Wet Gas Flowrates Metering Based on Double Differential Pressures of Venturi Meter

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Abstract: In order to measure the wet gas not separating, a wet gas measuring method based on double differential pressures of an alone venturi meter is presented in this study. In traditional over-reading (viz. OR) correlations, only the liquid phase fraction is known, can the OR be solved. This deficiency is analyzed by error propagation method theoretically. The change characteristics and the inherent physics laws of the differential pressures of the contraction and expansion sections of a venturi tube which were affected by the relative amount of liquid phase and gas flow rates were investigated deeply. Using a new dimensionless metering parameter, viz. the differential pressures ratio of contraction and expansion sections of venturi tube, a novel form of the OR correlation was, therefore, developed to improve the metering accuracy effectively. The gas and liquid flowrates of wet gas were solved respectively by iterations. Taking a prototype with DN80 diameter of 0.38 beta ratio designed and made for example, with the experimental devices of the wet gas flow measurement, the experimental research and the performance verification of the prototype was carried out in the flow laboratory of TianJin University. The experimental results show that the relative error of gas flow rates is less than ±2%, and the full scale error of liquid flow rates is less than ±10%, under the condition like the test pressure range from 0.1~0.16MPa, Froude number range from 0.4~0.7, mass ratio of liquid and gas range from 0~1.

Keyword: Wet gas metering; Venturi; Double differential pressure; Over-reading

1. Introduction

Wet gas flow is usually defined as the two phase flow of a continuous gas phase with dispersed liquid phase [1]. All the differential pressure flow meter will over read in wet gas flow. Much research work has been done on the wet gas performance of differential pressure flow meters, and a series of over-reading correlations have been acquired. However, all these correlations are created for a special restriction device under some certain working conditions, furthermore only the liquid fraction is known can these correlations be used to determine the over-reading. Therefore, the use of these correlations is greatly limited for the liquid fraction is unknown in actual metering. The on line metering of wet gas aims to realize the metering of gas and liquid flow rates simultaneously without separation, one single restriction device with a single differential pressure signal can only get one metering parameter which is inadequate to realize the metering of gas and liquid flow rates [2]. In this paper, a wet gas measuring method based on double differential pressure of a venturi meter is investigated by theoretical analysis and experiments, the resolution of the liquid fraction and the metering of the gas and liquid flow rates are realized by the combination of the differential pressure of the contraction and expansion sections of a venturi meter.

2. Wet Gas Performance of Differential Pressure Flow Meter

In normal metering, differential pressure flow meters can only be used when the flow is single-phase and homogeneous in physics and thermodynamics. By the deducing of Bernoulli and continuity equations and a discharge coefficient, the flow rate can be get as

$$W_g = \frac{C \cdot \varepsilon}{\sqrt{1-\beta^4}} \times \frac{\pi}{4} \beta^2 D^2 \times \sqrt{2\Delta P_g \rho_g} \tag{1}$$

In this equation, W_g is for the gas flow rate, C is for the discharge coefficient, ε is expansibility factor, β is the beta ratio, D is the pipe internal diameter, ΔP_g is the differential pressure generated by restriction device and ρ_g is the gas density.

The study of the gas and liquid two-phase flow shows that the presence of liquid in the gas stream will generally cause the DP meters to have a positive shift in the differential pressure compared with the gas if it flowed alone [3]. This cause the uncorrected gas flow rate prediction of the DP meter to be usually a positive error when the flow is a wet gas flow. Therefore, it is said that the meter is "over-reading" .In order to get the actual gas flow rate, a correlation number over-reading which is denoted by the term "Φ_g" is defined as

$$\Phi_g = \frac{W_{tp}}{W_g} = \sqrt{\frac{\Delta P_{tp}}{\Delta P_g}} \tag{2}$$

In this equation, W_{tp} is the uncorrected gas flow rate prediction of the single phase gas flow DP meter if the flow is wet gas, ΔP_{tp} is the actual differential pressure read by the meter if the flow is wet gas, ΔP_g is the differential pressure that would be read if the gas flow rate flowed alone with the same equality flow rate (the flow is wet gas in fact)

3. The limitation of Traditional Correlations

Differential pressure flow meters are significantly affected by the presence of liquid in the gas flow. However, repeated experiments have shown that the positive bias error—over-reading is related to the Lockhart-Martinelli parameter, the gas to liquid density ratio, and the gas densiometric Froude number. Various correlations existed for dedicated differential pressure flow meter with set geometries that are all in the form shown as [4]

$$\Phi_g = f(X, F_{rg}, \left(\frac{\rho_g}{\rho_l}\right)) \tag{3}$$

In this equation, the Lockhart-Martinelli parameter [5] is defined by equation (4), and the gas densiometric Froude number (5) is defined as the square root of the ratio of gas inertia force if it flowed alone to the to the liquid gravity force. In these equations, W_l and W_g are the liquid and gas mass flow rates, ρ_g and ρ_l are gas and liquid densities respectively, U_{sg} is superficial gas velocity calculated by equation (6), g is the gravitational constant.

$$X = \frac{W_l}{W_g}\sqrt{\frac{\rho_g}{\rho_l}} \tag{4}$$

$$Fr_g = \frac{U_{sg}}{\sqrt{gD}}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}} \tag{5}$$

$$U_{sg} = \frac{4W_g}{\rho_g \pi D^2} \tag{6}$$

From the form of these classic correlations, it is evident that only when the liquid fraction is known can the over-reading be deduced from these correlations. However, on one hand, the liquid fraction and the gas densiometric Froude number are unknown in actual metering, it is an arduous work to acquire these parameters in wet gas flow, on the other hand, even if these parameters can be acquired by some other techniques (such as tracer dilution method [6]), the over-reading determined by these correlations will have a significant propagation error induced by the inaccuracies of these parameters. For example, if the uncertainty of the Lockhart-Martinelli number is 10%, the over-reading which is determined by Lockhart-Martinelli number may have 5% uncertainty. The propagation of error is shown in figure1. Therefore the use of these correlations with this form is quite limited in actual metering.

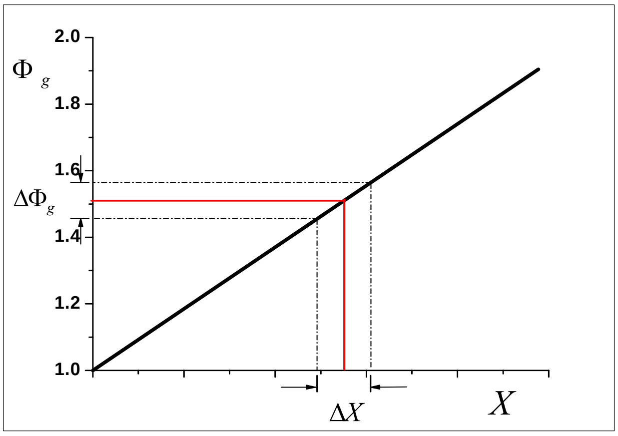

Figure 1 The over-reading error propagated by the Lockhart-Martinelli number

4. Over-reading Correlations Based on the Ratio of Two Differential Pressures

In order to improve the wet gas metering accuracy and avoid the propagation error discussed above, a dimensionless metering parameter, the ratio of the differential pressures of venturi contraction and expansion sections which is defined by equation(7) is presented.

$$K = \frac{\Delta P_1}{\Delta P_2} \tag{7}$$

where ΔP_1 stands for the differential pressure of venturi contraction section and ΔP_2 stands for the differential pressure of venturi expansion section, which is shown in figure2 respectively.

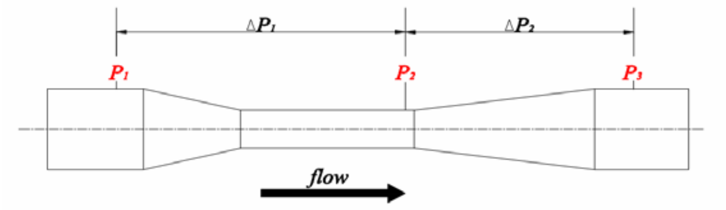

Figure 2 The block diagram of the venturi meter

Experimental study shows that the K value is a constant in the single-phase flow. Figure3 shows the relationship between the K value and the flow rate in single-phase water flow. It suggests clearly that the K value is a constant for a wide scale of flow rate. When the flow is wet gas, the presence of liquid phase in the gas stream will cause K value to have a positive shift compared with the gas if it flowed alone. It is shown in figure4 that as the ratio of liquid to gas mass increases the K value increases. It is obvious that the K value is a monotone increasing function of the liquid to gas mass ratio. The liquid fraction and the over-reading of venturi can be resolved by the change of the *K* value.

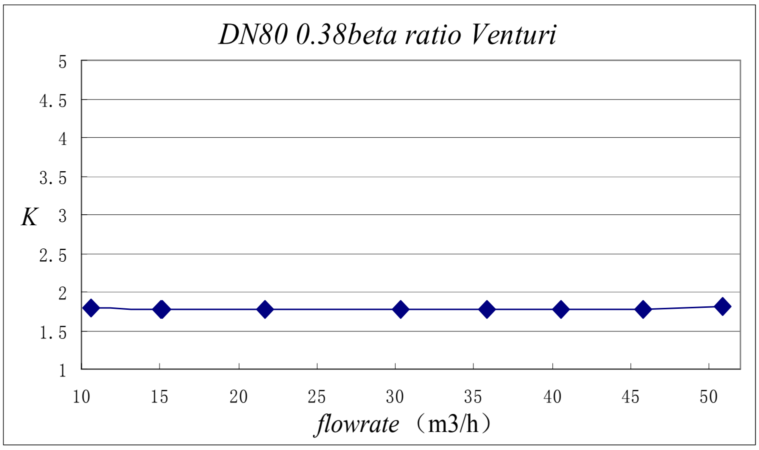

Figure 3 The relationship between the K value and the flow rate

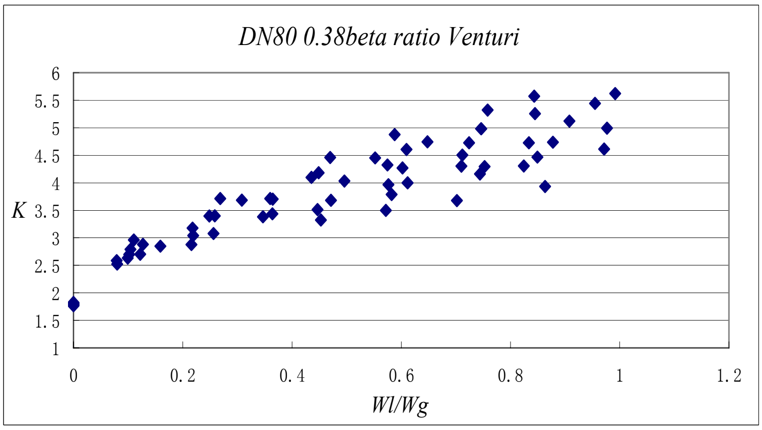

Figure 4 Relationship Between K Value and Liquid to Gas Mass Ratio

As discussed above, the venturi over-reading correlation and the function of liquid to gas mass ratio can be expressed in the form of equation (8) and equation (9) using the new dimensionless metering parameter—*K*. There is only one parameter—W_g unknown in these equations (examination of equations 1, 2, 5, 6, 7, 9). We can therefore get the gas flow rate by iteration and then get the liquid flow rate through equation (9). The *K* value is calculated from the differential pressure signals directly which can be accurately measured by the DP transmitters. Therefore, the propagation error can be greatly limited applying this method.

$$\Phi_g = f_1(K, Fr_g, \left(\frac{\rho_g}{\rho_l}\right)) \tag{8}$$

$$\frac{W_l}{W_g} = f_2(K, Fr_g, \left(\frac{\rho_g}{\rho_l}\right)) \tag{9}$$

5. The Wet Gas Test Loop

The experiments were carried out in the Tianjin University wet gas test loop. The research loop was designed for two-phase flow studies consisting of water and air. Figure5 is a simplified block diagram that shows the major components of the wet gas research loop. The air used in the test loop is pressurized by two air compressors to nearly 0.8 MPa. The operating pressure range in the test loop is between 0.1 to 0.4 MPa. A votex gas flow meter measures the flow rate of the air before mixing. The water is injected into to the test loop and the pressure of the water is maintained by a water tower. An electromagnetic flow meter measures the flow rate of the water. The gas drives the liquid through the test loop by the application of gas dynamic force. The water returned via the separator to the water tank and circulated. The gas is exhausted into the air.

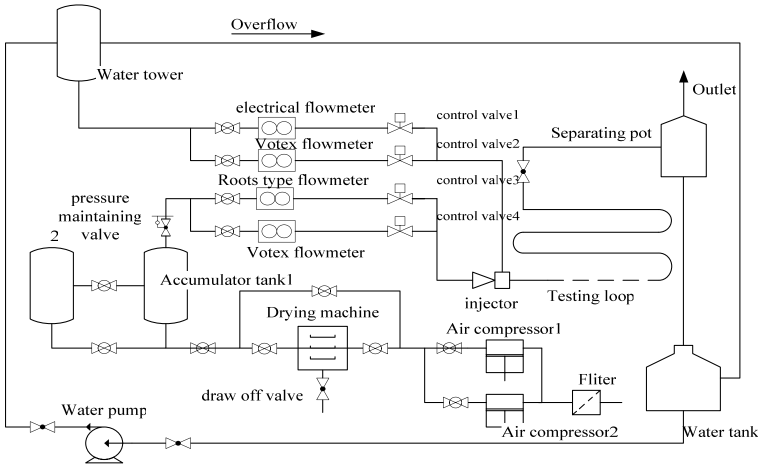

Figure 5 Schematic Diagram of Tianjin University Wet Gas Research Loop

6. The Tested Venturi Meter and the Test Results

Figure 6 is picture of the venturi meter that has been tested. The precise specification of the venturi meter is inlet bore of 80 mm, throat of 30.4 mm and a beta ratio of 0.38. In order to see the flow pattern, the venturi tube is made in organic glass.

Figure 6 The 0.38 Beta Ratio Tested Venturi Meter

The wet gas tests consisted of three pressures, 0.1, 0.13 and 0.16 MPa. At each pressure, there are three flow rates (the gas densiometric Froude number range from 0.5 to 0.7). And the liquid to gas mass ratio range from 0 to 1. Figure 7 and Figure 8 show all the wet gas test data.

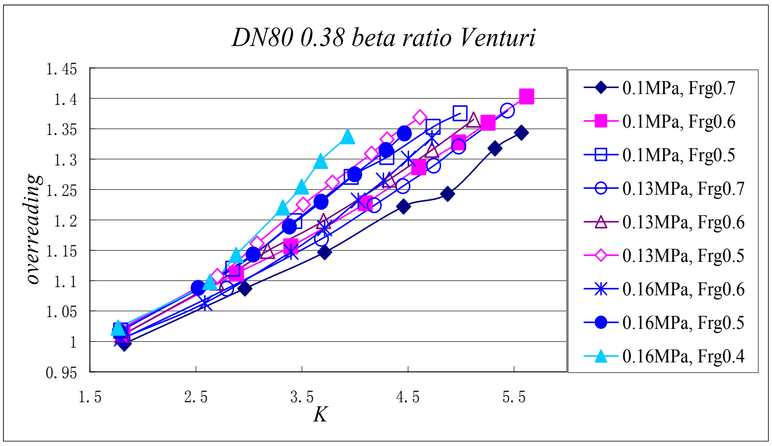

Figure 7 Relationship Between K Value and Over-reading

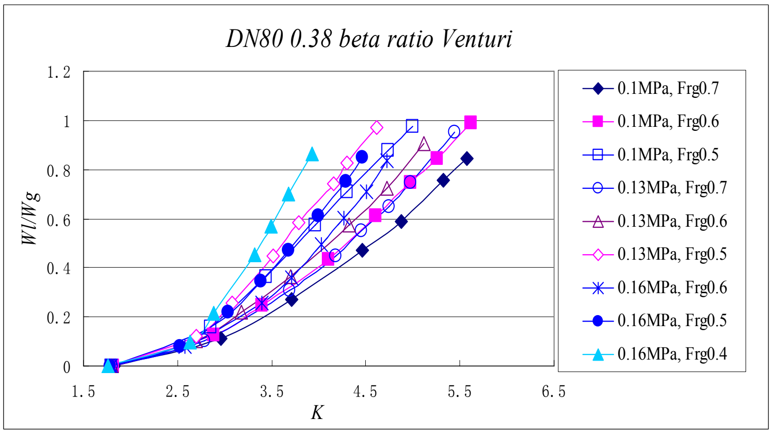

Figure 8 Relationship Between K Value and Liquid to Gas Mass Ratio

As expected, over-reading and the mass ratio of liquid to gas increase with increasing *K* value as the other parameter are equal. As the densiometric Froude number increases and other parameter of wet gas stay constant the over-reading and the liquid to gas mass ratio decrease. Therefore, the correlation of over-reading and the function of liquid to gas mass ratio can be well predicted by the data fitting of *K* value, gas to liquid density ratio (a pressure effect) and the gas densiometric Froude number in the form of equation (8) and (9).

Therefore, the gas and liquid mass flow rate can be solved by iteration of these equations. Finally the gas and liquid mass flow rate metering results are as follow. Figure 10 shows the relative error of gas mass flow rate metering result and figure 11 shows the full scale error of liquid mass flow rate metering result. The test data is divided into two groups, two thirds of the test data is used to data fit the correlations and the rest of it is used to verify the correlation. It is shown in figure 10 and figure 11 that the gas flow rate is measured to within ±2% respectively with a few outliers and the liquid flow rate is measured to within ±10% judged by full scale error.

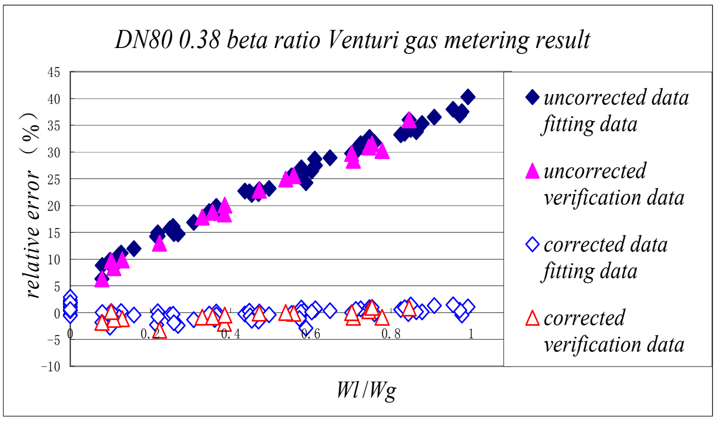

Figure 10 Relative Error of Gas Mass Flow Rate Metering Result

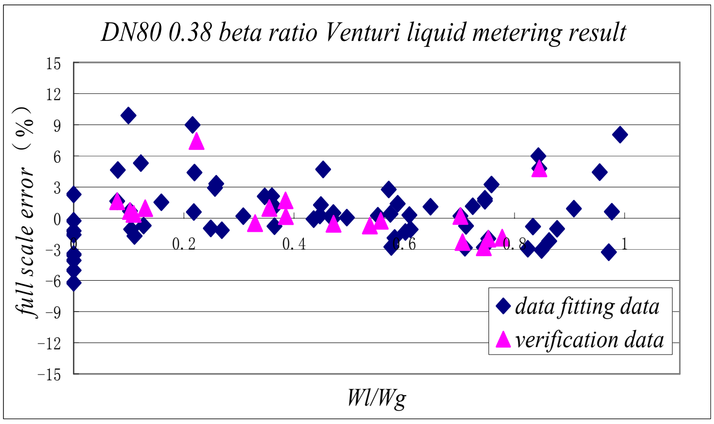

Figure 11 The Full scale Error of Liquid Mass Flow Rate Metering Result

7. Conclusion

The double differential pressures wet gas metering method based on venturi meter can realize the metering of the gas and liquid flow rates of wet gas simultaneously without separation. It is a simple and practical wet gas metering system. The experimental results show that the relative error of gas flow rates is less than ±2%, and the full scale error of liquid flow rates is less than ±10%, under the condition like the test pressure range from 0.1~0.16MPa, Froude number range from 0.4~0.7, mass ratio of liquid and gas range from 0~1.

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