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Numerical Simulation of Pig Motion through Gas Pipelines

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Abstract

Pigs are utilized in pipelines to perform operations such as dewatering, cleaning, and internal inspection for damages. Transient motion of pigs through gas pipelines has been simulated numerically in order to help engineers predict the variables related to pig motion such as estimating its speed, required driving pressure, and the amount of fluid bypass through the pig. In this paper, the continuity and linear momentum equations for compressible gas flows were discretized by finite difference method based on moving and staggered grids. These equations were solved together with dynamic equation for pig movement and the equation for modeling bypass flow. Besides, gas was considered both ideal and real. Test cases representing typical pigging operations in pipelines with or without flanges and branches were studied using the numerical model developed. The fluid flow and pig behavior predicted by the model have a reasonable behavior.

Introduction

A large variety of pigs has now evolved to perform operations such as cleaning out deposits and debris, locating obstructions, liquid and gas removal, and internal inspection for damage or corrosion spots in pipelines. Pigging helps keep the pipeline free of liquid, reducing the overall pressure drop, and thereby increasing the pipeline flow efficiency.

Pipeline pigs may be broken down into two fundamental groups: conventional pigs, which perform a function such as cleaning or dewatering, and intelligent pigs, which provide information about the condition of a pipeline. All intelligent pigs need a clean line for optimum performance, and this requires the development of highly effective conventional pigs and pigging programs. Engineers have to consider many parameters for designing a pigging operation such as the effects of velocity, and determination of optimum pig speeds; design of pigs capable of performing in widely differing diameters; the effects of by-pass and optimum by-pass configuration; the effects of the differential pressures across the seals. However, most of the available knowledge is based on field experience. Hence, selecting the best pig, often involves some guesswork, and, consequently, a high degree of uncertainty.

The speeds recommended for routine, conventional, on-stream pigging are 1 to 5m/sec for liquid lines and 2 to 7m/sec in gas lines [1]. Good estimations of pig velocity and the time pig reaches the end of pipeline will help engineers design and perform a suitable pigging operation.

We can find very few papers dealing with the numerical simulation of pig motion in gas and liquid pipelines. Sullivan [2], Haun [3], treat the dynamics of simplified pigs in gas lines. Short [4] conducted an experimental research program aimed at the understanding of the fundamental problems related to pipeline pigging. A simple model to predict the pig motion driven by incompressible fluids under steady-state conditions was presented by Azevedo et al. [5]. Vianes Campo and Rachid [6] studied the dynamics of pigs through pipelines using the method of characteristics. Recently, Nieckele et al. [7] investigated isothermal pigging operations through gas and liquid pipelines. In addition, the contact forces developed by disk pigs and the pipe wall were predicted by a post-buckling finite element analysis of the discs.

This paper deals with simulation and modeling of pigs through gas pipelines. The equations governing the conservation of mass, linear momentum for the fluid were numerically solved by a finite difference method based on staggered moving grids these equations were coupled with an equation that describes the pig dynamics. Mathematical model for the prediction of the bypass flow through pigs was based on Nieckele et al. [7]. In order to simulate more realistic pigging operations, pigging under high pressures around 90 bars and the deviation from ideal gas law was investigated. Gas consumption through pipeline branches was also considered.

Governing Equations

Equations of mass, momentum, state and dynamic of pig are solved simultaneously. The flow is considered to be isothermal. Fig. 1 represents an elementary section of a variable area duct. The centerline of the duct is inclined with the horizontal at an angle β. It is assumed that the area change over the length dx is small, so the flow is essentially one-dimensional. The density, velocity, pressure and area are, respectively, ρ, V, P, A. The acceleration of gravity vector is represented by $\mathbf{g}$, and τ_s is the viscous stress acting at the wall.

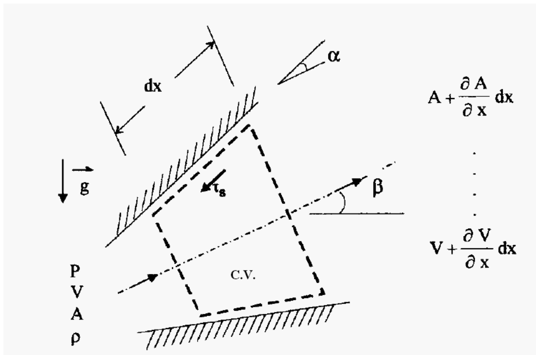

Figure 1. Control volume for one-dimensional flow analysis

For the control volume of Fig. 1, the mass conservation equation can be written as $\left(\partial m_{c.v.}/\partial t\right) = \dot{m}_{in} - \dot{m}_{out}$, where $m_{c.v.} = \rho A dx$ is the mass of fluid in the control volume and $\dot{m}$ is the mass flux through the boundaries. Thus, the continuity equation can be written in the following form: