Modelling and Simulation for PIG Flow Control in Natural Gas Pipeline

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Abstract

This paper deals with dynamic behaviour analysis for pipeline inspection gauge (PIG) flow control in natural gas pipeline. The dynamic behaviour of the PIG is depending on the different pressure between the rear and nose parts, which is generated by injected gas flow behind PIG's tail and expelled gas flow in front of its nose. To analyze the dynamic behaviour characteristics such as gas flow in pipeline, and the PIG's position and velocity, mathematical model is derived as two types of a nonlinear hyperbolic partial differential equation for unsteady flow analysis of the PIG driving and expelled gas, and nonhomogeneous differential equation for dynamic analysis of PIG. The nonlinear equation is solved by method of characteristics (MOC) with the regular rectangular grid under appropriate initial and boundary conditions. The Runge-Kuta method is used when we solve the steady flow equations to get initial flow values and the dynamic equation of PIG. The gas upstream and downstream of PIG are divided into a number of elements of equal length. The sampling time and distance are chosen under Courant-Friedrich-Lewy (CFL) restriction. The simulation is performed with a pipeline segment in the Korea Gas Corporation (KOGAS) low pressure system, Ueijungboo-Sangye line. The simulation results show us that the derived mathematical model and the proposed computational scheme are effective for estimating the position and velocity of PIG with different operational conditions of pipeline.

Nomenclatures

A	: pipe cross section	$[m^2]$
c	: wave speed	$[m/s]$
C	: linear damping coefficient of PIG	$[N/m.s]$
C_c	: convection heat transfer coefficient	$[W/m^2.K]$
C_v	: specific heat at constant volume	$[J/kg.K]$
d	: internal diameter of pipe	$[m]$
e	: internal energy per unit mass	$[J/kg]$
f	: Darcy friction coefficient	
F_b	: braking force	$[N]$
F_f	: friction force per unit pipe length	$[N/m]$
F_{fp}	: friction force between PIG and pipe wall including	$[N]$
- F_{fpsta}	: static friction force	
- F_{fpdyn}	: dynamic friction force	
F_p	: PIG driving force	$[N]$
g	: gravity acceleration	$[m/s^2]$
h_f	: pipe head loss	$[m]$
k	: pipe wall roughness	$[m]$
K	: wear factor per distance travel	$[N/m]$
l	: length of pipeline	$[m]$
L_{PIG}	: length of PIG	$[m]$
m	: hydraulic mean radius of pipe	$[m]$
M	: weight of PIG	$[kg]$
p	: fluid pressure	$[N/m^2]$
q	: compound rate of heat inflow per unit area of pipe wall	$[W/m^2]$
R	: gas constant	$[J/kg.K]$
S	: perimeter of pipe	$[m]$
T	: fluid temperature	$[K]$
T_{ext}	: seabed temperature	$[K]$
u	: fluid velocity	$[m/s]$
x	: distance from pipe inlet	$[m]$
x_{PIG}	: position of PIG	$[m]$
v_{PIG}	: velocity of PIG	$[m/s]$

Greeks:

γ	: the ratio of specific heat	
ν	: kinetic viscosity of fluid	$[m^2/s]$
ρ	: fluid density	$[kg/m^3]$

Subscripts:

L, R, M, N, S, O, P denote the grid points, and
$0, l$ denote the points at inlet and outlet of pipeline.

1. Introduction

Pipelines are the most common way and the safest method to transport oil and gas products. During operation, the walls of pipelines suffer a deterioration process and the pipeline conditions get worse: pipe wall's roughness is increased and internal diameter is reduced. To prevent above problems, pipeline must be pigged regularly. The tool used for