Coupled numerical simulation of the dynamics of deepwater steel lazy-wave riser under the full-stages of severe slugging

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ABSTRACT

Severe slugging is a flow assurance problem that threatens the integrity of offshore production systems due to its cyclic behaviour and a source for fatigue damage in the material structure. Due to the complicated nature of the physics of severe slugging and its interactions with the pipe structure, no study has fully understood the dynamic behaviour of steel lazy-wave risers induced by the 4 stages of severe slugging and of which this research draws its originality from. In this paper, a 2-way full coupled FSI numerical model is simulated with ANSYS-FLUENT, ABAQUS and MpCCI, respectively, for the numerical investigation of the interaction between the complete flow stages of severe slugging and the dynamic response & stress impact on a steel lazy-wave riser. A comimgled two-phase flow and 2D pipe with 0.05 m ID, 0.075 m OD and -5° pipe inclination was modelled. MpCCI serves as the coupling interface server for real-time pressure and structural deformation data exchanges. Results show that the dynamic response is critical at the downcomer during the gas blowout and liquid fallback stages. Findings from this study will help to improve on the fatigue design of deepwater risers for structural reliability, safety and enhanced fatigue life.

KEY WORDS: Severe slugging; steel flexible riser; fluid-structure interaction; Abaqus; MpCCI; dynamic response; stress impact.

INTRODUCTION

Severe slugging also referred to as terrain-induced slugging can be defined as a two-phase flow phenomenon which is peculiar in subsea production systems and occur mostly in aged oil fields which are susceptible to heavier oil deposits, low flow rates, pressure fluctuations, and the unevenness in the seabed topography. It is a critical condition that results in fatigue loading and material damage in the pipeline riser system, and as a result, poses a threat on the structural integrity, reliability and safety of offshore production facilities.

Yocum (1973) was the first to report the phenomenon of severe slug flows which has a prone occurrence in petroleum offshore facilities, where usually there are downward sections (pipelines) and upward sections (risers). In the history of experimental studies on severe slugging, Schmidt, James, and Beggs, (1980) were the first to describe the occurrence of severe slug flows in pipeline riser systems. Their research majorly classified severe slugging into four stages: slug formation, slug production, gas blowout and liquid fallback. Studies such as (Boe, 1981; Balino, Burr, and Lovate, 2007; Fabre, Peresson, Corteville, Odello, and Bourgeois, 1990; Schmidt, James, and Beggs, 1980; Taitel and Barnea, 1990) have highlighted several severe slugging problems such as high back pressure at the wellhead, loss in production due to separator process failure caused by stream surges, instability in control systems of the separator, reservoir flow oscillations, platform trips and equipment failure due to fatigue loads.

Most studies have inched towards mitigating severe slugging problems and have proposed measures such as topside choking, gas-lift injection, smart valve control methods to control and eliminate the occurrence of severe slugging (Yocum, 1973; Schmidt, James and Beggs, 1980; Jansen, Shoham and Taitel, 1996; Hill, Fairhurst and Nelson, 1996; Schmidt, Dale and Kunal, 1985). However, these mitigation methods proposed by researchers have shown prospects of being theoretically achievable but not practically feasible. These methods can lead to a loss in daily production rate of 50% and high cost of setting up gas injection facilities (Onuoha, Li and Duan, 2018). So far, no economically viable mitigation method has been presented and as such, improving the structural integrity and reliability of this equipment to boost their service life while ensuring operational safety and environmental protection is of key importance to the industry. To attain this, all sources of fatigue loads exerted on the pipeline-riser system needs to be considered during riser design which includes the accurate prediction of the dynamic behaviour of risers subjected to severe slugging which happens to be a fatigue load.

Several studies have investigated the dynamic behaviour of risers subjected to multiphase flows and more so on severe slug flows. Zhu, Gao, and Zhao (2018) experimentally studied the vibrational response of a free-hanging riser induced by an unstable slug flow. They observed that the slug flow generated vibrations in the system and the maximum response amplitude appeared when the pressure reached its peak. They also observed that both the geometry and flexibility of the riser contributes to the response along the riser length. Ortega, Rivera, Larsen, and Nydal (2012) developed a computational model and numerically analyzed the effect of internal two-phase slug flow on the structural