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Multiphase Flow Rate Measurement Through A Conductance Venturi Meter

MULTIPHASE FLOW RATE MEASUREMENT THROUGH A CONDUCTANCE VENTURI METER: EXPERIMENTAL AND THEORETICAL STUDY IN DIFFERENT FLOW REGIMES

by

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OVERVIEW AND RESEARCH OBJECTIVES

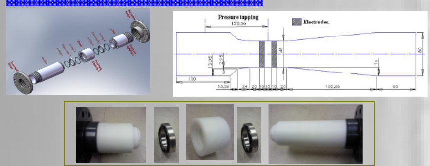
Multiphase flows, where two or even three fluids flow simultaneously in a pipe are becoming increasingly important in the oil industry. Although much research has been done to measure the phase flow rates of two-phase flows in a Venturi meter, accurate flow rate measurement of two/three phase flows with a Venturi meter in different flow regimes remains elusive. The aim of the research is to develop a new solution for non-invasive multiphase flow rate measurement with a targeted accuracy of 5% per phase in unsteady two-phase water/gas, water continuous, vertical and horizontal flows. The instrument will be based on an advanced Conductance Multiphase Venturi Meter (CMVM)) which is capable of measuring the gas volume fractions at the inlet and the throat of the CMVM. A new model was investigated to measure the gas flow rate. This model is based on the measurement of the gas volume fractions at the inlet and the throat of the Venturi meter using a conductance technique rather than relaying on the prior knowledge of the mass quality x. The objectives, providing the solution to achieve the aims, are outlined below;

- ✓ **To measure the flow rate of the gas-water mixture with a Venturi flow meter and flow density meter (FDM) in a homogenous flow.**
- ✓ **To design a novel conductive multiphase Venturi meter (CMVM) and conductive inlet void fraction meter which capable to extract the gas volume fraction at the inlet and the throat of the Venturi.**
- ✓ **To measure the gas flow rate and the gas volume fractions at the inlet and the throat of the CMVM in vertical annular and slug flows.**
- ✓ **To measure the gas flow rate and the gas volume fractions at the inlet and the throat of the CMVM in horizontal slug and stratified flows.**
- ✓ **To measure the liquid flow rate in vertical annular and slug flows.**
- ✓ **To measure the liquid flow rate in horizontal slug and stratified flows.**

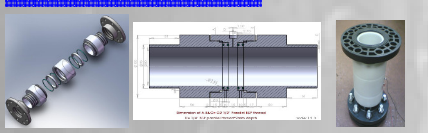
DESIGN OF THE CONDUCTANCE MULTIPHASE VENTURI METER (CMVM)

Since for non-homogenous flow the gas volume fraction at the inlet, α_1 differs from the gas volume fraction at the throat α_2 (and also the mixture density at the inlet and the throat, ρ_{m1} and ρ_{m2} respectively), it is necessary to measure the gas volume fractions at the inlet and the throat of the Venturi. To do so, a new Venturi with two ring electrodes at the throat was designed and manufactured. The system comprises two sections; CMVM (to extract α_2) and the CIVFM (to extract α_1).

Design of the CMVM

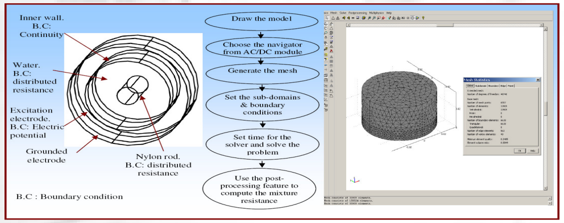


Design of the CIVFM



FINITE ELEMENT MODELLING OF THE CONDUCTANCE METER

Finite element software called "COMSOL" was used to simulate vertical annular flow in which the gas forms a core at the pipe centre and the liquid forms a film between the gas core and the pipe wall. In the simulation model, the electrical conductance of the mixture can be calculated from the current density at the virtual earth electrode and the applied potential. It is therefore possible to obtain the conductance of the mixture in the CMVM comprising two ring electrodes (a virtual earth electrode and an excitation electrode) by integrating the current flow over the area of the virtual earth electrode and dividing by the potential of the excitation electrode.



MATHEMATICAL MODELS

Homogenous flow model

In case of homogenous flow where the two phases are normally well mixed, the gas and water are assumed to have the same velocity (slip ratio, S=1). The mixture volumetric flow rate Q_m can be written as;

$$Q_m = \frac{C_{dm} A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2\Delta P}{\rho_m} + \frac{2 g h_t \cos\theta(\rho_w - \rho_m)}{\rho_m}} \quad \text{where} \quad \rho_m = \alpha\rho_g + (1-\alpha)\rho_w$$

It is clear from the above equations that, in homogenous flow it is possible to assume that the gas volume fraction at the inlet and the throat are equal to α.

Separated flow model

The assumption of equal mixture densities at Venturi is no longer valid for a separated flow and therefore, the measurement of the gas volume fraction at the throat must also be introduced. The study of multiphase flow through contraction meters is described for example by; Murdock, Chisholm, Lin, Smith and Leang, de Leeuw and Steven.

Correlation	Expression of gas mass flow rate
Murdock (1962)	$\dot{m}_g = \frac{A_t k_g \sqrt{2\Delta P_{TP}\rho_g}}{1+1.26\frac{1-x}{x}\frac{k_g}{k_w}\sqrt{\frac{\rho_g}{\rho_w}}} = \frac{(\dot{m}_g)_{apparent}}{1+1.26\frac{1-x}{x}\frac{k_g}{k_w}\sqrt{\frac{\rho_g}{\rho_w}}}$
Chisholm (1974)	$\dot{m}_g = \frac{k_g A_t \sqrt{2\Delta P_{TP}\rho_g}}{\sqrt{1+CX+X^2}} = \frac{k_g A_t \sqrt{2\Delta P_{TP}\rho_g}}{\sqrt{1+\left[\left(\frac{\rho_w}{\rho_g}\right)^{\frac{1}{4}}+\left(\frac{\rho_g}{\rho_w}\right)^{\frac{1}{4}}\right]X+X^2}}$
Smith & Leang (1975)	$\dot{m}_g = k_g A_g (BF)\sqrt{2\Delta P_g \rho_g}$
Lin (1982)	$\dot{m}_g = \frac{k_w A_t x \sqrt{2\Delta P_{TP}\rho_w}}{K(1-x)+x\sqrt{\frac{\rho_w}{\rho_g}}}$
de Leeuw (1997)	$\dot{m}_g = \frac{k_g A_t \sqrt{2\Delta P_{TP}\rho_g}}{\sqrt{1+C_{Leeuw}X+X^2}}$
Steven (2002)	$\dot{m}_g = k_g A_t \sqrt{2\Delta P_{TP}\rho_g}\left(\frac{1+C_{St}X_{mod}+D_{St}Fr_g}{1+A_{St}X_{mod}+B_{St}Fr_g}\right)$

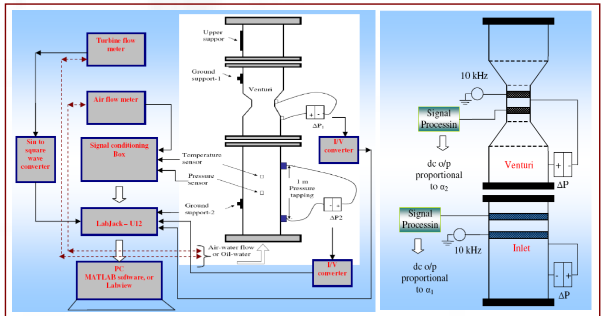
It is clear that the Previous models depend either on mass flow quality, x or empirical constants. None of these models depend on the measurements of gas volume fractions at the inlet and the throat of the Venturi/orifice meter.!!

Online measurement of x is very difficult and not practical. Therefore , CMVM was Designed to solve this problem

The new separated flow model is given by;

$$\dot{m}_g = \rho_{g1} U_{g1} A_1 \alpha_1 = \frac{A_1\alpha_1 A_2 \alpha_2}{\left(\alpha_1^2 A_1^2 \left(\overline{P}\right)^{-1/\gamma} - \alpha_2^2 A_2^2\right)^{1/2}} \left(2\Delta P_{TP}\rho_{g1}\right)^{1/2}$$

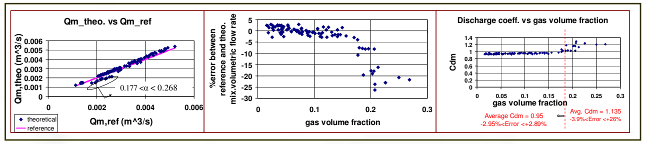
EXPERIMENTAL SETUP FOR HOMOGENOUS AND SEPARATED FLOW



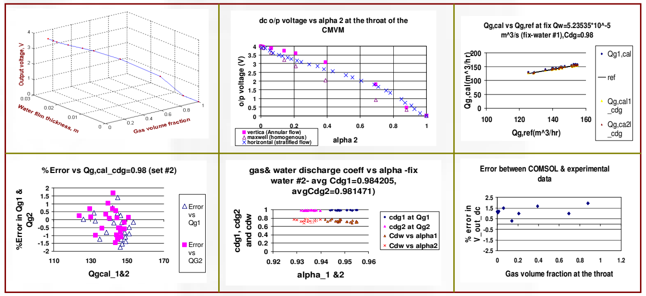
(a) Homogenous vertical flow (b) Separated vertical flow

EXPERIMENTAL RESULTS

HOMOGENOUS FLOW RESULTS



SEPARATED FLOW RESULTS



CONCLUSION AND FURTHER WORK

- ➢ The Homogenous flow results showed that, for 0 %<α<17.04%, the error was within ±2.95 %. After that the homogenous flow model has broken due to the transition from bubbly to slug flow regimes.
- ➢ Therefore, an advance conductance multiphase Venturi meter was designed and constructed to measure the phase flow rate in a separated flow regime.
- ➢ A good results was obtained from a new separated flow model in which the error in the gas flow rate (in vertical annular flow regime) was within ± 1.95 %.
- ➢ The multiphase flow loop has to be modified to achieve the horizontal stratified and slug flow regimes.
- ➢ An intermittent model for slug flow has to be investigated which may combine the homogenous and separated flow models described in this poster.