A united model for predicting pressure wave speeds in oil and gas two-phase pipeflows

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Abstract

A pressure wave, caused by unsteady operations such as a shutdown or restart, pigging, slug flow or input flow rate transient changes during an oil–gas pipeline transmission, could cause a safety hazard to the whole pipeline system. Because of the compressibility of the gas phase, the changes of interface between the gas and liquid, the momentum and energy transfer between the two-phase and the single-phase to the wall, all make it complicated for predicting the pressure wave speeds for oil and gas two-phase flow in long-distance pipelines. On the basis of the gas–liquid two-fluid model, this paper analyzes the pressure wave propagation for the two-phase flow. Pressure sources of gas–liquid momentum equations are described as the function of the gas–liquid flow velocities, gas void fraction, void fraction gradient and their differentiations, which make the two-fluid model hyperbolic. With the introduction of virtual mass force, the united model for prediction of the pressure wave speeds has been developed. And the gas–liquid Equations of State (EOS) has also been used in the united model, which can analyze the effects of the different system pressures. Important factors, such as the virtual mass coefficient and the gas void fraction, are also discussed. The developed model fits well with the experimental data, and can be used to predict wave speeds for different flow patterns, such as stratified flow, dispersed bubble flow and slug flow.
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Keywords: Pressure wave; Two fluid model; Hyperbolic equations; Virtual mass force; Two-phase flow

1. Introduction

With the rapid development of offshore and desert gas-condensate fields (or oil fields with accompanying gas ones), pre-treatment of natural gas at the wellhead to remove the heavies generally remains not an option because of the hostile environment. The produced oil and gas must, therefore, be transported by pipelines over substantial distances by a mixed system.

During the oil–gas pipeline transmission, unsteady operations (such as a system shutdown, restart, pigging, slugging, input flow rate transient changes, etc.) will cause a great pressure wave propagation, which would threaten the whole pipeline systems from the upstream to the downstream treatment facilities.

Table 1
Statistical list of pressure wave models with different flow patterns

Flow pattern	Researchers	Pressure wave speeds
The separated (stratified) flow	Wallis (1969)	$c = \left[\left(\dfrac{R_G}{\rho_G} + \dfrac{R_L}{\rho_L} \right) \Big/ \left(\dfrac{R_G}{\rho_G a_G^2} + \dfrac{R_L}{\rho_L a_L^2} \right) \right]^{1/2}$
	Nguyen (1976)	$c = \dfrac{a_{STG} a_{STL}}{R_G a_{STL} + R_L a_{STG}}, \; where, \; a_{STG}^2 = \dfrac{1}{\frac{1}{a_G^2} + \frac{R_L}{R_G} \frac{\rho_G}{\rho_L} \frac{1}{a_L^2}}, a_{STL}^2 = \dfrac{1}{\frac{1}{a_L^2} + \frac{R_G}{R_L} \frac{\rho_L}{\rho_G} \frac{1}{a_G^2}}$
	Nguyen et al. (1981)	$c = \dfrac{a_G a_L \sqrt{\dfrac{R_G R_L \rho_G \rho_L}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}{R_L \sqrt{\alpha \rho_L} + R_G \sqrt{R_L \rho_G}}$
	Lee et al. (1998)	$c = \dfrac{a_G a_L \sqrt{\dfrac{R_L \rho_G a_G^2}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}{R_L a_G + R_G a_L \sqrt{\dfrac{R_G \rho_G a_G^2}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}$
The Humongous (Bubble) flow	Wallis (1969)	$c^2 = \left[\left(\dfrac{R_G}{\rho_G a_G^2} + \dfrac{R_L}{\rho_L a_L^2} \right) \rho_s \right]^{-1}, \; where, \; \rho_s = R_L \rho_L + R_G \rho_G$
	Henry (1969) Wylie (1983)	$c^2 = p/(R_L R_G \rho_m)$ $c^2 = \dfrac{K_L / \rho_m}{1 + \frac{K_L}{E} \frac{D}{e} + R_G \left(\frac{K_L}{K_G} - 1 \right)}, \; where, \rho_m = R_L \rho_G + R_G \rho_L$
	Martin and Padamanabhan (1979)	$c^2 = \dfrac{a_G^2}{R_L R_G \frac{\rho_L}{\rho_G} + R_G^2 + \left(\frac{a_G}{\rho_G} \right)^2 \left(R_L^2 + R_L R_G \frac{\rho_G}{\rho_L} \right)}$
	Nguyen (1976)	$c = \dfrac{a_G}{R_L \sqrt{R_G \frac{\rho_L}{\rho_G}} + R_G \sqrt{R_L}}$
	Nguyen et al. (1981)	$c = \dfrac{a_G a_L \sqrt{\dfrac{\rho_G \rho_L}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}{R_L \sqrt{\rho_L} + R_G \sqrt{\rho_G}}$
	Lee et al. (1998)	$c = \dfrac{a_G a_L \sqrt{\dfrac{\rho_G a_G^2}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}{R_L a_G + R_G a_L \sqrt{\dfrac{R_L \rho_G a_G^2}{R_L \rho_G a_G^2 + R_G \rho_L a_L^2}}}$
The Slug Flow	Henry (1971)	$c = \dfrac{a_L a_G}{\lambda a_L + (1 - \lambda) a_G}, \; where, \lambda = \dfrac{L_B}{L_B + L_S}$
	Nguyen (1976) Nguyen et al. (1981) Lee et al. (1998)	$c = \dfrac{a_L a_G}{R_L a_G + R_G a_L}$