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Crude oil emulsion: A review on formation, classification and stability of water-in-oil emulsions

S.F. Wong*, J.S. Lim, S.S. Dol

Petroleum Engineering Department, Curtin University, Sarawak Campus CDT 250, 98009 Miri, Sarawak, Malaysia

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ABSTRACT

The principal objective of this review paper is to review the current state of understanding in the formation, classification and stability of crude oil emulsification. In the oil and gas industry, emulsions formation in the pipeline is unwanted as emulsions will have negative effects or problems to the field. The presence of emulsions in the crude oil will reduce the quality of the crude itself, increase the operating cost due to emulsions separation as well as cause of corrosion to the transport system and will contaminate catalyst used for the refining process. Since emulsions bring numerous disadvantages to the oil and gas industry, it is important to review on the formation of emulsions so that the research gaps in the emulsification field can be discovered and hence the preventive measures can be investigated or introduced. This review paper is focused on water-in-crude oil emulsion only because water-in-oil emulsion is regularly occurring in the oil and gas industries.

1. Introduction

Emulsion can be defined as a system, whereby one immiscible liquid phase is dispersed as globules (dispersed phase) in the second phase of immiscible liquid (continuous phase) (Lim et al., 2015). There are three types of emulsions: they are, water-in-oil (W/O) emulsion, oil-in-water (O/W) emulsion and multiple emulsion. W/O emulsion is formed when the water globules are dispersed throughout the oil continuous phase, as shown in Fig. 1. O/W emulsion is formed when the oil globules are dispersed throughout the water continuous phase, as shown in Fig. 2. Multiple emulsion is a complex emulsion system, whereby W/O or O/W emulsions are dispersed throughout another immiscible phase (Khan et al., 2011). Multiple emulsion includes water-in-oil-in-water (W/O/W) emulsion and oil-in-water-in-oil (O/W/O) emulsion (Agarwal and Khanna, 2007). All of these emulsions can be found in many areas either as a desirable type or an undesirable type. For example, multiple emulsions can be found in food processing field (Garti, 1997), pharmaceutics or clinical field (Okochi and Nakano, 2000), chemistry field (Oh et al., 2002) and cosmetics field (Lee et al., 2004) and have different applications in each of these field. For the O/W emulsion and W/O emulsions, they can be easily found in petroleum industry (Schramm, 1992), in food matrices (Julio et al., 2015) as well as pharmaceutical field (Nielloud, 2000).

Emulsification is the process of formation of emulsions. In the oil and gas industries, emulsification problem faced by the industries are mostly due to W/O emulsions. W/O emulsion is also known as “chocolate mousse” or “mousse” among oil spill workers (Fingas and Fieldhouse, 2003, 2004; Fingas, 1995). The majority of researchers believe that emulsification is the next most crucial behavioural characteristics of oil after evaporation because emulsification significantly influences the nature of oil spills at sea as well as clean-up response (Fingas and Fieldhouse, 2003; Fingas et al., 2002, 1993). Besides that, in the upstream oil production industries, pipeline emulsification flow is a very common occurrence. As crude oil continues to be produced towards the end of the reservoir life, the amount of produced water increases as well, especially if the reservoir is driven by water aquifer (Lim et al., 2015). Although crude oil and water are initially present in two separated phases, the turbulence, mixing, as well as agitation through downhole wellbore, surface chokes, valves, pumps and pipes will cause emulsions to form (Fingas et al., 1993). Fig. 3 gives an overview of surface facilities for producing crude oil, from oil wellhead to pipeline. Fig. 4 shows where emulsions are being formed in the crude oil process.

Due to emulsification, the properties and characteristics of oil spills will alter to a significant extend, especially in the volume of spilled materials, density and viscosity of oil (Fingas and Fieldhouse, 2003, 2004; Fingas, 1995). It has been reported that emulsification caused the volume of spilled materials increased from two to five times the original volume, the density increased up to 1.03 g/ml from the original density of around 0.80 g/ml and the viscosity increased from an original of a few hundred mPa s to

* Corresponding author. Fax: +60 85443837.
E-mail address: wong.siew.fan@postgrad.curtin.edu.my (S.F. Wong).

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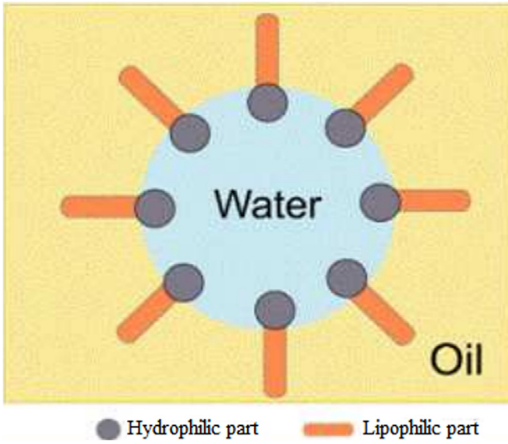

Fig. 1. W/O Emulsion (Khan et al., 2011).

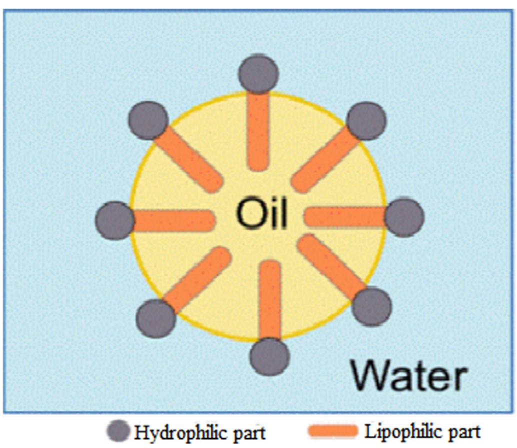

Fig. 2. O/W Emulsion (Khan et al., 2011).

as high as one hundred thousand mPa s (Fingas and Fieldhouse, 2003, 2004; Fingas, 1995). This will then lead to the production of a liquid which is heavy, semi-solid material (Fingas and Fieldhouse, 2003, 2004; Fingas, 1995).

The objectives of this review paper are to present an overview of the previous research findings on the formation of emulsion, classification of water-in-oil emulsions and stability of emulsions as well as to identify the research gaps in the transport of emulsions flow. This review paper will enhance the understanding of emulsification especially in relating the process with turbulence flow transport.

2. Emulsion formation

Many researchers (Canevari, 1982; Berridge et al., 1968; Fingas, 2014; Ortiz et al., 2010; Chaverot et al., 2008; Pauchard et al., 2009; Yarranton et al., 2000; McLean and Kilpatrick, 1997; Sjoblom et al., 1992; Schubert and Armbruster, 1992) have studied as well as reviewed on the emulsion formation process and their research studies are in general agreement on emulsion formation. They reviewed that emulsion formation was mainly correlated with the oil compositions, mainly asphaltenes and resins. Asphaltenes and resins are natural emulsifying agents or natural surfactants in crude oil.

According to Canevari (Canevari, 1982), natural emulsifying agents of crude oil prevent dispersed water droplets from coalescing because these agents will be attached to the surface of the water droplets and will resist water droplets from rupture. Berridge et al. (1968) declared that the presence of asphaltenes and resins contents in the crude oil were the main reason for emulsion formation. Fingas (2014) reported that asphaltenes are the main content in crude oil that stabilize W/O emulsions and resins are the content that solvate the asphaltenes. Ortiz et al. (2010), Chaverot et al. (2008), Pauchard et al. (2009), Yarranton et al. (2000), McLean and Kilpatrick (1997), and Sjoblom et al. (1992) reported the same finding which is asphaltenes tend to form a strong interfacial films at the emulsions interface which prevent the emulsions from coalesce.

Schubert and Armbruster (1992) emphasized three criteria for crude oil emulsion to form:

i. The contact of two immiscible liquids, such as oil and water
ii. The presence of surface active component as emulsifying agent, which is usually contributed by asphaltenes and resins
iii. Availability of sufficient turbulence or mixing energy to disperse one liquid into another, so that there will be liquid droplets in a continuous liquid phase

Researchers in the 1970s (Haegh and Ellingsen, 1977; Wang and Huang, 1979) concluded that the primary reason leading to the emulsion formation was the increase in turbulence or mixing energy. According to Schubert and Armbruster (1992), turbulence plays an important role in the distribution and mixing of the phases in the pipeline flow of water/oil system. Coalescence, as well as break up of emulsions, is affected by turbulence energy (Schubert and Armbruster, 1992). Turbulence suppression results in the turbulent flow of emulsions when the emulsions/droplets interact with the liquid (continuous phase) (Schubert and Armbruster, 1992). Turbulence suppression is the occurrence where the local kinetic energy in single-phase flow becomes larger than that in two-phase flow at the same averaged liquid flux (Schubert and Armbruster, 1992). The local kinetic energy in two-

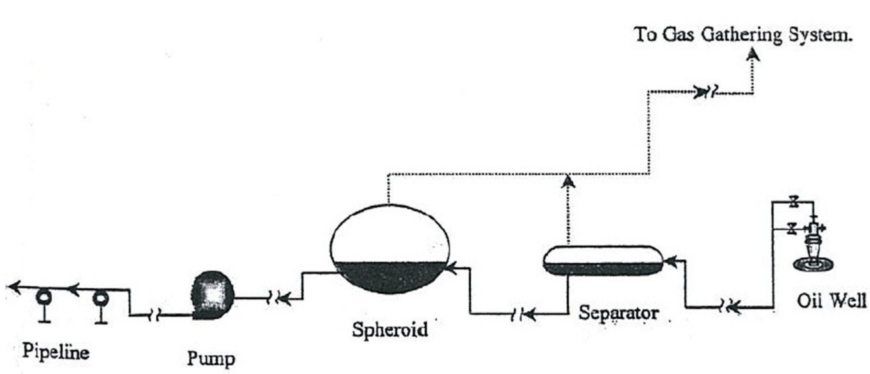

Fig. 3. Overview of crude oil surface production facilities (Wang et al., 2005).