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Experimental study on movement characteristics of bypass pig

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ABSTRACT

In order to investigate the movement characteristics of bypass pigs, experimental variables of pressure fluctuation, average and instantaneous pig velocity and pig generated liquid volume were studied by a large experimental pigging system with horizontal, up-and-down, riser pipeline structures. Results obtained in this study show that there are multiple peaks at pressure fluctuation curves and each peak represents a pig pause state. Compared with conventional pigs, bypass pigs which eliminate the significant fluctuation of peak pressure have better adaptability for the variations of liquid loading. Differential pressure at the front and rear ends of the pig, which is self-regulated until a force balance is achieved, is independent of bypass fraction, but hinges on the resistance force. The average pig velocities decrease linearly with the increase of bypass fraction. The instantaneous pig velocities are generally low and less sensitive to the variations of gas flow rates at the bottom of the riser pipe, while it is much higher and exhibits the most obvious downtrend as bypass fraction increases at the top of the riser. When increasing bypass fraction, the duration of terminal liquid outflow is prolonged, indicating bypass pigging is conducive to reducing the pig generated liquid volume.

1. Introduction

Pigging, as a significant flow assurance measure, is an integral part of the pipeline operation and maintenance. For natural gas pipelines, due to the slip effect between gas and liquid, the volume of liquid loading increases after long operation, enlarging the gas transport resistance, thus seriously reducing the production efficiency (Ayala and Adewumi, 2003; Langsholt and Holm, 2007; Norris and Rydahl, 2003; Talaie and Deilamani, 2014; Waltrich et al., 2015). Regular pigging can provide guarantee for improving the pipeline efficiency. The control of pig velocity is of great significance to pigging risk reduction and efficiency enhancements (Mirshamsi and Rafeeyan, 2012; Money et al., 2012; Nguyen et al., 2001a, 2001b; Zhu et al., 2014). There exists an optimal efficiency when the pig velocity remains constant. The velocity of conventional pig is the same as that of the gas behind it due to the airtight pig body (Groote et al., 2015; Olaniyan and Larrey, 2014; Wu and Van, 2005). Such high velocity could bring a series of problems such as severe bend bumps, damages to pipe internal coatings and terminal equipment. In particular, the liquid loading gradually accumulates in front of the pig leading to a huge amount of slug volume larger than processing capacity of the terminal receiving equipment, thus causing overflow accidents and damages to the production system. However, in order to address the problems brought by conventional pigging, gas flow rates are often adjusted by operators to control pig velocity, and slug outflow rate at the receiver is reduced by using terminal throttling, both of which increase the difficulty and complexity of pig operation and workload of personnel. Sometimes, the reduction of gas production may cause the problem of gas starvation, affecting downstream gas supply.

On account of the disadvantages of conventional pigging in gas pipeline, the bypass pigging technology is proposed as shown in Fig. 1. The pig velocity is decreased through a bypass port in the pig body, thus eliminating pig generated slug volume and bringing great advantages to the production (Entaban et al., 2013; Groote et al., 2015; Lee et al., 2012; O'donoghue, 2004; Olaniyan and Larrey, 2014; Van et al., 2013; Wu and Van, 2005). Van et al. (2013) pointed out that compared with conventional pigging, bypass pigging has the following advantages: 1) reduce the production deferment as a result of pigging, 2) decrease the capacity requirements for the slug catcher, 3) cut the cost of wax inhibitors and risk of wax maintenance. Meanwhile, the complexity of pig operation and workload of personnel are reduced significantly by putting the bypass pigging technology into practice.

Based on the fact that bypass pigging technology has great potential for gas pipeline application, scholars have conducted wide research since the late 20th century. A pressure drop equation through bypass port was put forward to form the bypass pigging model, which can be solved by Finite Difference Method or Method of Characteristics (Botros and Golshan, 2010; Durali et al., 2007; Esmaeilzadeh et al., 2009;

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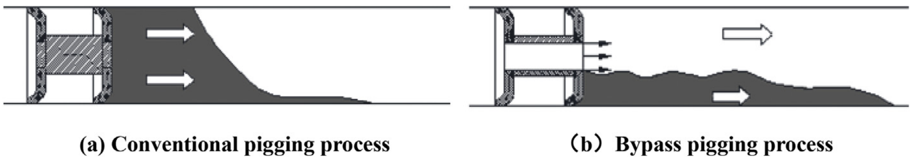

Fig. 1. Comparison between conventional pigging and bypass pigging.

Hosseinalipour et al., 2007; Kim et al., 2003; Nieckele et al., 2001; Nguyen et al., 2001a, 2001b; Tolmasquim and Nieckele, 2008). Pressure drop coefficient across the bypass pig and friction between pig cups and pipe wall are the main uncertain factors of the model. Therefore, relevant research on pressure drop coefficient was conducted by CFD simulation method (Azpiroz et al., 2015; Hendrix et al., 2017; Liang, 2015; Singh and Henkes, 2012), the obtained results of which showed the pressure drop coefficient mainly depends on the bypass structures. The research on the friction between pig cups and pipe wall was carried out with corresponding analytical models (Den, 2016; Hendrix et al., 2016; Nieckele et al., 2001; O'donoghue, 1996; Zhu et al., 2015a, 2015b; 2017; Zhang et al., 2015). Optimization of bypass fraction, which is one of the primary tasks in the feasibility study for a specific gas field, is the key to bypass pigging technology, The size of bypass port has two main constraints (Groote et al., 2015): 1) an inappropriate small opening will cause a large driving force and a high pig velocity, leading to a large pig generated liquid volume; 2) an unsuitable large opening will create too weak a driving force on the pig to overcome necessary resistance. Therefore, the optimum opening is to assure minimum liquid surge volume as well as prevent pig from getting stuck. Dynamic simulation software OLGA and LedaFlow have developed the bypass pigging module to simulate the dynamic bypass pigging process for choosing the optimum bypass fraction, which have provided successful guidance for related industrial applications (Entaban et al., 2013; Groote et al., 2015; Lee et al., 2012; Olaniyan and Larrey, 2014; Van et al., 2013). However, the current pigging models often fail to estimate the variations of friction force between pig and pipewall, as well as fail to capture the pig stick-slip behavior correctly. Ijsseldijk (2016) conducted indoor bypass pigging experiments in a horizontal pipeline system with single gas condition. Nevertheless the up-and-down, riser pipe structures and gas-liquid two phase flow, which may have considerable influence on the pig motion, were not included in the experiments. Therefore, further research on the mechanism of bypass pig in a more complex experimental system with gas and liquid mediums is demanded.

By and large, the research on bypass pigging technology is still in its preliminary stage with limited applications to engineering projects. The effects of bypass fraction, pipeline structure, and volume of liquid loading on movement characteristics of bypass pig still demand further discussions and analyses in order to figure out the complex mechanisms of bypass pig for reducing pig velocity and eliminating pig generated liquid volume. Hence, based on the limitation of current research, the paper has studied the movement characteristics of bypass pig conducted in a large indoor horizontal, up-and-down, riser system with gas-liquid two phase flow. The experimental phenomena, pressure fluctuations, pig velocity variations, and pig generated liquid volume during bypass pigging were analyzed accordingly.

2. Experimental system

2.1. Experimental apparatus

The experimental rig as shown in Fig. 2 consists of horizontal, up-and-down, riser pipeline structures. The total length of the loop is 102.7 m, which is made of stainless steel with an inner diameter of 53.4 mm. After being launched from the pig launcher, the pig will go through a horizontal pipe section with a length of 2 m, followed by the up-and-down pipe structure with an angle of 6° and a length of 19.6 m. Afterwards, the pig enters into the horizontal pipe section again, then traverses an inclined pipe with an angle of −4° and a length of 27.4 m, after which it reaches the bottom of the riser pipe with a length of 6 m. Upon that, the pig gets through the riser and final horizontal pipe with a length of 2.3 m before arriving at the pig receiver. The system can be used to measure gas flow rates, pressure fluctuations along the pipeline, and terminal outflow liquid volume.

Experimental devices mainly include a Swedish Atlas Copco's GA37VSD twin-rotor screw gas compressor with a maximum working pressure of 1.3 Mpa, as well as a maximum gas displacement of 434.88 std. m^3/h for absorbing the air from outdoor atmosphere, and a buffer tank for providing stable gas sources. A digital vortex flowmeter with a measurement range of 0–275.1 std. m^3/h and the maximum error of 1% was used for metering gas flow rates precisely. A temperature transmitter with a range of 0–120 °C was placed beside the digital vortex flowmeter for measuring the real-time gas temperature. Combined with parameters of measured real-time gas temperature and pressure, the actual gas flowrates measured by the flowmeter can be converted into the flowrates under standard conditions, which are important experimental variables for post analyses. Liquid water with the temperature around 20 °C and the volume of 2 L, 4 L, 6 L, 8 L (L = liter) was respectively injected into the pipeline through water injection opening before the pig launch. The residual water released by two water outlets after a pigging period is used for evaluating the backflow and liquid clearance effects by bypass pigging. There are a total of 11 Keller PA23 pressure transmitters with a range of 0–2 bar and the maximum error of 0.2% along the pipeline. P1 and P11 were installed at the pipe entrance and terminal used not only for measuring the pressure fluctuations, but also as time recorders for calculating average pig velocity. P2−P11 were arranged in pairs and each pair has the interval of 20 cm, which is minimal enough for calculating the instantaneous pig velocity in related locations. The differential pressure in the terminal container reflects the outflow liquid volume and helps evaluate the effects of bypass pigs on eliminating the pig generated liquid volume.

2.2. Design of bypass pig

The optimization of bypass fraction Φ, defined as the ratio of minimum bypass area of the pig to cross-sectional area of the pipeline, is the key to bypass pigging technology. Therefore, the dimension variations of bypass port were prioritized when designing the bypass pig experimental prototype, as shown in Fig. 3.

Different bypass nozzles were installed with threaded connections in the front of the pig body with the values of 0%, 2%, 4%, 6%, 8% bypass fractions in total. The bypass fractions of 0%, 2%, 4%, 6% were set by applying different bypass nozzles as shown in Fig. 3 (c). When there exists no bypass nozzle, the bypass fraction equals to 8%. The pig cup with the weight of 245 g is made of polyurethane and cup interference remains 3%, which corresponds to a cup diameter of 55 mm. The physical illustration is shown in Fig. 4.

The experimental independent variables are shown in Table 1:

The experimental procedures are as follows:

1) Adjust gas flow rates;

Gas flow rates were adjusted to the appropriate values before each experiment starts by handling the precision regulating valve.