THEORETICAL AND EXPERIMENTAL ANALYSIS OF TWO-PHASE FLOW THROUGH PIPE FITTINGS

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ABSTRACT:

Two-phase air water flow through pipe fittings has been studied experimentally and validated theoretically with developed formulas. Pressure drop across pipe fitting such as thin and thick plate orifice, both sudden contraction and sudden expansion and Venturi meters has been measured. Formulation for contraction coefficient and also discharge coefficient are conducted. The results demonstrate that the contraction in two-phase flow is depicted in a narrow ranges of mass flow qualities, less than 1.2% and a greater than 90% where the flow regimes are specified as bubbly and spray ones respectively. In addition the discharge coefficient is greatly affected with air mass flow quality. Empirical formulas are presented for discharge and contraction coefficients as function of Reynolds number, gas mass flow quality and area ratio. The experimental measurements have been simulated with the predicted formula.

1. INTRODUCTION:

Nowadays two-phase gas liquid systems in industrial process occupy an important place and pose many problems to the engineer during conception and dimensioning of installations concerned by such systems.

Precise knowledge of two-phase flows, either a better understanding of certain phenomena (void migration, blocking, coalescence, etc) or control of industrial operations (pressure drop, heat and mass transfer) is of basic interest. Transport circuits in two-phase industrial installations are mainly composed of various singularities which provoke significant modifications of the flow. Among these singularities, the cases of sharp edge thin plate orifice, sudden contraction, sudden expansion and Venturi tubes corresponds to common situation in practice.

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A considerable effort is then generally needed to calculate the pressure drop across piping components. Many studies have been conducted in this direction through the pipe fittings. Chisholm [1] has developed a formula for predicting the static pressure across pipe fitting for the flow of two-phase. A comparison has been made for the predicted results and the experimental data. Tapucu et. al [2] have investigated the irreversible form pressure losses caused by plate and smooth blockages for air-water flows in a square vertical channel. They visualized the blockage region showing that a recirculation zone forms on both sides of the blockage. They observed that the contraction coefficients for two-phase flow differ some what from those for single-phase flows. Also the irreversible pressure loss coefficients for plate and smooth blockages depend on both blockage severity and flow void fraction. Schmidt and Friedel [3] developed a new model to calculate the two-phase (air-water) pressure drop across a sudden contraction in a duct, taking into consideration all the relevant theoretical boundary conditions. To validate the new model, an experimental program was carried out. The model was checked against the experimental data and results from others. The new model predicts the experimental results sufficiently accurate. Shannak et. al [4] have predicted a new model for the contraction coefficient of single and two-phase flows through sharp-edged short orifice. They checked the suggested model against data from other investigators. The predictions are validated for a wide range of conditions and physical properties typically encountered in industrial fluid dynamic systems. Predictions based on this model are sufficiently accurate for engineering purposes. Shannak et al., [5] have produced a set of measurements for the flow contraction through sharp-edged short orifices for water, air and air-water mixture. The results demonstrate that the contraction in the case of subcritical single phase flow is restricted to values between 0.62 and one. While in the two-phase flow it is limited to very narrow ranges of air mass flow qualities where the flow regime is specified as bubbly or spray which are of great importance in the process industry.

The present work is concerned with the pressure drop that occurs across different types of pipe fittings for the flow of two-phase air/water mixture where the compressibility effects of the gas component can be neglected and no evaporation of the liquid component occurs. The fittings discussed are sudden expansion, sudden contraction, thin and thick-plates and Venturi pipe as shown in Fig. (1).

2. ANALYTICAL STUDY

2.1 Prediction of Two-Phase Pressure Drop

The relation between the two-phase pressure drop over an orifice plate or similar restriction (ΔP_{TP}) and the pressure drop if the total mass of the mixture treated as liquid only (ΔP_{LO}) is developed as quoted by Chisholm [1] and Hoopes [6], as,

$$\frac{\Delta P_{TP}}{\Delta P_{LO}} = \frac{X^2}{\alpha_G}\frac{V_G}{V_L} + \frac{(1-X)^2}{1-\alpha_G} \quad (1)$$

The model which is simulated by the above equation can be rewritten in another form as reported in [1 , 7] as,

$$\frac{\Delta P_{TP}}{\Delta P_L} = 1 + \frac{C}{Y} + \frac{1}{Y^2} \quad (2)$$

Where Y is the Lockhart-Martinelli parameter which is defined for an orifice and similar restriction by,

$$Y = \left(\frac{\Delta P_L}{\Delta P_G}\right)^{0.5} = \frac{1-X}{X}\left(\frac{V_L}{V_G}\right)^{0.5} \quad (3)$$

$$C = \frac{1}{K}\left(\frac{V_G}{V_L}\right)^{0.5} + K\left(\frac{V_L}{V_G}\right)^{0.5} \quad (4)$$

A suitable form to evaluate the parameter C as reported in [8 , 9] is,

$$C = C_2\left\{\left(\frac{V_L}{V_G}\right)^{0.5} + \left(\frac{V_G}{V_L}\right)^{0.5}\right\} \quad (5)$$

where, $C_2 = \frac{B.(\Gamma^2 - 1) + 2}{(\Gamma^2 + 1)}$

From equations (4) and (5), it is clear that for homogenous flow the value of C_2 equal unity, ($C_2 = 1$).

Equation (1) can be transformed [1] using the phase continuity equation to;

$$\frac{\Delta P_{TP}}{\Delta P_{LO}} = 1 + \left(\frac{V_G}{V_L} - 1\right)\{BX + (1-B)X^2\} \quad (6)$$

Where;

$$B = \frac{\frac{1}{K}\left[\frac{V_G}{V_L}\right] + K - 2}{\frac{V_G}{V_L} - 1} \quad (7)$$

It can also be shown that,

$$B = \frac{C_2\left[\frac{V_G}{V_L} + 1\right] - 2}{\frac{V_G}{V_L} - 1} \quad (8)$$

From this equation it can be seen that $B = C_2$ except when V_G/V_L approaches unity. If $C_2 = 0.5$, if $V_G/V_L = 50$ from equation (8), $B = 0.48$

Baroczy [10] has introduced a "physical property index" $(\Delta P_{LO}/\Delta P_{GO})^{0.5}$ in Eqn. (9). This index has a value less than unity thus in some ways it is preferable to work with the reciprocal of this previous index. This reciprocal will be referred to as the "physical property coefficient" and is thus defined as,

$$\Gamma = (\Delta P_{GO} / \Delta P_{LO})^{0.5} \quad (9)$$

For flow across changes of section,

$$\Gamma = (V_G / V_L)^{0.5} \quad (10)$$

Substituting equation. (10) in (6) gives the following general equation;

$$\frac{\Delta P_{TP}}{\Delta P_{LO}} = 1 + (\Gamma^2 - 1).[BX + (1-B).X^2] \quad (11)$$

Another form of equation (11) is drawn to relate (ΔP_{TP}) with (ΔP_{GO}).

$$\frac{\Delta P_{TP}}{\Delta P_{GO}} = \frac{1}{\Gamma^2}[1+(\Gamma^2-1).(BX+(1-B).X^2)] \tag{12}$$

Equation (11) is used in the case of two-phase bubbly flow, while Eqn. (12) is preferable in case of two-phase spray flow.

Substituting equation (10) into equations (3, 4 and 5) through equation (7) then,

$$Y = \frac{1-X}{X.\Gamma} \tag{13}$$

$$C = \frac{\text{Б}.(\Gamma^2-1)+2}{\Gamma} \tag{14}$$

Substituting equations (13 and 14) into equation (2) gives,

$$\frac{\Delta P_{TP}}{\Delta P_L} = 1 + \frac{[B.(\Gamma^2-1)+2].X}{(1-X)} + \frac{X^2\,\Gamma^2}{(1-X)^2} \tag{15}$$

Dividing equation. (15) by (11) gives,

$$\frac{\Delta P_{LO}}{\Delta P_L} = \frac{1+\dfrac{[B.(\Gamma^2-1)+2].X}{(1-X)}+\dfrac{X^2\,\Gamma^2}{(1-X)^2}}{1+(\Gamma^2-1)\,[B.X+(1-B).X^2]} \tag{16}$$

From equations (11) and (12) it is noted that, regardless of the value of B, the following boundary conditions are satisfied,

When, $X = 0$, then $\quad \Delta P_{TP} = \Delta P_{LO}$

$X = 1, \quad \Delta P_{TP} = \Delta P_{GO}$

$\Gamma^2 = 1, \quad \Delta P_{TP} = \Delta P_{LO} = \Delta P_{GO}$

The values of the coefficients B and K which are recommended by Chisholm [1] and others for various fittings such as sudden contraction, sudden expansion and thin plate are shown in Table-1. While for thick plate, Chisholm [1 , 9] assume that B = 1 for contraction and B = 0.5 for expansion. The overall value of the coefficient B is given by,

$$B = 1 + \frac{(AR - AR^2)}{(\frac{1}{C_c}-1)^2 + (AR-1)^2} \tag{17}$$

where, AR is the downstream to upstream flow cross-sections and C_c is the contraction coefficient for single-phase flow. The value of B = 1.5 for thick-plate was recommended [1].

2.2. Prediction of Single and Two-Phase Flow Contraction Coefficient Through Sharp-Edged Short Orifice.

The ratio made of the narrowest cross-section of the core flow, vena contracta and the geometrically available orifice cross-section is described as the contraction coefficient. Several compensation functions and models for the calculation of the contraction coefficient in single-phase flow through an orifice are available in the literature, like those of Benedict [11 , 12], Chisholm [9], among others. These are based on water free jet experimental results. Therefore the effective cross-sections that have been calculated are used in safety technical design but with considerable reservations.

For the case of the two-phase flow the calculation method is reported by Chisholm [9]. This method is based on simplified assumptions that each phase flows separately through the orifice without one phase being entrained in the other, in addition to that the flow is contracted in the whole range of the air mass flow quality. The latter assumption is in contradicting with the literature results [5, 9, 11 and 12].

The flow contraction in certain ranges is controlled by both geometrical and flow parameters. Geometrically, a sharp-edged short orifice is considered in this study.

The effect of the natural wall roughness of both pipe and orifice is assumed to be negligibly small, hence the contraction coefficient can take the form.

$$C_{cTP} = f(M_L, M_G, P_u, P_d, \beta)$$

All the above parameters should be taken into consideration for the development of a reliable calculation method.

Applying Bernoulli equation over a control volume for the range from the fully developed flow upstream the orifice (1) to the narrowest cross-section downstream, the vena contracta (2), Fig. (1) with the assumption that the horizontal flow is one-dimensional, stationary, frictionless and adiabatic, the contraction coefficients for incompressible and compressible single-phase flows [4] are given respectively as:

$$C_{c\ \text{incomp.}} = \frac{0.002.m_1}{\beta\sqrt{\rho_1 P_1}} + \beta^{0.1}\left(1.095 - 0.037\ \text{Ln}\ \frac{Re_P}{40}\right) \tag{18}$$

$$C_{c\ \text{comp.}} = \frac{0.04.m_1}{\beta\sqrt{\rho_1 P_1}} + 0.62 + \left[\left(1.15\ .\ 10^{-6}\right) Re_P \left(\frac{1-\beta}{\beta}\right)\left(\frac{P_a}{P_1}\right)^{0.286}\right]^5 \tag{19}$$

The opening ratio β being between zero and unity and Reynolds number in excess of 3000.

The total mass flow rate is give by

$$M_{TP} = M_L + M_G \tag{20}$$

With the individual mass flow rate;

$$M_j = \rho_j V_j C_{c_j} A_o \tag{21}$$

where; j = L, G or TP and each fluid contracts as when flowing alone.

Both fluid mass flux and ratio of gas flow rate to total flow rate are given by,

$$m_j = \rho_j V_j \tag{22}$$

$$X = \frac{m_G}{m_G + m_L} \tag{23}$$

The contraction coefficient for two-phase flow is taken [4] to be in the following form;

$$C_{c\,Tp} = (1-X)^a.C_{c\ \text{incomp.}} + X^b.C_{c\ \text{comp.}} \tag{24}$$

The values of the constants (a and b) are determined empirically based on experimental data concerning air/water mixture [4] using the least-square method. In this method the square absolute deviation between measured and calculated values was minimized and therefore, values of (a and b) becomes 0.4 and 0.15, respectively.

Equation (24) holds [4 , 5] for two-phase flow as long as bubbly flow or spray flow are available with air mass flow qualities less than 1.2% and greater than 90% where the flow regimes are specified as bubbly or spray flow, respectively.

2.3 Prediction of Single and Two-Phase Flow Discharge Coefficients Through Sharp-Edged Short Orifice.

In analogy to the single-phase flow; a relation for calculating the discharge coefficient at two-phase flow, with the help of the contraction coefficient and the velocity coefficient can be suggested;

$$C_{d\,TP} = C_{c\,TP} . C_{v\,TP} \tag{25}$$

A mean value of 0.97 for the velocity coefficient at single-phase flow by a sharp-edged orifice can also be acceptable [5] for two-phase flow. The contraction coefficient of bubbly and spray flow usually lies between 0.75 and unity. Therefore, the discharge coefficient of two-phase orifice flow applies in this range as,

$$0.73 < C_{d\,TP} < 0.97$$

In the other flow regimes where no flow contraction is expected; the contraction coefficient [5] is equal to unity; the discharge coefficient then applies.

$$C_{d\,TP} \approx C_{v\,TP} = 0.97$$

The discharge coefficient of an orifice with D and 0.5 D taps for liquids only is given [13] by the following empirical formula;

$$C_d = f(\beta) + 91.71.\beta^{2.5}.Re_p^{-0.75} + \frac{0.09\ \beta^4}{1-\beta^4} F_1 - 0.0337.\beta^3.F_2 \tag{26}$$

where;

$$f(\beta) = 0.5959 + 0.0312.\beta^{2.1} - 0.184.\beta^8$$

, $F_1 = 0.4333$ and $F_2 = 0.47$

3. EXPERIMENTAL STUDY:

3.1 Apparatus and Experimental procedure

An experimental set-up is constructed as shown in Fig. (2) to study the flow of single phase of water and two-phase of air and water mixture through pipe fittings, such as an orifice, thick-plate, sudden contraction and Verturi. The water is supplied by a pump, which is driven by an electric motor, from the storage tank (23), to a mixer (15), where water is combined with air taken from air supply line through volume flowmeter. After the mixer, the water or air water mixture flow through a horizontal test section back to the storage tank. The horizontal test section was made up from two straight pipes with a length of 2 m of each after the mixer and upstream the fitting and 1 m length downstream the fitting section, respectively. The pipe diameter is 50 mm. The arrangement of the long straight pipe, at least, ensure that the flow is fully developed in front of the orifice. The mixing chamber consists of an inner perforated tube of 50 mm inner diameter and 200 mm length enclosed in a housing of a larger tube of 100 mm inner diameter with two tubes of 12.5 mm diameter supplying the air to the mixing chamber as shown in Fig. (2.b).

The volume flow rate of water was determined using a metering tank (21). The water was collected in the metering tank for a period of time with uncertainty of ±0.5%. Compressed air, which is supplied from the compressor (19) air-tank through an air-supply line after passing through pressure regulating valve (26), flow control valve (27) and an air flow meter to the mixing chamber. The air flow rate is measured using a calibrated sharp-edged orifice meter (25), connected to water U-tube inclined manometer with uncertainty of ±3.5%. The pressure distribution along the pipe and across the pipe fittings are measured using a set of U-tube mercury manometers filled with mercury.

3.2 Cases of Study:

The dimensions of tested pipe fitting are shown in Table -1

Table -1 Approximate B, K Coefficients and Dimension of Tested Pipe Fittings

Device	B	K	Reference	AR	D
Sudden contraction	1	1	[1 , 10]	0.25	2"
Sudden expansion	0.5	2	[10]	0.25	1"
Thin plate orifice	0.5	-	[1 , 9]	0.25	2"
Thick plate orifice	1.5	-	Eqn (17)	0.25	2"
Venturi	0.5		-	0.242	1"

4. RESULTS AND DISCUSSION

The experimental measurements together with the predicted results are presented here for single and two-phase flow as follows:

Predicted contraction coefficient for single phase flows of water is shown in Fig. (3) as a function of the mass flux, the area ratio and the upstream pressure. The predicted results of Eqn. (18) are compared with experimental data [5]. Behaviour of Fig. (3) results illustrates that the contraction coefficient decreases with higher mass flux as well as with lower area ratio due to an increasing of inertia force effect.

In the case of air flow, the predicted contraction coefficient Eqn. (19) rises with higher mass flux at constant parameters as shown in Fig. (4). The results of Fig. (4) show that the contraction coefficient is decreased with increasing the area ratio while the upstream pressure and air mass flux are constant. The same behaviour of contraction coefficient is obtained with increasing the upstream pressure at constant value of area ratio and air mass flux. This behaviour is explained where the minimum local pressure is always developed in vena contracta where the flow velocity is maximum. While as the pressure and so the density is decreasing, the air volume expands and hence the core flow cross section becomes larger, leading to higher contraction coefficient with increasing the air mass flux due to the relatively more effective inertia effect. To validate the present prediction, a comparison with the experimental data from [5] is carried out.

Fig. (5) shows the variation of pressure drop ratio versus the air mass flow quality for different pipe fittings. It is seen that increasing the air mass flow quality for both bubbly and spray flow increased the pressure drop ratio. The measured results are included with the predicted formulas of different pipe fittings for the bubbly flow ($X< 1.2\%$). The variation of pressure drop ratio against air mass flow quality for thin orifice is shown in Fig. (6) for two-phase flow of air/water spray flow ($X > 90\%$). The results indicate that increasing the air mass flow quality increased the pressure drop ratio.

In the view of the previous results reported in the literature that contraction can not appear in the two-phase flow for wide ranges of the air mass flow quality [4 , 5]. The flow contraction is confirmed under the prevailing test conditions when the air mass flow quality is less than 1.25% or greater than 90% [5] where the regimes can be specified as bubble flow and spray flow, respectively. A predicted model as depicted by Eqn. (24) is developed and the results of the model together with the experimental data from [5] are presented in Fig. (7) for bubbly flow and Fig. (8), for spray flow. From the comparison, an acceptable agreement is shown. The results are showing that for air mass flow quality less than 1.2%, bubbly flow the two-phase contracts with decreasing mass flux due to the decrease in the inertia force, therefore the contraction coefficient will increase. While for spray flow, it can be seen that the contraction coefficient increases with decreasing air mass flow quality.

A course of static pressure drop measurements along the pipe fitting for two-phase flow of air-water mixture with air mass flow quality less than 1.2%, where the flow regimes can be specified as bubbly flow, have been conducted. The results of the measurements are presented in Fig. (9) and Fig. (10). All the figures show the variation of pressure drop versus the axial distance along the pipe for different air qualities. The pressure curves show an expected minimum in the narrowest flow cross section. The location of the vena contracta is established at a distance between 0.4 to 0.6 times the inlet pipe diameter for all studied pipe fittings. When the air mass flow quality is less than 1.2%, i.e. bubble flow, the two-phase contracts with decreasing mass flux in a similar manner as in water single-phase flow. From the figures (9 and 10), it can be seen that, increasing the air mass flow quality, increased the pressure drop amplitude. While in the case of sudden expansion the pressure drop is less and the contraction is less. This is referred to the recovery in pressure in the downstream pipe.

The measurements of discharge and contraction coefficients for single-phase and two-phase flows across sharp edged short orifice and sudden contraction are presented in Fig. (11) and Fig. (12), respectively. Fig. (11) shows that, increasing the air flow quality increases the discharge coefficient for thin plate orifice and it takes nearly a constant value with increasing Reynolds number. The calculated values of discharge coefficient for thin plate orifice are fitted in the following empirical formula,

$$C_{dTP} = 0.62.Re_w^{-0.0273}.X^{0.1851}.AR^{-1.3115} \tag{27}$$

Fig. (12) shows the variation of contraction coefficient verses the Reynolds number for single phase and two-phase flow with different air mass flow quality. The contraction coefficient is increasing with increasing the mass flow quality. In addition the contraction coefficient takes a constant value with increasing Reynolds number. The calculated values of contraction coefficient for sudden contraction are fitted in the following empirical formula,

$$C_{cTP} = 1.2371.Re_w^{-0.0021}.X^{0.1809}.AR^{0.1643} \tag{28}$$

The values of discharge coefficient calculated from measurements and correspondingly predicted values from the empirical formula for thin plate orifice Eqn. (27) is shown in Fig. (13-a). While the values of contraction coefficient calculated from measurements and correspondingly predicted values from the empirical formula for sudden contraction Eqn. (28) is shown in Fig. (13-b). It is of great importance to note here that the experimental results are simulated with the developed formula and it shows an acceptable agreement.

5. CONCLUSION

The results of the present paper led to a series of an important finding about the contraction in single and two-phase flow in pipe fittings which are of great interest for the design of fluid devices.

The results demonstrate that the contraction in two-phase flow is depicted in a narrow ranges of mass flow qualities, less than 1.2% and a greater than 90% where the flow regimes are specified as bubbly and spray ones respectively.

The location of the vena contracta is established at about 0.4- 0.6 times the upstream-pipe diameter behind the transitional cross section and depends slightly on both the air flow quality and upstream pressure. The value of contraction coefficient for single-phase flow depends greatly on the area ratio, upstream pressure and mass flux. The value of discharge coefficient for two-phase flow increases with increasing the air mass flow quality in the range tested.

Empirical formulas are presented for discharge and contraction coefficients as function of Reynolds number, gas mass flow quality and area ratio.

NOMENCLATURE

AR:	Area ratio (downstream to upstream flow cross-sections),	-
B:	Coefficient in equation (6)	-
a , b:	Constants in equation (24)	-
C:	Coefficient in equation (2)	-
C_2:	Coefficient in equation (5)	-
C_c:	Contraction coefficient	-
C_D:	Discharge coefficient	-
C_v:	Velocity coefficient	-
D:	Upstream pipe diameter	m
H:	Pressure difference or static pressure head	m
K:	Ratio of gas to liquid velocity	-
M:	Mass flow rate	$kg.s^{-1}$
m:	Mass flux	$kg.m^{-2}.s^{-1}$
P:	Static pressure	$N.m^{-2}$
Q:	Discharge or volumetric flow rate	$m^3.s^{-1}$
Re:	Reynolds number	-
V_G:	Gas specific volume	$m^3.kg^{-1}$
V_L:	Liquid specific volume	$m^3.kg^{-1}$
X:	Ratio of gas to total mass flow rates (gas mass flow quality),-	
Y:	Lockhart-Martinelli parameter in equation (2)	
ρ:	Density	$kg.m^{-3}$
ΔP_{TP}:	Pressure drop due to restriction during two-phase flow	$N.m^{-2}$
ΔP_{LO}:	Pressure drop due to restriction if all mixture flows as liquid	$N.m^{-2}$

ΔP_L:	Pressure drop due to restriction if liquid component flows alone	$N.m^{-2}$
ΔP_G:	Pressure drop due to restriction if gas component flows alone	$N.m^{-2}$
ΔP_{GO}:	Pressure drop due to restriction if all mixture flows as gas	$N.m^{-2}$
Γ:	Physical property coefficient defined by equation (9)	-
α_G:	Proportion of flow cross-section occupied by gas or air	-
β:	Diameter ratio (downstream to upstream)	-

SUBSCRIPTS

1: Fully developed flow upstream of the fitting.
2: Narrowest flow cross-section downstream of the fitting.
TP: Two-phase flow.
A: Atmosphere.
comp: Compressible.
D: Downstream.
G: Gas or air.
incomp: Incompressible.
L: Liquid.
O: Orifice.
P: Pipe.
U: Upstream.
w: Water.

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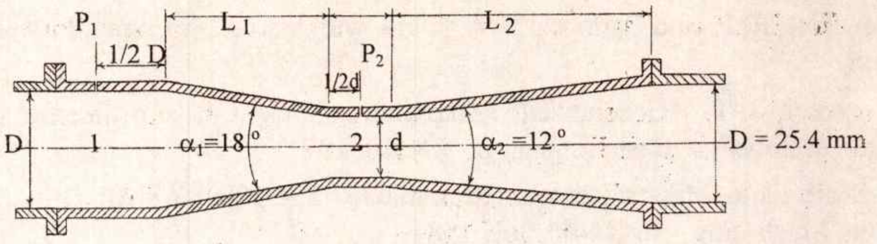
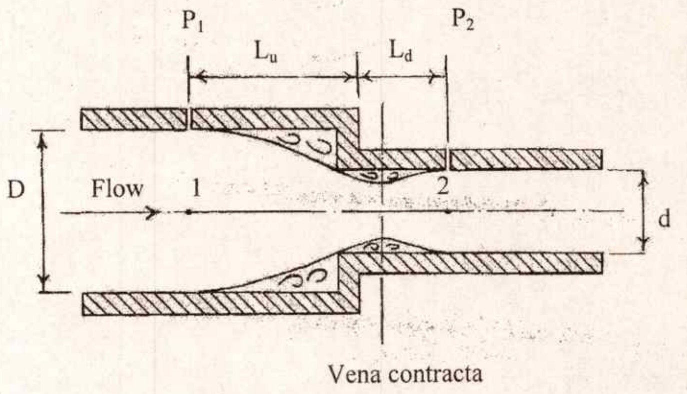
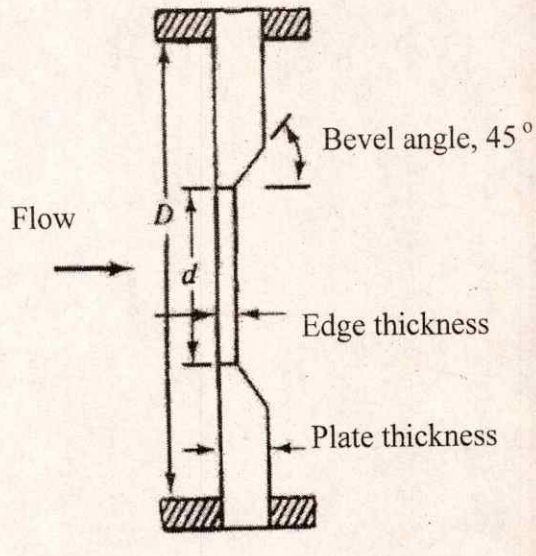
Converging cone, L_1= 40 mm Throat, d=12.5 mm Diverging cone, L_2= 60 mm



a- Venturi

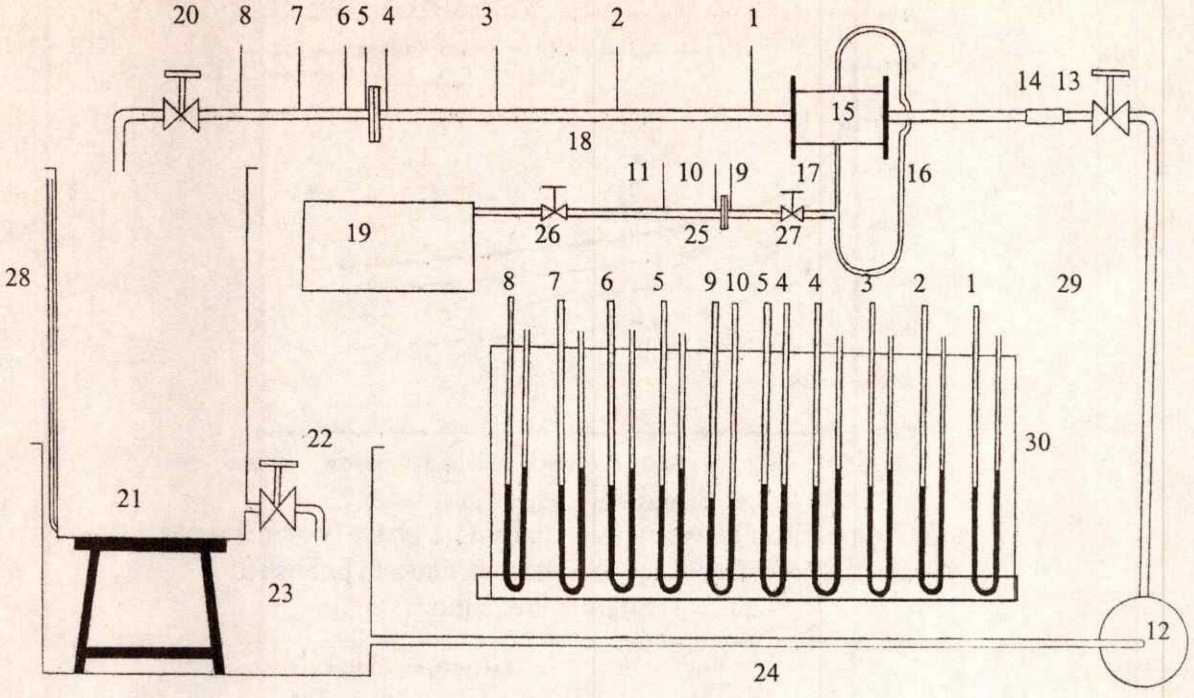


b- Sudden contraction



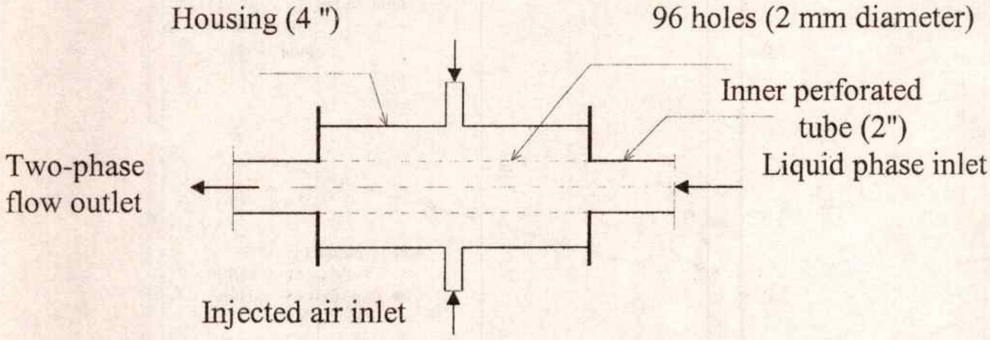
c- Thin plate orifice

Fig. (1) Tested pipe fittings.



1,2 to 8: Eight static pressure taps.
4, 5: U-tube manometer of the replaceable pipe fitting.
9, 10: U-tube manometer of the air orifice flow meter.
11: Air pressure bourdon gauge. 12: Centrifugal pump.
13, 20, 22, 26 ,27: Control valves. 14: Non-return valve.
15: Mixing chamber. 16,17 : Connecting lines.
18: Main replaceable flow metering pipe fitting.
19: Reciprocating air compressor. 21: Complementary reservoir for calibration.
23: Main reservoir. 24: Pump suction line.
25: Air flow meter (orifice). 28: Height indicator on a scale.
29: Pump discharge line. 30: Scaled board.

a Experimental layout.



b- Mixing chamber

Fig. (2) Experimental apparatus.

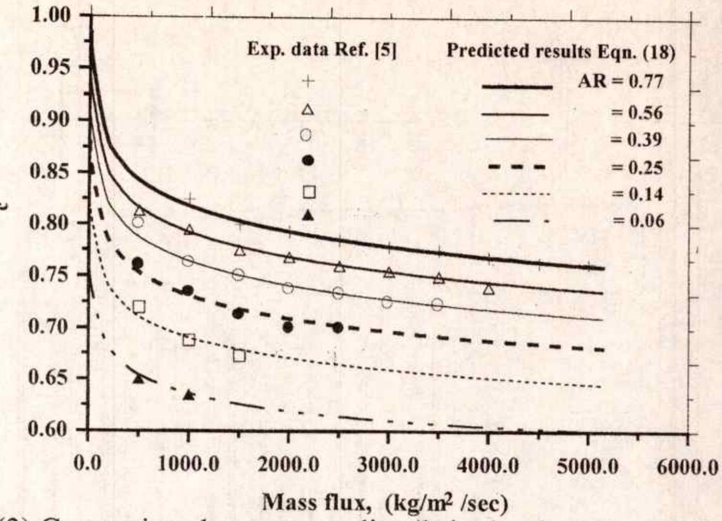


Fig. (3) Comparison between predicted single-phase (water flow) contraction coefficient for thin plate orifice and published data for different area ratio.

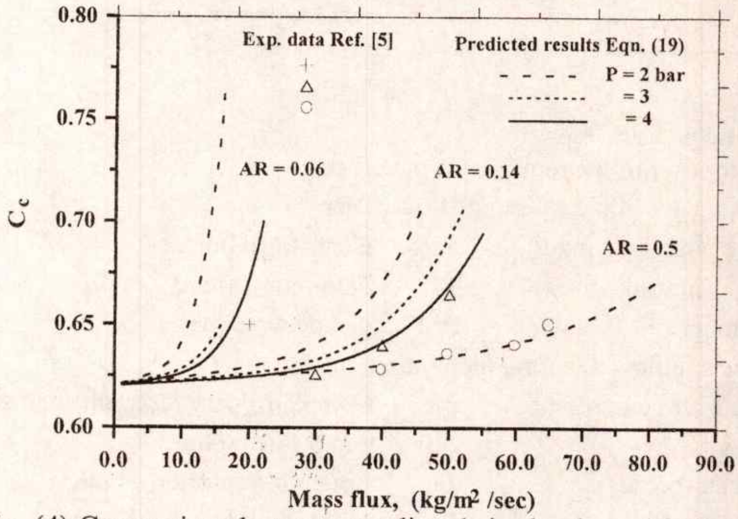


Fig. (4) Comparison between predicted single-phase (air flow) contraction coefficient for thin plate orifice and published data for different area ratio and inlet pressure.

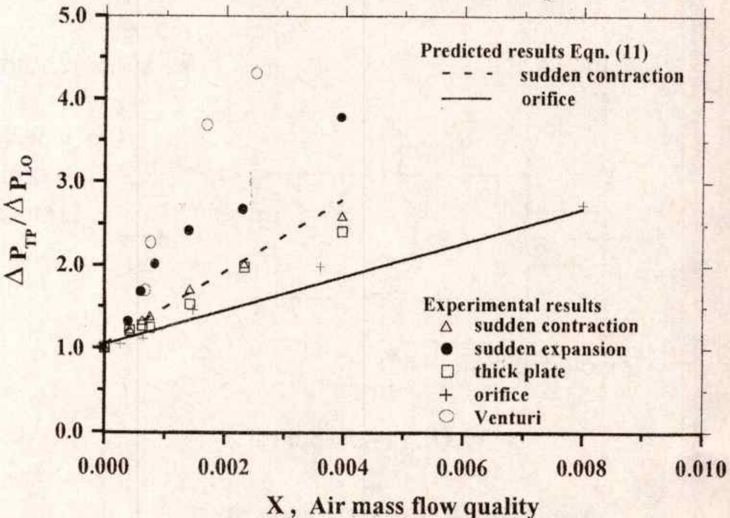


Fig. (5) Variation of pressure drop ratio against air mass flow quality, (air/water bubbly flow) for different pipe fittings.

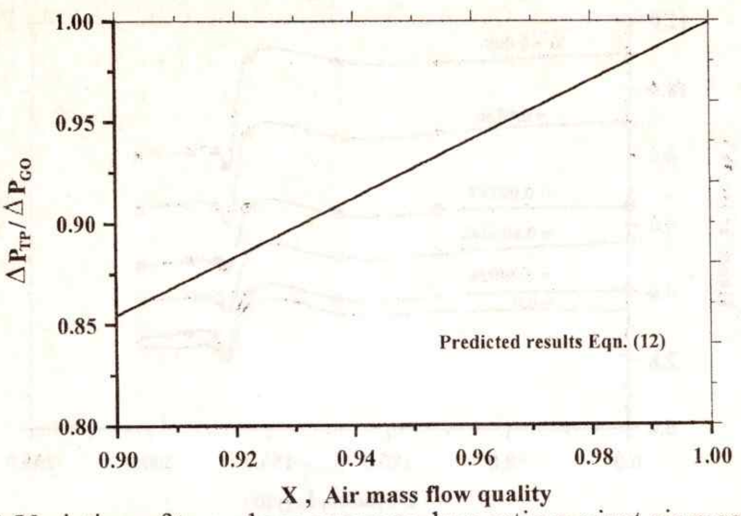


Fig. (6) Variation of two-phase pressure drop ratio against air mass flow quality, for thin plate orifice, (air/water spray flow).

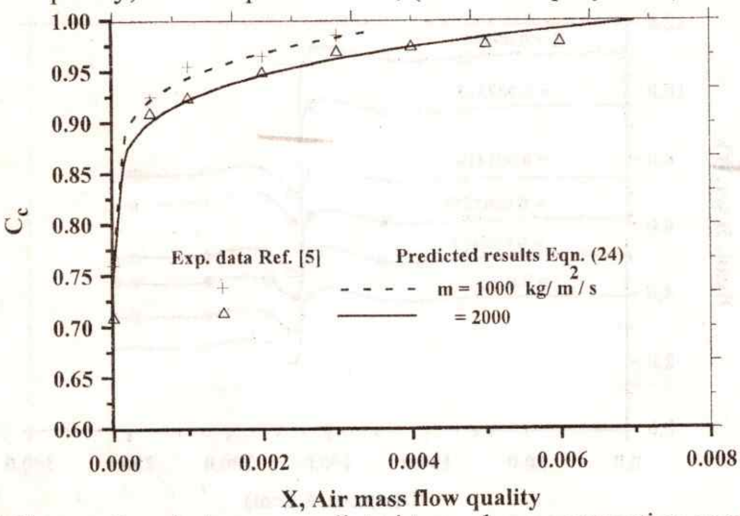


Fig. (7) Comparison between predicted two-phase contraction coefficient for thin plate orifice and published data for different inlet pressure and mass flux, (air/water bubbly flow).

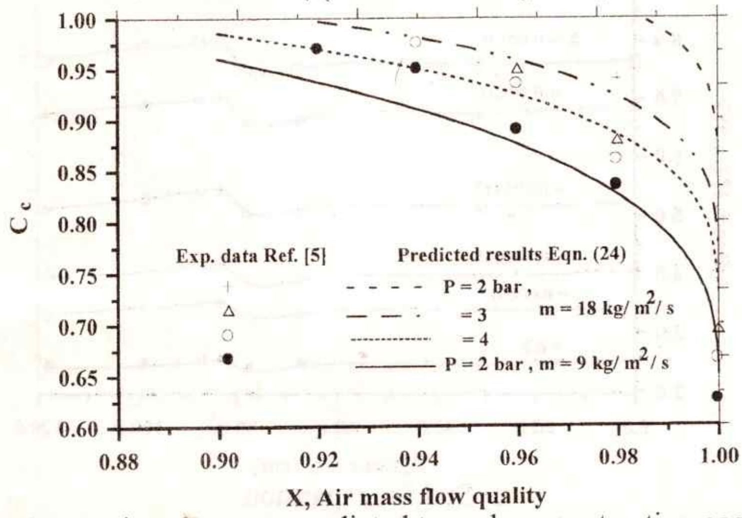
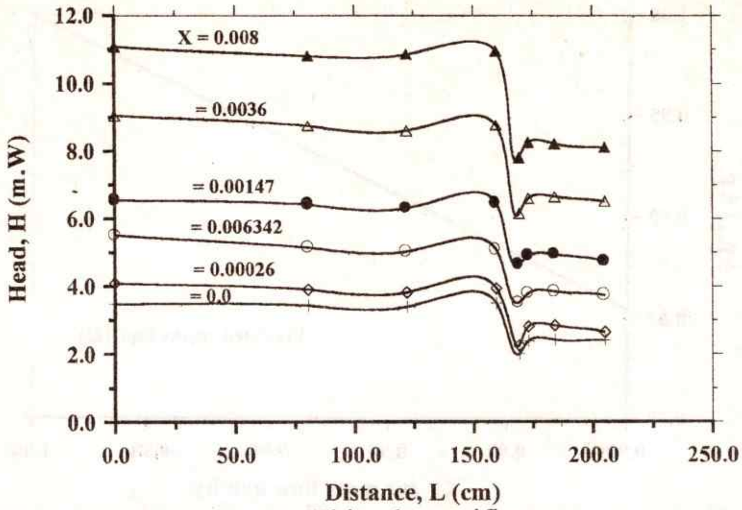
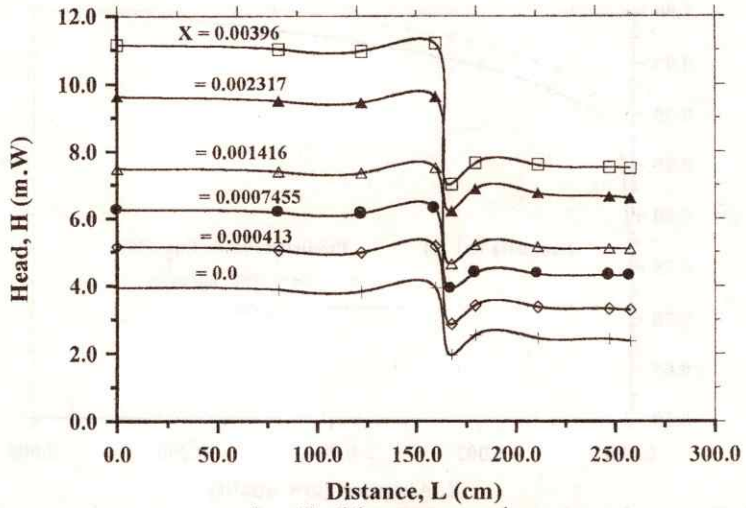


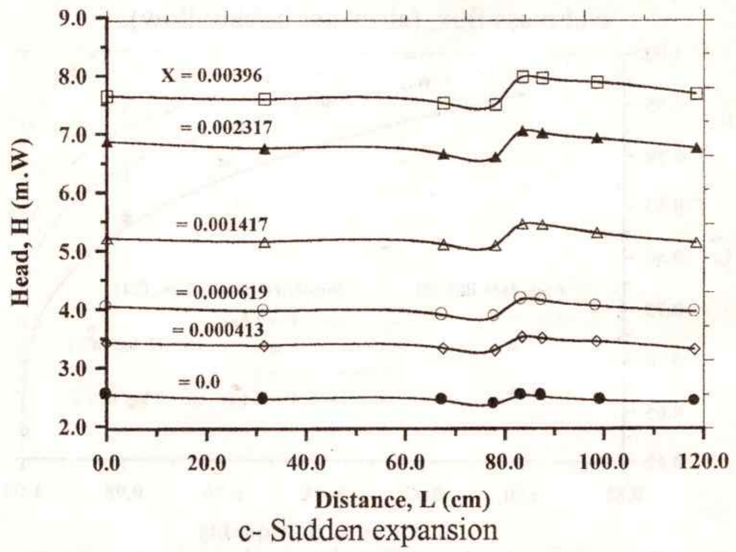
Fig. (8) Comparison between predicted two-phase contraction coefficient for thin plate orifice and published data for different mass flux, (air/water spray flow).



a- Thin plate orifice

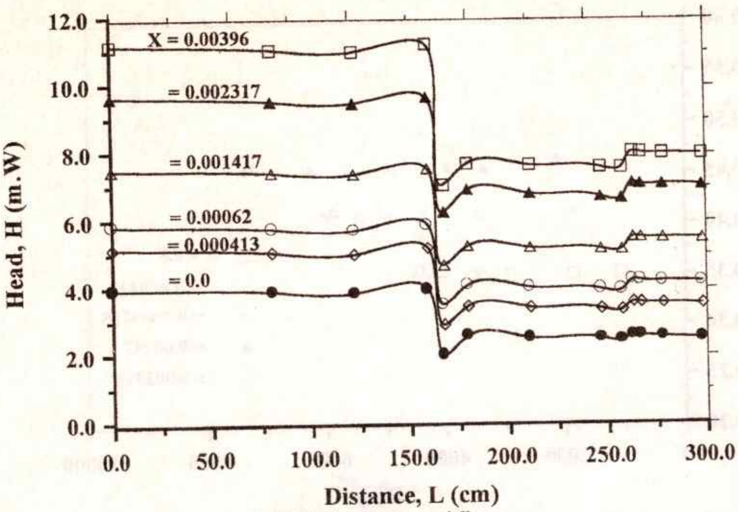


b- Sudden contraction

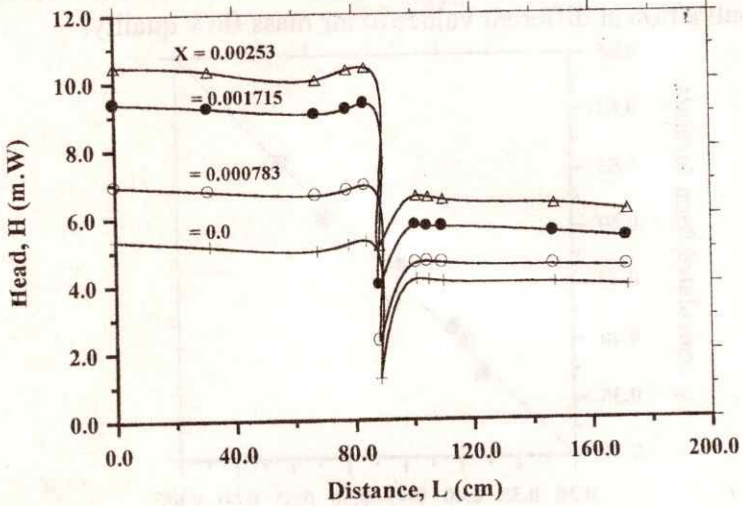


c- Sudden expansion

Fig. (9) Measured pressure distribution for two-phase flow along a different pipe fittings various air mass flow quality.



d-Thick plate orifice



e- Vevturi

Fig. (10) Measured pressure distribution for two-phase flow along a different pipe fittings various air mass flow quality.

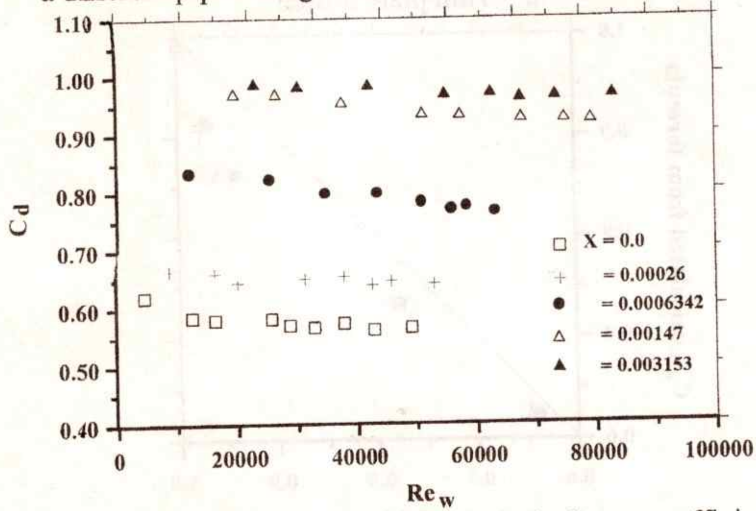


Fig. (11) Effect of water Reynolds number on discharge coefficient for thin plate orifice at different values of air mass flow quality.

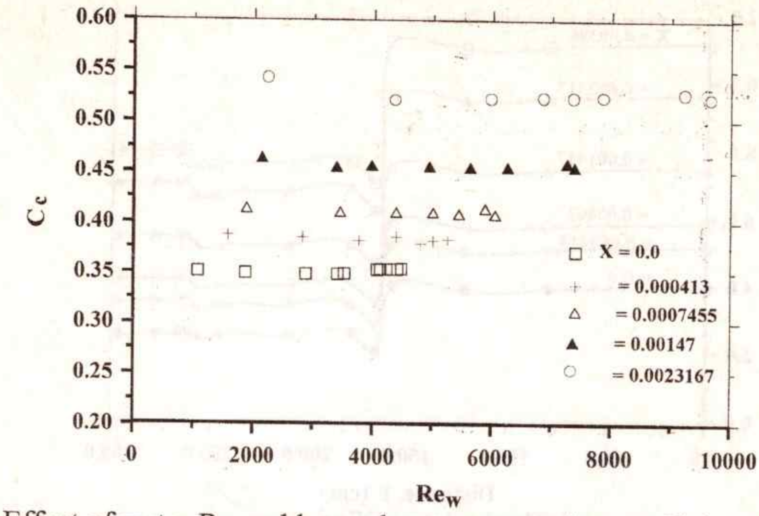
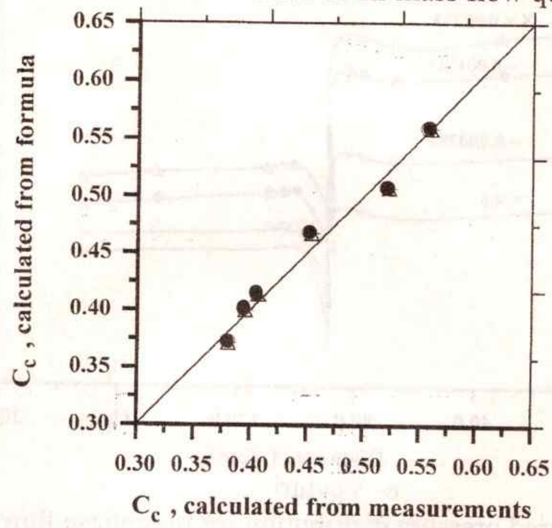
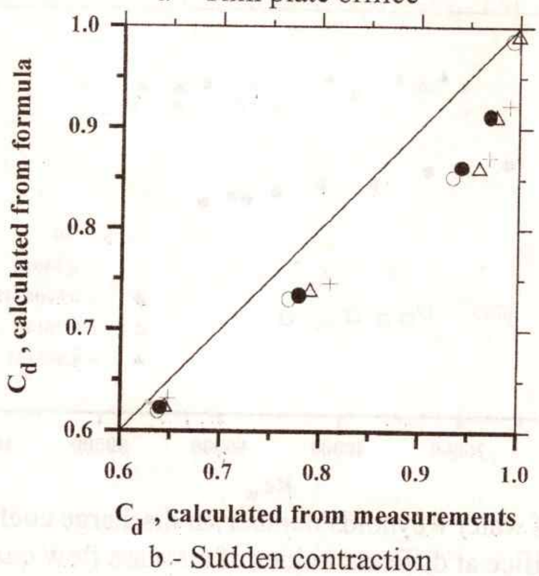


Fig. (12) Effect of water Reynolds number on contraction coefficient for sudden contraction at different values of air mass flow quality.



a Thin plate orifice



b - Sudden contraction

Fig. (13) Reproductive accuracy of the empirically derived two-phase discharge and contraction coefficients formulas.

" تحليل نظرى وعملى لسريان ثنائى الطور خلال ملحقات الأنابيب "

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ملخص البحـــث :-

يشــمل هــذا البحــث دراسة نظرية وعمليه لسريان ثنائى الطور (هواء + ماء) خلال ملحقــات الأنابيــب مثل الفتحات الرقيقة والسميكة ، الخنق والأتساع المفاجئ فى الأنابيب وكذا مقياس الفينشورى .

ولإجراء الدراسة النظرية تم عمل تحليل نظرى من خلاله تم حساب كل من معامل الفقد فى الضغط ومعامل الخنق ومعامل التصرف .

ولإجــراء الدراســة المعملــية اللازمة تم إعداد جهاز معملى متكامل ومركب عليه كل أجهــزة القــياس اللازمــة حيث تم تصنيع النماذج المختلفة وملحقات الأنابيب والتى تم دراسة الســريان خلالهــا ، وقــد أظهرت النتائج المعملية أن ظهور الخنق (contraction) فى حالة السريان ثنائى الطور (هواء + مــاء) يكون محدود وفى مدى ضيق لكل من السريان الفقاعــى (bubbly flow،X <1.2 %) والــرذاذى (spray flow ، X >90 %) بالإضــافة إلــى أن معامل التصرف تأثر كثيراً بنسبة جودة الهواء المار خلال الأنابيب المختبرة .

وقد تم استنتاج علاقات عددية من النتائج المعملية كدالة فى رقم الرينولدز وكمية الهواء وكــذا نســبة المساحات ، وأظهرت هذه العلاقات توافقاً مقبولاً للاستخدام. وللتحقق من التحليل النظرى فقد تم عقد مقارنة بين النتاج النظرية والنتائج العملية وكذا نتائج معملية لأبحاث منشورة حيث أظهرت المقارنة توافقاً مرضياً .