ISSN: 2664-9640

Control of severe slug flow in a submarine pipeline based on PID controller

Ziwei Ding [1], Huiru Guo [2] and Guichen Zhang [2]

[1] School of Logistics Engineering, Shanghai Maritime university;

[2]School of Merchant Marine, Shanghai Maritime university.

Abstract

In the process of oil and gas exploitation, the multi-phase gathering and transportation in the submarine pipeline is prone to severe slug flow in the riser section. The formation of slug flow will affect the normal operation of the pipeline and downstream processing equipment and cause huge economic losses. This article uses Multiphase flow transient simulation software OLGA is a typical case of severe slug flow, and the OLGA software can simulate the PID controller to automatically control the severe slug flow. The results show that the pressure at the bottom of the riser is selected as the controlled quantity, and the opening of the top throttle is the adjustment opening. The PID controller can be used to control severe slug flow.

Keywords

OLGA; Severe Slug Flow; PID control; Top throttling method ; Numerical Simulation .

1. Introduction

In the mining process of my country's offshore oil and gas fields, because the mining products are in a multi-phase mixed state, in order to reduce costs and speed up the mining speed, multi-phase mixed transportation technology is often used. Submarine pipelines have long transportation distances. Undercover pipes are distributed along the seabed. There are horizontal and inclined pipe types. There will be risers at the end of the pipeline. The existence of such risers makes the flow of gas and liquid in the pipeline more unstable, causing Strong slug flow. The formation of severe slug flow causes the pressure in the pipe to fluctuate sharply, causing the wellhead back pressure to reduce the oil and gas production capacity. [1-3]At the same time, the length of the liquid plug can reach several riser heights, which makes the liquid flow at the outlet of the riser fluctuate greatly, and the gas-liquid two-phase flow at the outlet alternates Outflow may cause damage to equipment and pipelines or stop production. Therefore, the research on the mechanism and control method of severe slugging is very important. Domestic and foreign scholars have analyzed the formation mechanism of severe slug flow, and proposed a variety of methods to control and eliminate severe slug flow, among which throttling method is the most commonly used. Schmidt et al. [4] first proposed in 1979 to install a throttling valve before the separator to eliminate severe slug flow. The advantage of this method is simple equipment, but the disadvantage is that it increases upstream pipeline back pressure and reduces oil well output; To achieve good results, fine adjustment of the throttle valve is required.

2. Overview of Subsea Pipeline and numerical simulation

2.1. Overview of Subsea Pipeline

In this paper, a case of severe slug in the multiphase transient software OLGA, which is recognized worldwide, is taken as the research object. The total length of the mixed submarine

ISSN: 2664-9640

pipeline is 7.911Km. The entire pipeline is composed of two vertical risers and a down-dipping pipe distributed along the coast (Figure 1), and a throttle valve is installed at the outlet. The dimensions of the entire submarine pipeline are shown in Table 1.

Table 1: Schematic diagram of mixed transportation subsea pipeline

Pipe	Length(m)	Elevation(m)	Diameter(m)
INLET	100	0	0.362
INLET_B	173	-173	0.362
PIPE_1A	151	0	0.3714
PIPE_1	355.217	-0.001	0.3714
PIPE_16	514.012	3.507	0.3714
PIPE_17	514.012	3.508	0.3714
PIPE_18	521.536	6.165	0.3714
PIPE_19	506.22	0	0.3714
PIPE_20	481.443	1.626	0.3714
PIPE_21	481.453	1.625	0.3714
PIPE_35	486.504	-1.932	0.3714
PIPE_36	408.1	0.473	0.3714
PIPE_38	230.301	0.658	0.3714
PIPE_39	207.402	-0.903	0.3714
PIPE_41	207.402	-0.903	0.3714
PIPE_42	174.513	2.14	0.3714
PIPE_43	207.302	-0.902	0.3714
PIPE_44	207.302	-0.902	0.3714
PIPE_47	207.402	-0.902	0.3714
PIPE_48	95.0334	2.518	0.3714
PIPE_50	231.006	1.67	0.3714
PIPE_51	231.006	1.67	0.3714
PIPE_52	174.513	2.14	0.3714
PIPE_56	209.014	-2.4	0.3714
PIPE_59	308.6	-0.902	0.3714
PIPE_61A	235.4	0	0.3714
PIPE_61D	82.8	-1	0.362
RISER	140	140	0.362
TO-SEP	70	0	0.362

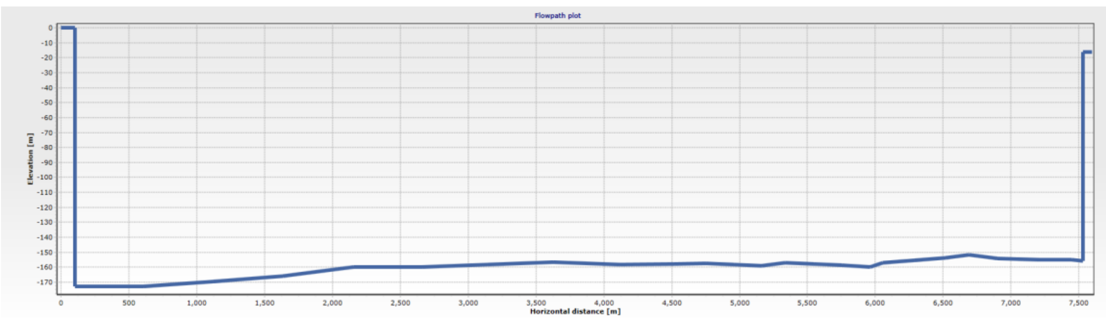


Figure 1: Schematic diagram of mixed transportation subsea pipeline

ISSN: 2664-9640

2.2. Numerical Simulation

OLGA software is currently recognized as a dynamic simulation software for multi-phase mixed transportation pipelines at home and abroad, which can realize dynamic tracking simulation of severe slug flow in pipelines. The OLGA software uses an extended two-fluid model. In addition to the continuity equation of the continuous gas phase and the continuous liquid phase in the conventional two-fluid model, it also contains a droplet phase continuity equation. The momentum equation includes the mixed momentum equation of the gas phase and the possible droplet phase and the momentum equation of the continuous liquid phase. In addition, it also includes a mixed energy conservation equation and a pressure equation derived from the three-phase continuous equation. Establish a mathematical model of the pipeline system to dynamically simulate the slug flow of the submarine pipeline. Set the simulation time to 3h. [4]

The boundary conditions of the model are set by the inlet node and the outlet node: the pipeline inlet is closed, and the inlet flow is given by the quality source term; the outlet node is set as the pressure outlet boundary. The inlet mass flow rate is 20Kg/s, among which the mass flow rates of oil, gas and water are 10.63 Kg/s, 5.37 Kg/s and 4Kg/s respectively, and the inlet temperature is 72.2°C. The outlet pressure is 68.3 bar, the outlet temperature is 20°C, and the throttle valve opening is the only variable in the system.

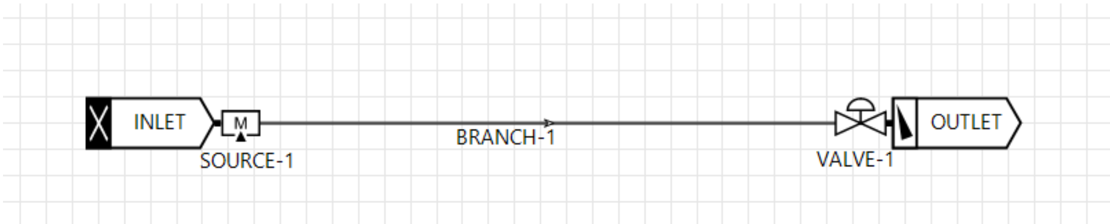


Figure 2: Schematic diagram of slug flow tracking in OLGA

The pressure at the bottom of the riser fluctuates very obviously, with a fluctuation amplitude of 68-78 bar (Figure 3), with obvious periodicity, while the instantaneous liquid mass flow at the outlet of the pipe fluctuates with a amplitude of 0~120Kg/s (Figure 4), which also shows A certain regularity and periodicity. The liquid mass flow rate at the outlet of the pipeline is 0 at regular intervals and maintained for a certain period of time, which indicates that there is no liquid outflow from the submarine pipeline during this period, and severe slugging occurs in the submarine pipeline.

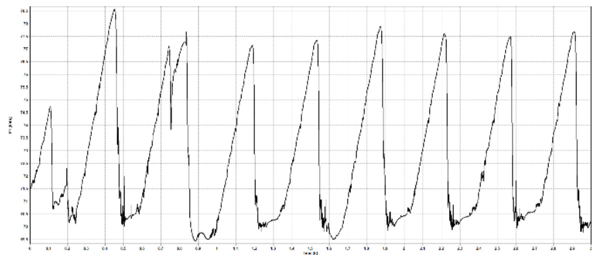


Figure 3: The pressure at the bottom of the riser changes with time

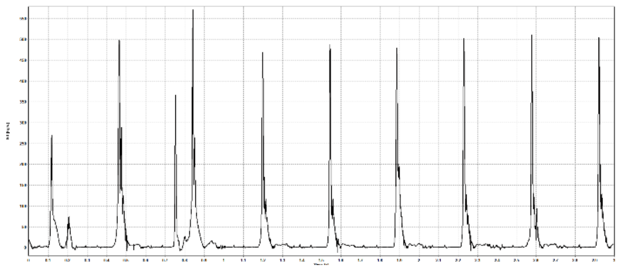


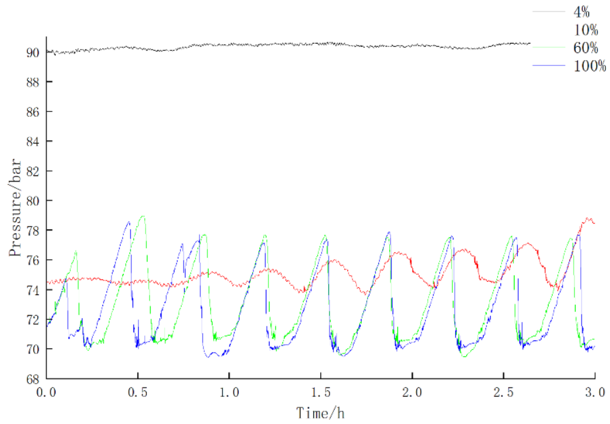
Figure 4: The instantaneous liquid mass flow rate at the outlet of the pipeline changes with time

ISSN: 2664-9640

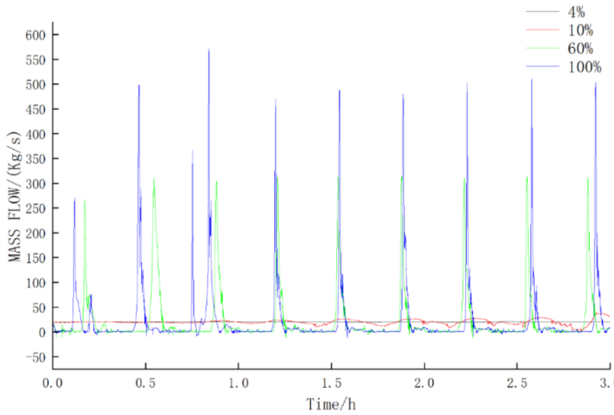
3. Control measures

3.1. Top throttling method

The most effective and economical method at present is the top throttling method.[5-6] In the case of different valve openings, the severe slug flow is simulated. The analysis shows that with the decrease of the throttle valve opening, the pressure fluctuation range at the bottom of the riser decreases (Figure 5a), and the instantaneous liquid mass flow fluctuation range at the pipeline outlet decreases (Figure 5b), indicating that severe slug flow has been greatly reduced. Good control. When the throttle valve opening is reduced to 3%, the severe slug flow is basically completely eliminated, indicating that the top throttling method can well control the severe slug flow. However, when the top throttling method is used to control severe slug flow, it is recommended that the throttle valve opening is 10%, which can ensure that the severe slug flow is basically controlled and the upstream back pressure of the pipeline is not too high.



The pressure at the bottom of the riser changes with time



(b) The instantaneous liquid mass flow at the outlet of the pipeline changes with time

Figure 5: Top throttling method-various parameters change with time under different throttle openings.

3.2. PID controller

Foreign countries use automatic control schemes on the 16" transmission pipeline in Dunbar Oilfield to solve the serious slug problem. The control valve upstream of the separator ensures a constant pressure at the base of the riser. The results of oilfield use show that this method is very effective [7].

The automatic control scheme can automatically adjust the valve according to the real-time situation of the mixed transportation pipeline, which is not available in the traditional throttling method. However, domestic offshore oil and gas fields rarely see examples of using automatic control schemes to control severe slug flow.[8-9]

PID controllers have been widely used and developed in industry because of their simple structure, easy implementation and robustness. The schematic diagram of the PID controller is shown in the figure below. The controller input is the system deviation e(t), which is the difference between the set value and the controlled variable r(t)-y(t). The output of the controller is determined by the proportional link P, integral link I, and differential link D are linear and combined. The proportional term, integral term and derivative term can be regarded as the weighting factor of the controller. The PID controller takes the error as the controller input value, and forms a simple and effective control strategy by continuously reducing the error between the control target and the actual controlled quantity.[10-11]

$$u(t)=K_P\left\{e(t)+\frac{1}{T_I}\int_0^t e(t)dt+T_D\frac{de(t)}{dt}\right\} \quad (1)$$

In the formula, u(t) is the output of the control system, e(t) is the system deviation, K_p is the proportional coefficient, T_I is the integral time constant, and T_D is the integral time constant.

In essence, the throttling method keeps the pressure at the bottom of the riser at a higher value by reducing the valve opening, thereby reducing the flow area. This pressure is sufficient to lift the fluid from the bottom of the riser to the upper part of the platform, so as to ensure that no liquid accumulation will form at the bottom of the riser and serious slug flow will occur. How to choose a proper value for the valve opening is a more difficult problem. If the opening is too small, the wellhead pressure is too large, which will affect the production; if the opening is too large, the slug cannot be effectively discharged. The PID controller effectively solves this problem. You only need to set the pressure value you want to maintain, measure the pressure at the bottom of the riser in real time through the pressure sensor, and transfer the value to the PID controller, and the PID controller can use its control algorithm Easily adjust the opening of the valve to an appropriate value.

The principle of selecting the constant pressure at the bottom of the riser is to ensure that the slug can be lifted to the platform smoothly. In this paper, the pressure value is selected as 78 bar according to Figure 3. The layout of the automatic control system for severe slug flow is shown in Figure 6. By repeatedly adjusting the control parameters of the PID controller, the bottom pressure control of the riser is finally realized. The simulation results are shown in Figure 7-9. The final value of the PID controller control parameters is the proportional coefficient Kp=0.01, the integral constant=100 s, and the derivative constant isTd = 0, it can be seen that it is actually a PI controller.

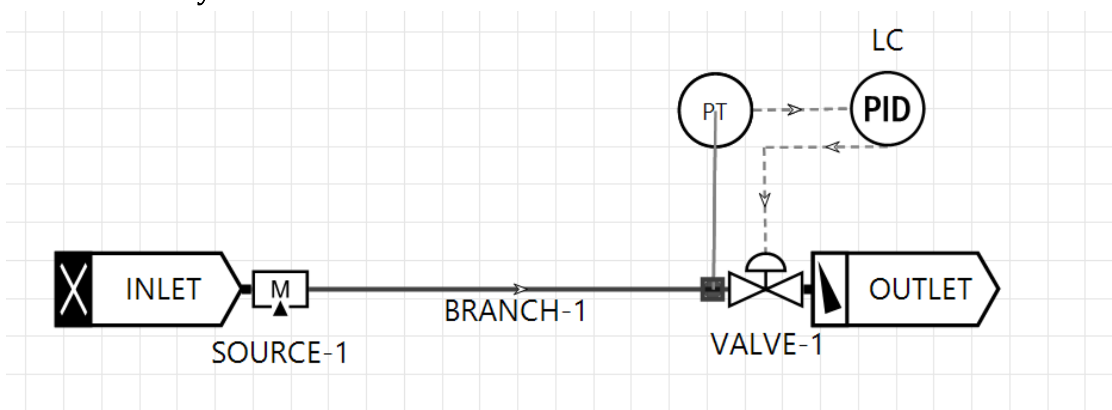


Figure 6: The layout of the automatic control system for severe slug flow

Figure 7-8 shows the change trend of the pipeline system parameters after the PID controller is used for control. It can be seen that after the control, the pressure at the bottom of the riser is maintained at 78 bar, the liquid holdup of the pipe at the inlet of the separator is maintained at 0.193m. It strongly proves that the PID controller can effectively control the slug flow at the inlet of the platform separator.

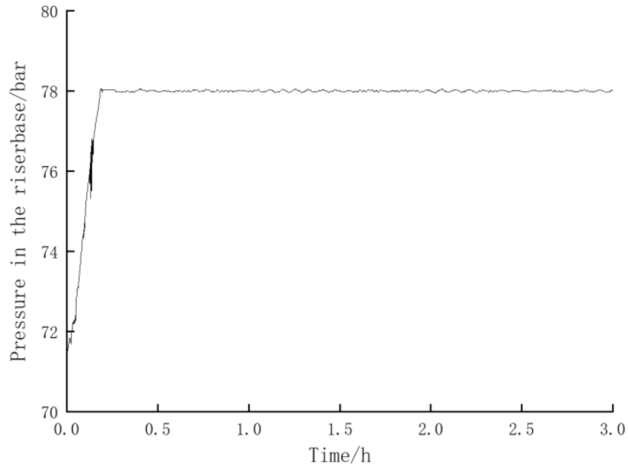


Figure 7: Pressure change at the bottom of the riser after PID control

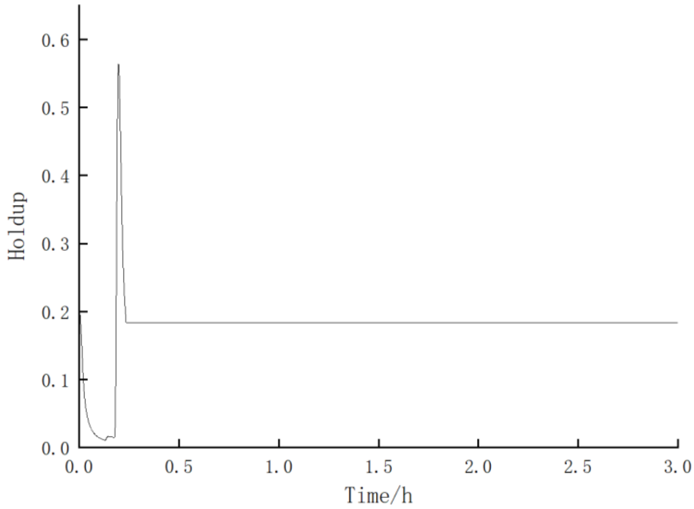


Figure 8: Liquid holdup rate of separator inlet pipe after PID control

Figure 9shows the change of the valve opening. The valve opening is finally maintained at 0.09. The PID controller is used to adjust the valve opening to ensure accurate and timely control of severe slug flow.

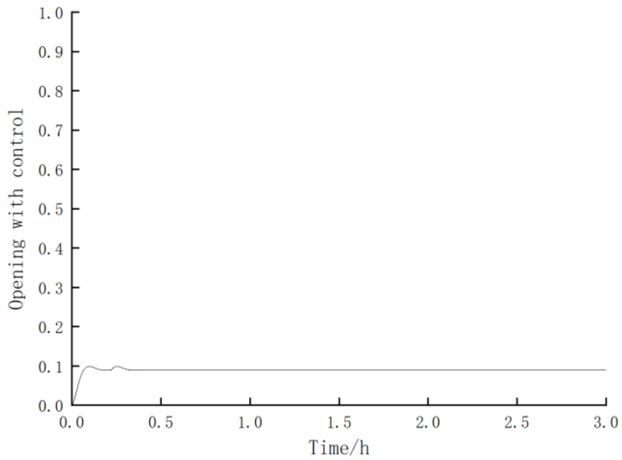


Figure 9: Change of valve opening with time after PID control

4. Conclusion

1)The PID controller can realize the automatic control of the severe slug flow of the platform separator, the control is more precise, the effect is more obvious, the operation is more

ISSN: 2664-9640

convenient, and the influence of the valve opening too large or too small on the oil and gas production is eliminated. For the control of severe slug flow in offshore oil and gas fields.

2)It is recommended to use OLGA software to tune PID parameters in advance before actually applying PID parameter tuning to save on-site operation time.

References

[1] R.J.Yan,W.Q. Wang, Z.M.Li: Progress of severe slug in marine riser system , Journal of Liaoning Shihua University, Vol. 37 (2017) No.5, p.26-30.

[2] X.C.Yu,Y.B.Ren,Y.L.Wu:The analysis of transient flow characteristics and sensitivity in the riser of subsea multiphase pipeline,China Offshore Oil and Gas, Vol. 19 (2007) No.1, p.60-64.

[3] X.J.Jin,K.Li,X.J.Hu: The harm of slug flow to offshore oil and gas process facilities and its prevention, Technical aspect, Vol. 30 (2011) No.30, p.101-102.

[4] C.J. Li, W.Wu, L. Zhang, et al. Numercial simulation on control measures of severe slug flow in Boxi Oilfield, Journal of Oil &Gas Storage and Transportation, vol. 37 (2018), p.95-99.

[5] Z. Schmidt,J.P. Brill , H.D.Begsss : Choking can eliminate severe pipeline slugging, Journal of Oil &Gas,(1979b) No.12, p.230-238.

[6] X.X.Xu,J.Jing.P.Zhou: Severe slugging prediction and elimination in deep-vater pipeline riser systems, The Ocean Engineering, vol. 23 (2005), No.4, p.121-126

[7] COURBOT A. Prevention of severe slugging in the Dun-bar 60”multiphase pipeline,OTC 8196 Offshore Technology Conference. (1996) ,p.445 -452.

[8] L.Chen,J.Jing.P.Zhou: Analysis of serious slugging in submarine oil and gas mixed pipeline, Oil &Gas Storage and Transportation, vol. 28 (2009), No.5, p.10-14

[9] B. Cheng. Y. H. Li,Q.P.Li: Control method of severe slug flow in riser of offshore oil multiphase flow, Oil &Gas Storage and Transportation, vol. 32 (2013), 1285-1287.

[10] X.Y.Zhang,N.L.Li,B.Q.Chen: Analysis and treatment on the severe slug flow in pipeline S-shaped riser of Wenchang Oilfields, Oil &Gas Storage and Transportation, vol. 38 (2019), 472-480.

[11] J.Dai,Y.F.Sun: PID algorithm and its evolution, Journal of Liaoning Transportation College, vol. 25 (2005), No.4, p.1-16.