EFFECT OF FLOW-OBSTRUCTION GEOMETRY ON PRESSURE DROPS IN HORIZONTAL AIR-WATER TWO-PHASE FLOW

Hameed Balassim Mahood *
Hala A. Kadim and Ali N. Salim
University of Missan – Missan - Iraq
hbmahood@yahoo.com*E-mail:

Abstract

An analytical solution for local pressure drop due to obstructions in horizontal air-water two-phase flow was presented. Various obstruction shapes with size were investigated. An analysis based on the momentum conservation through obstruction region. The relationship between two-phase multiplier and local (normalized) pressure drop with the gas superficial velocity were investigated. The results showed, a higher pressure drops pointed for larger obstructions. The present results was verified with experimental investigations.

Keywords: two-phase flow; pressure drop; obstructions; analytical solution; momentum conservation.

تأثير الشكل الهندسي للعارضة على تغير الضغط للجريان الثنائي الطور (ماء وهواء) في الانابيب الافقية

حميد بلاسم ماهود- هاله عدنان كاظم

علي ناجي سالم

جامعة ميسان

الخلاصة:

تم انجاز الحل التحليلي لحساب التغير الموقعي للضغط نتيجة لوجود عارضة في مسلك الجريان الثنائي الطور (ماء وهواء) . تم اختبار انواع مختلفة من حيث الشكل والحجم للعوارض ضمن الدراسة تحليليا اعتمادا على مبدأ معيارية حفظ الزخم . تم ايجاد علاقة رياضية تصف التغير في الضغط للجريان الثنائي الطور كدالة لسرعة الطور الغازي .وقد وجد ان مقدار التغير في الضغط يزداد مع زيادة حجم العارضة. قورنت النتائج التي تم الحصول عليها وقد وجد تقارب مع النتائج العملية المنشورة.

NOMENCLATURE

A	Flow cross sectional area, m^2
C_k	Head loss coefficient
G	Mass velocity, $\frac{kg}{m^2 \cdot s}$
$\dot{m}$	Mass flow rate, $\frac{kg}{s}$
P	Pressure, $\frac{kN}{m^2}$
ΔP	Pressure differences, $\frac{kN}{m^2}$
U	Velocity, $\frac{m}{s}$
v	specific volume, m^3/kg
x	Quality (mass dryness fraction)
S	Slip ratio

Greek symbols

α	Void fraction
ρ	Density , $\frac{kg}{m^3}$
ϕ^2	Two-phase multiplier

Subscript

c	Throat section
g	Gas
f	Liquid
fo	Liquid only
OB	Obstruction
non-dim.	Non-dimensional
sf	Superficial liquid
sg	Superficial gas
Tp	Two phase
L	Liquid

Introduction:

Flow systems involving a mixture of air-water(gas-water) have many applications in chemical, and mechanical industries and in nuclear – power generation. The systems usually contain straight pipes, valves, abrupt changes of section and bends. These components of pressure losses are of particular importance since these losses can be large proportional of the local pressure drop, especially in natural circulation systems where the total pressure drops can have an effect on convicted flow rate.

Pressure drops with obstructions in two-phase flow are usually expressed by multiplying the single – phase pressure drop by a two- phase multiplayer. The two-phase multiplier depends on several parameters, one of them being the relative velocity between these two phases.

Chisholm(1967) has developed a correlation for the pressure drop for the two-phase flow in pipes and through orifices and ventures, which introduced the shear forces between the phases. Beattie(1973) adopted the mixing length theory to drive correlation for pressure drop in spacers in reactor cores and orifices. Salcuden et al. (1983) investigated experimentally the local pressure drop due to obstruction in horizontal air-water flow for different shapes and sizes obstructions. The local pressure drop was found depends strongly on the kinetic energy and momentum of liquid intercepted by the flow obstruction. Simpson et al.(1985) correlated an experimental data for the two-phase pressure losses through valves and other pipe fitting. The effect of compressibility and mass transfer were analyzed and presented in terms of a correlation factor to the pressure loss multiplier. Salcuden et al. (1988) measured the local pressure drop for single and two-phase flows through obstruction along a vertical and a-horizontal channel. The results have indicated that the pressure drop depends strongly upon the size and the location of the blockage. Tapucu et al (1988) obtained experimentally and analytically the local pressure losses due to plate and smooth blockage under two-phase flow conditions in a square vertical channel. The analysis used based on the Janssen-Kerrinen and momentum energy models. The irreversible pressure loss coefficient for plate and smooth blockages was found depends on the blockage severity and void fraction. Mahood et al.(2003) performed analytically the pressure drop of two-phase flow due to obstruction in vertical pipes. The analysis contained different type and shapes of obstructions. The high pressure drop were demonstrated when large obstruction used.

In this work, the influence of the degree of flow blockage and the shape of the flow on pressure drop were computed using an analytical solution for different obstruction sizes and shapes which illustrated in **Figure (A٢).**

Analytical Approach :

The local pressure drop of two-phase flow due to obstruction is usually expressed in terms of a two-phase multiplier, as:

$$\phi^2{}_{fo} = (\frac{\Delta P_{TP}}{\Delta P_L})_{OB.} \qquad (1)$$

The local single-phase (liquid) pressure drop due to obstruction may be calculated by using the momentum conservation through obstruction region (see Fig.A١) as:

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

where Pc and Ac refers to the pressure drop and cross-section area at the obstruction and downstream region respectfully.

For two-phase (air-water) flow, the local pressure drop due to obstruction may be calculated as:(see **Figure A٢)**

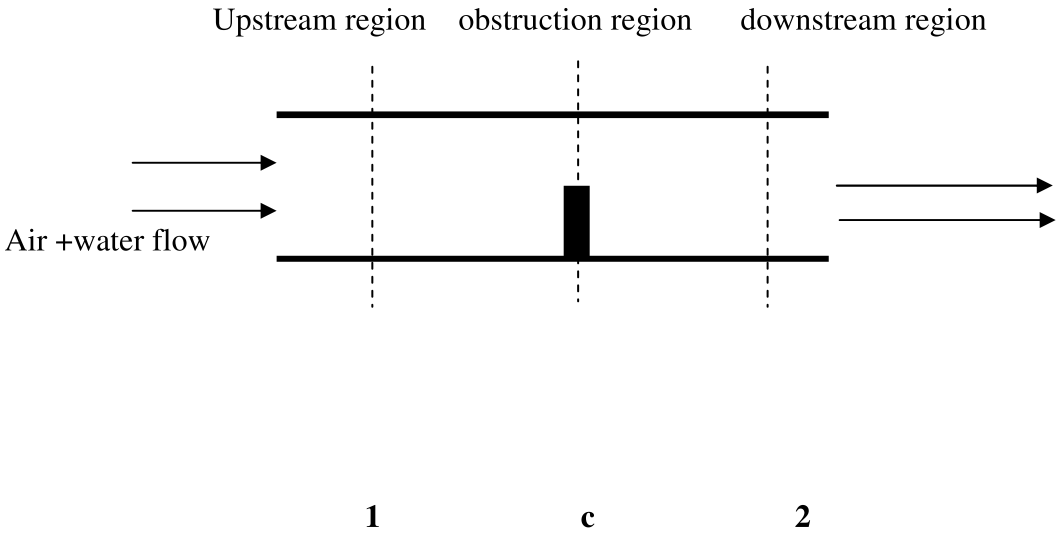


Fig.(A١): A Schematic diagram for present flow obstruction

$$(P_2 - P_c) = \frac{G_2^2}{\rho_f}\left(\frac{A_2}{A_c}\right)\left[\left(1-\frac{A_c}{A_2}\right)\right]\left[\frac{x^2}{\alpha\rho_g}+\frac{(1-x)^2}{(1-\alpha)}\right] \qquad (3)$$

Dividing Eq.(3) by Eq.(2) , gives an expression for two-phase multiplier as:

$$\phi_{fo}^2 = \frac{x^2\rho_f}{\alpha\rho_g}+\frac{(1-x)^2}{(1-\alpha)} \qquad (4)$$

The void fraction (α) is unknown and a simple analytical solution for a two-phase multiplier is generally unobtainable, however a value may be calculated if simplistic two-phase flow model are assumed.

Using separated flow model that is assumes that the two-phase flow are separated flow such that a set of equations may be written for each phase. Therefore a slip in taken place between the two-phase will be occurs due to the differences velocities,

Hence,the slip ratio (S): between

$$S = \frac{U_g}{U_f} \tag{5}$$

where Ug and Uf is gas and liquid velocity respectfully .

and the relationship between the gas and liquid velocities with there superficial velocities can be given respectively as:

$$U_g = \frac{U_{sg}}{\alpha} \tag{6}$$

And

$$U_f = \frac{U_{sf}}{(1-\alpha)} \tag{7}$$

Substituting Eq.(6) and Eq.(7) into Eq.(5) yield:

$$S = \frac{(1-\alpha)}{\alpha} \frac{U_{sg}}{U_{sl}} \tag{9}$$

and the slip void fraction can be calculated from well known formula Salcuden et al. (1983)as:

$$\alpha = [1 + \frac{(1-x)}{x} \frac{\rho_g}{\rho_f} \cdot S]^{-1} \tag{10}$$

Now, substituting Eq.(9) into Eq.(10) and substituting the result into Eq.(4) given:

$$\phi_{fo}^2 = \frac{x(1-\alpha)}{\alpha} \left(\frac{U_{sg}}{U_{sf}} \right) + \frac{x\alpha}{(1-\alpha)} \frac{\rho_f}{\rho_g} \left(\frac{U_{sf}}{U_{sg}} \right) + 1 \tag{11}$$

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

$$\phi_{fo}^2 (corrected) = k \cdot \phi_{fo}^2 (predicted) \tag{12}$$

with :

$$k = \left[1 + G^2 \left(x \frac{\partial v}{\partial P} + (1-x) \frac{\partial v}{\partial P} \right) \right]^{-1} \tag{13}$$

The effect of compressibility (k) , were studied and computed for air-water two-phase flow by Simpson et al.(1985), their were found to be very small , usually with a maximum value less than 2%. Therefore this effect can be ignored and the original equation Eq.(11) is valid.

From Eq.(1), the two-phase pressure drop due to obstruction can be calculated as :

$$\Delta P_{TP} = \left(\phi_{fo}^{2}\right)_{OB} \left(\Delta P_{f}\right)_{OB} \qquad (14)$$

The single-phase (liquid) pressure drop due to obstruction can be calculated from the relation Salcuden et al. (1983) :

$$\Delta P_{f} = \frac{1}{2} C_{K} \rho_{f} U_{f}^{2} \qquad (15)$$

where C_K is total head loss coefficient of obstruction given in Table (1) Salcuden et al. (1983) for different sizes and shapes.

And

$$U_{f} = \frac{\alpha(1-x)}{x(1-\alpha)} \frac{\rho_{g}}{\rho_{f}} U_{g} \qquad (16)$$

Sub. Eq.(6) into Eq.(16) yields:

$$U_{f} = \frac{(1-x)}{x(1-\alpha)} \frac{\rho_{g}}{\rho_{f}} U_{sg} \qquad (17)$$

Substitute Eq.(17) into Eq.(15) yield

$$\Delta P_{f} = \frac{1}{2} C_{K} \left[\frac{(1-x)}{x(1-\alpha)} \rho_{g} U_{sg} \right]^{2} \qquad (18)$$

Now, the local two-phase pressure drop due to obstruction can be calculated by using Eq.(14) together with Eq.(11) and Eq.(18) .

The dimensionless pressure drop calculated by using the relation Salcuden et al. (1983):

$$\left(\Delta P_{TP}\right)_{non-\dim.} = \frac{\left(\Delta P_{TP}\right)_{OB}}{\frac{1}{2} \rho_{f} U_{sf}^{2}} \qquad (19)$$

Results and Discussion:

Figures(1)and (2) gives comparison between the present (analytical) work results with different results given by Salcudean et al.(1983). It is shows that the Chasholm (1967),experimental of central obstruction and homogeneous model results is identical with present work. while the bottom segment gives the bigger divergent from the present work, although, both results have the same behaviors. From **Figure(2)** the same state as shown in **Figure (3)** with a few divergent between the bottom segment experimental and theoretical results. **Figure (3) and Figure (4)** gives the relationship between the present analytical non- dimensional pressure drop and experimental results for 25% and 40% vertical segment obstruction. They are clearly shows that the 40% obstruction area gives a best agreement between the present and experimental results than 25% and the 40% obstruction area has a high values of non-dimensional pressure drop than 25% because of that the increasing in obstruction area in stream flow tends to intercept a much amount of fluid flowing and of cores caused a high pressure drop. **Figure (5)and Figure (6)** gives the relationship between the theoretical (present) and experimental results of Salcudean et al. (1983) for bottom segment obstruction. They are showed a similar behavior indicated in **Figure (3)and (4)** with a highest values of non-dimensional pressure drop for 40% obstruction area than the 25% **Figure(9)** and **Figure (10)** shows a comparison between present analytical results and experimental results of Salcudean et al.(1983). The figures shows a very good agreement orientated for both 25% and 40 % central obstruction area results with the same notes indicated for 40%which has a highest non-dimensional pressure drop than 25%.

From all results given a good agreement obtained between the theoretical (present) and experimental results for both 25% and 40% obstruction area with noting that the 40% obstruction area has a best agreement than the 25%.

Conclusions:

A correlation study on the two-phase multipliers and local pressure drop for two-phase , air-water mixture flows through obstructions in horizontal 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 Salcuden et al. (1983): .

References:

(Beattie, D. R. H. ,1973)” A not on the calculation of two-phase pressure losses “ , Nucl. Engr. Des. , V. 25 (395) .

(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).

(Mahood ,H.B , Farhan L. Resheed and Ali S. Baqir ,2003)" Two-phase pressure drop through obstruction" Iraqi J. Che. Pet. Eng., Vol.4, June.

(Simpson , H.C. , Roony, D.H. and callander , T.M.S,1985)", Pressure loss through gate valves with Liquid – vapor flows ", 2^{nd}. International Conference on multiphase flow,Lodon, England , June 19-21 , BHRA , Fluid Engineering center , 67-80 .

(Salcudean, M. , Groeneved, D. and Leung, L,1983)"Effect of flow-obstruction geometry on pressyre drops in horizontal air-water flow", Int. J. Multiphase flow, Vol.9, No.1, 73-85.

(Tapucue,A. , Teyssedeu , N. , Trouche and Merilo,M, 1988)"Pressure losses caused by area in a single – channel flow under two – phase flow conditions", Int. J. Multiphase Flow, Vol.15, No.1 , PP. 51- 64.

Table.1. Head coefficients for obstructions in horizontal tow-phase flow

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

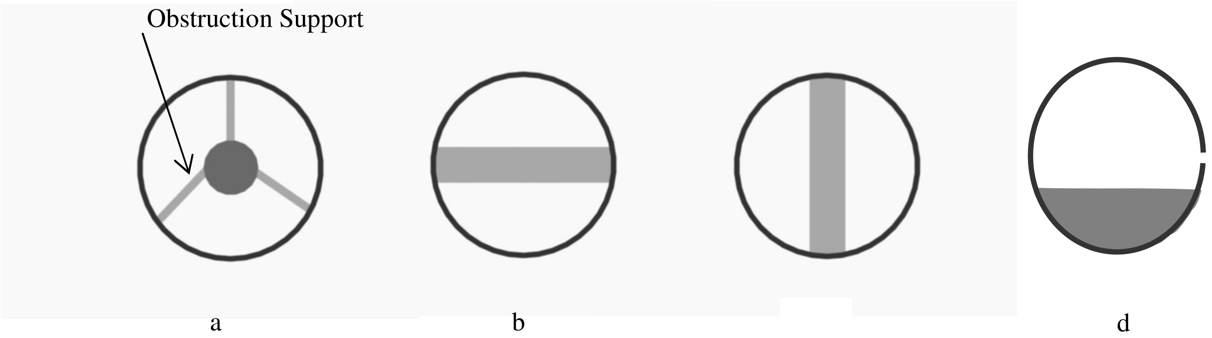


Figure A2: Shape and location of the obstruction in the channel.
a- Central, b- Horizontal segment, c- Vertical segment and
d- Bottom segment.

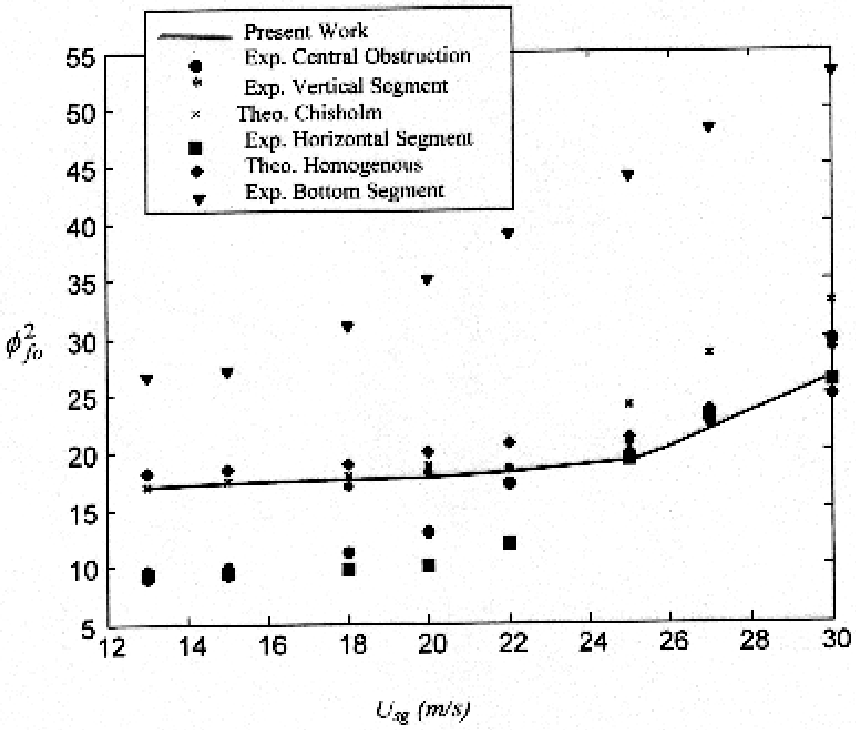


Figure 1: Two-phase obstruction pressure drop multiplier for 25% obstruction.

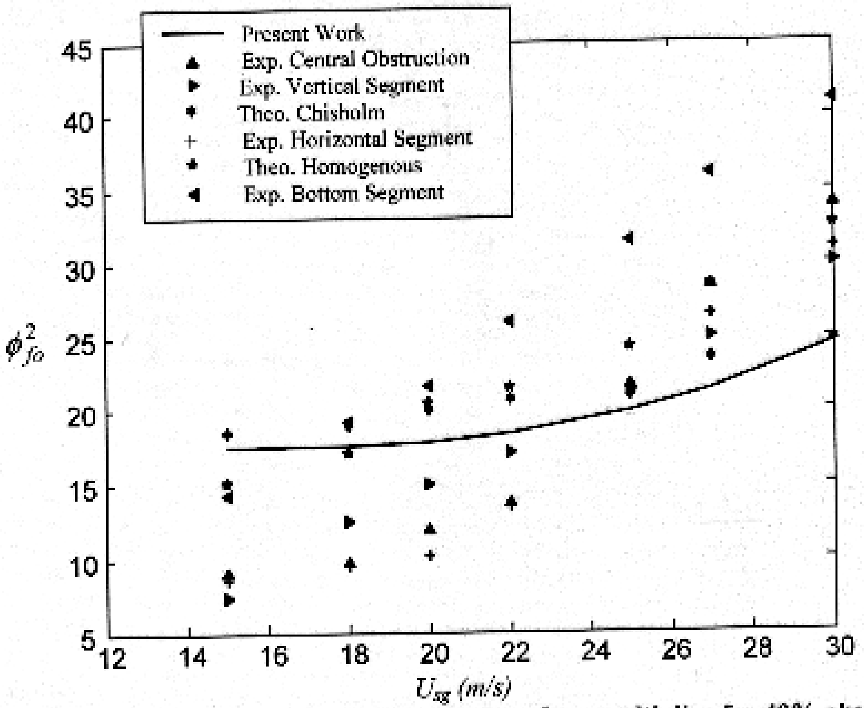


Figure 2: Two-phase obstruction pressure drop multiplier for 40% obstruction.

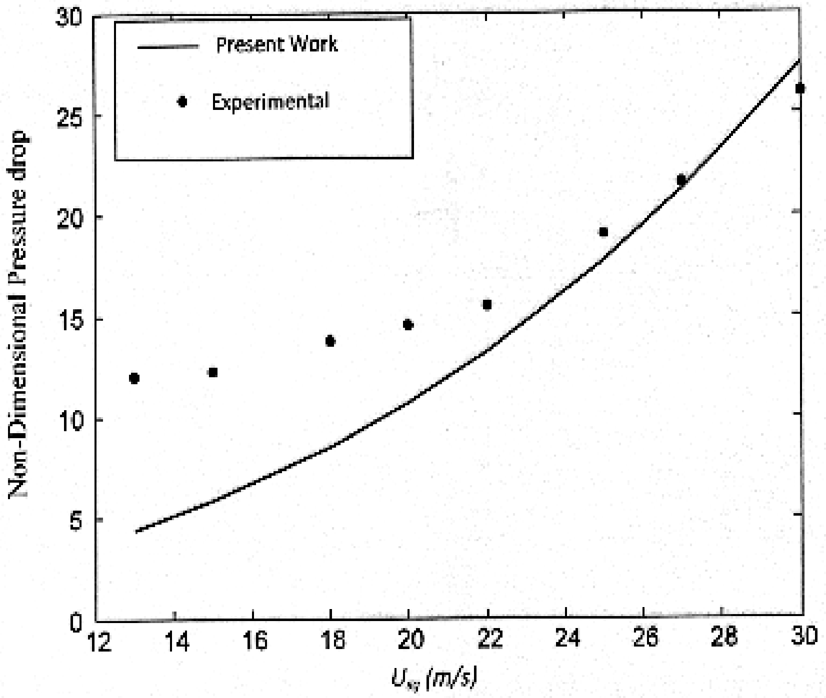
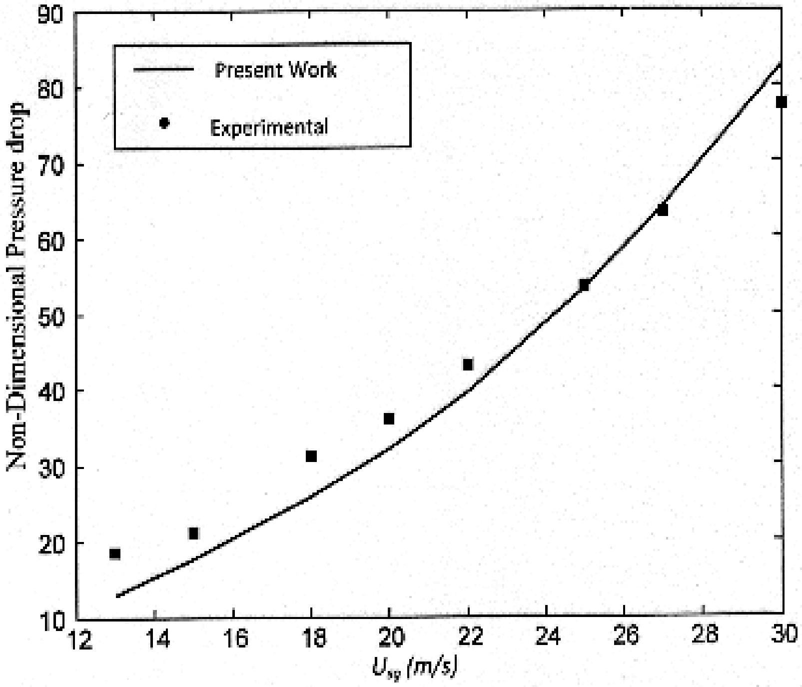


Fig.(3): Non-dimensional obstruction pressure drop for 25% vertical segment obstruction.



Fig(4): Non-dimensional obstruction pressure drop for 40% vertical segment obstruction.

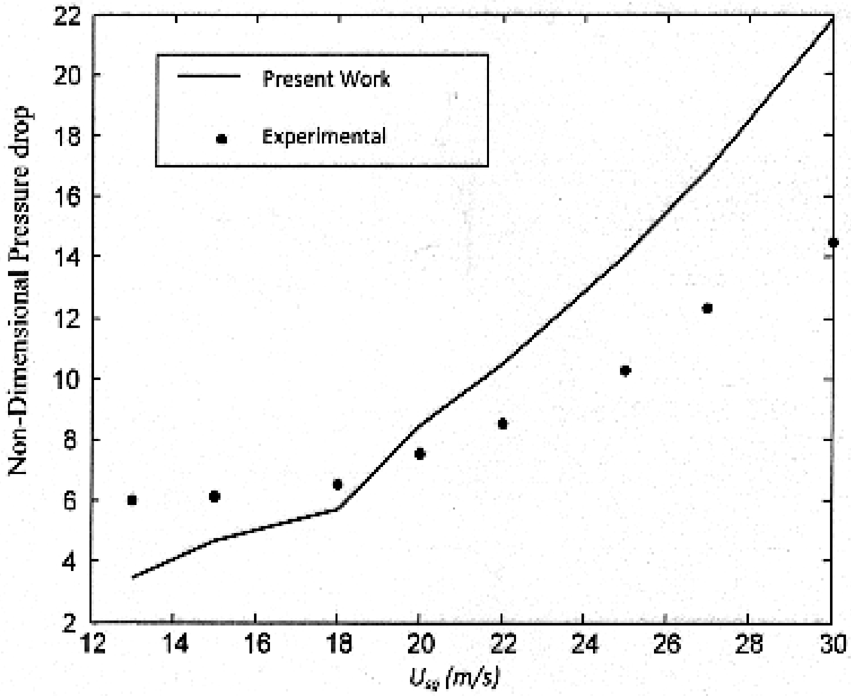


Fig.(5): Non-dimensional obstruction pressure drop for 25% bottom segment obstruction.

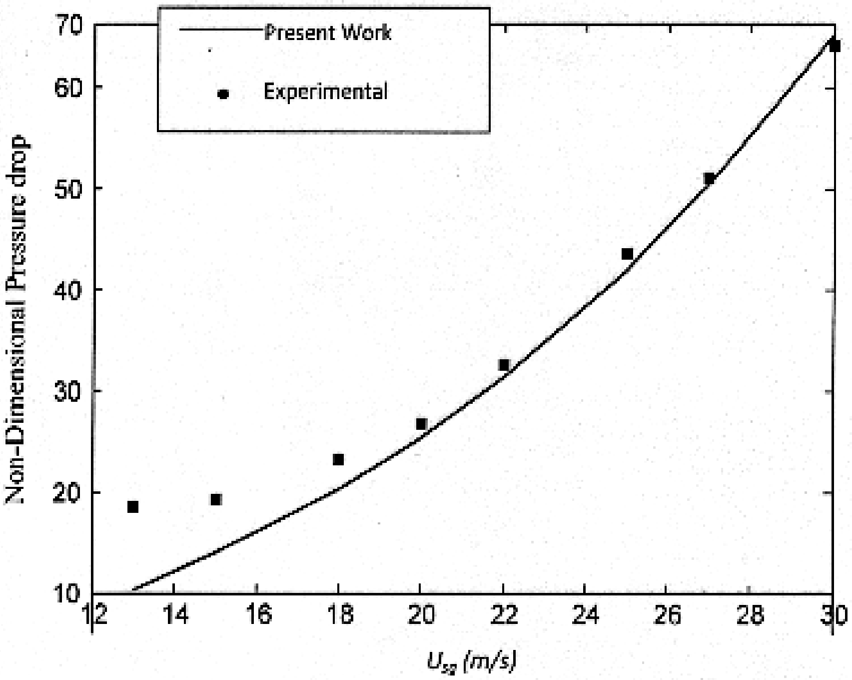


Fig.(6): Non-dimensional obstruction pressure drop for 40% bottom segment obstruction.

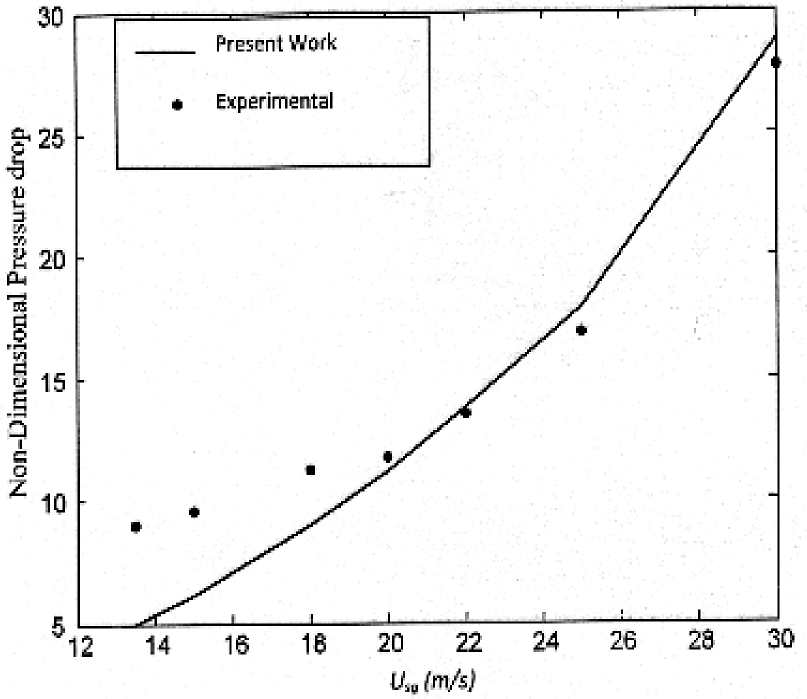


Fig.(7): Non-dimensional obstruction pressure drop for 25% central segment obstruction.

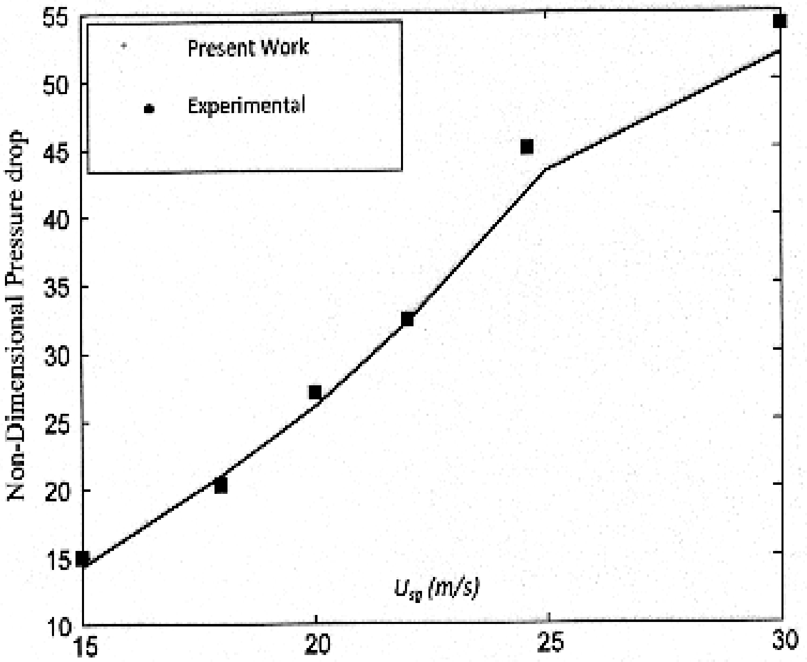


Fig.(8): Non-dimensional obstruction pressure drop for 40% central segment obstruction.

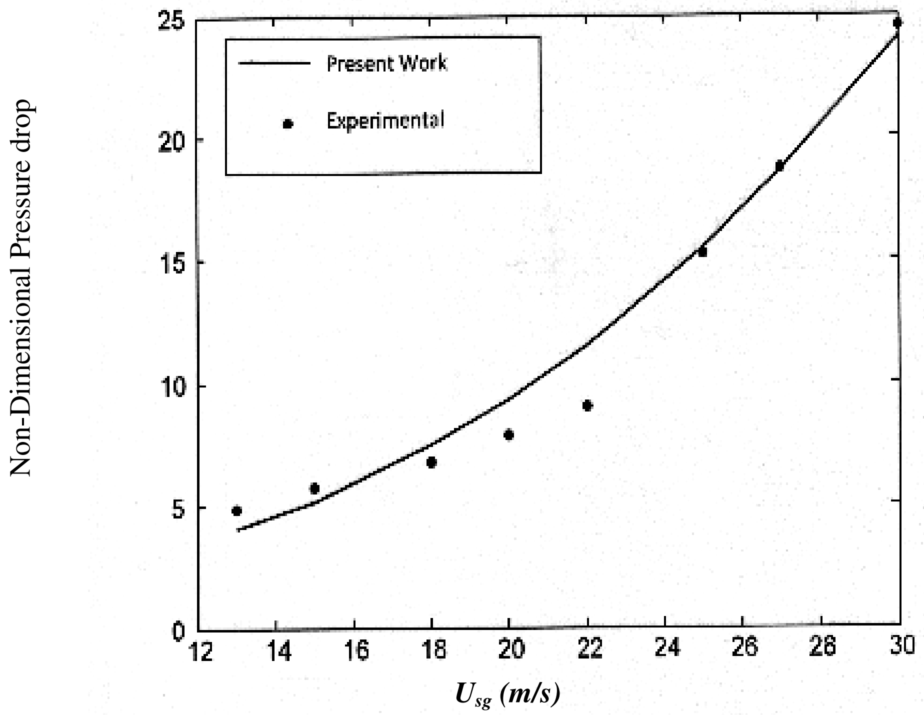


Fig.(9): Non-dimensional obstruction pressure drop for 25% horizontal

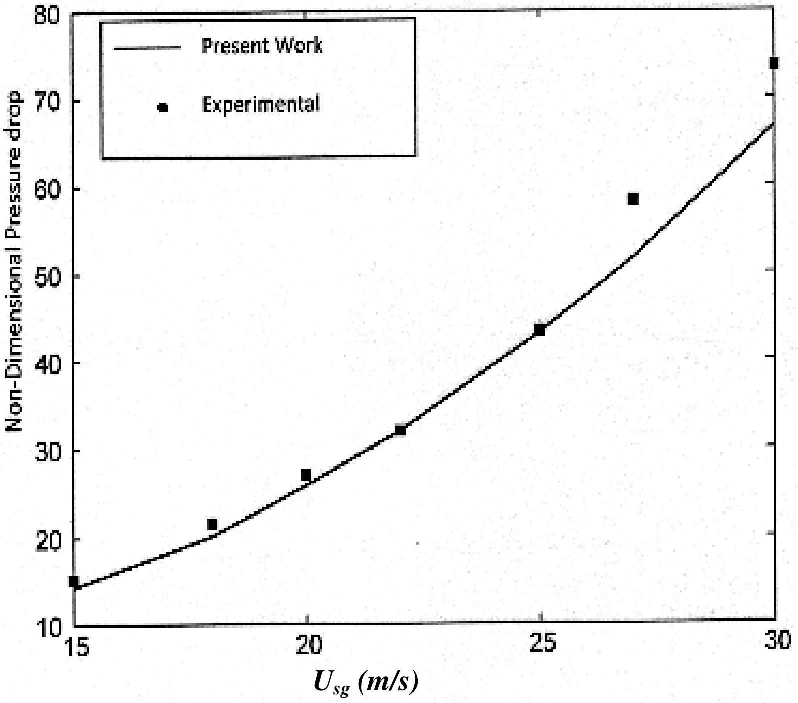


Fig.(10): Non-dimensional obstruction pressure drop for 40% horizontal segment obstruction.