TWO-PHASE PRESSURE DROP THROUGH OBSTRUCTIONS

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ABSTRACT

Local pressure drop analytical solution for two-phase, air-water mixture flows through obstruction has been carried out a long horizontal channel. Only bubbly flow pattern has been investigated. An analysis based on momentum conservation for obstructed blockage region. The relationship between two-phase multiplier, ($\phi_{fo}{}^2$), and pressure drop with quality have been investigated. The results indicated that the local pressure drop depends strongly upon the size of obstructed blockage. Large pressure drops have been observed for larger obstructions. The results compared very well with experimental data available.

INTRODUCTION

Two-phase flows occur by design in many engineering applications, particularly in equipment related to nuclear and process plant. Such flows may be also appear following departure from normal operating conditions in single- phase plant. The system usually contains straight pipes , valves , abrupt changes of section , and bends . These components of pressure losses are of particular importance since these losses can be a large proportion of the total pressure drop, especially in natural circulation systems where the total pressure drops can have a large effect on convicted flow rate.

Two-phase pressure drop due to flow obstructions influences significantly the performance of two-phase flow equipment. Two-phase mixture flowing through fixture such as spacers used in nuclear reactors are associated with considerable pressure drop.

Prediction of pressure drop relies strongly on experimental investigations. Most of studies have been performed on orifice and pipes fitting which are commonly found in piping systems. Chisholm[1] (1967) has recommended the use of an equation drive to predict the frictional two-phase pressure drop to orifices and Ventures. Beattie [2] (1973) adopted the mixing length theory to drive correlation for spacers in reactor cores and for orifices. Salcudean et al. (1983)[3] measured the local pressure drop caused by obstructions in low quality for horizontal and vertical air-water flow .

The results showed that the pressure drop was dependent not only on the size but also on the location of the obstruction.

The present work deals with tow-phase multiplier and pressure drop calculations through obstruction of different sizes and shapes,[see Fig.1] for horizontal two-phase flow using an analytical method.

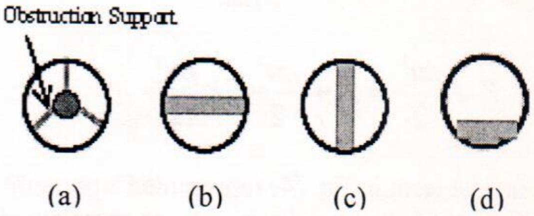

Figure A1 Shape and location of the obstruction in the channel. (a) Central, (b) Horizontal segment, (c) Vertical segment and (d) Bottom segment.

Analytical Approach

The two-phase pressure drop can be calculated depending on single- phase pressure drop using the general relation:

$$\Delta P_{TP} = \phi_{fo}^2 \Delta P_L \tag{1}$$

Where $\phi_{fo}{}^2$ represents the two-phase multiplier which is defined as the ratio of the two-phase pressure change to that obtained if the total mass flows with the liquid – phase properties :

$$\phi_{fo}^2 = \left(\frac{\Delta P_{TP}}{\Delta P_L} \right) \tag{2}$$

The local pressure drop of two-phase flow ,due to the obstruction is usually expressed in terms of a two-phase multiplier similar to Eq.(2) above:

Hence ,

$$\phi_{fo}^2 = \left(\frac{\Delta P_{TP}}{\Delta P_L}\right)_{OB} . \qquad (3)$$

To calculate $\phi^2{}_{fo}$ must be beginning with the single –phase pressure drop approach as follow:

Consider the single-phase flow of a liquid through an abrupt component illustrated in Fig. (A2). Steady state, turbulent flow conditions are assumed and compressibility effects are ignored. The Bernolli energy equation, written for (constant density) one- dimensional flow is:

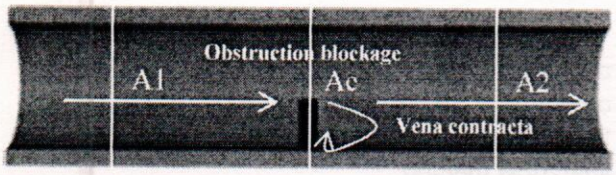

Figure A2 Single-phase (liquid) flow through obstructed region.

$$P_c + \frac{\rho u_c^2}{2} = P_2 + \frac{\rho u_2^2}{2} + k\frac{\rho u_c^2}{2} \qquad (4)$$

The last term in Eq. (4) represented a pressure loss because of viscous dissipation as the flow slows down. [Ei-Wakil (1971)[4]]. The symbol k is a dimensionless loss coefficient , also called the Borda- Carnot coefficient . The value of k is obtained with the help of momentum balance in which the upstream pressure P_c is assumed to still act on the expanded or downstream area A_2 immediately after expansion. Thus

$$P_c A - P_2 A_2 = \dot{m}_t (u_2 - u_c) \qquad (5a)$$

using continuity equation $\dot{m}_t = \rho A_2 u_2^2$ Eq.(5) may be written as:

$$P_2 - P_c = \rho u_2 (u_c - u_2) \qquad (5b)$$

$$P_c + \rho u_2 u_c = P_2 + \rho u_2^2 \qquad (6)$$

From Eq.(4) and Eq.(6)

$$k\frac{\rho u_c^2}{2} = \frac{\rho u_c^2}{2} - \rho u_c u_2 + \frac{\rho u_2^2}{2} \qquad (7)$$

$$k = 1 - 2\left(\frac{u_2}{u_c}\right) + \left(\frac{u_2}{u_c}\right)^2 \qquad (8)$$

$$k = \left(1 - \frac{u_2}{u_c}\right)^2 = \left(1 - \frac{A_c}{A_2}\right)^2 \qquad (9)$$

Equation (9) plotted in Fig.A3, that is clearly shown that the loss coefficient (k) is inversely proportional with the obstruction fraction.

From Eq. (7), the pressure loss term can be calculated as:

$$k\frac{\rho u_c^2}{2} = \frac{\rho}{2}\left(u_c^2 - 2u_c u_2 + u_2^2\right) \qquad (10)$$

$$k\frac{\rho u_c^2}{2} = \frac{\rho}{2}(u_c - u_2)^2 \qquad (11)$$

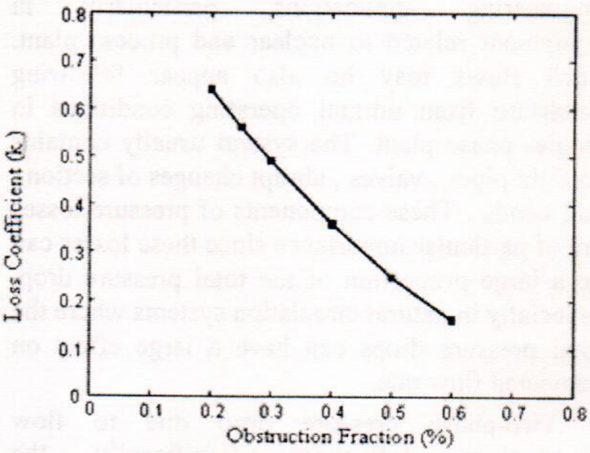

Fig. A3 Loss coefficient vs. obstruction fraction

The total pressure change is obtained by combining Eq.(4) and Eq.(11) as:

$$P_2 - P_c = \rho u_c^2 \left[\left(\frac{u_c}{u_c}\right) - 1\right] \qquad (12)$$

$$P_2 - P_c = \frac{G_2^2}{\rho_L}\left(\frac{A_2}{A_c}\right)\left[1 - \left(\frac{A_c}{A_2}\right)\right] \qquad (13)$$

Equation (13) represents the expression for the single- phase static pressure change due to an obstructs component .

For two-phase flow, consider the separated flow model illustrate in Fig. (A4). No mass transfer between the phases and compressibility effects are ignored. The momentum balance for the combined flow is:

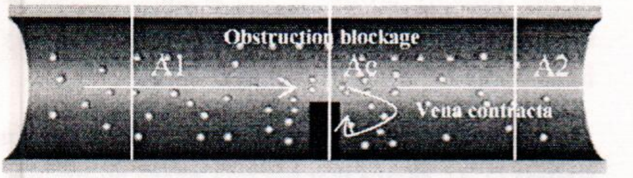

Fig. A4 Two-phase flow through obstructed region

$$A_2(P_2 - P_c) = \dot{m}_g(u_{gc} - u_{g2}) + \dot{m}_f(u_{fc} - u_{f2}) \quad (14)$$

Using:

$$u_{gc} = \frac{x^2}{\alpha_c}\frac{m_t}{\rho_g A_c} \quad \& \quad u_{g2} = \frac{x^2}{\alpha_2}\frac{m_t}{\rho_g A_2} \quad (15)$$

$$u_{fc} = \frac{(1-x)^2}{(1-\alpha_c)}\frac{m_t}{\rho_f A_c} \quad \& \quad u_{f2} = \frac{(1-x)^2}{(1-\alpha_2)}\frac{m_t}{\rho_f A_2} \quad (16)$$

Substituting Eq.(15) & Eq.(16) in to Eq.(14) gives:

$$(P_2 - P_c) = \frac{m_t^2}{A_2}\left\{\left[\frac{x^2}{\alpha_c \rho_g A_c} - \frac{x^2}{\alpha_2 \rho_g A_2}\right] + \left[\frac{(1-x)^2}{(1-\alpha_c)\rho_f A_c} - \frac{(1-x)^2}{(1-\alpha_2)\rho_f A_2}\right]\right. \quad (17)$$

$$(P_2 - P_c) = \frac{m_t^2}{A_2}\left\{\frac{x^2}{\rho_g A_c}\left(\frac{1}{\alpha_c} - \frac{A_c}{\alpha_2 A_2}\right) + \frac{(1-x)^2}{\rho_f A_c}\left(\frac{(1-x)^2}{(1-\alpha_c)} - \frac{A_c}{(1-\alpha_2)A_2}\right)\right. \quad (18)$$

If we assumed that the void fraction remains unchanged, i.e. $\alpha_c = \alpha_2 = \alpha$, Eq.(18) can be reducer to:

$$(P_2 - P_c) = G_2^2 A_2\left\{\frac{x^2}{\rho_g A_c}\left(\frac{1}{\alpha} - \frac{A_c}{\alpha\ A_2}\right) + \frac{(1-x)^2}{\rho_f A_c}\left(\frac{}{(1-\alpha)} - \frac{A_c}{(1-\alpha)A_2}\right)\right. \quad (19)$$

$$(P_2 - P_c) = \frac{G_2^2}{\rho_f}\frac{A_2}{A_c}\left(\frac{A_2}{A_1}\right)\left(1 - \frac{A_c}{A_2}\right)\left(\frac{x^2\rho_f}{\alpha\rho_g} + \frac{(1-x)^2}{(1-\alpha)}\right) \quad (20)$$

Equation (20) represents the two-phase pressure change due to an obstructs component .

Dividing Eq. (20) by Eq. (13) gives an expression for the two-phase multiplier $\phi_{fo}{}^2$

$$\phi_{fo}{}^2 = \frac{x^2 \rho_f}{\alpha\rho_g} + \frac{(1-x)^2}{(1-\alpha)} \quad (21)$$

In practice, the void fraction (α) is unknown and a direct solution for $\phi_{fo}{}^2$ is generally unobtainable, however , a value may be calculated if simplistic two-phase model are assumed Using separated flow model, which is, assumes that the two-phases are separated such that a set of equations may be written for each phase. Therefore a slip between the two-phases will be occurs due to the differences velocities.

Hence

$$S = \frac{u_g}{u_f}$$

Simpson et al. (1985)[5] suggested an expression for slip ratio (S) as:

$$S = \left(\frac{\rho_f}{\rho_g}\right)^y \quad (22)$$

Where " y " is slip index which has a different values Now, the slip void fraction can be calculated as:

$$\alpha = [1 + \frac{(1-x)}{x}\frac{\rho_g}{\rho_f}\cdot S]^{-1} \quad (23)$$

Substituting Eq. (23) in to Eq. (21) with many simplification gives a slip two-phase multiplier $\phi_{fo}{}^2$ as;

$$\phi_{fo}{}^2 = 1 + \frac{x\rho_f}{S\,\rho_g} \quad (24)$$

In gas-liquid two-phase flow (i.e. two-component , two-phase flow) the effects of compressibility can be allowed for through a correlation factor k_1 ,such that :

$$\phi_{fo}{}^2(corrected) = k_1 \cdot \phi_{fo}{}^2(predicted) \quad (26)$$

With

$$k_1 = \{1 + G^2[x\frac{\partial v_g}{\partial P} + (1-x)\frac{\partial v_f}{\partial P}]\}^{-1} \quad (27)$$

The effect of compressibility (k_1)[Eq. (27)] were computed for air-water, two-phase flow by Simpson et al. (1985)[5], these were found to be very small usually ,with a maximum value less than 2% . Thus this effect can be ignored and the original [Eq. (24)] validation stand.

To calculate two-phase pressure drop using Eq. (1), the single-phase (liquid) pressure drop calculated using the relation:

$$\Delta P_L = C_k \cdot \frac{1}{2} \rho_f u_f^{\ 2} \qquad (28)$$

Where C_k is the head loss coefficient for obstructions illustrated in Table (1) for different shapes and sizes.

Table.1. Head coefficients for obstructions in horizontal tow-phase flow (Salcudean et al.1983)

Obstruction type	C_k (25)	C_k (40 %)
Central	0.91	2.19
Horizontal segment	0.76	2.11
Vertical segment	0.75	2.15
Peripheral bottom segment	0.69	2.06

RESULTS AND DISCUSSION

The presence of gaseous increases the pressure drop through the increased liquid velocity as well as increased interface drag therefore the pressure drop of two-phase flow greater than the single-phase flow under the same conditions.

When the two-phase flows through pipe or channel, a relative movement (slip) between the phases must be occurs. This slip caused a very complexes momentum transfer between the two-phases, to analysis. However it is relatively simple exercise to change the values of the exponent "y" in slip equation [eq.(22)] and make a comparisons between experimental and predicted two- phase multiplier values to avoid the difficulty [Simpson et. al.(1985)[5]]. According to this, we are saw that the better agreement between the experimental and predicted values is apparently obtained using y=0.1. This values is the same value suggested and derived by Simpson et al.(1985)[5] .

From the results obtained theoretically for various locations and shapes of obstructions, the blockage located in the central region of the channel causes a higher pressure drop than these located in the peripheral region. That is, because of the velocity profile in the channel, it can be concluded that greater pressure loss is caused by interception of the higher velocity flow.

The two-phase multipliers are illustrated in figures (1-4), shows that the two-phase multipliers are nearly the same for various obstructions except for the 25% vertical segment obstruction [fig.3], which is shows a high value than others.

The local pressure drops as a function of quality for different obstruction sizes and locations are illustrate in figures (5-12). A high pressure drops are observed for obstruction with large size .Since, the pressure drop for 40% obstruction is largest than the 25% obstruction. From the results given the pressure drop of 40% central obstruction [fig.(6)] is a largest one whereas the pressure drop for 25% bottom segment obstruction [fig.(11)] is the smallest one.

A good agreement observed between the experimental results given by Salcudean et al. (1988)[6] and predicted (theoretical) results at all values of quality examined.

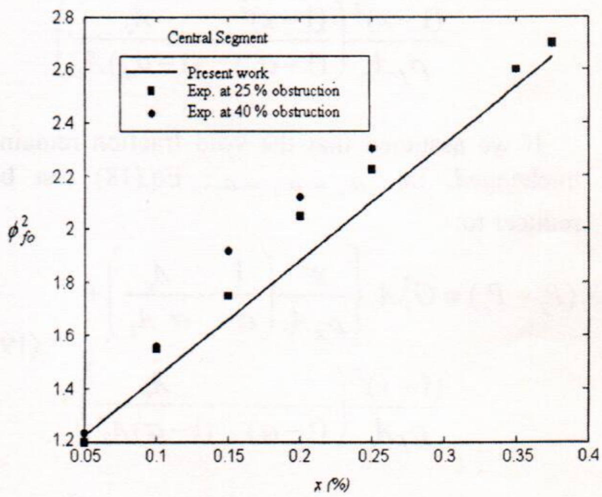

Fig.1 Two phase multiplier for 25% and 40% central obstruction in horizontal flow

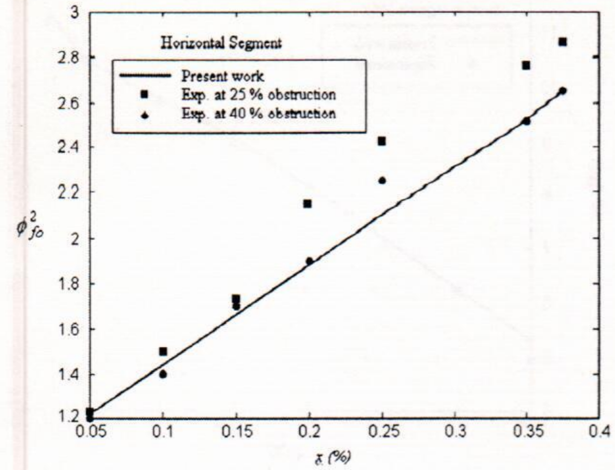

Fig. 2 Two phase multiplier for 25% and 40% horizontal segment obstruction in horizontal flow

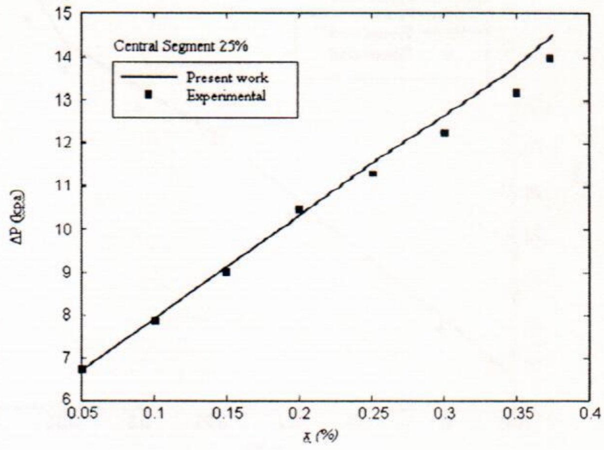

Fig. 5 Local pressure drop due to 25% central obstruction in horizontal two-phase flow

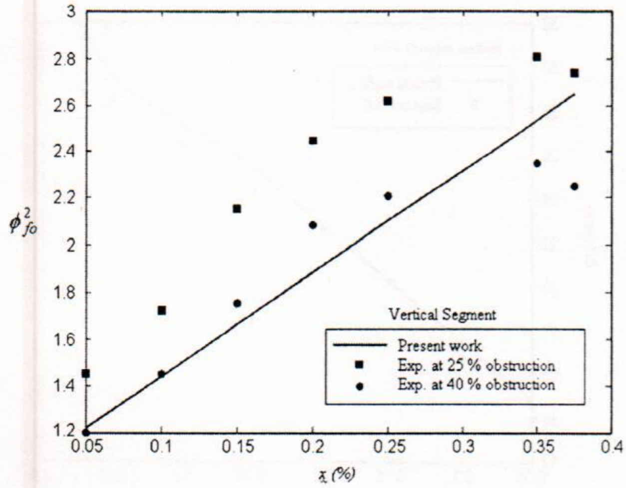

Fig. 3 Two-phase multiplier for 25% and 40% vertical segment obstruction in horizontal flow

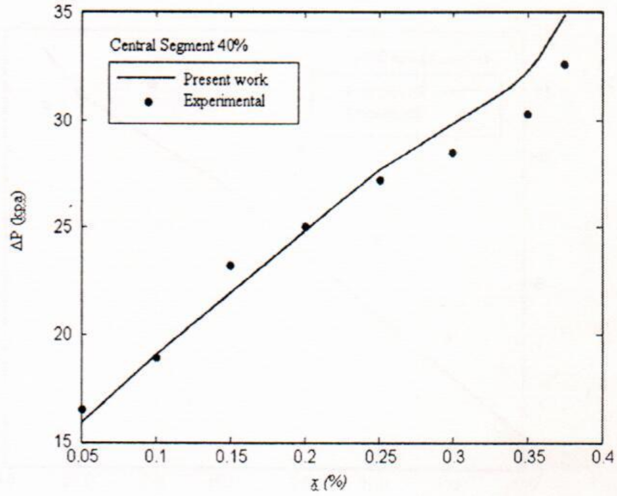

Fig. 6 Local pressure drop due to 40% central obstruction in horizontal two-phase flow

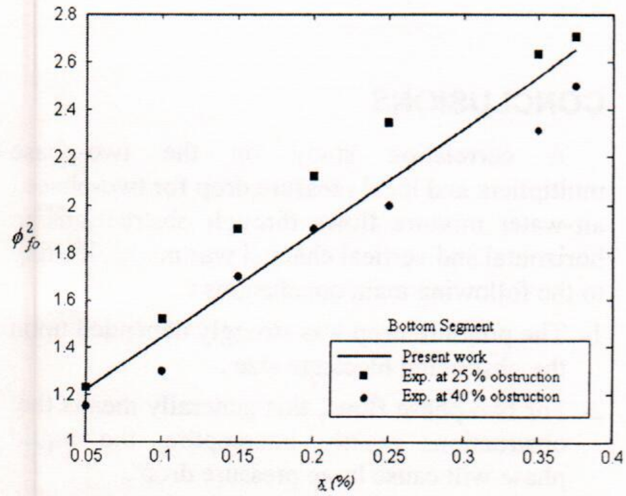

Fig. 4 Two-phase multiplier for 25% and 40% buttom segment obstruction in horizontal flow

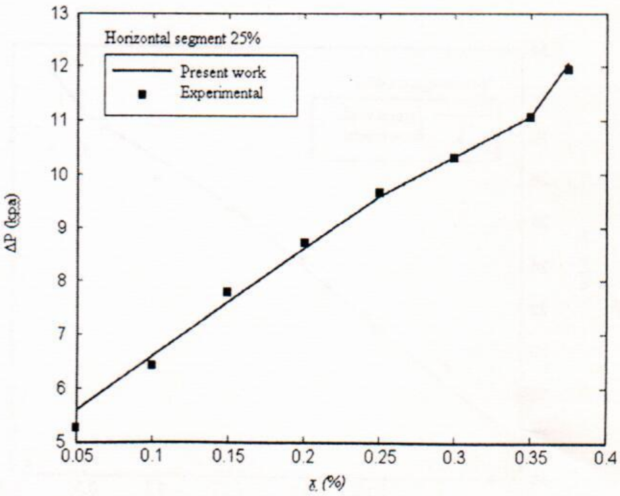

Fig. 7 Local pressure drop due to 25% horizontal segment obstruction in horizontal two-phase flow

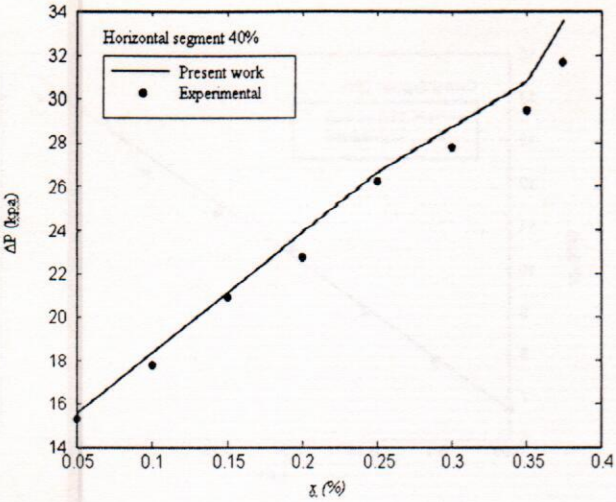

Fig. 8 Local pressure drop due to 40% horizontal segment obstruction in horizontal two-phase flow

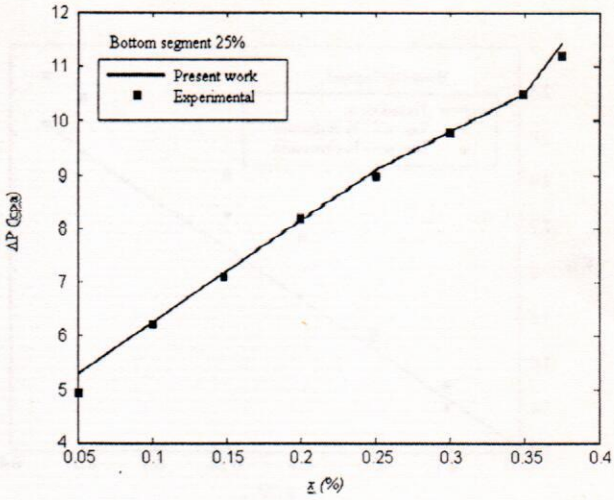

Fig. 11 Local pressure drop due to 25% bottom segment obstruction in horizontal two-phase flow

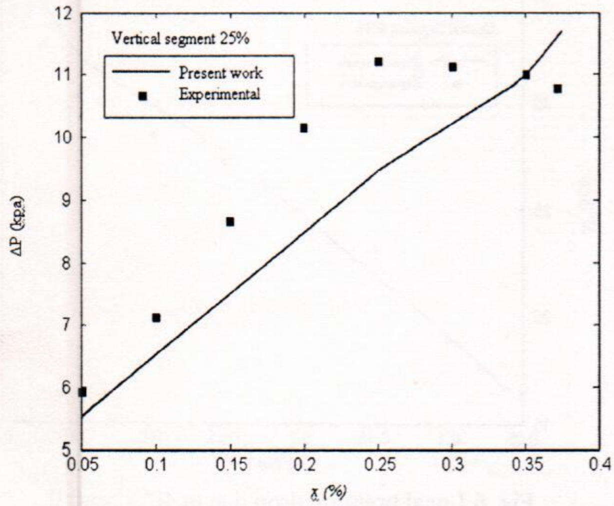

Fig. 9 Local pressure drop due to 25% vertical segment obstruction in horizontal two-phase flow

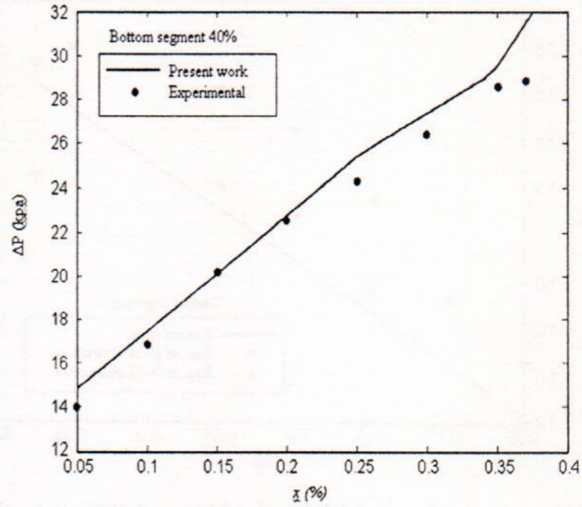

Fig. 12 Local pressure drop due to 40% bottom segment obstruction in horizontal two-phase flow

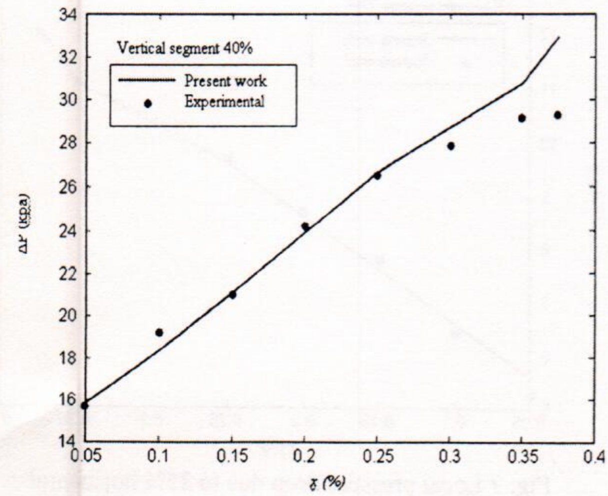

Fig. 10 Local pressure drop due to 40% vertical segment obstruction in horizontal two-phase flow

CONCLUSIONS

A correlation study on the two-phase multipliers and local pressure drop for two-phase , air-water mixture flows through obstructions in horizontal and vertical channel was made , leading to the following main conclusions :

1- The pressure drop was strongly depended upon the obstructed blockage size .
2- For two-phase flow , this generally means that obstructions mainly intercepting the liquid phase will cause large pressure drop .
3- The correlation presented can be used for valves , orifice , and sudden changes in flow cross-sections .

4- A good agreements between the predicted values and experimental data given by Salcudean and Leung (1988)[6].

NOMENCLATURE

A	Flow cross sectional area , m^2
C_k	Head loss coefficient
G	Mass velocity, kg/m^2
k_1	Correlation factor , calculated from eq(27)
$\dot{m}$	Mass flow rate, kg/s
P	Pressure, kN/m^2
ΔP	Pressure differences, kN/m^2
u	Velocity, m/s
v	Specific volume, m^3/kg
x	Quality i.e. mass dryness fraction
S	Slip ratio
Y	Slip ratio index

Greek symbols

α	Void fraction
ρ	Density, kg/m^3
ϕ^2	Two-phase multiplier
ψ	Factor appears in eq(24)

Subscript

C	Throat section
G	Gas
Go	Gas only
F	Liquid
Fo	Liquid only
L	Liquid
OB	Obstruction

REFERENCES

1. Chisholm, D. (1967)"Pressure gradients during the flow of incompressible two-phase mixtures Through pipes , ventures and orifice plates ",Chemical Engr. V.12, No.9(1368).
2. Beattie, D. R. H. (1973)" A note on the calculation of two-phase pressure losses "Nucl. Engr. Des. , V. 25 (395) .
3. Salcudean, M. , Groeneved, D. and Leung, L.(1983)"Effect of flow-obstruction geometry on pressure drops in horizontal air-water flow", Int. J. Multiphase flow, Vol.9, No.1, 73-85.
4. El-Wakil ,M.M. (1971)" Nuclear heat transport ", International textbook company .
5. Simpson , H.C. , Roony, D.H. and callander , T.M.S. (1985)", Pressure loss through gate valves with Liquid – vapor flows ", 2nd. International Conference on multiphase flow,Lodon, England , June 19-21 , BHRA , Fluid Engineering center , 67-80 .
6. Salcudean, M.E. and Leung, L.K.(1988)"Two-phase pressure drop through obstruction", Int. J. Multiphase flow,Vol.105, 394-361.