Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 14 (22): 3036-3045, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.3036.3045

CFD Study of the Effect of Venturi Convergent and Divergent Angles on Low Pressure Wet Gas Metering

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Abstract: Wet gas flow measurement using differential pressure meters such as venturi meter is becoming popular in the oil and gas industry. This is because the venturi geometry is less intrusive and the flow meter calibration is minimal. In this study, the effect of venturi convergent and divergent angles on wet gas metering is studied by Computational Fluid Dynamics (CFD) modelling of the wet gas flow. Nine venturi designs with β ratio of 0.4, three different convergent angles (θ_1 = 10.5, 21, 31.5) and three different divergent angles (θ_2 = 7, 10, 15) were simulated in a horizontal pipe using the k-ε turbulence model over a range of parameters such as the Gas Volume Fraction (GVF), gas mass flow rate and pressure. ANSYS FLUENT was used to model the wet gas flow. The simulation results showed that the convergent and divergent angles have no effect on the differential pressure. However, divergent angles have influential effect on the over-reading values while convergent angles have significant effect on the discharge coefficient. The higher over-reading obtained for venturi meter indicates more sensitivity to the liquid presence in the stream which is preferable for wet gas metering. The geometry of venturi meter does not influence the prediction by the wet gas correlations. The mass flow prediction by wet gas correlations revealed that the homogeneous model and venturi correlations, Steven and De Leeuw have better performance for standard and non-standard venturi designs.

Key words: Gas valume fraction, convergent and divergent angle, venturi meter

INTRODUCTION

The general terminology of wet gas is defined as natural gas flow comprising relatively small amount of free liquid volume, whereby the GVF is greater than 90% but less than 100% (Kumar *et al*., 2011). There are two approaches employed to meter wet gas, whereby one of the approaches is to use a multiphase flow meter in wet gas whereas the other approach is to use a standard dry gas meter with corrections applied to the measurements (Fang and Zhang, 2008). It is further stated by Hua and Geng (2011) that the latter approach can be used to measure the gas flow rate with an available correlation if the liquid fraction remained reasonably constant. Many industries are still depending on bulky three phase separators to measure wet gas flow rate as significant measurement error is produced by the standard orifice when it is used for wet gas flow measurement (Kumar *et al*., 2011).

Venturi meter is a single-phase flow measurement device considered for two-phase flow measurement. According to Steven (2008), venturi meter is used to meter wet gas or two-phase flows in three ways: (1) As an individual device along with other independent systems, (2) The venturi meter is used in series with another gas flow meter that has a different liquid gas flow rate error than the venturi and (3) While the third one is the venturi meter with phase fraction devices imbedded in some part of the meter body or neighbouring spool pieces and used in wet gas mathematical model to predict the gas and liquid flow rates.

Generally, flowmeters can be classified as differential pressure, positive displacement and mass flowmeters. According to Zhang *et al*. (2010), the measuring methods for mass flowrate can be mainly divided into two types which are direct mass flowrate measurement such as the Coriolis mass flowmeter and indirect volumetric measurement methods with phase density compensation, whereby both methods have their unique advantages. However, compared to the methods mentioned above, Differential Pressure (DP) metersare better in terms of low cost, free from radiation risk, no limitation in terms of fluid conductance and clear physical interpretation (Zhang *et al*., 2010). In this case, the study will be focused on DP meter that is investigated for two-phase flow metering.

A lot of researches have been done over the years to determine the relationship and effects of diameter ratio (β-ratio), upstream velocity profile, pressure and swirls on the orifice meters. Most of these studies considered

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single phase flows rather than two-phase flows. According to Steven and Hall (2009), the performance of orifice meters in single phase flows is well documented in the standards. However, it does not perform well when it deals with some extremely adverse flow conditions (Steven, 2009). It is further proven by Steven and Hall (2009) that orifice meter wet gas response is less sensitive to changes in parameters such as β-ratio, liquid properties and gas densiometric Froude numbers compared to venturi meters and cone meters.

In the past, general two-phase flow orifice plate meter correlations were applied on venturi metering wet gas flow as the venturi correlation were still not developed. These correlations work on the same principle of using the DP meter single phase equation and applyinga correction factor based on the liquid quantity to correct the two-phase differential pressure (Steven, 2002). The findings by Steven (2002) on the correlation comparison showed that the orifice plate meter general two-phase correlations should not be implemented in wet gas metering with venturi meters.

According to Steven (2002), the de Leeuw correlation performed better than the modified Murdock correlation which is due to the wide range of wet gas conditions used in the de Leeuw correlation and took into account of pressure and gas flow rate effectsas both of these parameters have significant influence on the Venturi meter when used in wet gas flows (Steven, 2002). The data that fit this correlation with good performance is of a 4” and 0.401 diameter ratio. It was expected that a 6” and 0.55 diameter ratio venturi could fit the correlation better as these parameters affect the wet gas meter reading for given pressures and phase flow rates (Steven, 2002). It is also important to have a wet gas meter without the requirement of initial liquid flowrate as it could affect the accuracy of the correlations (Steven, 2002).

Lide *et al.* (2007) did a comparison of correlations used for venturi wet gas metering in oil and gas industry which evaluated eight correlations used in high pressure and high Lockhart-Martinelli as well as low pressure and low Lockhart-Martinelliwet gas flow. It is concluded that the gas pressure has substantial effect on meter over-reading under low pressure whereas β-value has significant effect on meter over-reading. Apart from that, Fang and Zhang (2008) researched on the performance of a horizontally mounted venturi in low pressure wet gas flow. It was found out that the over-reading under low pressure is influenced by several parameters such as Lockhart-Martinelli parameter, pressure, β value, gas Froude number and gas liquid quality ratio.

The differential pressure measured in wet gas by the venturi meter is higher than it was measured in single gas phase flowing and the over-reading of gas mass flow rate is obtained when this additional pressure drop is not corrected (Lide *et al.*, 2007). The over-reading is indicated as OR or Φ_g which was introduced by Martinelli and his co-workers, assuming the flows are incompressible, no appreciable thermal dynamic effects, the liquid flow rate is initially known and no phase change between gas and liquid (Geng *et al.*, 2006). The over-reading is defined in Eq. 1 (Lide *et al.*, 2007):

$$OR = \frac{m_g^{'}}{m_g} = \sqrt{\frac{\Delta P_{tp}}{\Delta P_g}} \tag{1}$$

where m_g is the modified gas mass flowrate, m_g’ the apparent gas mass flowrate determined from the two-phase measured differential pressure ($\triangle P_{tp}$), $\triangle P_{tp}$ is the actual two-phase differential pressures between the upstream and throat tappings, $\triangle P_g$ is the superficial gas differential pressures between the upstream and throat tappings respectively. Both m_g and m_g’ are defined in Eq. 2 and 3 (Fang and Zhang, 2008):

$$m_g = \frac{C_d \varepsilon A_T \sqrt{2\rho_g \Delta P_g}}{\sqrt{1-\beta^4}} \tag{2}$$

$$m_g^{'} = \frac{C_d \varepsilon A_T \sqrt{2\rho_g \Delta P_{tp}}}{\sqrt{1-\beta^4}} \tag{3}$$

where C_d is the discharge coefficient; A_T is the area of the venturi throat; ε is expansibility factor, ρ_g is gas density, β is diameter ratio.

Numerous studies have been conducted comparing the correlations used for venturi wet gas metering with standard and non-standard convergent angles. There has been no study investigating the combined effect of divergent angles.

Therefore, this study will focus on investigating the effect of venture convergent and divergent angles on wet gas metering. This has been done numerically using a commercial CFD software, ANSYS FLUENT.

CFD MODEL DEVELOPMENT

Geometry details: Figure 1 shows the geometry of the venturi meter used in this flow investigation. For allventuri meter, the wall thickness is 0.005 m, designed to fit Schedule 80 horizontal pipe which is equivalent to inner diameter of 0.10574 m. The geometric details of the venturi meter are summarized in Table 1.

In the present study, the venturi meter is placed between upstream pipe length of 5 D and downstream pipe length of 10 D as the specification of the boundary conditions. This is to ensure the inlet and outlet boundary conditions with no constraining effect on the flow field

Table 1: Dimensions of the venturi meter with $\beta = 0.40$

Design	Convergent Angle (°)	Divergent Angle (°)	D (m)	d (m)	x (m)	y (m)	z (m)
1A	10.5	7	0.10574	0.042296	0.03172	0.1712	0.2584
1B	10.5	10	0.10574	0.042296	0.03172	0.1712	0.1799
1C	10.5	15	0.10574	0.042296	0.03172	0.1712	0.1184
2A	21.0	7	0.10574	0.042296	0.03172	0.0826	0.2584
2B	21.0	10	0.10574	0.042296	0.03172	0.0826	0.1799
2D	21.0	15	0.10574	0.042296	0.03172	0.0826	0.1184
3A	31.5	7	0.10574	0.042296	0.03172	0.0518	0.2584
3B	31.5	10	0.10574	0.042296	0.03172	0.0518	0.1799
3C	31.5	15	0.10574	0.042296	0.03172	0.0518	0.1184

Table 2: Wet gas details

Run No.	Gas volume fraction	Air mass fraction	Air mass flow (kg sec^{-1})	Total mass flow (kg sec^{-1})
1	0.99996	0.9774	0.33	0.3376
2	0.99989	0.9436	0.33	0.3497
3	0.99982	0.9102	0.33	0.3626
4	0.99977	0.8880	0.33	0.3716
5	0.99996	0.9774	0.50	0.5116
6	0.99988	0.9436	0.50	0.5299
7	0.99979	0.9102	0.50	0.5493
8	0.99972	0.8880	0.50	0.5631
9	0.99993	0.9774	0.80	0.8185
10	0.99981	0.9436	0.80	0.8478
11	0.99966	0.9102	0.80	0.8789
12	0.99955	0.8880	0.80	0.9009
13	1.00000	1.0000	0.33	0.3300
14	1.00000	1.0000	0.50	0.5000
15	1.00000	1.0000	0.80	0.8000

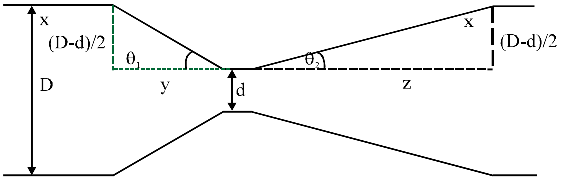

Fig. 1: Geometric details of the venturimeter

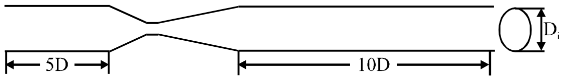

Fig. 2: 1-D schematic layout of the pipe

near the venturi. The one-dimensional (1-D) schematic layout of the pipe is as shown in Fig. 2. The geometrics of venturi meter were created in ANSYS pre-processor.

Mesh details: Grid generation is a vital issue in flow simulation as it controls the stability and accuracy of the flow predictions. The meshedgeometry ofventuri meter is as shown in Fig. 3.

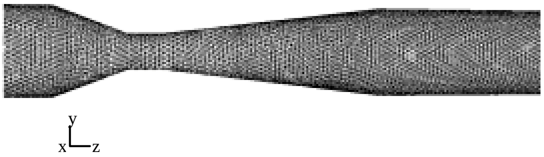

Fig. 3: Meshed geometry of venturi meter for standard venturi design 2A

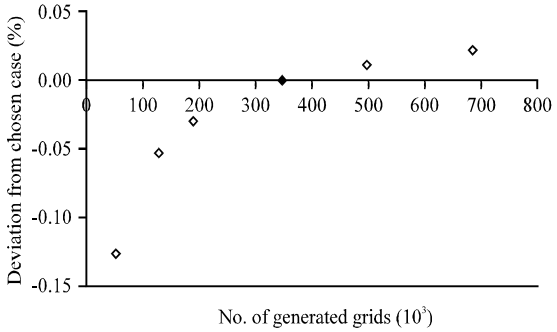

Fig. 4: Grid independence study-pressure drop result showing percentage deviation from the chosen base case versus number of grids

A grid independence study was performed for all the designs by using progressively larger number of cell elements. The results for GVF more than 99% and total mass flow rate of 0.5116 kg sec^{-1} corresponding to a pressure of 0.25 MPa is shown in Fig. 4. From Fig. 4, it can be deduced that the pressure drop increases as the number of grid increases. The marked data point (♦) indicates z the chosen mesh density for subsequent simulations. Since other designs portray the same plot as Fig. 4, thus only one plot is showed.

Governing equations: Wet gas was assumed to be Newtonian, compressible and non-reactive with constant physical properties, except density and specific heat capacity (Kumar and Bing, 2011). The non-reactive species transport model was used to model the wet gas flow, whereby GVF is greater than 90%. The wet gas details are tabulated in Table 2. Steady state simulations were carried out by solving the species transport model along with the mass, momentum and energy conservation equations. The standard k-ε turbulence model was used to model turbulence.

Boundary conditions and solution strategy: For the present study, air-water mixture at ambient temperature of 300 K was used as the working fluid and simulations were carried out by specifying the mass flow rate of the mixture including species mass fraction of water at the inlet of the horizontal pipeline (Kumar *et al*., 2011). The turbulent intensity, I and the hydraulic diameter, D_h were specified for an initial guess of turbulent quantities. The turbulent intensity was about 3% for all the cases. Outlet pressures of 0.25, 0.20 and 0.15 MPa were specified at the outlet boundary for each case. No slip boundary condition was imposed at the wall surface and the pipe wall was assumed to be perfectly smooth with zero roughness height. The commercial CFD software ANSYS FLUENT was used to solve the governing equations (Kumar and Bing, 2011).

RESULTS AND DISCUSSION

Effect of liquid mass fraction on pressure drop: Simulations were made under fully developed turbulent conditions in the horizontal pipeline equipped with venturi meter having β ratio of 0.40. The air mass flow rate and GVF were varied from 0.33-0.80 kg $\sec^{-1}$ and 0.99-1.00, respectively. The wet gas details were as shown in Table 2. The venturi meter results are compared with the standard venturi meter with the same β ratio.

The permanent head loss as a function of liquid mass fraction is as shown in Fig. 5. Since all the designs share the same pattern of plot, the effect of liquid mass fraction on pressure drop is plotted for the standard venturi design 2A only. It can be observed that the head loss increases when the liquid mass fraction increases. The head loss increases more when the gas Froude number is higher. The convergent and divergent angles seem to have significant effect on the pressure drop. Wet gas flow through venturi meter is led through a contraction section to a throat with a smaller cross section. In this case, the velocity in the throat is higher which led to reduction in static pressure.

Effect on wet gas Over-Reading (OR): The dominant factors of gas meter OR are gas-liquid ratio in the wet gas flow and gas flow rate. The gas-liquid ratio in the wet gas is expressed in the form of Lockhart-Martinelli parameter (X_{LM}) whereas the gas flow rate is defined using the gas Froude number.

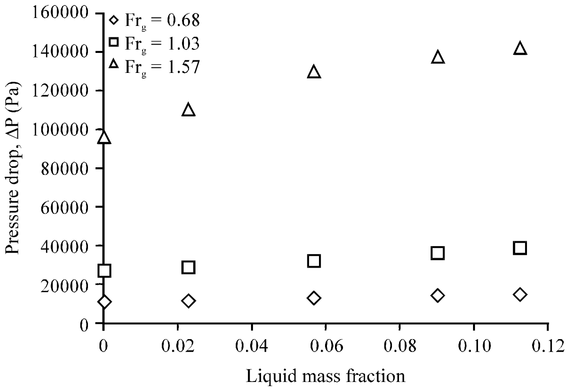

Fig. 5: Effect of liquid mass fraction on pressure drop for standard design 2A for P = 0.25 MPa

These two dimensionless parameters are effective in evaluating the performance of wet gas meter as they take into consideration of the effects of gas to liquid density ratio in the stream. Figure 6a-c show the effect of Froude number on OR as a function of X_{LM}. Since all the designs have the same pattern of plot, only one design which is the standard design 2A, is shown for each pressure in this case.

It can be deduced that the OR of each design increases with the increase of Lockhart-Martinelli parameter. However, the plot pattern of each pressure is different due to different gas Froude number. This is mainly due to low gas liquid density ratio under low pressure. It can be easily seen (Fig. 6), that the OR values increase with increasing order of Fr_g values. But the effect decreases as the pressure increases from 0.15-0.25 MPa. The gas velocity under low-pressure is higher compared to the higher pressure which indicates that OR is affected by the gas Froude number.

Figure 7-9 illustrate the effects on over-readings for different venturi designs as a function of Lockhart-Martinelli parameter at different Froude numbers for three pressures. The venturi meter in low pressure (0.15 MPa) is found to have higher OR compared to 0.20 and 0.25 MPa for lower portion of average Froude number (Fr_g = 0.77) as shown in Fig. 7. It can be observed from Fig. 8 that the OR is increasing with the low gas Froude number. This is supported by Fang and Zhang (2008), whereby OR under low pressure is higher than that under high pressure. However, there is no significant change in variation of the data sets which means the convergent and divergent angles of venturi has no effect in terms of lower range of Froude number.

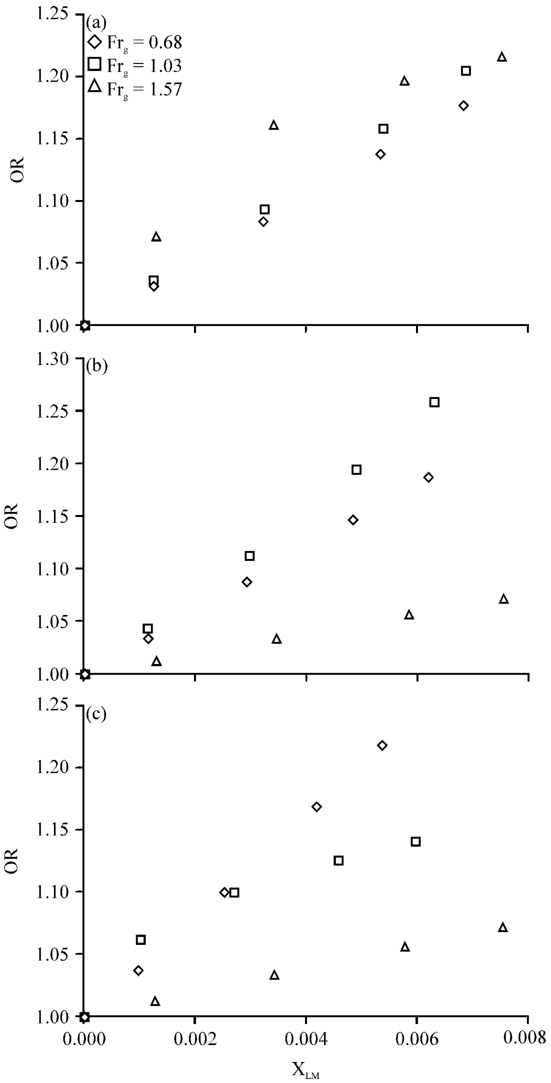

Fig. 6(a-c): Effect of Fr$_g$ on over-reading values for standard design 2A as a function of Lockhart-Martinelli parameter for (a) P = 0.25 MPa, (b) P = 0.20 MPa and (c) P = 0.15 MPa

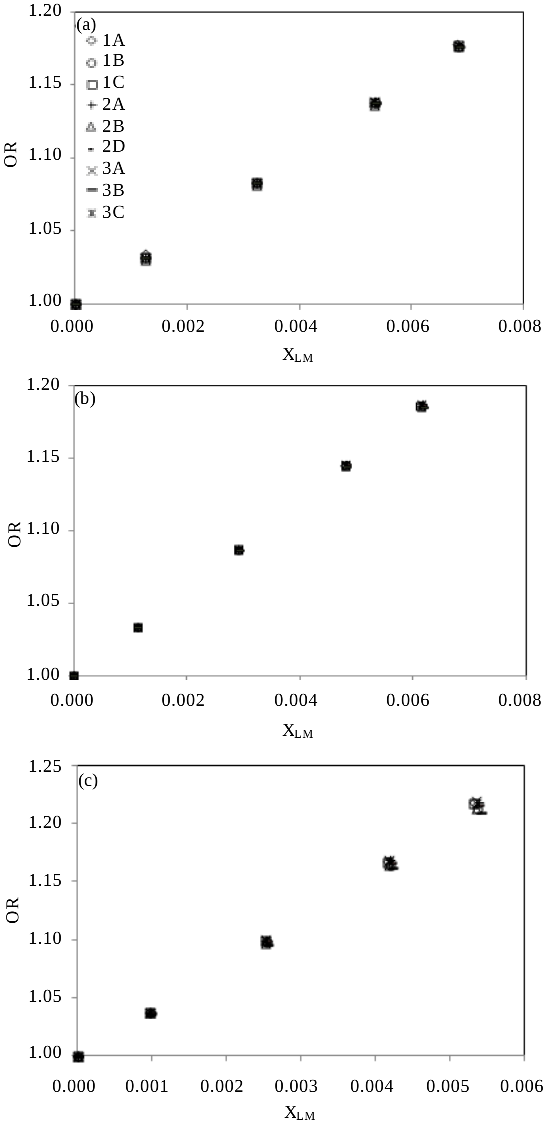

Fig. 7(a-c): Over-reading values for different venturi designs as a function of Lockhart-Martinelli parameter at Fr$_g$ = 0.77 for (a) P = 0.25 MPa, (b) P = 0.20 MPa and (c) P = 0.15 MPa

From Fig. 8, venturi meter in 0.20 MPa is found to have the highest OR which is approximately 1.25 MPa. It is also observed that the OR values in 0.15 MPa is not increasing constantly as shown by the OR in 0.20 and 0.25 MPa. For the OR with average Froude number more than 1 (Fr$_g$ = 1.14) for 0.15 MPa, the divergent angle seems to have effect on the different designs. The divergent angle of 15° (Design 3C) has higher OR followed by 10° and 7°. It is observed that the sensitivity of data increases when Lockhart-Martinelli parameter is more than 0.002 with decreasing pressures. This can be deduced that the venturi design with larger divergent angle in middle range of gas Froude number is more sensitive to the liquid presence compared to the standard venturi design.

Based on Fig. 9, venturi meter in 0.25 MPa has the highest OR compared to 0.20 and 0.15 MPa which is around 1.25. The OR trends for venturi design in 0.25 and 0.20 MPa are relatively similar while the OR in 0.15 MPa is constant for all designs except design 3C. The exceptional OR values for design 3C might due to large convergent

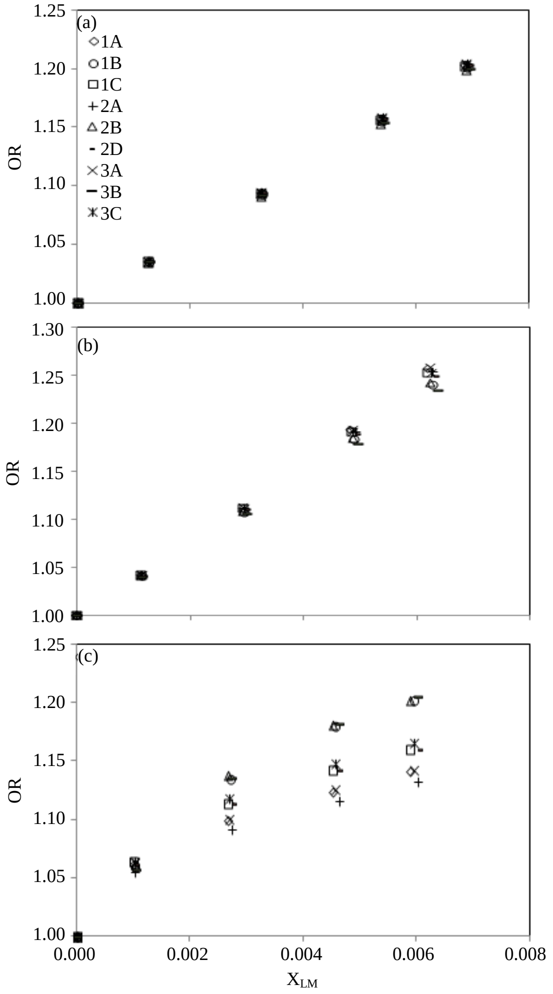

Fig. 8(a-c): Over-reading values for different venturi designs as a function of Lockhart-Martinelli parameter at $Fr_g = 1.14$ for (a) P = 0.25 MPa, (b) P = 0.20 MPa and (c) P = 0.15 MPa

and divergent angles. It is observed that the difference in OR values for divergent angle of 15° is obvious (Fig. 9a and b) when the Lockhart-Martinelli parameter is greater than 0.004 with increasing pressure. This indicates the sensitivity of venturi with larger divergent angle increases with increasing pressure. In this case, it can be deduced that venturi with larger divergent angle in high Froude number ($Fr_g = 1.57$) is more sensitive to the liquid presence in higher pressure (0.25 MPa).

Effect on wet gas discharge coefficient: Discharge coefficient (C_d) can be affected by gas flow rate and gas-liquid ratio as well. The discharge coefficient can be re-arranged from Eq. 2 to the following equation:

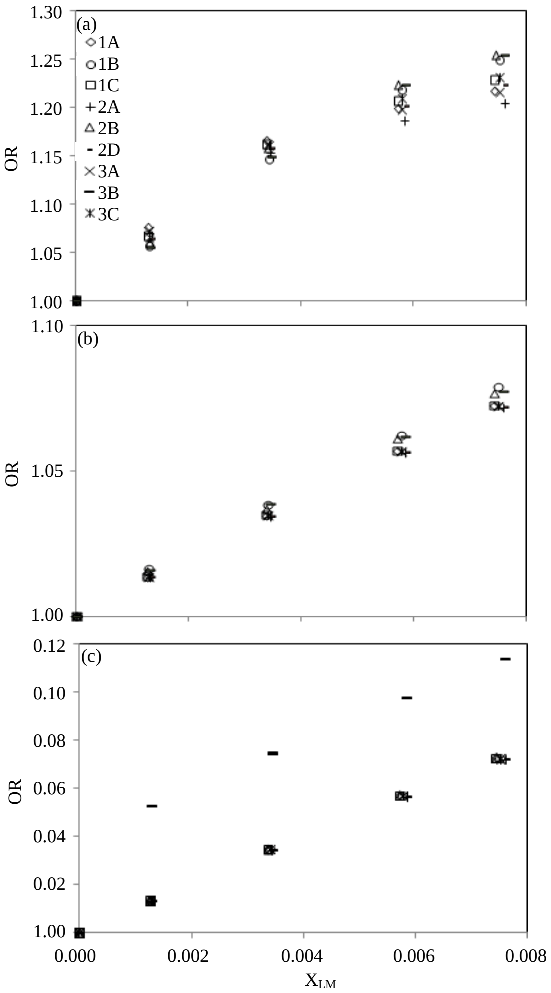

Fig. 9(a-c): Over-reading values for different venturi designs as a function of Lockhart-Martinelli parameter at $Fr_g = 1.57$ for (a) P = 0.25 MPa, (b) P = 0.20 MPa and (c) P = 0.15 MPa

$$Cd = \frac{m_g\sqrt{1-\beta^4}}{\varepsilon A_T\sqrt{2\rho_g\Delta P_g}} \quad (4)$$

Figure 10a-c illustrate the effects on discharge coefficient (C_d) for different venturi designs as a function of Lockhart-Martinelli parameter at a Froude number of 0.77, for three pressures. It can be seen that as Lockhart-Martinelli parameter increases, the discharge coefficient decreases for all the designs at all the three different pressures. It shows that the discharge coefficient is the highest in 0.25 MPa, followed by 0.20 and 0.15 MPa. In this case, convergent angle has an effect on discharge coefficient, whereby the design with smaller convergent

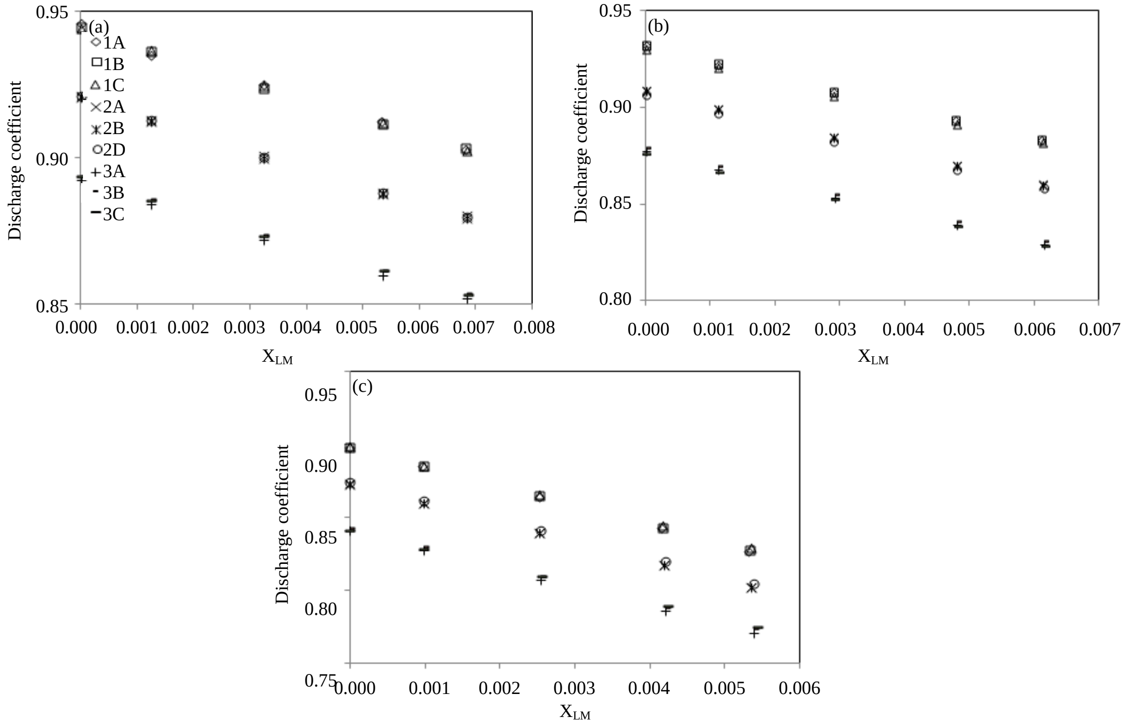

Fig. 10(a-c): Discharge coefficient values for different venturi designs as a function of Lockhart-Martinelli parameter at $Fr_g = 0.77$ for (a) P = 0.25 MPa, (b) P = 0.20 MPa and (c) P = 0.15 MPa

Table 3: RMS fractional deviation for all venturi designs at P = 0.25 MPa

Correlations	1A	1B	1C	2A	2B	2D	3A	3B	3C
Homogeneous	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375
Steven	0.0397	0.0397	0.0397	0.0397	0.0396	0.0396	0.0396	0.0396	0.0396
De Leeuw	0.0525	0.0525	0.0525	0.0526	0.0526	0.0526	0.0526	0.0526	0.0526
Steven (modified)	0.0623	0.0622	0.0622	0.0622	0.0622	0.0622	0.0622	0.0622	0.0621
Chisholm	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0666	0.0666	0.0666
Lin	0.0676	0.0676	0.0676	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675
Modified Murdock	0.0701	0.0701	0.0701	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
Murdock	0.0712	0.0712	0.0712	0.0712	0.0712	0.0711	0.0711	0.0711	0.0711
Smith and Leang	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995

angle (10.5°) has the higher discharge coefficient. Similar observations are made with higher higher Fr_g (1.14 and 1.57). But the discharge coefficient of venturi is found to be higher at high pressure and low Froude number ($Fr_g<1$).

Gas mass flow prediction using wet gas correlations: The gas mass flow rate predicted by nine wet gas correlations can be compared using Root Mean Square (RMS) fractional deviation (δ) as expressed in Eq. 5:

$$\delta = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{m_{g(predicted)i} - m_{g(actual)i}}{m_{g(actual)i}}\right)^2} \qquad (5)$$

where, n is the number of simulation runs performed for each design of venturi which is 15 runs in this study. The deviations of each correlation for each individual data set are obtained from the independent simulation results. The results are as tabulated in Table 3-5 for three pressures studied.

From Table 3-5, it is observed that the convergent and divergent angles do not influence the prediction by the correlations. Only ±0.0001 of RMS fractional deviation is applied to some of the designs which can be considered negligible. It can be deduced that as the pressure increases, the RMS fractional deviation decreases for all correlations except homogeneous model and Smith and Leang correlation. It is expected that the venturi correlations such as Steven and De Leeuw correlations to perform better than the orifice correlations. However, the Modified Murdock correlation did not perform well in comparison. This might due to De Leeuw correlation covers the data from wide range of wet gas conditions (Steven, 2002).

Apart from that, it is interesting that the homogeneous model has the best performance compared to others. This is due to the fact that homogeneous model treats the two phase flow as single phase flow by using a homogeneous density expression and it does not take into consideration of flow pattern which is an important point to consider when correcting the differential pressure error (Steven, 2002). This is supported by the results reported by Steven (2002). The remaining correlations which are the empirically modified Steven's correlation, Chisholm, Lin, Modified Murdock, Murdock and Smith and Leang did not perform as well as Steven or De Leeuw correlations due to fewer parameters are considered. The poor performance of those correlations mentioned denotes the different behaviour of wet gas flow from the general two-phase flow. The assumption of stratified flow condition might be one of the factors that attributed to the correlations' performance. It is shown that the Smith and Leang correlation has the poorest performance among all correlations which indicates that the blockage factor equation is not suitable to predict the wet gas flow through venturi meter. The plots of the ratio of predictedto actual gas flow rate against Gas Volume Fraction (GVF) are as shown in Fig. 11a-c.

Figure 11 shows the decreasing trend of ratio of predicted to actual gas flow rate with respect to GVF

Table 4: RMS fractional deviation for all venturi designs at P = 0.20 MPa

Correlations	1A	1B	1C	2A	2B	2D	3A	3B	3C
Homogeneous	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375
Steven	0.0403	0.0403	0.0403	0.0403	0.0403	0.0403	0.0402	0.0402	0.0402
De Leeuw	0.0528	0.0528	0.0528	0.0529	0.0529	0.0529	0.0529	0.0529	0.0529
Steven (modified)	0.0630	0.0630	0.0629	0.0629	0.0629	0.0629	0.0629	0.0629	0.0628
Chisholm	0.0671	0.0671	0.0671	0.0671	0.0671	0.0670	0.0670	0.0670	0.0670
Lin	0.0682	0.0682	0.0682	0.0682	0.0682	0.0681	0.0681	0.0681	0.0680
Modified Murdock	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0704	0.0704	0.0704
Murdock	0.0716	0.0716	0.0716	0.0716	0.0715	0.0715	0.0715	0.0715	0.0715
Smith and Leang	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995

Table 5: RMS fractional deviation for all venturi designs at P = 0.15 MPa

Correlations	1A	1B	1C	2A	2B	2D	3A	3B	3C
Homogeneous	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375
Steven	0.0408	0.0408	0.0408	0.0408	0.0408	0.0408	0.0407	0.0407	0.0407
De Leeuw	0.0531	0.0531	0.0531	0.0532	0.0532	0.0532	0.0532	0.0532	0.0532
Steven (modified)	0.0637	0.0637	0.0637	0.0637	0.0637	0.0636	0.0636	0.0636	0.0636
Chisholm	0.0674	0.0674	0.0674	0.0674	0.0674	0.0674	0.0673	0.0673	0.0673
Lin	0.0687	0.0687	0.0687	0.0687	0.0687	0.0687	0.0686	0.0686	0.0686
Modified murdock	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0708	0.0708	0.0708
Murdock	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0718	0.0718	0.0718
Smith and Leang	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995	0.0995

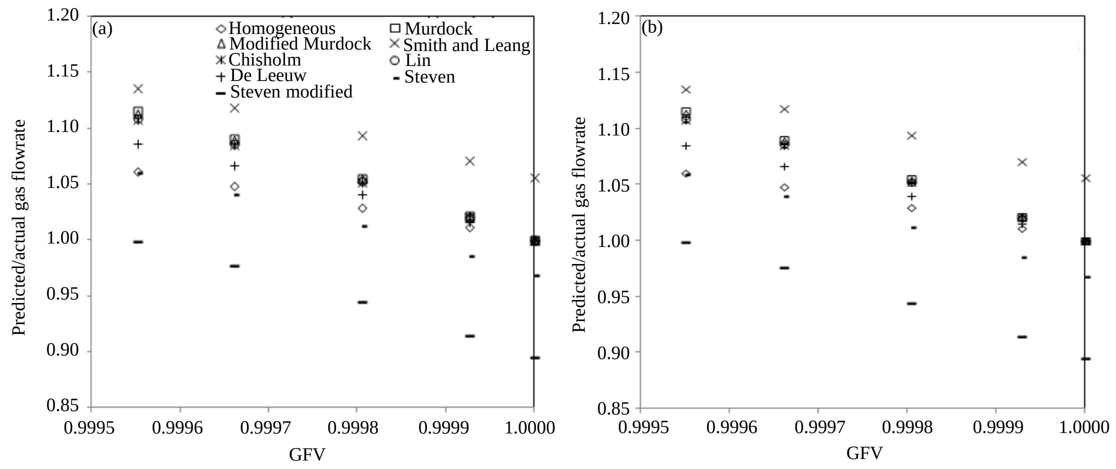

Fig. 11(a-c): Continue

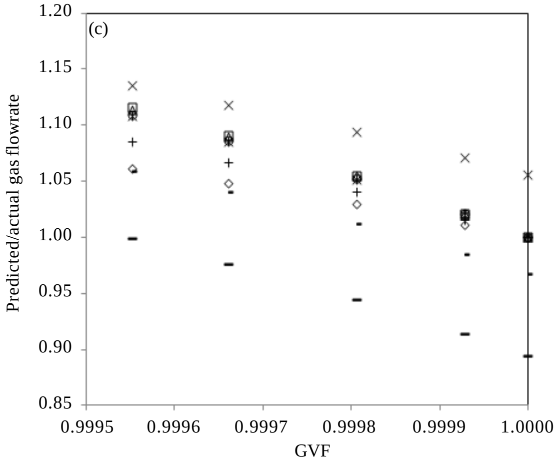

Fig. 11(a-c): Comparisons of wet gas correlations at Fr_g =1.57 for (a) 0.25 MPa, (b) 0.20 MPa and (c) 0.15 MPa

regardless of pressure of the gas. This indicates that the pressure has no effect on the wet gas correlations. Dry gas flow (GVF = 1) is predicted well by all correlations except Steven, empirically modified Steven and Smith and Leang correlations. They failed to predict a zero error situation for dry gas properties. The Smith and Leang correlation over-predicts whereas Steven and Steven modified correlations under-predict the ratio of predicted to actual gas flow rate.

CONCLUSION

The effect on OR and discharge coefficient of venturi meter has been studied by CFD modelling of the wet gas flow. The numerical results show that higher pressure flow (0.25 MPa) has lower pressure drop with increasing liquid mass fraction. The venturi design with divergent angle of 15° has higher sensitivity compared to 10° and 7°. It is found to be more sensitive at a higher pressure (0.25 MPa) at Lockhart-Martinelli parameter more than 0.002. It can also be concluded that venturi with larger divergent angle for higher Froude number is more sensitive to the presence of liquid. Apart from that, venturi design with smaller convergent angle of 10.5° has higher discharge coefficient and it is higher at high pressure (0.25 MPa). Therefore, it can be concluded that small convergent angle (10.5°) with large divergent angle (15°) is more sensitive to the liquid presence and thus, preferable for wet gas metering. Apart from that, the performance of wet gas correlations with standard and non-standard venturi design for low pressure wet gas metering by using the homogeneous model yields the best performance at higher pressure (0.25 MPa). Nevertheless, the pattern should be taken into consideration so that the differential pressure error can be corrected. The venturi correlations such as Steven and De Leeuw correlations are found to perform better than orifice correlations as they are the designated correlations for venturi meter. In addition, the RMS fractional deviation at 0.25 MPa is the least and the homogeneous model and Steven correlation have the best performance as their RMS values are smaller compared to others.

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