GAS-LIQUID FLOW MEASUREMENT BY MEANS OF THE DUAL PRESSURE DROP TECHNIQUE: VARIANCE ANALYSIS OF OUTPUT PARAMETERS FROM INPUT PARAMETERS.

André Pianissolla Zorzal
Universidade Federal do Espírito Santo
andre_zorzal@yahoo.com.br

Rogério Ramos
Universidade Federal do Espírito Santo
ramosrogerio@hotmail.com

Márcio Coelho de Mattos
Universidade Federal do Espírito Santo
marcio.mattos@ufes.br

Abstract. *The multiphase flows measurement is a current technological challenge, especially to valuable oil and gas flows. Among diverse technologies which measure the flow of each phase, in a so-called gas-liquid two-phase flow, the dual pressure drop technique has been prominent in the industry, mainly due to its simplicity, robustness, price and for being non-radioactive, unlike some models available on the market. In order to understand the uncertainty of this type of flow measurement, it is important to estimate the sensibility of each variable in the whole measurement process. The evaluation of the variability of the differential pressure taps (basics input parameter on the model) was performed through random disturbances and the consequent variability in the measurement of the void fraction and the total volumetric flow (output parameters) were computed by a meter model found in the open literature. It was found that, using this dual pressure drop model, the variability in the pressure drops with a standard deviation (SD) of 1% returns void fraction SD of 2.69% to 9.33%, and 1.15 to 8.02% for the velocity, depending on the flow condition. It was also observed that larger SD for the void fraction are found when the void fraction is low (<0.5) and larger SD for the velocity when the void fraction is high (> 0.5) comparing to same fluctuations.*

Keywords: *Flow Measurement, Multiphase Flow, Homogenous Two-Phase, Gas-Liquid, Variance Analysis.*

1. INTRODUCTION

The flow measurement in a multiphase flow is complex and contains more than one measurement device. One single-phase measurement flow device is not enough to measure the mass flow of each phase. Thus, the traditional flow measurement devices in single phase flows, such as Orifice Plate and Venturi, leads to uncertainty when are used to measure wet gas (a two-phase flow) without a specific correction factor that can be estimated with the support of others devices [Steven, 2002].

There are three mains possibilities of measuring a multiphase flow among available alternatives. First, to make all measurements when the flow is in its natural state (no perturbation). Second, to homogenize the mixture to make all phases velocities equal. Third, to separate the phases and measure each individual phase using single-phase techniques [Boyer & Lemonier, 1996].

The second possibility has good relation complexity and accuracy. A simple set of devices which contains a mixer (before the meter), an anemometry and a volumetric fraction meter device. Although this method has simple technology, has limited uncertainty due to the hypothesis of non-slip and homogenous flow [Falcone, et al, 2009].

It is known that multiphase flows have unstable flow conditions and, for example, the pressure measurement will never be a constant even in permanent regimes. This work is objected in the study of sensibility of the flow measurement when using a double pressure drop technology with fictional simulations of measurement condition. More about this method is discussed in the section 2.3, but, in order to clarify, the double pressure drop is capable of metering the velocity and the fraction of the flow when the hypothesis of homogenous and non-slip flow are assumed.

2. PRESSURE DROP

First, is remembered the equations used for single phase flow measurement when using pressure drop technology. Then, section 2.2 explains about the double pressure drop equations for two-phase gas-liquid flows.

2.1 Single phase

It is known that the measurement of the mass flow rate in a single phase flow can be measured by one pressure drop device. The mass flow rate is demonstrated in Eq. (1), where: $\dot{m}$ is the mass flow rate, C_D is the discharge coefficient, A is the area of the through, β diameter ratio between the through and the pipe, ρ is the density of the fluid, Δp is the pressure drop measured, Y is the expansibility of the fluid and F_a is the thermal expansion factor. If the fluid is incompressible and considered an adiabatic process, the Equation of the mass flow rate can be reduced to Eq. (2) (Fox, et al. 2010).

$$\dot{m} = \frac{C_D \cdot A \cdot Y \cdot F_a}{\sqrt{1-\beta^4}} \sqrt{2\rho \cdot \Delta p} \tag{1}$$

$$\dot{m} = \frac{C_D \cdot A}{\sqrt{1-\beta^4}} \sqrt{2\rho \cdot \Delta p} \tag{2}$$

The pressure loss along the pipe can be represented by the Eq. (3). *L* is the length of the pipe, *D* the diameter, *V* velocity, *f* friction factor and *hl* is the pressure loss per density. The friction factor was studied by many authors like Blasius (apud Moody, 1944), Nikuradse (apud Moody, 1944), Colebrook (1939) and Moody (1944) and are studied until today especially on the transition laminar-turbulent zone.

$$hl = f \frac{L}{D} \frac{V^2}{2} \tag{3}$$

2.2 Two-Phase Gas-Liquid

Lockhart and Martinelli (1949) noted an increasing of pressure drop as the increasing of the liquid phase presence when the fluid passes by an obstruction (Orifice Plate, Venturi, V-Cone), in a two-phase flow. Murdock (1962) and James (1965) proposed equations that correlate the pressure drop with the flow rate depending on the liquid presence, Lockhart-Martinelli parameter, void fraction or quality. A considerable number of correlations were developed afterwards. Each equation reaching the uncertainty related to the respective conditions and limitations.

Specifically in the two-phase flow, the so-called Wet Gas, which is considered to behave as single phase, has been studied recently focusing in the measurement of the flow on a more precise way by R. Steven (Steven, 2002) (Steven, 2007).

The pressure loss along the pipe for two-phase gas-liquid has the same idea of single phase using equations of authors or the Moody diagram. The Reynolds Number, needed to estimate the friction factor on a two-phase flow with hypothesis of homogenous flow, can be determined by the Eq. (4). Re_{TP} is the two-phase Reynolds Number, ρ_{TP} is the two-phase density, μ_{TP} is the two-phase viscosity, $\overline{V}$ is the average velocity and *D* is the diameter. There are a considerable number of correlations for the two-phase viscosity. Saisorn and Wongwises (2008) tested some of these correlations, so did Spedding et al. (2006). Both found better results with the Beattie and Whalley (1982) correlation.

$$\mathrm{Re}_{TP} = \frac{\rho_{TP} \cdot \overline{V} \cdot D}{\mu_{TP}} \tag{4}$$

2.3 Double Pressure Drop Two-Phase Gas-Liquid Measurement

When the flow is two-phased, a single meter based on pressure drop technology (orifice plate, venturi) is not enough to measure the actual flow rate. In such case, two variables are needed to solve the flow rate: the velocity and the void fraction. One pressure drop equation but two variables is not enough to solve the two phase flow rate and, from this conclusion, comes the idea of adding another pressure drop and another equation. So, the double pressure drop technology is a technique that uses not one but two equations to estimate the flow rate.

Davis and Wang (1994) proposed a model of two equations that together are supposed to solve the velocity and the void fraction in a two-phase fluid by means of a two pressure drop devices. The scheme can be seen in the Fig. 1. The first pressure drop occurs due to an obstruction in a throat, and the second pressure drop occurs due to pressure loss along a straight pipe.

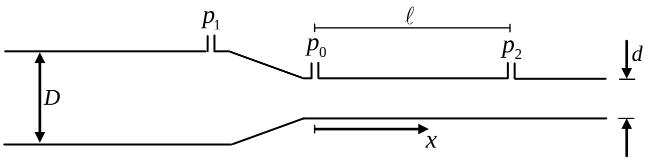

Figure 1. Scheme of the double pressure drop technique that measure a two-phase flow by Davis and Wang (1994).

Figure 1 shows two different processes. One has a dynamic pressure drop between p_1 and p_0, the other presents loss pressure drop between p_0 and p_2 (considering horizontal flow). *D* is the input pipe diameter, *l* is the length of the output pipe and *d* is the output pipe diameter.

Davis and Wang (1994) understood that since the gas phase is compressible, it wouldn't be prudent to be modeled as incompressible even with the liquid being compressible. More details of the equation sequence are found in the work (Davis & Wang, 1994). Since the gas is compressible, the density of the two-phase flow is a function of pressure and can be described in Eq. 5 (Davis & Wang, 1994). ρ_{TP} is the density of the fluid on a pressure p. ρ_{TP0} is the density of the fluid on a referenced pressure p_0. α_0 is the void fraction of the fluid on a referenced pressure p_0. Which means that the void fraction also changes with pressure, and that is correct because the gas is compressible and to maintain the mass conservation in a different pressure and density, the velocity and void fraction of the flow would also change. So, the density of the fluid will change as the condition (pressure) of the flow change.

$$\rho_{TP} = \rho_{TP0}\left[1-\alpha_0+\alpha_0\left(\frac{p_0}{p}\right)^{\frac{1}{n}}\right]^{-1} \tag{5}$$

The first pressure drop happens on the throat and has dynamic transfer with mass conservation. The equation proposed by Davis and Wang (1994) is shown on Eq. 6. A_1 is the pipe diameter and A_0 is the diameter of the throat as you can see in the Fig. 1. D_0 is called by the authors by dynamic flux and has the following formula: $D_0 = {\rho_{TP0} \cdot u_0^{\,2}}\big/{p_0}$. The velocity of the flow will be expressed by the dynamic flux and is notorious in the equation that the velocity (D_0) is a function of the pressure and void fraction confirming the need of another pressure drop or a fraction meter.

$$\frac{D_0}{2}\left[\left(1-\alpha_0+\frac{\alpha_0\cdot p_0}{p_1}\right)^2\left(\frac{A_0}{A_1}\right)^2-1\right]=\phi_n^{\,2}\left[(1-\alpha_0)\left(1-\frac{p_1}{p_0}\right)-\alpha_0\ln\left(\frac{p_1}{p_0}\right)\right] \tag{6}$$

The second pressure drop is related to losses in a strait pipe. The equation proposed by Davis (Davis, 1974) the pressure drop is shown in Eq. 7. *f* is the friction factor.

$$\frac{f\cdot l}{d}=\frac{1}{D_0}\left[\Delta\cdot A(\hat{p}_2-1)-\frac{2A\cdot\Delta^2}{a_1}I+B\ln\left(\frac{\hat{p}_2^{\,2}+a_2\hat{p}+b_2}{1+a_2+b_2}\right)\right]+\frac{1}{2}\ln(\hat{p}_2)-\frac{1}{4}\ln\left(\frac{\hat{p}_2^{\,2}+a_2\cdot\hat{p}+b_2}{1+a_2+b_2}\right) \tag{7}$$

Where the parameters are defined as:

$$a_1=\sqrt{\frac{F_0\cdot f}{2}} \qquad b_1=2(1-\alpha_0)\alpha_1 \qquad A=-\frac{1-\alpha_0}{\alpha_0}$$

$$a_2 = 4(1-\alpha_0)\Delta \qquad b_2 = 2\alpha_0 \cdot \Delta \qquad B = \frac{\Delta}{2} - \frac{\Delta^2}{\alpha_0 \cdot F_0 \cdot f}$$

$$\Delta = \frac{2\alpha_0 \cdot a_1^{\,2}}{b_1^{\,2}+1} \qquad I = \tan^{-1}\left(\frac{a_1 \cdot \hat{p}_2}{\Delta} + b_1\right) - \tan^{-1}\left(\frac{a_1}{\Delta} + b_1\right) \qquad F_0 = \frac{u_0^{\,2}}{g \cdot d \cdot sen(\theta)}.$$

It is a more complex equation than the first one, for single-phase flow, but the relation between the pressure with velocity and void fraction is also clear. Then, two equations (Eq. 6 and Eq. 7) relate the pressure, velocity and void fraction, of which the pressure is a measured variable. So, solving equations 6 and 7, it is possible to estimate the void fraction and velocity of the flow and consequently the mass flow rate of each phase.

3. SIMULATIONS, RESULTS AND VARIANCY ANALISYS

A computational code was developed to solve the two equations (Eq. 6 and Eq. 7) for velocity and void fraction. Is possible to isolate the velocity in Eq. 6 but even replacing it on the second equation is not possible to isolate the void fraction in function of pressure only because it is an implicit equation. So, the complete solution is numerically reached by iterations. In this way, providing fictional pressures measuring, the second equation has only the void fraction as variable. So, the solution is found when the right side of the equation is equal to the left side, within an acceptance criterion.

Therefore, the flow measurement of a two-phase flow using the double pressure drop technology has a simple idea. A set of geometric parameters, fluid properties and measured parameters (flow conditions) has a solution for the velocity and the void fraction.

With the objective to compare the results obtained by the computational code, a single-phase flow condition was tested. Since it is a single-phase, with geometry and liquid fluid properties well established, it is possible to prevent the pressure drop on the obstruction (Orifice Plate and Venturi) and due to the strait pipe (pressure loss) for each velocity level. Loading this pressure drops as inputs on the program leads to solutions for velocity and void fractions very closed to the pre-established data, reaching average differences about 0.007%.

Also aiming code test, simulations using data and conditions published by Davis and Wang (1994) of two-phase flow, were also compared to the program output. For comparison, arbitrarily selected points were chosen to be simulated. The points can be seen in Fig. 2, which represents one of the map results described by Davis and Wang (1994), the selected points marked on. The present results reaches a difference about 0,8% when compared to those expressed in the article. So, the outputs of the program are considered satisfactorily closed to the expected.

In order to obtain data for the variance analysis, the program simulated random values, generated with a known standard deviation (SD) of pressure drop (input) and the output (velocity and void fraction) was generated and recorded. The results of variation of input and output were analyzed. The analysis was executed under arbitrary conditions: low, intermediate and high value for the dynamic flux (velocity = 0.1, 0.2 and 0.3, respectively) and for the void fraction (0.3, 0.5 and 0.7, respectively). Each one combining with other parameters, taking a wide range of spaced points.

The standard deviation varies depending on the condition analyzed and has a limit to operate. For example, when the dynamic flux is low, only a low standard deviation will find all correct output. A larger deviation would leads to unviable solutions as can be seen on Fig. 3. The combination of the points and the standard deviation can be better understood by the following definitions (for this demonstration, final results are included, as well):

- D_0 = 0.1 and α =0.3 (SD = 0.2%); α = 0.5 (SD = 0.2%, 0.3%); α =0.7 (SD = 0.2%);
- D_0 = 0.2 and α =0.3 (SD = 1%, 2%); α = 0.5 (SD = 1%, 2%, 3%); α =0.7 (SD = 1%, 2%);
- D_0 = 0.3 and α =0.3 (SD = 1%, 2%, 3%); α =0.5 (SD = 1%, 2%, 3%).

Pressures drop in the obstruction and at straight pipe are the variables inputs that are analyzed joint to the corresponding output. The fixed parameters used for all simulations are listed in Tab. 1, as defined in Davis and Wang, 1994.

T is the temperature, R the gas constant, g gravity, μ_L is the viscosity of the liquid phase, $\rho_L$is the density of the liquid phase, d is the diameter of the throat, D the diameter of the pipe, L is the length of the straight pipe and p_0 is the static pressure.

The results for low values of dynamic flux (D_0 = 0.1) are shown in Tab.2 . The standard deviation around 0.2% is explained due to the small feasible domain. Only for the middle value (α = 0.5) it was possible to simulate with a wider SD (0.3%), but not very higher. Also by the same reason, the friction factor, in this case, was considered uniform in each condition with the valor of 0.006. Any little change in the friction factor leads to unviable solution.

Table 1. Fixed parameters in all simulations of the program that solve Davis and Wang model.

T (K)	293	μ_L (Pa s)	0.001003	D (m)	0.0381
R (J/Kg K)	287	ρ_L (Kg/m³)	997	L (m)	2.54
g (m/s²)	9.81	d (m)	0.0254	p_0 (kPa)	200

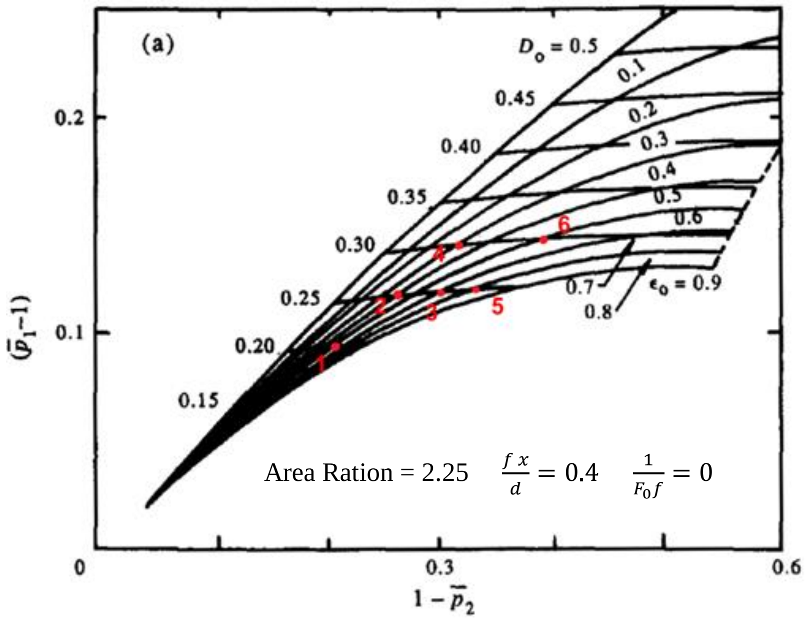

Figure 2. Selected points presentation marked on one of the article's maps in Davis and Wang (1994). Adapted from Davis and Wang (1994).

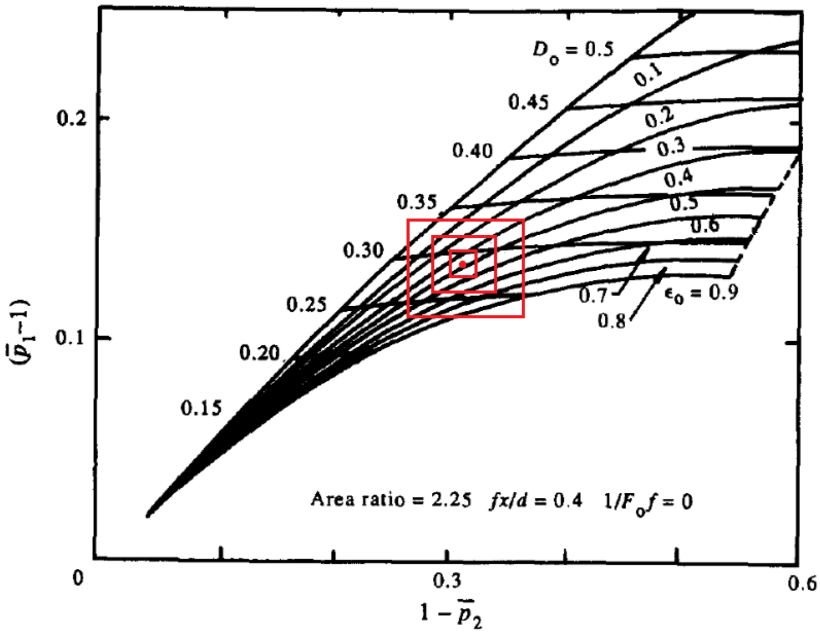

Figure 3.Representation of the variance around one point depending on the standard deviation. Adapted from Davis and Wang (1994).

Table 2. Results from the simulations for low value of dynamic flux (0.1) and 0.2% of standard deviation.

$\overline{\Delta P}_C$ (Pa)	2500	2500		2500
$\overline{\Delta P}_T$ (Pa)	7570	7625		7690
α	0.3135	0.4953		0.7071
$\bar{V}$ (m/s)	3.0096	3.5042		4.5861
f	0.006	0.006		0.006
$\sigma_{\Delta P_C}$	0.192%	0.202%	0.305%	0.203%
$\sigma_{\Delta P_T}$	0.196%	0.199%	0.312%	0.214%
σ_α	14.85%	9.68%	15.12%	7.50%
$\sigma_{\bar{V}}$	3.70%	5.30%	9.06%	10.44%

In Tab. 2, $\sigma_{\Delta P_C}$ is the standard deviation (SD) of the contraction. $\sigma_{\Delta P_T}$ is the SD of the pressure loss at strait pipe. σ_α is the SD of the estimated void fraction. $\sigma_{\bar{V}}$ is the SD of the estimated velocity. It is notorious that, from Tab. 2, with an average SD of 0.2% in the pressure drop resulted in much higher SD for the outputs variables void fraction and velocity.

Table 3. Results from the simulations for intermediate value of dynamic flux (0,2) with 1, 2% of standard deviation.

$\overline{\Delta P}_C$ (Pa)	16000		16000			16000	
$\overline{\Delta P}_T$ (Pa)	43000		50000			62000	
α	0.3040		0.5164			0.7174	
$\bar{V}$ (m/s)	7.4919		8.9113			11.5519	
f	0.0049		0.0053			0.0058	
$\sigma_{\Delta P_C}$	1.04%	2.10%	0.92%	1.96%	2.90%	0.95%	1.91%
$\sigma_{\Delta P_T}$	0.91%	2.17%	1.00%	2.14%	2.86%	1.00%	1.92%
σ_α	9.33%	21.69%	5.37%	11.46%	14.55%	3.13%	6.13%
$\sigma_{\bar{V}}$	1.95%	4.86%	2.74%	6.04%	9.86%	4.06%	8.02%

Since the solution domain is wider when the dynamic flux is 0.2 than when it is 0.1, it was possible for the standard deviation for the pressure drop to be higher: 1% and 2% (3% when void fraction is 0.5). The friction factor in Tab. 3 is constant for each void fraction separately for the average condition, but not for all simulations as in Tab. 2. In the same way it is observed in Tab. 2, the Tab. 3 shows a decreasing SD for the void fraction and an increasing SD for the velocity as is changed from low (0.3), average (0.5) and high (0.7) values of void fraction.

Table 4. Results from the simulations with high value of dynamic flux (0.3) and SD σ = 1, 2 and 3%.

$\overline{\Delta P}_C$ (Pa)	24000			24000		
$\overline{\Delta P}_T$ (Pa)	65000			80000		
α	0.3088			0.48480		
$\bar{V}$ (m/s)	9.1583			10.5063		
f	0.0046			0.0048		
$\sigma_{\Delta P_C}$	1.16%	1.90%	3.12%	0.93%	1.91%	3.02%
$\sigma_{\Delta P_T}$	1.01%	1.99%	2.75%	0.97%	2.06%	2.89%
σ_α	5.61%	10.97%	14.41%	2.69%	5.72%	7.57%
$\sigma_{\bar{V}}$	1.15%	2.29%	3.28%	1.20%	2.59%	3.90%

Data from Table 4 do not simulate conditions of highest values of void fraction because, as can be seen in Fig. 2, dynamic flux = 0.3 and high void fraction do not allow analysis. In Fig. 2, following the iso-dynamic flux line = 0.3 the least values are near 0.7 for the given void fraction. So, Tab. 4 only shows low and intermediate values for void fraction. The friction factor is estimated with the average condition in each void fraction and fixed as constant on the variability simulations. As well, it is observed a decreasing SD for the void fraction and an increasing SD for the velocity as is changed from low (0.3), average (0.5) and high (0.7) values of void fraction.

In order to compare the friction factor as a function in the model or as a constant, a couple of simulations were executed. Tab 5 and Tab 6 shows the output results correcting the friction factor in each simulation and each point condition.

Table 5. Results from the simulations for intermediate value of dynamic flux (0.2) with 1% of standard deviation and friction factor correction.

$\overline{\Delta P_C}$ (Pa)	16000	16000		16000
$\overline{\Delta P_T}$ (Pa)	43000	50000		62000
α	0.3040	0.5164		0.7174
$\bar{V}$ (m/s)	7.4919	8.9113		11.5519
f	0.0049	0.0053		0.0058
$\sigma_{\Delta P_C}$	1.09%	1.09%	1.99%	0.98%
$\sigma_{\Delta P_T}$	1.00%	1.02%	1.96%	0.98%
σ_{α}	5.62%	2.49%	4.86%	1.13%
$\sigma_{\bar{V}}$	1.15%	1.30%	2.50%	1.40%
σ_f	0.45%	0.51%	0.98%	0.55%

Table 6. Results from the simulations with high value of dynamic flux (0.3) and SD σ = 1 and 2% and friction factor correction.

$\overline{\Delta P_C}$ (Pa)	24000		24000	
$\overline{\Delta P_T}$ (Pa)	65000		80000	
α	0.3088		0.48480	
$\bar{V}$ (m/s)	9.1583		10.5063	
f	0.0046		0.0048	
$\sigma_{\Delta P_C}$	1.01%	1.94%	0.98%	2.01%
$\sigma_{\Delta P_T}$	0.96%	1.92%	0.98%	1.89%
σ_{α}	3.65%	7.15%	1.77%	3.44%
$\sigma_{\bar{V}}$	0.75%	1.50%	0.80%	1.55%
σ_f	0.29%	0.59%	0.30%	0.59%

Tables 5 and 6 are results of simulations which the friction factor was corrected in each point condition generated randomly by the program.

4. CONCLUSION

The model proposed by Davis and Wang (1994) has a typical behavior when compared to some proprietary patents developed at the same period. A simulation of single phase was calculated for two pressure drops levels as input and the results gathered from the program were similar to the predicted by the literature. Simulations for two-phase flow with published conditions were also compared reaching very closed results.

Aiming the variance analysis involving input/output, it was simulated the horizontal two-phase flow in different conditions. Variation of pressure drop was imposed simultaneously and the output results compared with the input. Firstly, it was observed that by low dynamic flow, the sensibility of the output is several times higher compared to the input variation. Also, for the present model and for all simulations, it was demonstrated that for low void fraction value (< 0.5), more sensible is the void fraction estimation. On the other hand, the velocity estimation is more sensible when the void fraction is high. This can be seen from Tab. 2 to Tab. 4.

At the end, simulations with friction factor correction inserted in the program, is noted that the output variability is less than without the correction, comparing Tab. 3 with Tab. 5 and Tab. 4 with Tab. 6. This shows the importance of friction factor variable in the double pressure drop models.

Others inputs variability, such as geometric and properties, should be also analyzed, in order to better understand their relative importance in the model. It is essential to compare the present results to experimental data, in order to confirm the physical behavior. Since the Davis and Wang model was developed for homogenous dispersed two-phase flow, it is necessary to develop mathematical models that consider the slip and different flow patterns.

5. REFERENCES

Beattie, D. R. H. and Whalley, P. B. (1982). "A simple Two-Phase Flow Frictional Pressure Drop Calculation Method." Int. Journal of Multiphase Flow. Vol 8, p. 83-87.

Boyer, C. and Lemonier, H. (1996) "Design of a Flow Metering Process in a Two-Phase Dispersed Flows." Int. J. of Multiphase Flow, Vol. 22, 4, pp.713-732.

Colebrook, F.C. (1939); "Turbulent Flow in Pipes, With Particular Reference to the Transition Region Between The Smooth and Rough Pipe Laws." J. Inst. Civ. Eng. London, 11, p. 133-156.

Davis, M. R. (1974). "Determination of Wall Friction in Vertical and Horizontal Two Phase Flow." Trans. ASME J. Fluids Engineering 96, p. 173-179.

Davis, M. R. and Wang, D. (1994). "Dual Pressure Drop Metering of Gas-Liquid Mixture Flows." Int. J. Multiphase Flow Vol. 20, No. 5. p. 865-884.

Falcone, G., Hewitt, G. F. and Alimonti, C. (2009). "Multiphase Flow Metering: Principles and Applications." Developments in Petroleum Science.

Fox, R. W., Prichard, P. J. and McDonald, A. T. (2010). 'Introduction to Fluids Mechanics". John Wiley & Sons, INC. Seventh Edition.

James, R. (1965). "Metering of steam-water two-phase flow by sharped-edged orifices." Instn Mech Engrs 180 (23).

Lockhart, R.W. and Martinelli, R.C. (1949). "Proposed correlation of data for isothermal two-phase, two-component flow in pipes." Chemical Engr. Progress, 45, N-l:39—48

Moody, L.F. (1944). "Friction Factors for Pipe Flow." ASME Trans. 66, p. 671-683.

Murdok, J. W. (1962). "Two-phase flow measurements with orifices." J. Basic Eng., 84(4): 419-433.

Saisorn, S. and Wongwises, S. (2008). "An Inspection of Viscosity model for Homogeneous two-phase Flow Pressure drop prediction in a Horizontal circular micro-channel." Int. Com. in Heat and Mass Transfer 35, 833-838.

Steven, R. N, (2002). "Wet Gas Metering with a Horizontally Mounted Venturi Meter." Flow Measurement and Instrumentation. Vol 12, pp. 361-372. UK.

Steven, R. N. (2007). "V-Cone Wet-Gas Metering." Colorado Engineering Experiment Station Inc.

Spedding, P.L., Benard, E. and Donnelly, G.F. (2006). "Prediction of pressure drop in multiphase horizontal pipe flow." International Communications in Heat and Mass Transfer. Vol 33-9, pp. 1053-1062.

6. RESPONSIBILITY NOTICE