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Influence of riser-induced slugs on the downstream separation processes

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A R T I C L E I N F O

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A B S T R A C T

In Oil & Gas installations the severe slug is an undesired flow regime due to the negative impact on the production rate and facility safety. This study will evaluate the severe riser-induced slugs' influence to a typical separation process, consisting of a 3-phase gravity separator physically linked to a de-oiling hydrocyclone, based on experimental tests performed on a laboratory testing facility. Several scenarios are compared, while three PID controllers' coefficients are kept constant for all the tests: The separator pressure, water level, and hydrocyclone pressure-drop-ratio (PDR) controllers. Each respective scenario makes a comparison between uncontrolled, open-, and closed-loop anti-slug control configurations. It is concluded that both open- and closed-loop anti-slug control strategies improve the water level and PDR setpoint tracking equally well, but that the closed-loop strategy gives the best average production rate. Furthermore, it is confirmed that a PWT-efficient riser bottom pressure (P_{rb}) anti-slug control strategy has to guarantee stabilization of the mass inflow rate to the separator ($\omega_{sep,in}$) for archiving acceptable hydrocyclone separation. A stable $\omega_{sep,in}$ is observed not to be directly linked to a stable P_{rb}.

1. Introduction

In offshore Oil & Gas installations severe slug is an undesired flow regime in the well-pipeline-riser systems, as it has proved to have negative impact on the daily production (Havre et al., 2000; Pedersen et al., 2015). The issues related to the severe slugs are numerous (Hill and Wood, 1994): Overload on gas compressors, fatigue in the transporation pipelines, increased corrosion (Sun and Jepson, 1992; Zhou and Jepson, 1994; Kang et al., 1996), production reduction (Isaac et al., 2011), production slop and high pressure and liquid overflow in the downstream gravity separators (Yang et al., 2010). Anti-slug feedback control is one effective solution for changing the slug flow to a stable flow regime (Pedersen et al., 2014). A common approach is to stabilize the fluctuating pressure and/or flow by manipulating the topside choke valve at the riser top (Jahanshahi et al., 2012; Jahanshahi, 2013). However, as the controllers lack robustness to process or condition changes, the operators sometimes manually choke the valves to conservatively low opening degrees to eliminate the severe slugs with the consequence of simultaneously reducing the productions (Jansen et al., 1996).

The traditional upstream separation technology in the North Sea consists of 3-phase gravity separators and de-oiling hydrocyclones. This configuration represents 90% of the existing de-oiling technologies in the North Sea (Cullivan et al., 2004). The outlet of a well-pipeline-riser transportation process is typically physically linked to a 3-phase gas/water/oil gravity separator. The first step in the separation consists of a single or multiple 3-phase separators to completely separate the gas and separate most of the oil in the water. The water outlet of the last 3-phase separator is connected to a de-oiling facility consisting of multiple hydrocyclone liners (Husveg et al., 2007; Husveg, 2007).

The highly fluctuating production rate induced by severe slugs occurring in the riser can cause liquid overflow in the 3-phase separator if the separator's size is designed for a non-slugging buffer time (Yang et al., 2010). Furthermore the study from Husveg et al. (2007) proved that a poor separation in the separator will affect the performance in the rest of the typical produced water separation process. Thus handling the slugs upstream the separator would be preferable as the slugs can reduce the separation efficiency of the separator, ultimately resulting in a limited production rate, reduced production quality, as well as difficulties and challenges for the produced water treatment. The study in Wilhelmsen (2013) proposed control methods for gravity separator outlet valves to handle the large slug disturbances to the separation process. However, the work did only investigate the gravity separator isolated with no downstream de-oiling separation included.

This paper will examine the relationship between different kinds of severe slugs (under different running conditions) and the associated produced water treatment performance. The main contribution of the work is based on experimental data obtained from a laboratory testing facility. The testing facility can test both the transportation well-

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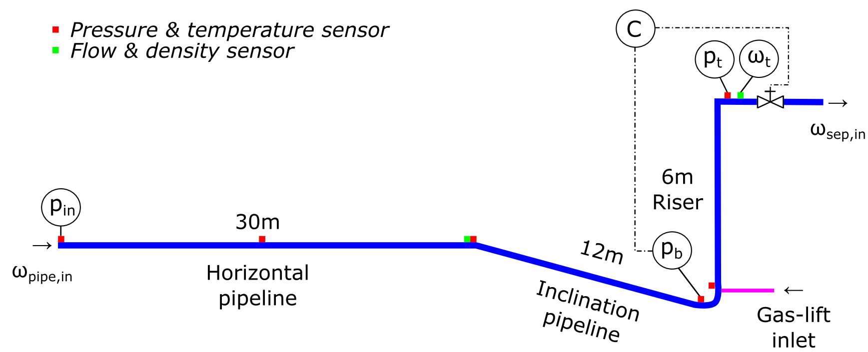
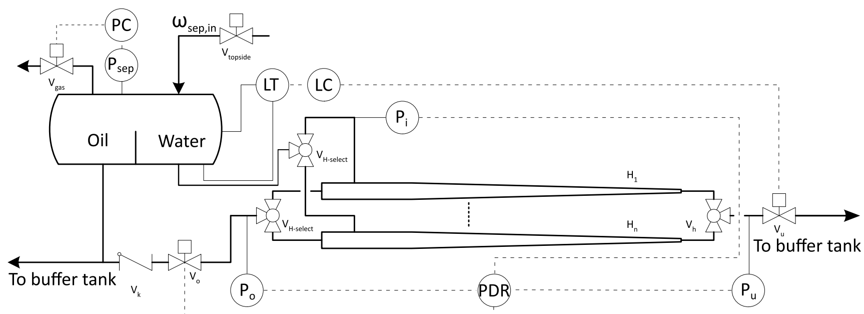


(a) The pipeline-riser section including the anti-slug controller actuated by the topside choke valve with feedback data from P_b. The riser outlet ($\omega_{sep,in}$) is the inlet to the gravity separator. Furthermore, several unused pressure, temperature, flow and density measurements are available for monitoring the system.



(b) The 3-phase gravity separator and de-oiling hydrocyclone. The water level and PDR control loops are illustrated. Only one hydrocyclone (H_1) is applied in this paper. A more detailed separator and hydrocyclone laboratory description can be found in [18].

Fig. 1. Two illustrations of the linked laboratory-scaled pipeline-riser and separator-hydrocyclone processes, including the respective control loops.

pipeline-riser transportation and the separator-hydrocyclone separation systems, as well as the entire system running at once in a flow-loop manner (Durdevic et al., 2015, 2016; Pedersen et al., 2016). Thus, several testing scenarios will be considered with different operation condition configurations for each individual scenario, respectively. The paper's main objective is to provide some solid experimental evidences that the varying inflow indeed has negative impact on the downstream hydrocylone's separation performance.

The rest of the paper is organized as following: Section 2 briefly describes the testing facility, Section 3 illustrates considered testing scenarios, Section 4 summarizes the experimental results and finally a conclusion is carried out in Section 5.

2. Testing facility

The testing facility described in this section is an extension of the facility examined in Biltoft et al. (2013). Fig. 1 shows P & ID drawings of two parts of the laboratory testing facility where all examined experiments are obtained from. The facility consists of a pipeline-riser-separator-hydrocyclone system in a complete flow-loop. Each individual part of system can be tested respectively. In the this paper's work the configuration consists of the following subsystems will be applied together: Pipeline-riser-separator-hydrocyclone. Fig. 1a shows the pipeline-riser with the anti-slug control configuration examined in this paper, and Fig. 1b illustrates the gravity separator with water level control loop and the hydrocyclone with the pressure drop ratio (PDR) control loop.

There is a number of transmitters and actuators installed to manipulate and monitor the system. There are temperature and pressure transmitters at all relevant position on the facility, as well as several flow transmitters to measure in- and outflows of each subsystem. In the gravity separator there is also a multi-level transmitter installed to measure the water and oil levels, respectively. The actuators consist of inflow oil and water pumps, gas compressor, with control valves to regulate the gas inflow, a riser gas-lifting valve, a riser topside choke valve, outlet valves on each of the gravity separator's three outlets and control valves on both hydrocylone over- and underflow outlets.

All data acquisition and control is performed using a standard PC running Simulink Real-time (xPC) through a target PC which guarantees real-time simulations. The transmitters and actuators are connected to the target PC through National Instruments (NI) data acquisition and output PCI cards, which are installed in an electrical distribution box.

3. Experimental design

In this section the experimental design is described, as well as an examination of the slug and separation emulation properties.

Some key physical properties are expected to be present for the considered process. The relationship between water in- and outflow of the gravity separator is important as the inflow can be controlled by the topside riser valve and the outflow is transported directly to the hydrocyclone. If all other running conditions are constant, the initial water level is equal to the controller reference ($level_{w,init} = ref_{w,level}$), and a perfect (infinity fast) water level controller is installed in a gravity separator the separator's water mass inflow ($\omega_{sep,l,in}$) will at any point in time be equal to the separator's water mass outflow ($\omega_{sep,w,out}$). In reality a time delay is also expected to be present.

As the de-oiling hydrocyclone is directly linked downstream the gravity separator's water outlet, the varying water inflow to the separator will simultaneously result in oscillations for at the hydrocyclone's inlet flow, when a water level controller is applied for the gravity separator. As the hydrocyclone's separation performance is highly sensitive to the fluctuating inflow, this can be a problem for the complete separation efficiency (Husveg, 2007; Wolbert et al., 1995; Schuetz et al., 2004). Furthermore, the hydrocyclone's underflow valve is the only applied actuator for manipulating the water level in the