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Multiphase flow measurements using coupled slotted orifice plate and swirl flow meter

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ABSTRACT

Multiphase flow metering is a major focus for oil and gas industries. The performance of a modified version of a close coupled slotted orifice plate and swirl flow meter for multiphase flow was evaluated to provide further development of a new type of multiphase flow meter. The slotted orifice provides well homogenized flow for several pipe diameters downstream of the plate. This characteristic provides a homogeneous mixture at the inlet of the swirl meter for a wide range of gas volume fractions (GVF) and flow rates. In order to evaluate the performance of the designed flow-meter, its response was investigated for varying pressures and water flow rates. The proper correlations were established to provide high accurate two-phase flow measurements. The new proposed approach provides the GVF measurement with less than $\pm 0.63\%$ uncertainty for GVF range from 60% to 95%.

1. Introduction

Two phase flow metering has been important for many years in a variety of industries, such as oil and gas, chemical, power generation and nuclear energy. The accurate and low cost measurement of flow rate and quality of the mixture are needed for many processes in multiphase flow systems. There are different methods to provide multiphase flow metering and flow characterization [1–5]. One of the methods is to measure the flow by making the homogeneous flow with equal phase velocities in a two-phase flow conditions. This method enables single phase flow metering devices to measure multiphase flows [6,7]. This approach eliminates flow separators and associated costs. Compact design multiphase flow meters result in reduced space and weight which increases capabilities for field managing and monitoring in remote areas. High accuracy measurement of mixture components provides a significant amount of cost savings.

The slotted orifice plate is a differential pressure (DP) flow meter. Morrison [8] designed the slotted orifice plate to measure two phase flow. He [9] studied the performance of the slotted plate by comparing the standard orifice plate for two phase flow measurement through a pipe. The slotted plate is shown in Fig. 1. This plate is designed to be insensitive to upstream flow conditions. The slotted plate provides quicker downstream pressure recovery than the standard orifice plate [10,11] and has a superior performance in homogenizing the two-phase flow in comparison with the standard orifice plate [12].

The swirl (vortex) flow meter is a density/velocity sensitive device. Because of reliability, high accuracy, wide flow rate scale and stationary parts, the swirl meter has become a common device in natural gas measurement [13]. A piezoelectric sensor embedded in the swirl meter captures pressure–velocity variations. The frequency (f) that is provided from the piezoelectric sensor corresponds with volumetric flow rate [13]. Goujon [14] studied the linearity of the vortex meter. The viscosity of fluid has a strong effect on the linearity of vortex meter when the Reynolds number is less than 30,000. The swirl flow meter might not provide accurate results when low pressure gas is used as an operating fluid. Sun [15] investigated an independent study from Goujon [14] to measure the pressure fluctuation for two-phase flow in a vortex flow meter. It is given that the frequency of the pressure fluctuations shows linearity with Reynolds number for 18% GVF range, and the mean amplitude of the pressure fluctuation reduces with GVF. It was also stated that under the same GVF, the mean amplitude increased when water flow rate increased.

Hua studied the swirl flow meter's working behavior under wet gas flow conditions in low pressures [16]. Using the vortex precession frequency of the swirl flow meter's sensor, the author proposed a correlation to measure the gas flow rate for a known liquid flow rate in very high gas volume fractions (GVF > 99.10%) within $\pm 5\%$ error. In another study, Hua [17] employed the same swirl flow meter combined with a slotted orifice plate to develop a wet gas flow meter to measure both liquid and gas flow rates. In this article, the author stated that higher than 99.10% GVF, the swirl flow meter – slotted plate combination provides usable

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Nomenclature

A	cross section area of the pipe
f	frequency measured from ABB Swirl Meter
GVF	Gas Volume Fraction, $Q_{gas}/(Q_{gas}+Q_{liq})$
D	diameter of the slotted plate
L	distance between the slotted orifice plate and inlet of the swirl flow meter
$\dot{m}_T$	total mass flow rate
P_s	pressure at inlet of swirl flow meter
Q_{gas}	volumetric flow rate of gas
Q_{liq}	volumetric flow rate of liquid
x	quality, $\rho_g Q_{gas}/(\rho_g Q_{gas}+\rho_l Q_{liq})$
$\Delta\alpha_i$	error in GVF calculation at step number i
ΔP	differential pressure from the slotted orifice plate
α_i	calculated GVF at step number i
ρ_g	gas density
$\rho_{g,s}$	gas density at standard condition
ρ_l	liquid density

results. However, the flow meter does not work well as the vortex precession vanishes when the Lockhart Martinelli parameter was larger than 0.12. The gas mass flow rate in the mixture was measured to be within $\pm 6\%$ error for 89.2% of all tested samples. In this study, a large distance to diameter ratio (L/D) of 20 between wet gas flow metering elements, the slotted orifice plate and swirl flow meter, was chosen. This large distance between the flow metering elements can suppress the homogenous flow generated by the slotted orifice plate at the swirl flow meter location.

The purpose of this study is to obtain a compact and high accuracy multiphase flow meter by combining swirl flow meter and slotted orifice plate in a closely coupled configuration. The slotted orifice plate has superior measurement and homogenization capabilities in multiphase flows. By employing the slotted orifice plate, for a known mixture density, the mixture mass flow rate can be accurately obtained. The slotted orifice plate also provides a homogenous mixture for the swirl flow meter. This combination produces two measurements that are utilized to determine the mixture density by the swirl flow meter and mixture mass flow rate by the slotted orifice plate. In comparison with other studies using this combination, a wider range of GVF with higher accuracy was achieved.

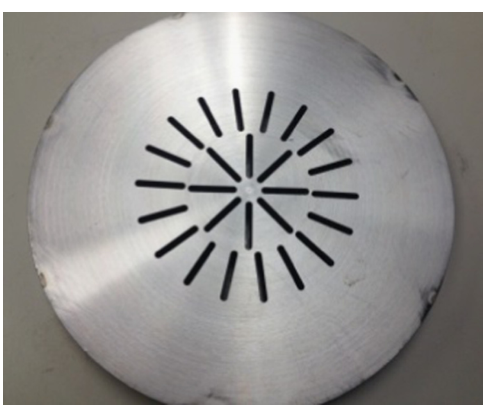

Fig. 1. Slotted orifice plate, β=0.467.

2. Experimental setup

The instrumentation, setup of the flow loop and the 50.8 mm diameter flow meter in the current study were similar to the work previously conducted at Turbomachinery Laboratory at Texas A&M University [4]. In the flow loop shown in Fig. 2, air was supplied by a compressor and was mixed with the water supplied by a pump from a 18.92 m^3 (5000 gallon) tank at 5D upstream of the multiphase flow meter. Two calibrated turbine flow meters were used to measure the liquid and gas flow rates in liquid line and gas line, respectively. Three pneumatic actuated control valves were employed to control water flow rate, pressure and gas volume fraction at the inlet of the swirl flow meter.

In this flow loop, the response of the current close coupled system was obtained in an air and water mixture for seven various liquid mass flow rates ranging from 108.8 kg/min to 353.8 kg/min, each with the GVF varying from 0% to 100% and four different gauge pressures varying from 138 *kPa* to 483 kPa pressure measured downstream of the slotted orifice plate.

According to the operating conditions of this flow meter, the distribution of experimental test points at the upstream of the multiphase flow meter was superimposed to the flow regime map [18] and is shown in Fig. 3. According to this figure, the flow regime at the upstream of the multiphase flow meter is considered to be slug flow.

The 50.8 mm diameter multiphase flow meter consisted of two close couples elements. A slotted orifice plate with orifice effective

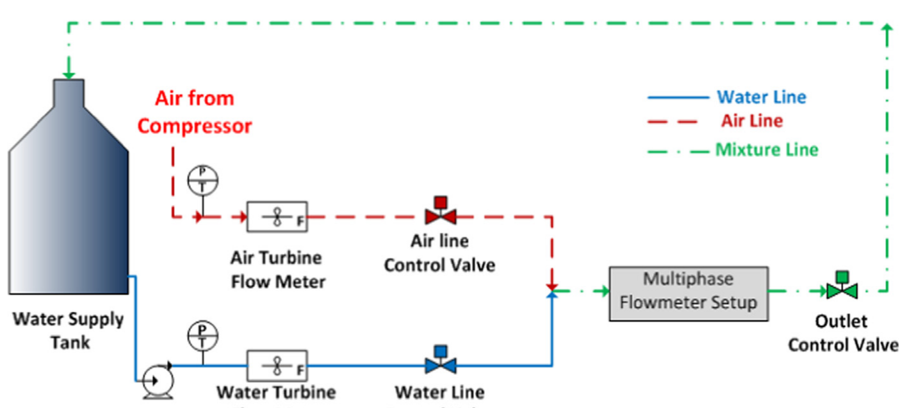

Fig. 2. Experimental setup to test multiphase flow meter. The blue solid line corresponds to water line. The red dashed line corresponds to air line. The green dash-dot line corresponds to air/water mixture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)