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Multi-interface level in oil tanks and applications of optical fiber sensors

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ABSTRACT

On the oil production also involves the production of water, gas and suspended solids, which are separated from the oil on three-phase separators. However, the control strategies of an oil separator are limited due to unavailability of suitable multi-interface level sensors. This paper presents a description of the multi-phase level problem on the oil industry and a review of the current technologies for multi-interface level assessment. Since optical fiber sensors present chemical stability, intrinsic safety, electromagnetic immunity, lightweight and multiplexing capabilities, it can be an alternative for multi-interface level measurement that can overcome some of the limitations of the current technologies. For this reason, Fiber Bragg Gratings (FBGs) based optical fiber sensor system for multi-interface level assessment is proposed, simulated and experimentally assessed. The results show that the proposed sensor system is capable of measuring interface level with a relative error of only 2.38%. Furthermore, the proposed sensor system is also capable of measuring the oil density with an error of 0.8 kg/m^3.

1. Introduction

Liquid level and the level of the interface between fluids are important parameters in industries such as agriculture, automobile, food storage, chemical, medical, oil and gas [1]. In the oil and gas industry, there is the necessity to measure level and interface level between fluids on wells, tanks, reservoirs, processing vessels and storage vessels for fluids with different density, corrosiveness and viscosity [2]. Furthermore, processes in oil and gas industry may have high range of pressure and temperature [3], which increase the complexity and robustness requirements for the instrumentation.

One of the key process on the oil and gas industry is the separation of the oil, water and gas. The hydrocarbons obtained on producing wells and transported are a mixture of oil, gas, the produced water and suspended solids [4]. These different components are separated on the oil separation unit, which generally makes the separation between oil, gas and water through the density difference of the immiscible fluids [4]. However, there is no laminar and well-defined layers for each one of the fluids. Instead, there is an emulsion layer between the oil and water, which has its composition and behavior affected by the water and oil properties [5], as will be depicted later in this paper. Furthermore, there may be the formation of foam between the oil and gas layers on atmospheric tanks, which also has a dynamic behavior [6]. The foam and emulsion layer discussed can introduce errors on the measurement of interface level sensors. In addition, there may be a formation of sludge or wax on the tank walls, which also can have influence on the sensors performance.

Besides the operational problems of the multi-interface level measurement caused by the formation of the emulsion and foam layers, there are also limitations on current technologies for multi-interface level measurement related to the variety of fluids that can be inside of an oil separator, the operation on harsh environments and safety issues [2]. There is a presence of high inflammable gases in crude oil tanks that may generate explosions. For this reason, the devices employed on the tank instrumentation cannot surpass certain limits of voltage, current and capacitance [7].

The lack of reliability on multi-interface level measurement systems takes to simplified control strategies on crude oil separators [2]. This limitation on the interface level measurement leads the companies to employ subsequent separators to achieve better separation of each phase of fluid, which greatly enhances the cost of the plant and the complexity on the maintenance [4]. If the separation between oil and water does not occur correctly, it is possible to obtain oil with high amount of water on the refining process, which has influence on the oil processing prices and efficiency [4]. Another scenario is the water with some amount of oil that can contaminate the environment. The effects of the oil contamination are broadly discussed in [8].

In order to overcome the limitations related to the interface level on

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the oil separation processes, a multi-interface level sensor must detect the water, oil, emulsion and foam layers [2]. In addition, the costs of its maintenance have to be low and the time between maintenances has to be high, in order to achieve high production rates and a more reliable control of the oil separators [7]. Furthermore, the device must be intrinsically safe [7]. If a device is capable of meet these requirements, it will provide a more effective utilization of the separator, which also includes the design of more compact separators with lower safety margins and higher efficiency [4].

Optical fibers sensors are technological systems that result on devices that are compact, lightweight, immune to electromagnetic fields, chemically stable and allow multiplexing [9]. In addition, they can be considered intrinsically safe, especially when compared to conventional electronic technologies. Optical fiber sensors have been employed in industrial applications on the measurement of different parameters, such as temperature [10], liquid level [11], acceleration [12], pressure [13], acoustic [14] and refractive index [15]. The advantages of optical fiber sensors and their broad use on industry make them an interesting option for multi-interface level sensing.

However, in order to obtain an efficient optical fiber based multi-interface level sensor, it is necessary a review of the oil separation process and its issues. Moreover, a review on the current technologies for multi-interface level assessment has to be made to evaluate the advantages and drawbacks of each technology and how the optical fiber based technology can overcome the limitations of conventional technologies. For this reason, this paper presents a review of the process of oil separation and the conventional technologies for interface level measurement. After this review, an optical fiber based multi-interface level measurement system is proposed and the principle of measuring water and oil layers are experimentally assessed and validated.

This paper is organized as follows. Section II presents the description of the oil separator and its layers. Moreover, the emulsion and foam layers are described and some of its properties are presented. A review of multi-interface level measurement technologies is discussed in Section III. Section IV presents an overview of optical fiber based sensors. Also, a novel proposal of optical fiber based multi-interface level sensor is presented on this section. Simulation analysis and experimental results of the sensor and its ability to detect water and oil layers are presented in Section V. Conclusions and suggestions for future works are discussed in Section VI.

2. Multi-interface level problem description

An important problem on oil extraction is the combined production of water and gas with the crude oil [16]. In order to address this issue, oil separators are employed. Since oil, water and gas are immiscible fluids and have different densities, the separation is achieved by settling them on large tanks until obtain a layer of water on the bottom of the tank, a layer of oil in the middle and gas at the top [17]. However, there may also be an emulsion formation, which is a layer with a mixture of water and oil [16]. A foam layer may also be formed between the oil and the gas due to carbonation processes [18]. The hydrocarbon multiphase mixture also includes sand or other solids, which are present on the well and form a sludge on the bottom of the separator [4]. The phases that are formed inside a tank or an oil separator are presented in Fig. 1.

A common approach to separate the phases abovementioned is to employ a three-phase separator, which is based on the principle that the gravity will separate immiscible fluids with different densities [4]. Fig. 2 shows a typical oil separator. In this device, a deflection plate obstructs the inlet flow of the mixture and redirects the fluid for the left part of the separator shown in Fig. 2. The reason for place the mixture on the left side is due to the positioning of the outlet valve of the water on the left side of the bulkhead presented in Fig. 2. There also may have a sand monitor and sand flushing nozzles on the separator or close to the separator stage [4]. For this reason, the presented separator does

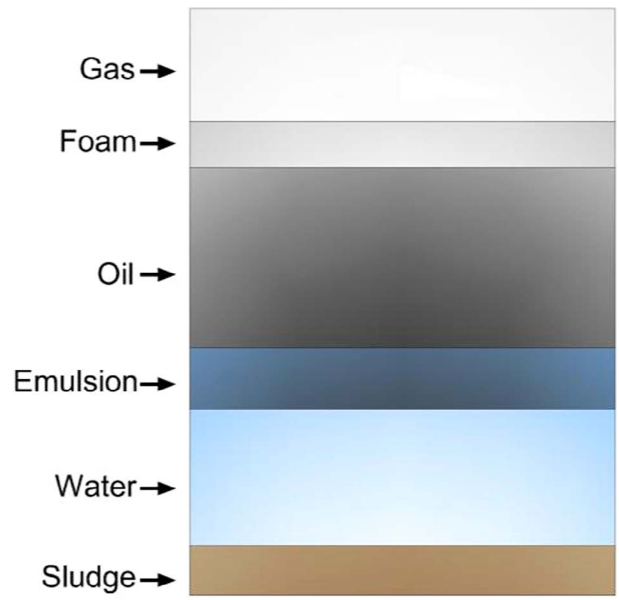

Fig. 1. Phase distribution of a tank containing oil, water and gas.

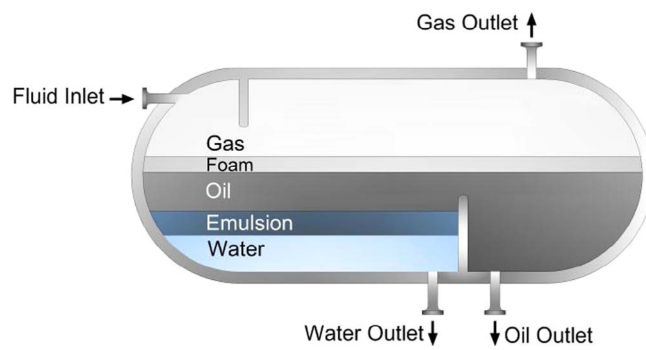

Fig. 2. Schematic illustration of a three-phase gravity separator.

not have the sludge layer. In addition, the oil phase collected on the oil outlet also present some amount of water, which is further separated on the next separation stages. Each gravity separator is able to separate about 90–95% of water on the oil [19].

There are different control strategies for the multiphase separator of Fig. 2, which are simplified due to the uncertainty of the interface level provided by the limitations of the current techniques for multi-interface level measurement [2]. One of these strategies is the one presented in [4], which consists in a closed loop control for real-time control of the level of interfaces and is presented on the block diagram of Fig. 3.

On the control strategy presented in Fig. 3, the three-phase separator controller has to be able to control the sand flushing, the control valve, the water pump and the chemical injection process. All the control commands have to be done with only two input data: the sand estimation and the multi-level interface measurement. Since the sand estimation is applied only to control the sand flushing, the interface level sensor system provides the information to control the pump, control the valve for oil inlet and to control the chemical injection on the oil.

Since the separator can reach its full capacity or the water layer can surpass the bulkhead, a control valve is applied to block the flow if the separator capacity is reached. Whereas, the chemical injection is made to reduce the layers of emulsion and foam, which generally are not precisely measured with some of the conventional technologies of multi-interface level measurement [20].

Besides the inaccuracies on the foam and emulsion layers