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Study of phase distribution in pipe cyclonic compact separator using wire mesh sensor

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ABSTRACT

Separation of gas–liquid mixture, which is achieved by using either large gravity separators or compact separators is a common and vital operation in the petroleum industry. Where space and cost are key project considerations, gas–liquid compact separators are very attractive because of their versatility and cost effectiveness. Efficient performance of the cyclonic separator depends on smooth and steady swirling flow. Unsteady swirling flow in the separator may be due to capacity constraint, improper design or unforeseen flow instability at the inlet. An understanding of phase distribution in gas discharge section of these separators would help design engineers make a better decision when selecting and sizing inlet nozzle, diameter and length of the separator. In this paper, the structure of phase distribution and liquid holdup in the gas discharge section of the separator was obtained using a 24x24 resolution wire mesh sensor (WMS). The acquired area average liquid holdup and the images were analysed using time series and 2D slice to discriminate between partial separation and critical separation condition.The liquid holdup as a function of separator inlet superficial velocity was quantified.

1. Introduction

This paper presents recent research findings on application of WMS in monitoring phase distribution in the gas disengagement section of a gas–liquid pipe cyclonic separator. Cyclone separators are traditionally used for gas–solid separation in process plant for material recovery as well as pollution control. In the oil and gas industry, cyclonic separators are commonly used as hydrocyclone, mist eliminator, separator internals and compact metering system. The emergence of subsea separation is now driving interest in using cyclonic separator for bulk gas–liquid separation.The fundamental reason why cyclonic separators are attractive for subsea application is because of their small footprint in comparison to their gravity counterpart. Unfortunately, their small footprint brought about complex flow phenomenon particularly when the inlet flow condition is highly unstable or exceed the separator handling capacity.

The overarching effect of the complex flow phenomenon is what is termed liquid carryover. Liquid carryover is effectively the amount of liquid that is entrained in the gas stream as a consequence of partial phase separation. Eventually, the performance of the separator is defined based on the envelope for liquid carryover. This envelope is nothing but the combination of gas and liquid flow rate under which liquid carryover does not exist. It is therefore desirable that a cyclonic separator has a wide operating envelope for liquid carryover. It is suffice to say that at this moment in time, the oil and gas industry is yet to see this cyclonic separator with a wide operating envelope for liquid carryover.

Apparently, for subsea separation, various configurations of cyclonic separators are at various stages of concept study by various researchers and technology vendors. One thing that appears to be scarce is fundamental study about phase distribution and liquid holdup in the separator during liquid carryover. This understanding is important as it will help designers of this equipment to identify critical component of the separator that could be better engineered. Liquid hold quantification is important in developing empirical correlations or validating mechanistic models for pressure drop in the gas leg of the gas–liquid cyclone.

1.1. Description of the separation process

Fig. 1 is a schematic diagram of a horizontal tangential inlet gas–liquid pipe cyclonic separator. The gas–liquid two-phase mixture is introduced tangentially into the separator body. As the flow enters the separator tangentially, centrifugal force acts on the phases causing them to swirl. The liquid phase because of its higher density is swung against the separator wall forming a liquid layer while the gas remained at the centre of the separator to constitute gas core. Buoyancy forces act on the gas phase causing it

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Nomenclature

D	dimensional
CFD	computational fluids dynamics
ECT	electrical capacitance tomography
cP	centipoise
ID	internal diameter [m]
GLPC	gas–liquid pipe cyclonic separator
PDF	probability density function
t	time [s]
U_{SL}	superficial liquid velocity [m/s]
U_{SG}	superficial gas velocity [m/s]

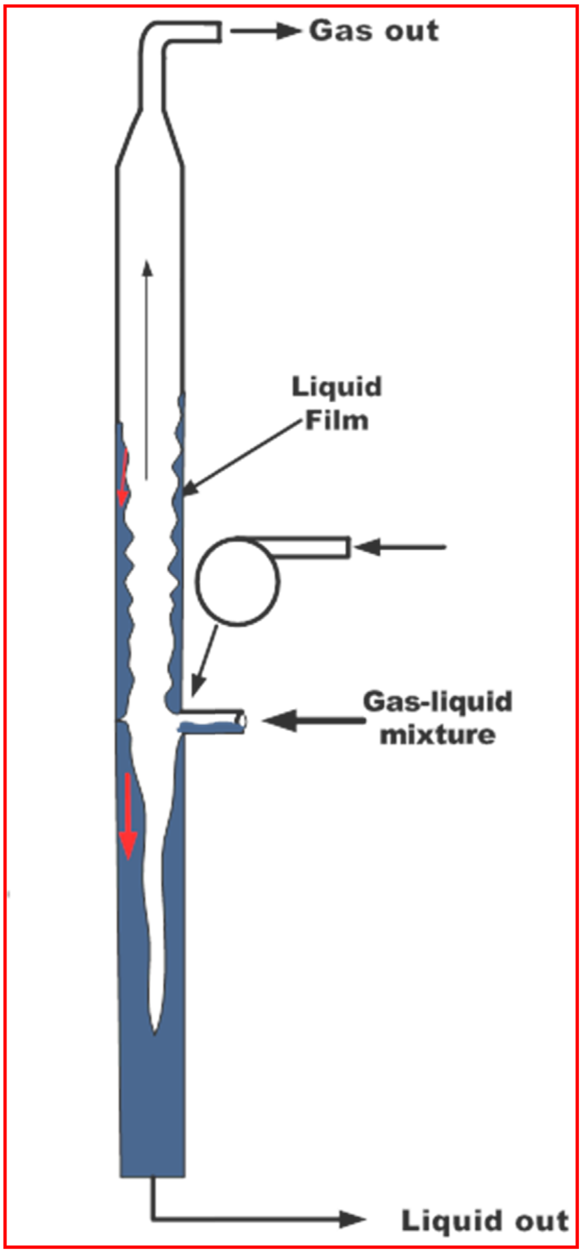

Fig. 1. Schematic view of a gas–liquid pipe cyclonic separator.

to rise upward. Gravity force prevailed on the liquid as it swirls downwardly. Under certain ranges of inlet flow rate of both phases; the gas phase will completely disengaged from the liquid and exit at the top as the liquid exit at the bottom of the separator. However, under adverse operating condition, the capacity of the separator is overwhelmed and the gas begins to strip the liquid upward and eventually carry it along to the gas exit. During liquid carryover, the flow in the separator gas outlet becomes typically gas–liquid two-phase flow. The liquid carryover could be droplets or large chunk depending on inlet flow condition and separator liquid level. The knowledge of phase distribution in the separator cross section is important when designing the separator and could be used for benchmarking the performance of various separation enhancement devices. For example, we know that the liquid always flows on the wall before being dragged into the exit pipe; we could design robust liquid film removal to improve separation performance. Similarly, knowing the amount liquid holdup during the carryover will help in validating pressure drop models. It is important to mention that phase distribution during liquid carryover is a very fast and highly dynamic process that is difficult to interpret by mere visual observation.

Literature review show that there is little or no research with respect to measurement of liquid holdup and phase distribution at the gas outlet of a gas–liquid cyclonic separator during liquid carryover. Isaksen et al. [1] investigated the application of electrical capacitance tomography (ECT) to detect interphase level in a vessel type three phase separator. However, the use of ECT for this application has limitation because during liquid carryover, the droplet may not establish good contact with the electrode and this will affect the electrostatic field in the separator which may result to poor image resolution considering that ECT is non-intrusive device. Seriesrco density profiler are said to be very good for separator diagnostics [2,3] but the authors are yet to stumble on literature showing the application of density profiler for liquid holdup measurement in cyclonic separator. Considering that liquid carryover phenomenon is very dynamic, one could rather rely on average holdup up to estimate mixture density rather using radioactive series; moreover, radioactive substance poses a health risk. Erdal et al. [4] applied CFD in estimating void fraction distribution in GLCC. However, this model was not validated due to lack of experimental data. Kataoka et al. [5] and Jaworski and Meng [6] used high speed video camera to visualise and then manipulated the image using C++ code to estimate the void fraction. If the separator is not made of very clear acrylic pipe, this approach cannot be applied and for dynamic phenomenon like liquid carryover the result of this manipulation may suffer from high level of uncertainty. Wire mesh sensor is widely used for measurement of void fraction in multiphase flow pipes. Shaban and Tavoularis [7] used wire mesh sensor for measurement of gas and liquid flow rate in a gas–liquid two-phase flow pipe. Olerni et al. [8] applied wire mesh sensor to measure air distribution and void fraction in vertical upward air–water flow. Da Silva et al. [9] compared accuracy of wire mesh sensor to that gamma densitometer and good agreement between two measurement instruments was reported.

2. Experimental setup

2.1. Description of the experimental facility

The experiment was conducted in a 3 in. (76.2 mm ID) and 2.7 m tall gas–liquid pipe cyclone (GLPC) separator test facility at Cranfield University, UK. As shown in Fig. 2, the test facility is a closed loop system consisting of fluids supply and metering

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