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Simulation of pigging dynamics in gas-liquid two-phase flow pipelines

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ABSTRACT

Pigging is mainly done for cleaning the deposits and liquid removal in order to reduce the overall pressure drop and increase the pipeline flow efficiency. In this study, a simplified pigging model in two-phase flow pipelines with 657 mm diameter and 108 km length sea line of South Pars located in south of Iran has been developed to predict the pigging operation. At the beginning, the steady state condition was modelled to find the initial values, then the transient state cause to variable of feed flow rate was modelled, and finally the transient model was coupled with pigging model to describe the pig behaviour based on three flowing zones. The one dimensional differential equations and explicit finite difference were used as solution method. The results obtained with the code were compared with OLGA simulation and three real field pigging displacement and there was good agreement between them, thereby validating the method.

1. Introduction

Gas and gas-condensate fluids contain a very wide range of hydrocarbons from methane to the components as heavy as wax and asphaltene. Broad volatility and melting-point range of these hydrocarbon components are two main parameters that will cause the formation of wax phases in response to thermodynamic state changes. The wax deposition from the gas condensate in the gas processing plant causes a number of severe problems include: (a) deposits form on the reboiler tubes of stabilizer column and tend to reduce its duty (b) forcing periodic shut-down and removal of deposits (c) interrupting normal processing operations.

In order to understand wax deposition problem and address it, significant research has been done on the mechanisms governing wax deposition in pipelines in order to model the process (Taitel et al., 1989a; Minami and Shoham, 1996; Jeirani et al., 2007; Tolmasquim and Nieckele, 2008; Rahimi et al., 2013). Matzain et al. (2002) found that the thickness, hardness and profile of wax deposition in two-phase gas–oil for horizontal flow varied around the circumference of the pipe such as stratified smooth, stratified wavy, intermittent and annular distribution depending on flow pattern. Rahimpour et al. (2013) used the multi solid phase model and Al-Mesharis' (Al-Meshari, 2004) method as the most accurate method showed that wax precipitation starts at 293 K and 86 bar. At this pressure and temperature the pipeline is 94 km away from the wellhead. Tribological behaviour study of wax-particles-in-oil mixture showed that the wax particles are entrapped at inlet region and pass through the contact region. It is also found that pigging efficiency was a function of Young's module in rubber and efficiency of pigging process decreased with the increasing degree of wear in sealing disc (Tan et al., 2014). The slug catcher level is controlled by sending condensate to condensate stabilization units to prevent shut down due to high alarm level. Selection the proper type of pig depends on different criteria such as internal line size, the maximum distance pig must travel, pipeline content and according that the pig velocity, required driving pressure and flow rate are determined.

Although many experimental and theoretical attempts has been directed toward exploring pigging motion and pig devices but due to the complexity of both transport and thermodynamic phenomena, and the lake of experimental data, researchers have not been successful in simulating this process.

In this work a simulation and modelling study has been carried out on steady and transient state. Pigging operation based on continuity and momentum equations using quasi steady state assumption for gas continuity equation; local equilibrium momentum balance between gas and liquid phases and also using pigging model is utilized. To validate the code developed, steady

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and transient two phases gas-condensate displacement of a pipeline employing gauge, brush and intelligent pig were simulated and the results were compared with field data.

2. Pigging model

The OLGA 6.0 dynamic simulation software can model gas and liquid flow in isothermal, thermal or transient thermal modes. In this study, the simulation was carried out in steady state and transition models. More detail about governed equations bring out in work of Davoudi et al. (2014). The pipeline model was developed based on data about the geometrical profile, and considering a relevant set of environmental conditions. Fig. 1 shows the sea pipeline geometry with simulated temperature and pressure profile along the sea line of the south pars gas processing plant, Phase 1.

The pressure and temperature at the inlet of the sea line are 101.54 bar and 322 K respectively. The selected material for the 108 km sea pipeline is carbon steel 657.28 mm OD and wall thickness of 20.6 mm with no insulation and ambient temperature of 288.15 K with total thermal conductivity of 2 W/m^2 °C. The feed composition used in simulation has been shown in Table 1.

The physical model used in the development of the pigging model was similar to (Kohda et al., 1988) and Minami and Shoham (1991) and Xu and Gong (2005), whose physical model is presented in Fig. 2. Based on it there are three main regions during a pigging operation: a) downstream zone from location of pig to end of pipeline which pig has not effected on it yet, b) slug zone which grows by moving the pig through the pipeline, c) upstream zone from pipeline inlet to behind the pig and is a very low liquid-hold up zone. For this purpose a steady state numerical code was written according to Taitel et al., method (Taitel and Dukler, 1976; Taitel et al., 1978) to calculate the initial values. Then transient state was modelled by using Taitel et al., method (Taitel et al., 1989b) coupled with Minami & Shoham model (Minami and Shoham, 1991) to predict the flow patterns. Finally pigging model was coupled with transient model to find out the pig behaviour such as pig velocity and time in pipeline and sludge volume.

For modelling the pigging phenomena, slug zone is considered as a moving and expanding control volume. By applying the mass and momentum conservative equations into slug control volume (Xu and Gong, 2005):

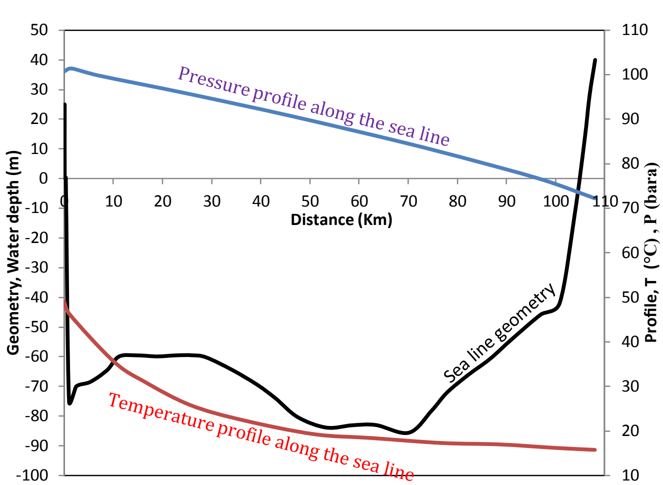

Fig. 1. Sea line geometry and condition.

Table 1
Feed composition to slug catcher.

Component	Mol %	Component	Mol %
H_2O	0.009	C_8	0.462
N_2	3.379	C_9	0.360
CO_2	1.998	C_{10}	0.381
H_2S	0.538	C_{11}	0.16
C_1	82.206	C_{12}	0.11
C_2	5.251	C_{13}	0.08
C_3	2.16	C_{14}	0.06
iC_4	0.42	C_{15}	0.04
nC_4	0.781	C_{16}	0.03
iC_5	0.32	C_{17}	0.02
nC_5	0.32	C_{18}	0.02
C_6	0.446	C_{19}	0.02
C_7	0.40	C_{20+}	0.02

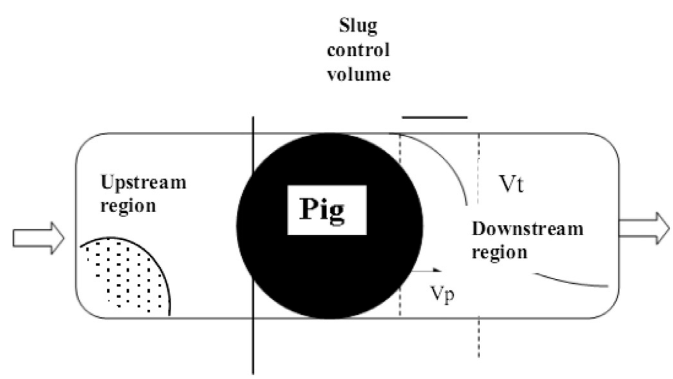

Fig. 2. Physical model for pigging phenomena.

$$\frac{d}{dt}\int_{v(t)} \rho dV + \int_{A(t)} \rho(v - v_{cs} dA = 0) \qquad (1)$$

By applying Equation (1) for available liquid into system:

$$\frac{d}{dt}(\rho_L\, \alpha_{LS} A\, L_S) + \rho_L(v_L - v_T)\alpha_L A + \rho_L(0. - v_p)(1 - E)\,(-A) = 0 \qquad (2)$$

where E is the pigging efficiency or gas void fraction left behind the pig. Therefore 1-E is the hold up of liquid left behind the pig with zero velocity. It has also considered and is time independent, so:

$$\alpha_{LS}\frac{dL_S}{dt} + (v_L - v_T)\alpha_L + (1 - E)v_p = 0 \qquad (3)$$

The change of slug length with time is set equal to differential velocity between transitional and pig velocity:

$$\frac{dL_S}{dt} = v_T - v_P = v_S \qquad (4)$$

From substituting Equation (4) into Equation (3), the transitional velocity is obtained:

$$v_T = \frac{\alpha_{LS} v_P - v_L \alpha_L - (1 - E)v_P}{\alpha_{LS} - \alpha_L} \qquad (5)$$

By inserting another liquid volumetric balance between a cross section just upstream and downstream of pig, a correlation according to pig and slug velocity will be obtained: