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# On the interaction between severe slug buildup and dynamic response of a submerged top-tensioned riser

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ABSTRACT

Severe slugging in deepwater flowlines and risers systems is one of the flow assurance problems that interrupts the steadily flow of reservoir fluids, most severely in offshore oilfields with undulated seabed terrain. This flow regime threatens the structural integrity of subsea production systems due to its fatigue loading behaviour which prompts the need to investigate its impact on the riser stability. A mathematical model which based on a modified Euler-Bernoulli beam theory and plug flow is presented to analyse the dynamic response of a riser during severe slug buildup. Solution for the transverse deflections of the riser in space and time was sought through finite difference approximations with implicit space and explicit time discretization scheme implemented in Matlab, with an adaptive algorithm that computes the changing hydrostatic pressure in the riser due to the severe slug buildup. The dynamic response of the riser was observed to be undergoing a damped vibration with decaying amplitude. Accuracy of the solution was verified with a coupled fluid-structure interaction simulation in Abaqus. Parametric studies on velocity variations and riser responses were conducted. The mathematical solution presented in this paper has opened a new idea for riser pipe analysis with respect to severe slug flow.

## 1. Introduction

Severe slugging otherwise known as terrain-induced slugging is a type of multiphase flow regime encountered in offshore oil and gas production systems. This flow regime is transient in nature and is of practical importance to offshore oil and gas industry because of the menace it imposes on the production facilities, due to its consequent fatigue loading behaviour and erratic liquid surges.

Schmidt et al. (1980) was the first to experimentally investigate the problem of severe slugging. In their study, they used Fig. 1 (a) – (d) to describe the physical phenomenon of severe slug flow which involves slug formation/buildup, slug movement into the separator, gas blowout/bubble penetration and liquid fallback. Their result findings revealed that severe slug flow is characterised with incessant pressure fluctuations at the riser base which causes equipment instabilities and damages to topsides processing facilities during over flooding of the separator due to high volume liquid surges. They concluded that severe slugs are longer than the riser length and further established criteria that cause severe slug flow in flowline-riser pipe systems, which are: low flow rates of oil and gas (typically of an aged oilfield with low daily production rate), flowline declination (encountered in an undulated seabed that creates a hilly terrain) and pressure buildup in the riser due to liquid accumulation resulting from the blockade of the incoming gas by the liquid slug owing to the downward declination of the flowline. Other researchers in the likes of Fabre et al. (1990), Baliño et al. (2007), Bert et al. (1987), Xing and Yeung. (2010), Wang et al. (2013), Issa et al. 2011, Oliveira et al. (2013), have all carried out different studies on severe slug flow and highlighted spectrum of other problems associated with this flow regime on production facilities such as: high average back pressure at the wellhead, production losses due to inoperability of separator at its designed capacity caused by stream surges, high instantaneous flow rates, instabilities in liquid control systems of the separators, reservoir flow oscillations, liquid carryover in the separator, pressure control problems at the separator, facility damage due to large pressure amplitude and instabilities, unsteady loadings on the piping systems and processing equipment which could result to catastrophic failure due to metal fatigue, risks of leaks due to equipment wear and tear. However, recommendations such as topsides choking of the riser to increase back pressure in order to dislodge the accumulated slug; gas lift injections at the riser base to unload the slug;

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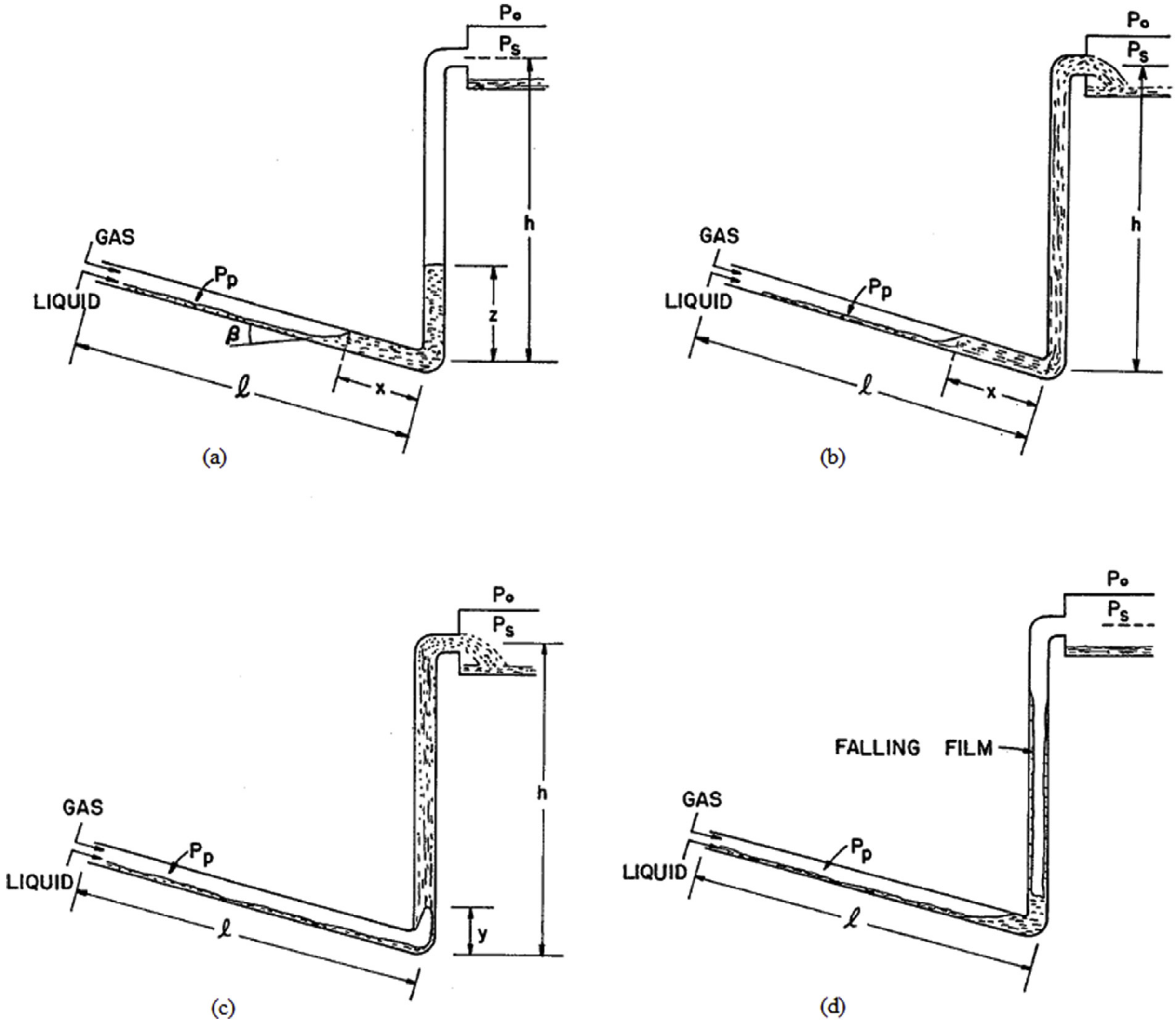

**Fig. 1.** Severe slug flow cycle: a) slug formation/buildup, b) slug movement into the separator, c) gas blowout/bubble penetration, d) liquid fallback.

smart valve controller have been proposed by Schmidt et al. (1985), Yocum (1973), Sarica and Tengesdal (2000), Jansen and Shoham (1991), Henriot et al. (1999) and host of other researchers for the control and mitigation of the problems of severe slug flow.

Inspite of all the proposed mitigation measures, their applicability has been found to be theoretically achievable but practically not feasible owing to its expensive tradeoffs such as 50% loss in daily production rate of reservoir fluids, high cost of daily gas injection facility. However, in the absence of no viable economic approach to mitigate the dangers of severe slug loadings on offshore production equipment, the best option remains to continually optimize the design capability of these equipment in order to increase their service life, and enhance its durability and reliability, which can be achieved by capturing all the loadings these systems are exposed to and it is the main contribution of this paper, which aimed at predicting the structural instability of a submerged, top-tensioned riser during a severe slug buildup.

Literature review on dynamic behaviour of production risers subject to intense severe slug flows shows that the study is still an open research, but more attention has been paid to slug related internal flows; Philip et al. (2009) analysed the fatigue damage on flowline systems caused by slug loads whereas Montoya-Hernandez et al. (2014) conducted frequency analysis on marine riser with respect to multiphase internal flow behaviour. Ibrahim et al. (2013) used a surrogate model to investigate the flexural loading in pipelines due to slug flow. Furthermore, Jia, 2012, 2013 investigated about slug flow induced vibration in a pipeline span and effect of slug length, slug frequency, flow rate and boundary conditions on slug flow induced vibration in a pipeline span. Darcy et al. (2013) conducted experimental study to investigate dynamic force on an elbow caused by a traveling liquid slug, while Peter and Jin (1995) carried out a three dimensional coupled analysis of vertical deep-ocean pipe with respect to the effect of periodic internal flow on shear stress. However, Chainarong et al. (2008) carried out the effects of axial extensibility on the three dimensional behaviour of tensioned pipes and risers transporting fluid. Paul et al. (2012) has proposed methodology for determining remnant fatigue life of flexible risers subjected to slugging and irregular waves, while Rabih et al. (2008) investigated on the fatigue life prediction of extra-long submarine gas pipelines due to slug flow. Armando and Euro (2010) worked on the interaction between slug flow and vortex induced vibration (VIV) in fatigue life of submarine pipelines. Arturo et al. (2012, 2013) studied on the dynamic response of flexible risers caused by internal slug and flexible riser response induced by combined slug flow and wave loads in which they used numerical simulations to establish their findings, Aravind et al. (2011) in their study, focused on flow induced forces on multi-planar rigid jumper systems. Duncan Chisholm (1985) studied the effect of two-phase flow in heat exchangers and pipelines, Tu et al. (2014) investigated the flow-induced vibration on a circular cylinder in planar shear flow, while Gosselin and Païdoussis (2014) analysed the dynamic stability of a hose to the sky. However, Amabili et al. (2008) studied the effect of geometric imperfections on