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Simulation Analysis of Slug Dispersion Process During Bypass Pigging Process in Vertical Riser

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Abstract. In offshore riser systems, the slug flow can aggravate the instability of pipeline system during pigging processes, resulting in problems, such as increased pressure fluctuations and the excessive load of the slug catcher over a short period. Bypass pig can disperse the slug due to the highly velocity passing through the bypass hole, thus mitigating the impact of the slug flow on the pigging process. This paper established a two-dimensional CFD model to study the effect of different bypass rates and inlet gas velocities on the downstream slug dispersion process in vertical riser. The results showed that increasing the bypass rate and inlet gas velocity can improve the dissipation effect of the bypass pig to the slug, but it is necessary to comprehensively consider the pigging efficiency and the changes of outlet fluid mass flow and liquid holdup. The research results can contribute to preventing pigging accidents as well as determining the pigging technology parameters during pigging processes in marine pipelines.

Keywords. Bypass pigging, CFD model, slug flow, offshore riser system

1. Introduction

To ensure pipeline transportation safety, efficiency, and stability, regular pigging operations are indispensable [1, 2]. The marine pipelines mainly transport azeotropic mixtures, and the transportation medium is likely prone to slug flow due to the interface interaction between the multiple-phase media. Meanwhile, the conventional pigging operation (without pass hole) in offshore pipelines can easily lead to pigging slugs. Pigging slug flow can result in a large amount of liquid retained in the pipeline, severe fluid flow rate, as well as dramatic pressure fluctuations. Moreover, the pigging slugging formed by pigging process seriously affects the pigging operation of the marine riser system, due to the large height difference of the riser [3]. In general, the slug catcher is used for separating gas and liquid during the production operation of subsea oil and gas resources. However, flood accidents of the pipelines can easily happen due to the insufficient volume of the slug catcher [4, 5].

Wu et al. [6] first presented using the bypass pig to solve the not enough size problem of the gas-liquid separator and inhibit the harm leaded to platform equipment by pigging

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slug flow in offshore pipelines during pigging operations. Van et al. [7] optimized the parameters of pig bypass size and found that bypass pig could significantly reduce the liquid slug volume, which verified that bypass pig could effectively inhibit slug flow and improve the reliability of pigging operation by the experiment research. Olaniyan et al. [8] using commercial software to simulate the pigging process for multiphase flow field, found that the simulation results are in good agreement with the field pigging data, and thought that the use of bypass pig for pigging operation can indeed reduce the volume requirements of gas-liquid separator, thereby saving expensive cost by huge slug volume. Li et al. [9, 10] studied the bypass pig movement and liquid accumulation characteristics in two-phase flow pipeline through pigging process experiment and numerical simulation, and proposed a condensate zone model based on the downstream liquid slug, which was used to calculate liquid holdup rate and liquid slug length and other parameters.

Figure 1 compares the traditional pigging (without bypass hole) and the bypass pigging process for dispersing slug flow. The gas passes through the bypass hole at a relatively large velocity, thus dispersing the downstream slug, decreasing the pressure difference across the pig, and reducing the pig speed. As a result, the bypass pig decreases the length of the slug in pipelines, consequently reducing the capacity requirements for the gas-liquid separator. Although some scholars have obtained effective achievement in overcoming liquid slug by using the bypass pig, minimal studies study the slug dispersion process during the bypass pigging in the riser. In this paper, the liquid slug dispersion process during the bypass pigging in the vertical riser is simulated by the CFD method. The dispersion effect of downstream slug at different bypass rates and inlet gas velocities are mainly studied to inhibit the happening of pigging accidents in the marine pipelines.

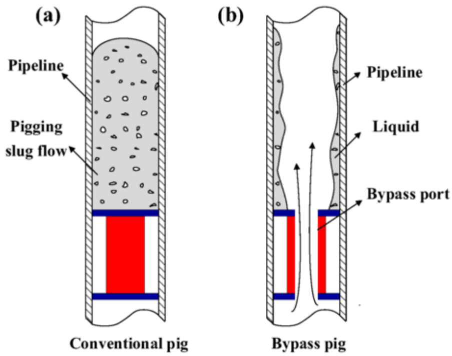

Figure 1. The comparison between traditional pigging (without bypass hole) and bypass pigging. (a) Traditional pigging. (b) Bypass pigging.

2. CFD Simulation Setup

A two-dimensional CFD model was set up based on the similarity principle to study the dispersion process of downstream liquid slug during bypass pigging process in the vertical riser, as shown in Figure 2. A gas inlet was established at the lowest end of the riser, while a pressure outlet was set at the riser outlet. The height and inner diameter of the vertical riser was respectively set as 1m and 0.051m. The distance between the gas inlet and the tail end of the pig was 0.255 m. The gas was represented as high compressible and the liquid is regard as incompressible fluid. Therefore, the gas-phase was set as ideal gas, while the liquid-phase was represented by the water. In the initialization, the area from the nose of the bypass pig to outlet of the riser was established as the liquid-phase, while the other areas were set as the gas-phase. The Reynolds average method was used to simulate the slug flow in the pigging process. The RNG turbulence model was used to for solving the numerical system equations, and VOF (volume of fluid) method was chosen for multiphase model. Furthermore, the structural mesh was used for mesh model. The boundary layer of the riser was set up according to the demands of the turbulence model and wall function, and the mesh independent analysis was carried out. The pig mass was set at 5.3kg, while the gravity acceleration was set at 9.81m/s2. The force of friction between the pig and the pipeline wall was ignored. The movement process for the bypass pig was realized by the layering method and six DOF. Considering the influence of different bypass rates and inlet gas velocities, the pigging process was simulated in different working conditions. In addition, the working condition parameters of each group are shown in Table 1.

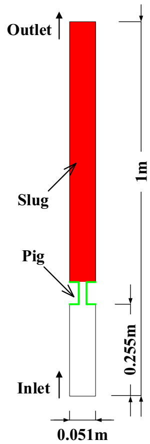

Figure 2. Bypass pigging CFD model in vertical riser.

Table 1. Boundary conditions in different working conditions in CFD model

Case	Inlet gas velocity (m/s)	Bypass rate (%)
1	1	2
2	1	4
3	1	6
4	2	6
5	3	6

3. Results and Discussions

3.1. The Influence of the Pig Bypass Rate

Considering the influence of bypass rates, the simulation results of case1, case2, and case3 were compared and analyzed. Figure 3 shows the liquid-phase distribution patterns at different bypass rates of 2%, 4% and 6% in the CFD model. Due to pressure difference across the pig, the gas behind the pig passes through the bypass hole, thus forming large gas holdup in front of the bypass pig and dispersing the liquid slug. As gas continuously enters the inlet, the gas in front of the pig gradually increases and finally breaches the riser outlet. At the bypass rate is 2%, 4% and 6%, the corresponding time for the gas to reach the riser outlet is 0.6s, 0.56s and 0.56s respectively. The results present that the bypass rate has little effect on the time for the gas to reach outlet of the riser. The larger the bypass rate is, the larger the gas holdup in front of the pig, indicating that increasing the bypass rate improves the dissipation effect of the bypass pig to the liquid slug.

During the pigging operation, if the pressure difference across the pig is large enough, the pig will overcome the resistance and move forward along the pipe wall. Figure 4 presents the position variations of the bypass pig in the riser at different bypass rates. When the bypass rate is 2% and 4%, the pig can move forward due to the gas pressure. When the driving force provided by the gas behind the pig is not enough to make the pig overcome the resistance, the pig will be blocked in the pipeline for a short time until the driving force is large enough to continue drive the pig forward. Furthermore, a smaller bypass rate reduces the time for the pig to reach the riser outlet. However, when the bypass rate is 6%, the pig hardly moves in the riser. The results present that increasing the bypass rate reduces the pigging efficiency, and even cannot provide enough differential pressure across the pig demanded for regular pig movement.

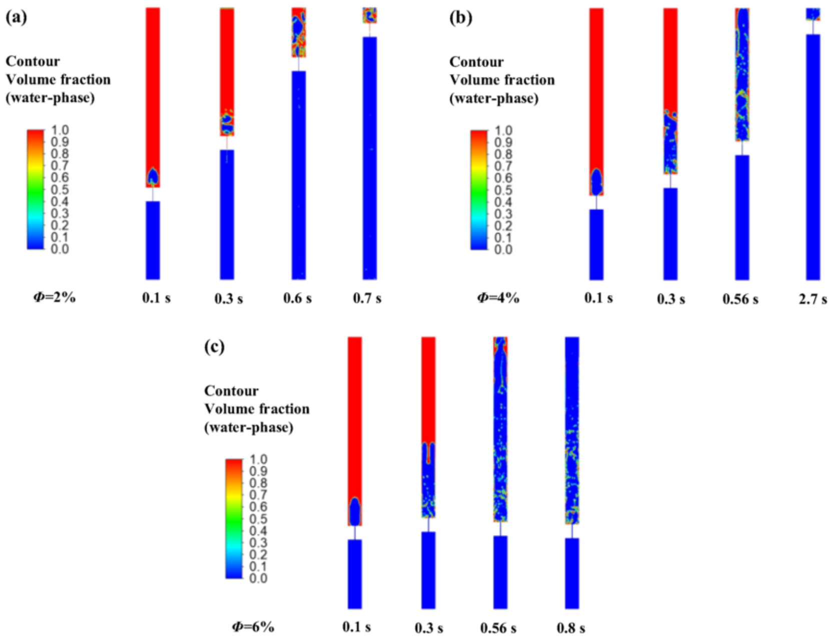

Figure 3. Liquid-phase distribution at different bypass rates. (a) A bypass rate of 2%. (b) A bypass rate of 4%. (c) A bypass rate of 6%.

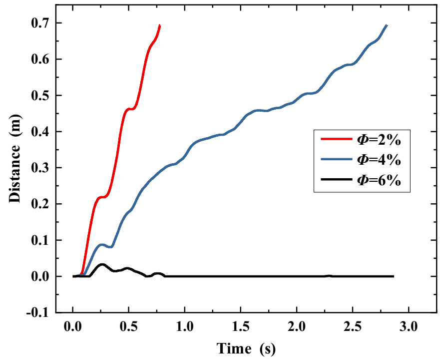

Figure 4. Position variations at different bypass rates.

Figure 5(a) and Figure 5(b) illustrates the variations of mass flow rate and liquid holdup in the riser outlet at different bypass rates. The outlet mass flow fluctuates significantly in the early stage, and the fluctuation amplitudes have little difference at different bypass rates, as shown in Figure 5(a). When the gas breaches the riser outlet, the fluctuation amplitude decreases. The smaller the bypass rate, the smaller the fluctuation amplitude of the outlet mass flow after the gas reaches the riser outlet. The liquid holdup at the riser outlet is about 1 due to the liquid slug outflow during the early stage as presented in Figure 5(b). Moreover, the liquid will fall back within a certain period of time and the liquid holdup will be reduced to 0 due to the effect of gravity. When the gas breaches the riser outlet, the outlet liquid holdup decreases, while the larger the bypass rate, the lower the outlet liquid holdup.

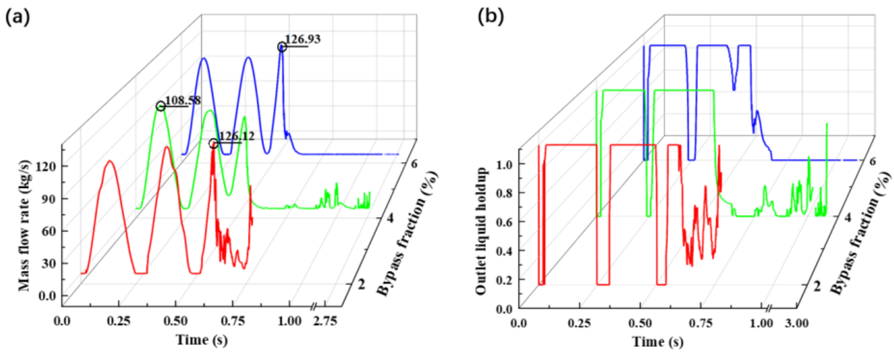

Figure 5. Variations of outlet mass flow rate and liquid holdup at different bypass rates. (a) Outlet mass flow rate. (b) Outlet liquid holdup.

3.2. The Influence of the Inlet Gas Velocity

Considering the influence of inlet gas velocity, the simulation results of case3, case4, and case5 were compared and analysed. Figure 6 shows the gas-liquid distribution patterns during bypass pigging process at different inlet gas velocities. At the inlet gas velocities of 1m/s, 2m/s, and 3m/s, the corresponding time for gas to reach the riser outlet is 0.56s, 0.3s, and 0.16s respectively. The higher the inlet gas velocity, the smaller the time for gas to reach the riser outlet. Meanwhile, the larger inlet gas velocity can lead to the larger gas space before the pig. It can be inferred that increasing the inlet gas velocity enhances the effect of the bypass pig to dissipate the liquid slug.

Figure 7 presents the position variations of the bypass pig at different inlet gas velocities. At the inlet gas velocities of 2m/s and 3m/s, the pig can move forward due to the effect of differential pressure and finally reach the riser outlet. A larger inlet gas velocity reduces the time for the pig to reach the riser outlet. However, when the inlet gas velocity is 1m/s, the pig hardly moves. The results present that too small inlet gas velocity also decreases the pigging efficiency, not providing enough differential pressure demanded for regular pig movement.

Figure 8(a) and Figure 8(b) illustrates the variations of outlet liquid mass flow and liquid holdup in the riser at different inlet gas velocities are respectively. The results present that the larger the inlet gas velocity, the greater the fluctuation amplitude of the outlet mass flow. Figure 8(b) illustrates that the greater the inlet gas velocity, the smaller the time for outlet liquid holdup to be 1, indicating that increasing the inlet gas velocity can improve the effect of dispersing the liquid slug. After the gas breaches the riser outlet, the greater the inlet gas velocity, the greater the outlet liquid holdup.

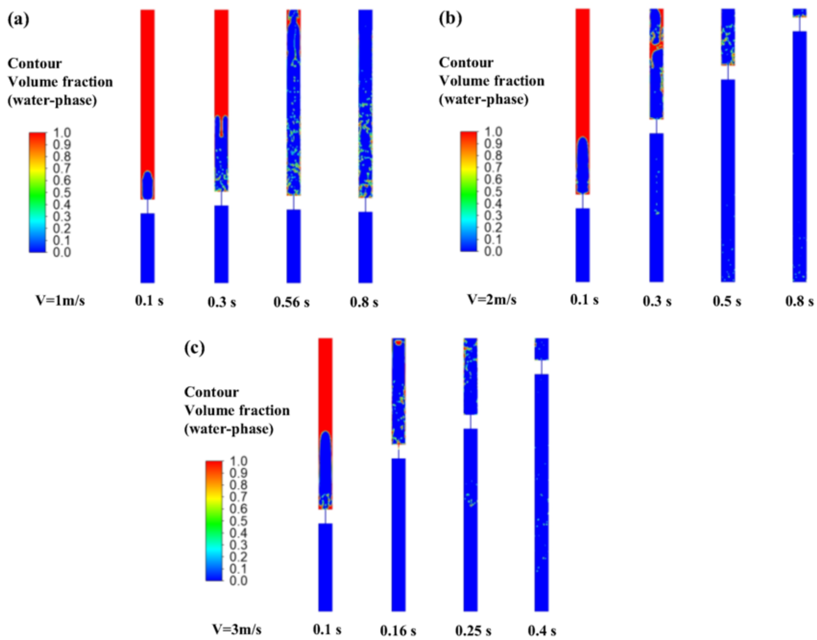

Figure 6. Liquid-phase distribution at different inlet gas velocities. (a) An inlet gas velocity of 1m/s. (b) An inlet gas velocity of 2m/s. (c) An inlet gas velocity of 3m/s.

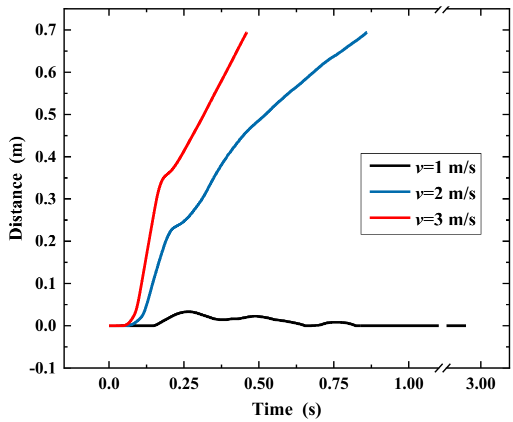

Figure 7. Position variations at different inlet gas velocities.

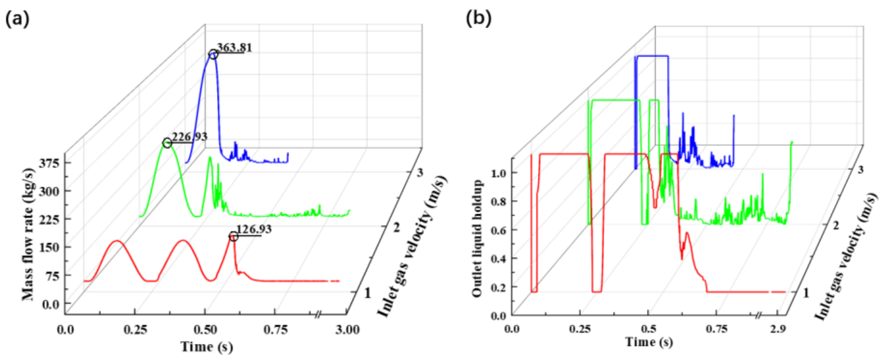

Figure 8. Variations of outlet mass flow rate and liquid holdup at different inlet gas velocities. (a) Outlet mass flow rate. (b) Outlet liquid holdup.

4. Results and Discussions

(1) The bypass pig can disperse the liquid slug and reduce the outlet mass flow rate as well as liquid holdup, thus alleviating the not enough size problem of the gas-liquid separator during the pigging process in the vertical riser.

(2) At a larger bypass rate, the effect of the bypass pig to dissipate the liquid slug is harder, and the outlet mass flow rate and liquid holdup is lower after the gas breaches the riser outlet. Moreover, the larger the inlet gas velocity is, the faster the bypass pig dissipates the liquid slug. Nevertheless, a higher inlet gas velocity leads to an increase in the outlet mass flow rate, and increases outlet liquid holdup after the gas breaches the riser outlet. An overlarge bypass rate or insufficient inlet gas velocity decreases pigging operation efficiency and cannot be able to offer the differential pressure across pig demanded for regulate pig movement.

(3) The optimal pigging parameters can be determined to minimize the adverse influence of slug on pigging operations and inhibit the pigging accidents in offshore pipelines by considering the influence of bypass rate and inlet gas velocity comprehensively.

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