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The influence of backpressure on severe slugging in multiphase flow pipeline-riser systems

Chen Xie, Liejin Guo *, Wensheng Li, Hongliang Zhou, Suifeng Zou

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China

HIGHLIGHTS

- A new large-scale pipelines-riser experimental system for high pressures.
- New experimental data, flow patterns and flow properties at various pressures.
- Effects of gas compressibility and gas solubility on severe slugging properties.
- A stability criterion for steady state operation under various backpressures.

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ABSTRACT

Severe slugging is a well-known instability in multiphase flow through a pipeline-riser system that is characterized by sharp pressure changes and violent flow fluctuations. This can cause safety and operational problems in the production of oil and gas. Particularly for deepwater risers, which can be up to 3000 m long, the operating pressure in the pipeline and riser can be high (that is a few hundreds of bar). Most lab experiments carried out so far for severe slugging were conducted at atmospheric pressure. The present study contains new experiments at elevated pressure. Thereto a new large-scale pipeline-riser system was established with 300 bar maximum pressure. To study the effect of the pressure at the riser top on severe slugging, experiments for the stability boundaries and for the amplitude and frequency of the slugging were carried out for pressures in the range of 0–50 barg. The results show that an increased backpressure gives a reduced region of severe slugging in the flow pattern map, whereas it also mitigates pressure fluctuations and decreases the slug frequency. Based on these experimental results, the existing prediction model for the stability of steady state operation and the transition to severe slugging was modified to incorporate the effect of the backpressure.

1. Introduction

Oil-gas mixed transportation is widely used in the production of offshore oil-gas fields. The subsea multiphase pipelines, which connect the subsea wells (manifolds) to the production platform or to a Floating Production Storage and Offloading (FPSO) facility, are usually constructed as a horizontal - inclined - vertical geometry, which is referred to as a pipeline-riser system. At turn down production rates or in the late life of the oil-gas field, the reduced oil and gas production gives a flow pattern that is stratified in the pipeline and hydrodynamic slug flow in the riser. Under such conditions, the blockage of the riser base with liquid can occur, which leads to gas accumulation in the pipeline and to the filling of the riser with liquid. As the oil and gas continue to flow into the pipeline, finally the liquid will reach the riser top and the pressure of the compressed gas will balance the hydrostatic head of the riser. Now the liquid slug is produced at the riser top and finally the gas penetrates into the riser. At some oil and gas flow rates, the gas blowout occurs in the riser. All these phenomena are closely linked to an undesired flow phenomenon that is called "severe slugging".

The severe slugging is characterized by the long liquid slug, periodic pressure fluctuations and vigorous gas blowout. These flow oscillations can give separator flooding, pipeline corrosion and production reduction. Therefore, it is important to investigate the severe slugging properties and to develop methods to mitigate or prevent such flow behaviour.

Since Yocum (1973) described severe slugging in an offshore oil field, the topic has been investigated by a large number of researchers. As shown in Table 1, the studies have considered a

* Corresponding author.
E-mail address: lj-guo@mail.xjtu.edu.cn (L. Guo).

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Nomenclature

A	areas in the cross section, m^2	α_c	void fraction through the choke
C	single phase choke coefficient	ρ	density, kg/m^3
D	pipe diameter, m	β	inclined angle from the horizontal, °
g	gravitational acceleration, m/s^2	ε	gas expansion ratio
GR	growth rate of the pressure in the pipeline, Pa/s	Φ	liquid holdup in the riser
h	liquid film height, m	λ	two-phase adjusted coefficient
H	riser height, m		
L	pipeline length, m	*Subscripts*	
m	gas mass, kg	0	standard conditions
P	pressure, Pa	c	choke
R	universal gas constant, J/(kg K)	DC	down comer
S	air solubility in water, m^3/kg	G	gas
T	temperature, K	L	liquid
U	velocity, m/s	*in-situ*	in-situ condition
		S	superficial
Greek symbols		s	separator
α	void fraction in the pipeline		
α'	void fraction of the gas cap		

Table 1
Overview of existing experimental data sets with the main parameters.

Author	Fluid	H/I/R (m)	I.D. (mm)	Inclined angle (°)	Riser type
Schmidt (1977)	Air-kerosene	–/30.5/15.2	50.8	−5 to 5	Vertical
Schmidt et al. (1985)	Air-water	21.7^e/9.1/3	25.4	−1	Vertical
Pots et al. (1987)	Air-water/glycerin	120^e/30/15	50	−2 to 0	Vertical
Taitel et al. (1990)	Air-water	1.69^e, 5.1^e, 10^e/9.1/3	25.4	−5	Vertical
Fabre et al. (1990)	Air-water	–/25/13.5	53	−1 to 1	Vertical
Tin (1991)	Air-water	–/60/33	50.8	−2	Catenary, S-shaped
Jansen et al. (1996)	Air-water	10^e/9.1/3	25.4	−1	Vertical
Wordsworth et al. (1998)	Air-water	–/57.4/9.9	50	−2	Catenary
Tengesdal (2002)	Air-water	7.57^e/2.82/1.88	19.05	−3	Vertical
	Air-mineral oil	85.3^e/19.8/14.9	76.2	−5 to 3	Vertical
Montgomery and Yeung (2002)	Air-water	–/69/9.9	50	−2	S-shaped
Mokhatab (2007)	Air-water	–/53.84/10.5	101.6	−2	Catenary
Ali and Yeung (2010)	Air-water	36/–/12.2	254	0	Vertical
Malekzadeh et al. (2012)	Air-water	123^e + 65/35/15.5	50.8/45	−2.54	Vertical
Li et al. (2013)	Air-water	114/16/15.3	50	−5 to −2	S-shaped
Luo et al. (2014)	Air-water	68.1/26.1/7.7	51	−4	Vertical

H/I/R: horizontal pipeline/inclined section/riser height.
I.D.: inner diameter.
Superscript e: equivalent pipeline length.

range of pipeline lengths, inclination angles, inner diameters, riser configurations and fluid properties.

Schmidt et al. (1979a, 1985) have conducted experiments for severe slugging both in a large-scale facility and in a relatively small facility. They indicated that severe slugging existed only when there is a downward inclination in the part of the pipeline just upstream of the riser base. This conclusion was also supported by the experiments of Fabre et al. (1990). Besides this, Pots et al. (1987) investigated the effects of liquid viscosity, pipe inclination angle, and riser base geometry on the flow behaviour in their test facility. Taitel et al. (1990) carried out experiments to study the effect of the length of the pipeline on severe slugging. Their results showed that the size of the severe slugging region in the flow map expanded with an increase of the pipeline length. Jansen et al. (1996) used the same facility as Taitel et al. (1990) to develop methods to eliminate severe slugging. As a result, two effective mitigation methods were found: choking at the riser top and gas lift at the riser base. They also gave a theoretical analysis for the elimination mechanism. Tengesdal (2002) performed experiments to develop a self-lifting method to eliminate severe slugging, which was shown to be insensitive to changes in both liquid and gas flow rates. Malekzadeh et al. (2012) conducted experiments in a long pipeline-riser system, in which severe slugging of type 3 was found for which the liquid slug was aerated during the slug growth stage.

Severe slugging in flexible risers was also studied, such as by Tin, 1991; Wordsworth et al., 1998; Montgomery and Yeung, 2002; Mokhatab, 2007; Ali and Yeung, 2010; Li et al., 2013. Severe slugging can also occur in a flexible riser, being quite similar to what is found in a rigid vertical riser. But a second surge can occur in an S-shaped riser. Furthermore, the S-shaped configuration can stabilize severe slugging and it can thus reduce the unstable flow region in the flow pattern map.

Based on the experimental results, some criteria for the transition to severe slugging were developed. For example, according to the criterion proposed by Bøe (1981) and Pots et al. (1987), severe slugging occurs when the increase in pressure over time at the riser base is larger than in the pipeline. Taitel (1986) carried out a theoretical analysis for the flow stability, and the derived criteria showed a reasonable agreement with experimental data (Schmidt, 1977; Taitel et al., 1990). Furthermore, Jansen et al. (1996)