Ocean Engineering 152 (2018) 234–248

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Severe slugging in deepwater risers: A coupled numerical technique for design optimisation

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ARTICLE INFO

Keywords:
Severe slugging
Finite element analysis
OLGA 7
ABAQUS
Fluid structural interaction
Top tensioned riser

ABSTRACT

This paper presents an improvised coupling technique for stress impact and dynamic response studies of a deepwater flowline-riser pipe system exposed to cyclic loadings resulting from severe slug flow. It involved partial coupling of transient multiphase flow simulator OLGA and structural finite element code ABAQUS. In this analysis, a parametric study was carried out where mass flow rates of 9.8 kg/s, 13 kg/s, and 16 kg/s were sampled in order to reflect the corresponding marginal flow rates of 6000 (950.4 m^3/day); 8000 (1267.2 m^3/day); and 10000 (1584 m^3/day) barrels of oil per day (bbl/day) for a typically aged offshore oilfield presumed to be piped with a 10 inch (0.254 m) diameter subsea production pipe system. Numerical results obtained, have shown that the 6000 bbl/day flow rate imposed predominant stress at the riser base by producing maximum stress values of 64 MPa, 63 MPa, and 68 MPa in the axial, transversal and lateral global directions of the flowline-riser cross-section, respectively. This observation has further validated the severity of severe slug flow to low flow rate of reservoir fluids. With this and other data provided in this paper will enhance the fatigue design optimisation of deepwater production risers.

1. Introduction

Equipment integrity and systems reliability are of paramount interest in oil and gas industry, as they guarantee not only the safety of personnel working in the field, but also for the protection of environmental degradation that could inadvertently occur due to unprecedented equipment failure. The determination of the life of an engineering structure is based on two precepts which are: the knowledge of the structure itself and knowledge of how that structure is loaded. Deepwater offshore production risers suffer fatigue loadings from various sources such as first order wave effects (direct wave loads and associated floater motions), second order floater motions, vortex induced vibrations, internal fluid slugging effect, thermal and pressure induced stress cycles etc. (DNV-RP-F204, 2010). In order to ensure adequate fatigue life of deepwater riser systems, it is important to have detailed technical data for all the identified fatigue loadings in a given operational condition of a certain riser system in service. Severe slugging is a flow assurance issue in offshore production systems especially for shallow and deepwater flowline-riser systems due to sagging (irregular) boundaries. Peculiar problems associated with such flow geometry are flow instabilities and production losses, pressure fluctuations at the riser base, flooding of separator due to accumulated liquid surges, separator damage due to high liquid and gas flow rates (Boe, 1981; Baliño et al., 2007; Bert et al., 1987; Fabre et al., 1990; Issa et al., 2011; Schmidt et al., 1980; Taitel and Barnea, 1990; Wang et al., 2013; Xing and Yeung, 2010). Other related slug flow problems include fatigue damage on the marine structures (Armando and Euro, 2010; Arturo et al., 2012, 2013; Audun, 1982; Chen and Jian, 2015; Ibrahim et al., 2013; Jia, 2012, 2013; Mac Darlington et al., 2016; Marcio and Motohiko, 2010; Monette and Pettigrew, 2004; Montoya-Hernández et al., 2014; Paul et al., 2012; Peter and Rogers, 1995; Philip et al., 2009; Rabih et al., 2008) especially that imposed by severe slug flow which is usually associated with hydrostatic pressure fluctuations and is significantly dominant at the base of an offshore production riser. The physical model describing the phenomenon of severe slugging was first presented by (Schmidt et al., 1980) where he described the four stages of severe slug cycle which are slug formation, slug movement into the separator, gas blowout and liquid fallback as shown in Fig. 1(a), (b), (c) and (d) respectively. The analytical model

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https://doi.org/10.1016/j.oceaneng.2018.01.070
Received 12 April 2017; Received in revised form 29 September 2017; Accepted 16 January 2018
Available online 23 February 2018

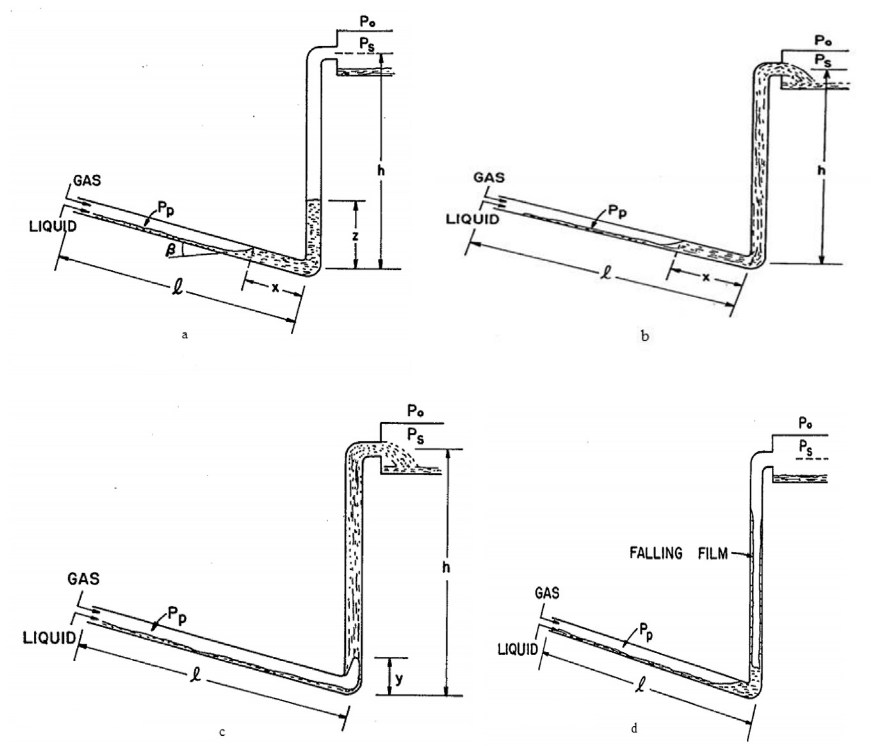

Fig. 1. a) Slug formation. b) Slug movement into the separator. c) Gas blowout. d) Liquid fallback.

Table 1
Fluid components.

Components	Molar %
C1	72.3926
C2	3.9559
C3	1.9255
iC4	0.4267
nC4	0.8707
iC5	0.2657
nC5	0.3694
C6	0.6521
C7	0.8089
C8	0.9728
C9	0.9472
C10	0.8035
C11	0.8183
C12	0.7203
C13	0.6129
C14	0.6856
C15	0.7077
C16	0.5276
C17	0.4486
C18	0.4802
C19	0.4234
C20+	8.0818
N_2	0.1026
CO_2	2.00

proposed by Schmidt was aimed at predicting the slug length, slug frequency, slug density, slug velocity, and pressure fluctuations at the riser base. Literature detailing the fluid-structure interactions between severe slug flow and offshore production risers are limited, but much research studies have been done on structural responses due to loadings coming from slug flow conditions (Arturo et al., 2013; Chen and Jian, 2015; Ibrahim et al., 2013; Jia, 2013; Monette and Pettigrew, 2004; Philip et al., 2009) thus, the need for optimising the design capability of offshore production risers which usually, is exposed to intense severe slug loadings during the later production life of an aged oilfield. During this stage, the production facilities of an offshore oilfield will experience severe slugging problems, otherwise known as flow assurance issues, and such flow conditions have impact on the structural integrity and reliability of the production equipment. Therefore, with the emergence of competent modeling and computing tools coupled with relevant field data, complex problems like multiphase flows and its structural interactions can be efficiently simulated and analysed, thereby providing a starting point for the design optimisation of these marine structures, which invariably will enhance in the extension of their service life. Presently, there's no single industrial commercial code that can simultaneously and effectively model multiphase flow problems and structural analysis. In view of this backdrop, this paper adopted a quasi-coupling technique involving the use of OLGA and ABAQUS simulators, which respectively, are renowned industrial commercial codes for multiphase flow studies and FEM/FEA analysis. Exploring the tenacity of this concept has enabled the provision of the much needed technical data that will enhance in the design improvement of a 10 inch (0.254 m) top-tensioned riser pipe by modeling a typical offshore oilfield production facility with the aforementioned production tubing, which is presumed to be experiencing repeated loadings posed by severe slug flow at the riser base. The modeling encompasses parametric studies that evaluated the stress state and dynamic behaviour of the riser base to three different mass flow rate scenarios: 9.8 kg/s, 13 kg/s, and 16 kg/s in flowline-riser pipe system. The riser base happens to be the vulnerable section of the riser that is exposed to fatigue damage due to the cyclic behaviour of the severe slug buildup in the riser. Emphasis on this analysis is aimed at providing detail understanding of the maximum stress distribution and dynamic responses to changes in flow conditions of a 10 inch (0.254 m) flowline-riser pipe system that is under severe slug loading since the pipe dimension and properties chosen in this study has been found to have wider applications in offshore oil and gas industry especially in deepwater oilfields. Simulation study with industry's acclaimed commercial software codes becomes indispensable when laboratory experiment is incapable enough to analyse the actual physical problem. Having said that, PVTsim and OLGA which are renowned industry codes on flow assurance study for multiphase flows of gas and oil in pipelines were chosen for the severe slug flow analysis in the riser pipe, while ABAQUS which is a famous software