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# Field experience and evaluation of the South Pars sea line pigging, based on dynamic simulations

Mehdi Davoudi [a,b,*], Yashar Heidari [b], Seied Ali Akbar Mansoori [b]

[a] Chemical Engineering Department, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71345, Iran
[b] Development & Engineering Management Department, South Pars Gas Complex Company, Assaluyeh, Iran

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ABSTRACT

Multi-phase flow is experienced in many instances of the oil and gas industry. There is multi-phase flow in the sea lines, transferring the production from the South Pars offshore platforms to the receiving onshore facilities. By pigging at frequent intervals, liquid inventory buildup in a sea pipeline and the maximum slug size can be reduced. Uncontrolled speed of a pig can cause to large liquid slugging formation and bursting of pipeline due to pig stuck. In June 2008 the slug catcher levels increased unexpectedly to 100–105%. The main objective of this study is composed of calculation for liquid holdup, pig velocity, amount of slug during pigging operation and the influence of the production flow rate during the pigging of South Pars sea lines that is located in south of Iran. Besides the slug catcher liquid level, some parameters such as liquid bottle level were measured during pigging time process. The comparison between the actual and simulated sea line glycol holdup, travel time for the pig, sea line inlet pressure and the liquid slug volume has been done in this work. The difference between the actual and simulated travel time for the pig was 0.7 and 1.3 h for 600 and 300 million standard cubic feet per day (MMSCFD) of the gas flow rate. The absolute average relative errors of condensate and water slug volume are 5.6% and 9.1% respectively, which are very satisfactory. The results showed that the optimum gas flow should be around 500 MMSCFD to handle the slug volume and running the pigs is most effective at a near constant speed.

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## 1. Introduction

A pipeline operating in the slug flow regime creates high fluctuations in gas and liquid flow rates at its outlet. The detection of slugs and the estimation of their length and velocity are necessary to minimize the upsets in the operation of downstream process facilities. To avoid possible shutdowns, operators should take appropriate action in case of the arrival of an excessively long slug by detecting them minutes before their arrival. Slug evolution along the pipeline length is not well understood and various theoretical and experimental studies are still in progress to identify its mechanisms. In particular, the mechanisms of slug growth by merging with other slugs or the mechanism of slug collapse, the evolution of wave front, are not yet well known. In order to size the separator or slug catcher, the length of the incoming slugs must be determined. Liquid slug lengths are difficult to determine, as there are at least four identifiable mechanisms for liquid slug generation. Slugs can form as the result of wave formation at the liquid–gas interface in a stratified flow, or due to terrain effects. Liquid collects at a sag in the pipeline and blocks the gas flow. The pressure in this blocked gas rises until a time that it blows the accumulated liquid out as a slug. Finally, pigging can cause very large liquid slugs as the entire liquid inventory of the line is swept ahead of the pig. Pipelines are pigged for several reasons. Pipelines are pigged to improve the pressure drop-flow rate performance. Water or hydrocarbon liquids that settle in the sags of the pipeline constitute partial blockages that increase pressure drop; pigging can removes liquids and improves pipelines efficiency. Pigging can also be used as a means of limiting the required slug catcher size. The required downstream slug catcher size must take into account pigging frequency. Operational hazards are associated with pigging, as the very large slugs swept ahead of the pig may overwhelm inadequately sized downstream facilities. Pigs may also occasionally be destroyed in the pipeline and the resulting debris may damage downstream fittings or equipment. Even worse, the pig may become stuck in the line and require an expensive shutdown for location and removal. Several attempts

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* Corresponding author. Chemical Engineering Department, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71345, Iran. Tel.: +98 917 7129567; fax: +98 772 7324805.

*E-mail addresses:* davoudimehdi888@gmail.com, davoudimehdi@yahoo.com (M. Davoudi).

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have been made to model and simulate the pigging process, 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.

McDonald and Baker (1964) used empirical correlations for both liquid holdup and pressure drop in successive steady-state approach to model the pigging phenomena of the gas–liquid pipelines. Barua (1982) assumed a successive steady-state approach by removing some limiting assumptions of the original model. Kohda et al. (1988) employed a pigging model with two-phase transient flow which is based on the Scoggins' (1977) study. Pauchon and Dhulesia (1994), Lima (1998), Larsen et al. (1997), Minami and Shoham (1996) developed a quasi-steady gas-flow pigging model with the Taitel et al. (1989) simplified transient and improved pig tracking and boundary conditions. An Eulerean–Lagrangean approach using a fixed and moving coordinate system is used to predict the position of the pig and the liquid slug front with respect to time. Azevedo et al. (2001) used the finite difference method to study the dynamics of pigs through pipelines and simplified the solution with assumptions of incompressible and steady state of flow. Nguyen et al. (2001a,b) used characteristics method for estimating the pig dynamics in natural gas pipelines. Xu et al. (2003) has given a review on the pigging simulation models in multiphase pipelines. They developed a simplified pigging model for predicting the pigging operation in gas-condensate horizontal pipelines with low liquid-loading, which couples the phase behavior model with the hydro-thermodynamic model in 2005. Hosseinalipour et al. (2007) proposed the finite difference numerical simulation of pigging operation through gas pipelines. Tolmasquim and Nieckele (2008) simulated the transient oil displacement of a pipeline employing a sealing pigging based on a finite difference scheme. Saeidbakhsh et al. (2009) developed the dynamic of small pigs in space pipeline. The differential equations of motion were combined and reduced to only one nonlinear differential equation with respect to the parameter of the space curve. Esmaeilzadeh et al. (2009) presented the mathematical modeling of the transient motion of a pig through liquid and gas pipelines.

## 2. Fluid dynamic equations

The OLGA 6.0 dynamic simulation software can model gas and liquid flow in isothermal, thermal or transient thermal modes. During the transient thermal mode of the operational dynamic, energy balances are generated between the fluid, pipe wall, wrapping and surroundings. The model performs its simulations by calculating flow, pressure and temperature at all locations in the system at various time intervals. For each time step, the hydraulic and the thermal balances are calculated. The program calculates gas and liquid properties via a user-specified equation of state. The thermal properties of all fluids are accurately modeled and the program considers the thermal characteristics of the vessel or pipe wall and its surrounding environment when performing temperature calculations. Separate continuity equations are applied for gas, liquid bulk and liquid droplets, which may be coupled with mass transfer. Conservation of mass for gas, liquid and droplet are as equations (1)–(3):

- The gas phase:

$$\frac{\partial}{\partial t}\left(V_{\mathrm{g}}\rho_{\mathrm{g}}\right) = -\frac{1}{A}\frac{\partial}{\partial t}\left(AV_{\mathrm{g}}\rho_{\mathrm{g}}\upsilon_{\mathrm{g}}\right) + \psi_{\mathrm{g}} + G_{\mathrm{g}} \tag{1}$$

- The liquid phase at the wall:

$$\frac{\partial}{\partial t}(V_{\mathrm{L}}\rho_{\mathrm{L}}) = -\frac{1}{A}\frac{\partial}{\partial z}(AV_{\mathrm{L}}\rho_{\mathrm{L}}\nu_{\mathrm{L}}) - \psi_{\mathrm{g}}\frac{V_{\mathrm{L}}}{V_{\mathrm{L}}+V_{\mathrm{D}}} - \psi_{\mathrm{e}} + \psi_{\mathrm{D}} + G_{\mathrm{L}} \tag{2}$$

- The liquid droplets:

$$\frac{\partial}{\partial t}(V_{\mathrm{L}}\rho_{\mathrm{L}}) = -\frac{1}{A}\frac{\partial}{\partial z}(AV_{\mathrm{D}}\rho_{\mathrm{L}}\nu_{\mathrm{D}}) - \psi_{\mathrm{g}}\frac{V_{\mathrm{D}}}{V_{\mathrm{L}}+V_{\mathrm{D}}} - \psi_{\mathrm{e}} + \psi_{\mathrm{D}} + G_{\mathrm{D}} \tag{3}$$

In the above equations, $V_{\mathrm{g}}$, $V_{\mathrm{L}}$, $V_{\mathrm{D}}$ denotes volume fractions of gas, liquid-film and liquid-droplets respectively. A is the pipe cross-section area, $\Psi_{\mathrm{g}}$ is the mass transfer rate between the phases, the $\Psi_{\mathrm{e}}$ and $\Psi_{\mathrm{d}}$ is the entrainment and deposition rates. A possible mass source of phase f is given as $G_{\mathrm{f}}$. Subscripts g, L, D and I denote gas, liquid, droplets and interphase. The conservation of mass equations (Equations (1)–(3)) may be expanded with regards to pressure, temperature and composition. This assumes that the densities are given in equation (4) as:

$$\rho_{\mathrm{f}} = \rho(p, T, R_{\mathrm{s}}) \tag{4}$$

$R_{\mathrm{s}}$ is the gas mass fraction. The coupling of the pig motion with the fluid flow in the pipeline was obtained through a balance of forces balance on the pig as:

$$m_{\mathrm{pig}}\frac{dV_{\mathrm{pig}}}{dt} = (p_1 - p_2)A - m_{\mathrm{pig}}g\sin\beta - F_{\mathrm{C}} \tag{5}$$

Where, $V_{\mathrm{pig}}$, $m_{\mathrm{pig}}$, $p_1$ and $p_2$ are the pig velocity, pig mass, and the pressure on the upstream and downstream faces of the pig, respectively. The term $F_{\mathrm{C}}$ represents the axial contact force between the pig and the pipe wall which can be obtained from the shrink fit correlation given by Shigley et al. (2004). Conservation of momentum is expressed in equations (6)–(8) for the gas, possible liquid droplets and liquid bulk or film.

- for the gas phase:

$$\begin{aligned}\frac{\partial}{\partial t}\left(V_{\mathrm{g}}\rho_{\mathrm{g}}\upsilon_{\mathrm{g}}\right) = {} & -V_{\mathrm{g}}\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}\left(AV_{\mathrm{g}}\rho_{\mathrm{g}}\nu_{\mathrm{g}}^2\right) - \lambda_{\mathrm{g}}\frac{1}{2}\rho_{\mathrm{g}}|\nu_{\mathrm{g}}|\nu_{\mathrm{g}} \times \frac{S_{\mathrm{g}}}{4A}\\ & + \lambda_{\mathrm{i}}\frac{1}{2}\rho_{\mathrm{g}}|\nu_{\mathrm{r}}|\nu_{\mathrm{r}}\frac{S_{\mathrm{i}}}{4A} + V_{\mathrm{g}}\rho_{\mathrm{g}}g\cos\alpha + \psi_{\mathrm{g}}\upsilon_{\mathrm{a}} - F_{\mathrm{D}}\end{aligned} \tag{6}$$

- for liquid droplets:

$$\begin{aligned}\frac{\partial}{\partial t}(V_{\mathrm{D}}\rho_{\mathrm{L}}\upsilon_{\mathrm{D}}) = {} & -V_{\mathrm{D}}\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}\left(AV_{\mathrm{D}}\rho_{\mathrm{L}}\nu_{\mathrm{D}}^2\right) + V_{\mathrm{D}}\rho_{\mathrm{L}}g\cos\alpha\\ & - \psi_{\mathrm{g}}\frac{V_{\mathrm{D}}}{V_{\mathrm{L}}+V_{\mathrm{D}}}\upsilon_{\mathrm{a}} + \psi_{\mathrm{e}}\upsilon_{\mathrm{i}} - \psi_{\mathrm{d}}\upsilon_{\mathrm{D}} + F_{\mathrm{D}}\end{aligned} \tag{7}$$

- for the liquid at the wall:

$$\begin{aligned}\frac{\partial}{\partial t}(V_{\mathrm{L}}\rho_{\mathrm{L}}\nu_{\mathrm{L}}) = {} & -V_{\mathrm{L}}\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial}\left(AV_{\mathrm{L}}\rho_{\mathrm{L}}\nu_{\mathrm{L}}^2\right) - \lambda_{\mathrm{L}}\frac{1}{2}\rho_{\mathrm{L}}|\nu_{\mathrm{L}}|\nu_{\mathrm{L}}\frac{S_{\mathrm{L}}}{4A}\\ & + \lambda_{\mathrm{i}}\rho_{\mathrm{g}}\frac{1}{2}|\nu_{\mathrm{r}}|\nu_{\mathrm{r}}\frac{S_{\mathrm{i}}}{4A} + V_{\mathrm{L}}\rho_{\mathrm{L}}g\cos\alpha - \psi_{\mathrm{g}}\frac{V_{\mathrm{L}}}{V_{\mathrm{L}}+V_{\mathrm{D}}}\upsilon_{\mathrm{a}}\\ & - \psi_{\mathrm{e}}\upsilon_{\mathrm{i}} + \psi_{\mathrm{d}}\upsilon_{\mathrm{d}} - V_{\mathrm{L}}d\left(\rho_{\mathrm{L}} - \rho_{\mathrm{g}}\right)g\frac{\partial V_{\mathrm{L}}}{\partial z}\sin\alpha\end{aligned} \tag{8}$$

After inserting the conservation of mass equations and applying equation (9):

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