Universal Library of Engineering Technology | Research Article

ISSN: 3064-996X | Volume 1, Issue 2

Open Access | PP: 08-13

DOI: https://doi.org/10.70315/uloap.ulete.2024.0102002

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Pipe Insertion Technique for Slug Attenuation in a Downwardly Inclined Pipeline

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Abstract

Slug flow is more prevalent in downwardly inclined pipelines and it is important to develop effective and suitable mitigation strategies to reduce its occurrence and enhance stable flow. In this work, the application of pipeline insertion was proposed to reduce slugging in pipeline. A simulation based approach was adopted and a model with smaller pipe sizes of 3.958-inch, 1.995-inch and 6-inch diameter, inserted near the pipeline riser system. The developed model was run for 2 hours to monitor the harsh nature of the slug on the total liquid volume flow, the pressure at the pipeline riser outlet, surge liquid volume and accumulated liquid volume. The result shows a stable liquid production of approximately 3797.08bbl/day and 3798.44bbl/day for the 3.958-inch and 1.995-inch diameter pipe size, while the total liquid flow oscillated between 7366.45bbl/day and 1.917.37bbl/day, and repeated at 0.22 hours. There was a pressure buildup and later steady at 761.978 psia and 762.127 psia for the 3.958-inch and 1.995-inch diameter pipe at the riser base while the 6-inch diameter pipe was fluctuating. Smaller diameter pipe of 3.958-inch and 1.995-inch gave a stable fluid pressure of 725.196 psia at the riser top (outlet) .Therefore, smaller diameter pipe is the best to insert since there was no cyclic fluctuation of pressure at the riser top, which can lead to severe slugging.

Keywords: *Pipe Insertion, Slug Attenuation, Inclined, Riser Pressure, Slug Liquid, Liquid Volume.*

INTRODUCTION

Slug flow is a complex and dynamic flow pattern which is predominant in multiphase flow pipelines and is characterized by the intermittent sequence of liquid slugs followed by gas bubbles flowing through a pipe (Fabre and Line 2006).

Slug flow can occur in horizontal, inclined, or vertical pipes, but more common in hilly terrain or downwardly inclined pipelines as a result of effects of gravitation (Li et al. 2012). The type of terrain where the pipe passes can cause changes in the hydrostatic pressure gradient along the pipe and can lead to the formation and growth of slugs. Slug flow can cause severe operational challenges, such as pressure fluctuations, vibration of pipeline, equipment damage, and flow instabilities (Okereke et al. 2018). Problem cause by slug formation and its flow assurance issue has given rise to several studies for slug mitigation strategies to ensure the safety and efficiency of pipeline systems. Slug mitigation strategies aim to reduce or eliminate the occurrence and severity of slug flow by modifying the pipeline geometry, fluid properties, or flow conditions. Some of the common slug mitigation techniques are active control techniques, passive devices, and pipeline design optimization (Okereke et al. 2023). Slugging can be observed within the vertical or inclined flexible riser and within the horizontal section of the piping lying on the seabed (Oseyande, 2010). The inclined orientation of flow lines, with hydrocarbon content flowing upwards, does tend to assist the initiation of slug flow (Al-Kandari and Koleshwar, 1999).Initiation and slug flow formation is also enhanced and increases for highly elevated pipeline with hydrocarbon fluid flowing upwards and severe slug occurs from the accumulation/blockage of liquid at the low point-elevation of negatively inclined/vertical piping or riser (Kinate et al.2022). The inclination is caused by the geometry of the pipeline (usually a dip at the riser base) or the terrain (seabed bathymetry).

Numerous changes in pipeline inclination are always encountered since the distance from the well to central gathering stations is often many miles (Kang et al., 2000). These changes in inclinations affect the flow pattern and flow characteristics and results to formation of slugs. Past studies on slug formation were purely experimental investigations focused on developing correlations for the void fractions, pressure drop, physical pipeline parameters (pipe diameters), and inclination angles to capture its sensitivities to slugging patterns (Andreussi and Bendiksen, 1989; Bendiksen, 1984). Other works have provided significant understanding on the behaviour of severe slug flow in pipeline-riser system (Baliño *et al.,* 2010; Taitel *et al.,* 1990; Tin and Sarshar, 1993; Xing *et al.,* 2013; Malekzadeh *et al.,* 2012). However, only few studies exist on hydrodynamic slug flow in pipeline-riser system and the impact of riser internal diameter (Guzman and Fairuzov, 2009). Pipeline that are downwardly inclined have a higher tendency for accumulation of liquid at the pipe bottom due to gravity, creating a favorable condition for formation of slug. Moreover, downwardly inclined pipelines have a lower frictional pressure drop than horizontally aligned pipelines, resulting in a lower resistance to slug movement. One of the slug mitigation techniques that has been proposed in the literature is the pipe insertion method and involves inserting a smaller pipe inside the main pipeline to create an annular flow region that reduces the cross-sectional area available for slug flow. The pipe insertion method has been shown to be effective in horizontal and upwardly inclined pipelines, but its performance in downwardly inclined pipelines has not been well studied. Therefore, this work investigates pipe insertion method for slug attenuation in a downwardly inclined pipe.

METHODOLOGY

A numerical simulation based method was utilized in this study to investigate the possibility of slug mitigation through the application of pipe insertion. Multiflash and OLGA were used for fluid characterization and modelling and generation of PVT file for pipeline-riser model development. A base case model was created after which sensitivity was conducted for different line sizes and slug mitigation evaluated.

Input Data and Simulation

Multiflash and OLGA and input variables on fluid composition, pipeline and riser materials, pipeline geometry, heat transfer, inlet and outlet boundary conditions presented in Table 1 to Table 5 were used for slug mitigation by pipeline insertion approach.

Table 1. Compositional analysis of the fluid

Component	Composition (mole %)	Molecular Weight	Density (g/cm^3)
N2	0.03		
CO2	1.23		
C1	39.29		
C2	7.65		
C3	6.43		
iC4	2.14		
nC4	4.44		
iC5	1.99		
nC5	2.57		
C6	4.35	86.178	0.664
C7	19.5	101.3	0.702
C8	3.62	213	0.755
C9+	6.76	302	0.82

Table 2. Pipeline and riser material data

Materials	Pipe properties			
	Thermal Conductivity (W/m.K)	Density (kg/m^3)	Heat Capacity (J/kg.K)	Wall thickness (mm)
Carbon Steel	50	7850	500	9
Insulator	0.1	450	2000	20

Table 3. Pipeline geometry data (base model)

Pipe	X-Coordinate (ft)	Y-Coordinate (ft)	Diameter (in)	Roughness (mm)
Pipeline-1	1000	-255	3.985	0.028
Pipeline-2	1400	-250	3.985	0.028
Pipeline-3	1800	-255	3.985	0.028
Pipeline-4	3400	-255	3.985	0.028
Pipeline-5	4300	-270	3.985	0.028
Riser-1	4300	30	3.985	0.028
To-Separator	4400	30	3.985	0.028

Table 4. Heat transfer data

Property	Value
Pipeline overall heat transfer coefficient	8W/m^2-C
Riser overall heat transfer coefficient	8W/m^2-C
Ambient temperature	6°C

Table 5. Inlet and outlet boundary conditions

Property	Value
Inlet mass flow rate	5kg/s
Inlet temperature	62°C
Outlet temperature	27°C
Outlet pressure	50bar

Simulation Process

Multiflash was set up for model selection and Redlich Kwong Soave(RKS Advanced) equation of state model selected for PVT characterization. The fluid composition in Table 1 were entered in the component section and a PVT Table file created. The PVT table file was imported in to OLGA and a base case pipeline model created. The flow path with the nodes for inlet and outlet were added.

The materials and geometry data in Table 2 and Table 3 were used to define the pipeline-riser system. The ambient condition and the overall heat transfer were defined with the data in Table 4. The inlet and outlet boundary conditions were set up with the data in Table 5. The model was run for 2 hrs for the slugging on liquid volume flow, surge liquid volume, accumulated liquid volume and pressure at the pipeline-riser outlet. After the base case model, sensitivity analysis was conducted for other riser internal diameter. Figure 1 and Figure 2 shows the pipeline-riser system and the simulation workflow.

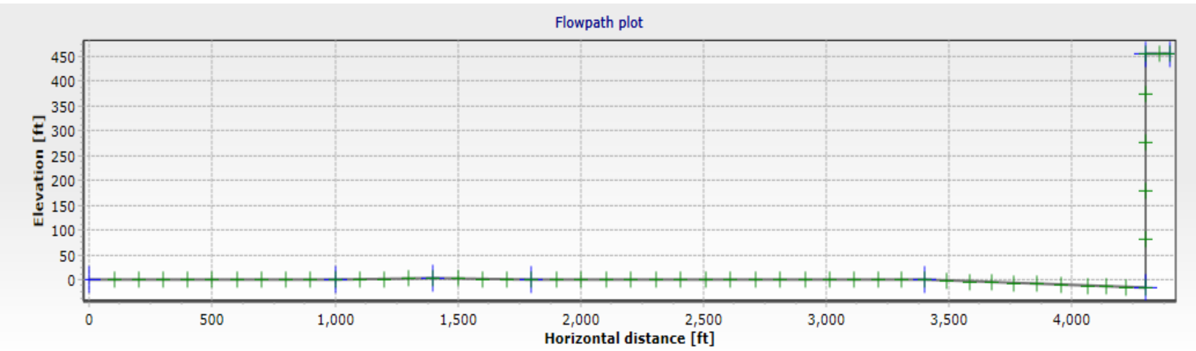

Figure 1. Profile of the pipeline-riser system

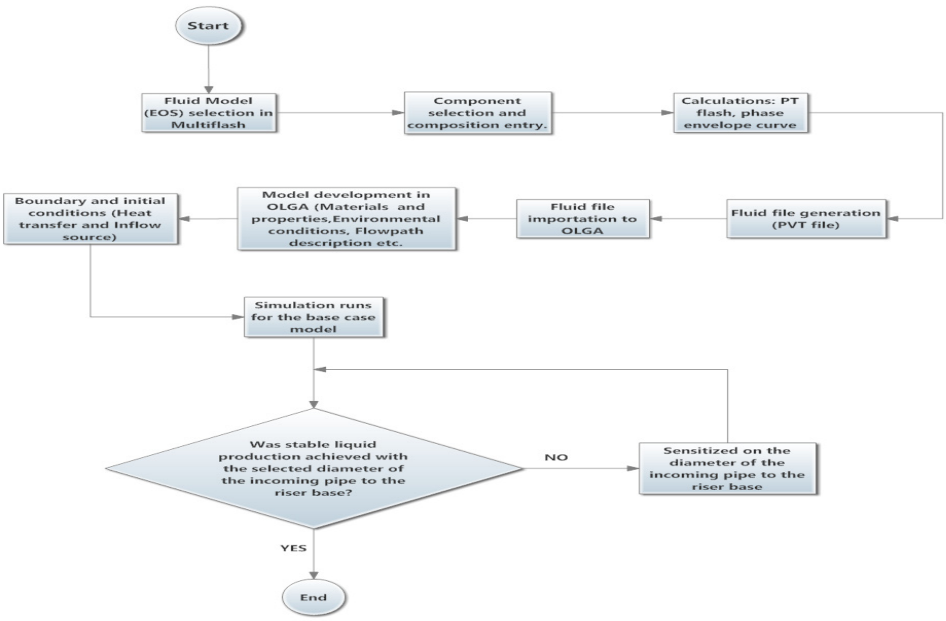

Figure 2. Simulation workflow

RESULTS

Total Liquid Volume Flow

The total liquid volume flow at the outlet of the pipeline-riser system with a smaller diameter pipe of 6-inch, 3.958-inch, and 1.995-inch inserted near the bottom of the riser is shown in figure 3. The black line shows the total liquid volume flow for the 6-inch, the red and blue lines show the total liquid volume flow for 3.958-inch and 1.995-inch pipe sizes respectively. There was a stable liquid production of 3797.08bbl/day and 3798.44bbl/day at the outlet when a smaller diameter pipe of 3.958-inch and 1.995-inch were inserted near the bottom of the riser, whereas for the 6-inch pipe size, the total liquid flow was oscillating between 7366.45bb/day and 1917.37bbl/day. This pattern was observed to be repeating every 0.22hrs.

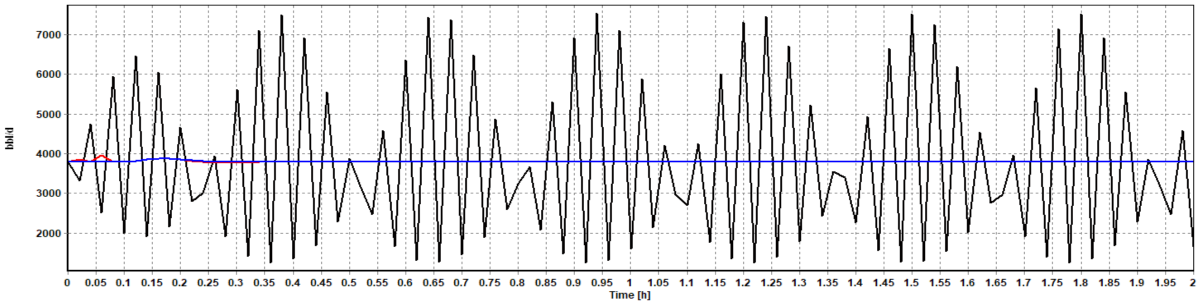

Figure 3. Total liquid volume flow

Surge liquid volume

Figure 4 shows the surge liquid volume at the outlet of the system with a smaller diameter pipe of 6-inch, 3.958-inch, and 1.995-inch inserted near the bottom of the riser system to reduce the incoming line diameter. The black line shows the surge liquid volume for a 6-inch line, the red and blue lines show the surge liquid volume for 3.958-inch, and 1.995-inch pipe sizes respectively. There was no surge liquid volume for all incoming pipe sizes to the riser base, which indicates the normal liquid level in the facility at the end of the pipeline-riser system. Later, the surge liquid volume was changing between 1.45587bbl and 0.098091bbl for the 6-inch with the pattern repeated every 0.25hrs. For the 3.958-inch, and 1.995-inch, the surge liquid volume increases from zero to 0.411bbl and 0.2901bbl before declining steadily to zero at 2hrs.

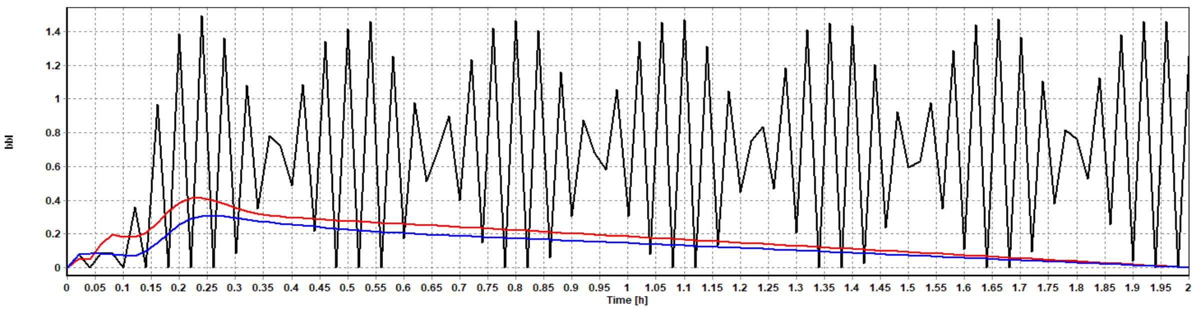

Figure 4. Surge liquid volume

Riser base pressure

The pressure variation at the riser base with time for a 6-inch, 3.958-inch, and 1.995-inch pipe inserted near the bottom of the riser system to reduce the incoming line diameter is presented in figure 5. The pressure at the riser base for the 1.995-inch pipe was higher than that of 3.958-inch pipe. There was a recurring pattern of the pressure at the riser-base between 766.555psia and 756.872psia for the 6-inch over a period of 0.32hrs.For the 3.958-inch pipe diameter, the riser base pressure builds up to a steady value of 761.978psia , while the 1.995-inch pipe build up to a steady value of 762.127psia.

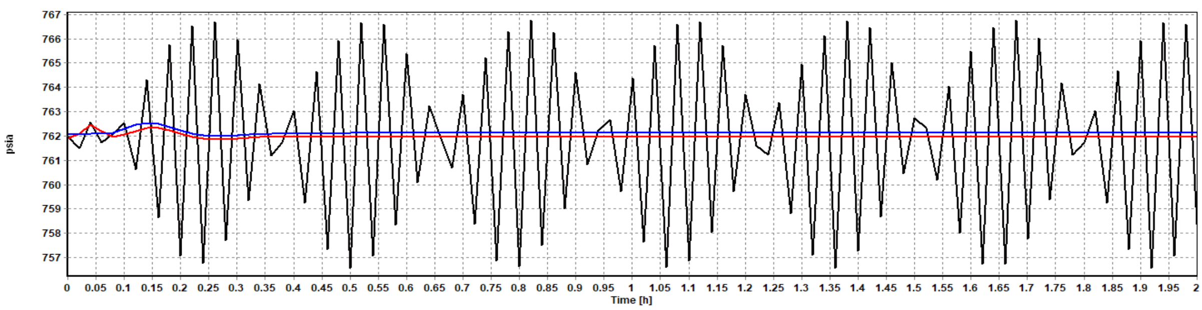

Figure 5. Riser base pressure

Fluid pressure at outlet

Figure 6 shows the fluid pressure at the outlet of the system for a 6-inch, 3.958-inch, and 1.995-inch pipe inserted near the bottom of the riser system to reduce the incoming line diameter. There was a stable fluid pressure of 725.196psia at the riser top for a system with both 3.958-inch, and 1.995-inch pipe whereas for the system with 6-inch riser ID, the fluid pressure was changing with time. The cyclic fluctuation of pressure at the riser top for the system with 6-inch riser ID implies the presence of severe slugging. For the 6-inch riser ID, the fluid pressure was oscillating between 725.233psia and 725.203psia respectively.

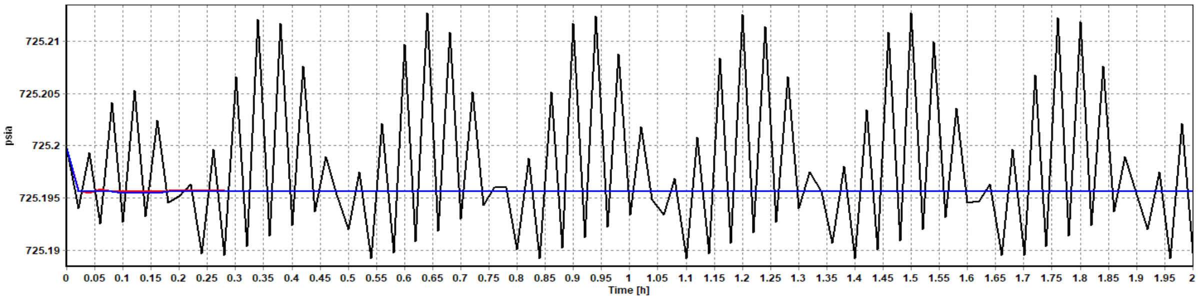

Figure 6. Pressure at the riser top

CONCLUSION

This work investigated the effect of reducing the incoming line diameter near the bottom of the riser on the slugging phenomenon in a pipeline-riser system. The total liquid volume flow at the outlet of the system was stable and slightly higher for the cases with a smaller diameter pipe. The surge liquid volume at the outlet of the system was stable and low for the cases with a smaller diameter pipe .The riser base pressure was higher and stable for the cases with a smaller diameter and the fluid pressure at the outlet of the system was stable and slightly lower for the cases with a smaller diameter pipe. The optimal size of the smaller diameter pipe depends on the operating conditions and the fluid properties of the system. A smaller diameter pipe can increase the pressure and reduce the slugging, and can also increase the friction and reduce the flow rate. Therefore, a trade-off analysis should be performed to determine the best size of the smaller diameter pipe for a given system.

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Citation: Lezor Marvin Kpea-ue, Somiari Iyowuna Epelle, Uchechi Alerechi, "Pipe Insertion Technique for Slug Attenuation in a Downwardly Inclined Pipeline", Universal Library of Engineering Technology, 2024; 1(2): 08-13. DOI: https://doi.org/10.70315/uloap.ulete.2024.0102002.