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Experimental investigation of hydrodynamic slug mitigation potential of an intermittent absorber

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ABSTRACT

The need to handle hydrodynamic slugs in a more efficient way becomes important as oil and gas activities shift deep offshore. This study describes the use of a vessel coupled to the pipeline-riser system upstream of the first stage separator for hydrodynamic slug attenuation. The experiments were carried out in a 2″ pipeline-riser system which comprises of a 40 m long horizontal pipe connected to a 11 m high vertical riser followed by a 3 m horizontal topside section. Air and water were used as experimental fluids. Bifurcation maps and slug attenuation index (SAI) have been used to quantify increase in oil production and the slug attenuation potential of this concept. The device was observed to reduce the pressure fluctuations characterising hydrodynamic slug flow up to 22%. The device also provides additional benefits of stabilising the flow at higher valve opening (choke setting) and lower pressure compared to traditional choking. This in practice translates to increase in oil production. Special case of hydrodynamic slugs which exhibit overchoking induced slugging (OIS) was also observed to be relatively attenuated by the introduction of the absorber.

1. Introduction

Slugging is one of the flow assurance challenges usually encountered in multiphase transportation of oil and gas. It is an intermittent flow of liquid and gas which manifests in pressure and flow fluctuations capable of causing upset in topside process facilities. This intermittent behaviour can induce structural defects in pipeline-riser system, and impact oil production negatively. The threat of slugging to oil and gas facilities has been known since the early 1970s. Three types of slugging are widely known: Terrain/severe, hydrodynamic and operation induced slugging.

During the life of a field, there are usually operational changes such as system depressurization and restart, flow ramp up, and pigging operations. These operations usually give rise to huge volume of liquid body in form of slugs. This type of slugging is referred to as operational induced slugging.

Terrain/Severe slugging is known to occur due to undulating pipeline geometry and has been extensively researched by many authors (Barbuto and Caetano, 1991; Ehinmowo, 2015; Malekzadeh et al., 2012; Sarica et al., 2014; Schmidt et al., 1985; Yocum, 1973). This type of slugging is known to exhibit large fluctuation in flow rates and pressure resulting in poor separator performance, pipeline fatigue, and sometimes eventual plant shutdown. On the other hand, hydrodynamic slug is usually encountered in horizontal or near horizontal pipelines. This slug is usually believed to be short, high frequency slugs. Many researcher including Danielson (2011), Issa and Woodburn (1998); Issa and Kempf (2003) have investigated this phenomenon and proposed model for its prediction.

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Hydrodynamic slugging when compared with severe slugging has higher frequency and short slug length. Its fluctuation behaviours have previously been considered manageable by the system or with the aid of slug catcher. Hence, very little efforts have been concentrated on the issue of stabilising hydrodynamic slugging compared with the amount of studies on control of severe/terrain induced slugs. However, the results in Brill et al. (1981) as reported in Schmidt et al. (1985) brought a new perspective to hydrodynamic slug flow. An experimental test was conducted on a large diameter of 16 in, 4.572 km nearly horizontal pipeline leading to a 9.14 m riser where the length of slugs up to 609.6 m was observed. This slug length is far greater than the riser. This implies that liquid volume surges caused by hydrodynamic slugs could be difficult for downstream facilities to cope with like severe slugging. Other authors have also reported results which support this view (Fairhurst, 1988; Guzman Vazquez and Fairuzov, 2009, 2007; Hassanein and Fairhurst, 1998; Scott et al., 1989; Scott and Kouba, 1990; Scott, 1987). The problematic behaviour of hydrodynamic slugs in pipeline-riser system was reported in (Guzman Vazquez and Fairuzov, 2009, 2007). This type of slug was reported to exhibit velocity in the riser of five order of magnitude compared with the average velocity in the horizontal pipeline and can also grow to be of length greater than the riser. A West African field for example has been reported to suffer from flow assurance issue due to hydrodynamic slugging despite the fact that the conventional strategy for severe slug control has been put in place (Schoppa et al., 2007).

The transient nature of hydrodynamic slugs has not been well understood till date. The commercial software packages used at the point of design usually do not have the capability to accurately predict hydrodynamic slugs and its interaction with terrain slugs which can cause a complex slugging. This type of complex slugging resulting from hydrodynamic-terrain slug interaction has been reported for a ConocoPhillips field in the North Sea (Danielson et al., 2012). Issa and Kempf (2003) also reported the interaction of severe (terrain) slugging and hydrodynamic slugs in a V-section of a pipe. The interaction resulted into much longer slugs than normally experienced in horizontal pipelines. All these have generated a renewed interest in the understanding and control of hydrodynamic slugs.

Slug catcher is one of the commonly used methods for hydrodynamic slug attenuation. Slug catchers are usually installed upstream the separators to serve as a damper for the slugs and oversized for fear of slugging problems. This practice is not economically friendly (Schmidt et al., 1985, 1981). Miyoshi et al. (1988) developed a model for slug catcher design and reported that various variables critical to performance could be quantified. Though this model could be used to achieve some level of proper sizing, the practice of oversizing slug catcher is still predominant. As production activities keep moving deep offshore and the space constraint becomes more and more critical, the use of slug catcher could therefore become less attractive. The ability of a slug catcher to handle gas surges associated with slugging has also been doubted (Kovalev et al., 2003, 2004).

Kovalev et al. (2004) proposed a technique for pipeline slugging which they claimed has the potential for taming hydrodynamic slugging. The device was called Vessel-Less S^3 and is shown in Fig. 1. It was an advanced version of the earlier proposed device S^3 which was considered less cost-efficient solution for slug control. The volume of the required vessel in the S^3 was reduced through the use of a stratifier

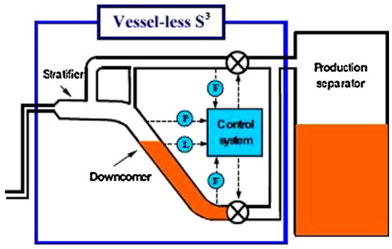

Fig. 1 – Vessel-Less S3 (Kovalev et al., 2004).

and T-junctions as secondary separator. Although the volume was claimed to have been reduced but the addition of stratifier, T-junctions to a downcomer which is also a tilted vessel can constitute additional cost. Also the effectiveness of the T-junctions depends critically on the stratifier and no systematic procedure for the sizing of the volume of this device has been reported.

Krima et al. (2012) proposed gas injection as an effective method for hydrodynamic slug control using OLGA. Different control strategies were studied and reported that with the aid of riser-top choking the volume of gas required to attenuate hydrodynamic slugs is reduced. Inyiama (2013) employed active feedback control strategy using riser base pressure as a controlled variable and riser top choke valve as manipulated variable with OLGA to control hydrodynamic slug. It was reported that the riser slugging was suppressed and the choke valve opening was improved from 5% to 12.65%. However, no theoretical explanation was reported for this concept. Xing (2011) and Xing et al. (2014) employed experimental and computational fluid dynamics (CFD) methods to investigate the use of wavy pipe for hydrodynamic slug control. The device acts like a mixer which allowed gas penetration into the slug body thereby reducing the density and effectively attenuate the slug flow. However, the slug flow was observed to redevelop few metres downstream the device.

It becomes evidently clear that hydrodynamic slug flow and control in pipeline-riser systems needs more attention and this work is therefore aimed at investigating the use of an intermittent absorber as a method for hydrodynamic slug attenuation.

One of the ways of suppressing or eliminating fluctuation due to intermittence is to tune the system parameters. When this is done the desired stable behaviour would ensue. In order to analyse the influence of parameter variations on the behaviour of multiphase slug flow in pipeline-riser system, bifurcation map can be employed.

The nature of multiphase flows generally is non-linear. The hydrodynamic stability of such non-linear system can be analysed using bifurcation map. Bifurcation theory is concerned with the understanding of the changes in the qualitative behaviour of the solutions of non-linear systems as a result of a parameter variation (Drazin and Reid, 2004). Previous investigators of multiphase flows in pipeline-riser systems have employed bifurcation theory to ascertain the bifurcation point, stable and unstable regions of the system. The parameter usually adopted is the valve opening. Establishing stable and unstable regions helps the investigators to consequently design controllers which are able to stabilise the system in an unstable region (Ogazi et al., 2010, 2009, 2011; Storkaas and Skogestad, 2007; Storkaas, 2005; Storkaas et al., 2002). In this study, we have investigated the possibility of stabilising the system in an open loop unstable region with the help of the