet size measurement system*

The Focused Beam Reflectance Measurement (FBRM) technique relies on the detection of the reflectance time of a laser light beam (with wavelength of 791.8 nm, which allows

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Nomenclature

BS&W	basic sediments and water [%]
DDD	droplet diameter distribution
W–O	water–oil
d	droplet diameter [m]
g	gravity [m/s^2]
IL	interface level [%]
$\Delta\rho$	density difference between oil and water phases [kg/m^3]
η_c	dynamic viscosity of the continuous phase [cP]
η_d	dynamic viscosity of the dispersed phase [cP]
$\upsilon_{St,visc}$	corrected droplet terminal segregation velocity [m/s]

insights into dark crude oil emulsions) rotated by optical lenses to scan a fluid dispersion. As the reflectance time is the time needed by the laser to cross a droplet chord and the laser rotational velocity is known, a chord length distribution (CLD) is obtained. A deeper insight into FBRM measurement and data analysis can be found in Sparks and Dobbs (1993) and Less and Vilagines (2013).

An FBRM probe system was specifically designed and built for use in hazardous areas and measurement in GOSP vessels at production conditions. The length of the instrument probe is 1.5 m and its diameter is 25 mm. The probe is made of stainless steel 316L, with pressed-in sapphire window on a Kalrez 6375 seal. The operating pressure and temperature ranges of the probe used in our work are 0–4 MPa and 0–100 °C, respectively. The probe is connected to a Lasentec D600PST ATEX controller by means of a 15 m long fiber optic cable. The optical components inside the probe were rotated using a filtered nitrogen supply line available at the plant. A total nitrogen volume flow of 68 L/min at 414 kPa was used for pressurizing the D600PST ATEX unit and the laser probe.

3. Experimental set-up

The test site is located in the northwest of the Ghawar oil field, in the Kingdom of Saudi Arabia. The study was conducted in a 45 m long by 4.3 m diameter horizontal separator vessel called a dehydrator. This vessel is operated at 1.11 MPa and the fluid temperature was stable at 64 ± 1 °C during the measurements. The fluids enter the dehydrator in the bottom region and the dehydrated oil exits from the top as shown on the schematic view in Fig. 1. Table 1 shows the API gravity and dynamic viscosity of the crude oil.

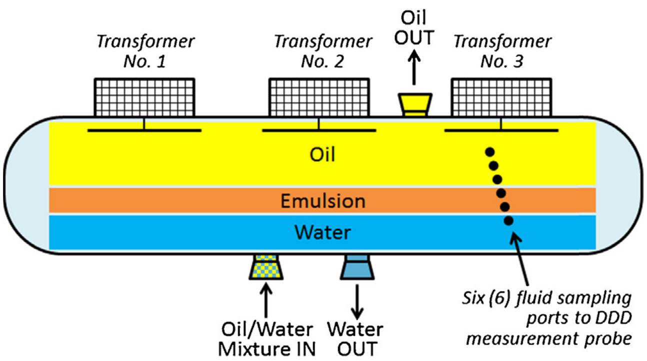

Fig. 1 – Schematic view of the dehydrator vessel.

Table 1 – Physico-chemical properties of the degassed crude oil.

Density at 15.6 °C (kg/m^3)	Kinematic viscosity at 37.8 °C (mm^2/s)
855	10.5

Fig. 2 – Sampling nozzles on the dehydrator vessel.

The DDD measurement probe was installed on a pipe spool allowing sampling fluid streams at six different heights of the dehydrator vessel. Fig. 2 shows the six 2-in. sampling nozzles connected to a manifold allowing the flow from any of the outlets to be routed to a single line where the DDD measurement probe is installed on a special purpose T-junction. The distance between the sampling nozzles and measuring probe is 4 m, approximately. The W/O interface level (IL) is kept at 50 ± 5% during normal operation. When equal to 50% the IL is between nozzles #6 and #5; therefore nozzle #6 is the only one exposed to water continuous fluids. The electrostatic coalescer grids are installed above nozzle #1.

The internal design of the T-junction's internal design is v-shaped to direct the fluids toward the probe window with an angle of 25°, to ensure that the population of dispersed droplets flows through the measurement volume of the FBRM probe. An ultrasonic flow meter for continuous non-intrusive flow monitoring was installed just upstream of the DDD probe to make sure that DDD data were acquired at a steady and known flow rate. A Panametrics DigitalFlow™ XMT868i liquid flow transmitter, designed for portable applications in hazardous areas such as crude oil and chemical plants, was used. During the experiments, the flow meter was used to verify that the sampled flow average velocity, regulated by a control valve installed far downstream of the measuring probe, was constant at 1 m/s ±0.1 m/s.

4. Results and discussion

4.1. *Normal operation conditions*

The DDDs measured during normal operation of the dehydrator are shown in Fig. 3. The data are presented in terms of water droplet volume-based distributions. The volume median and mean diameters are shown in Table 2. Details on the calculation method can be found in (Mettler, 2008) and (Heath et al., 2002). The number of counts represents the number of droplets scanned by the instrument over a 10 s measurement period.