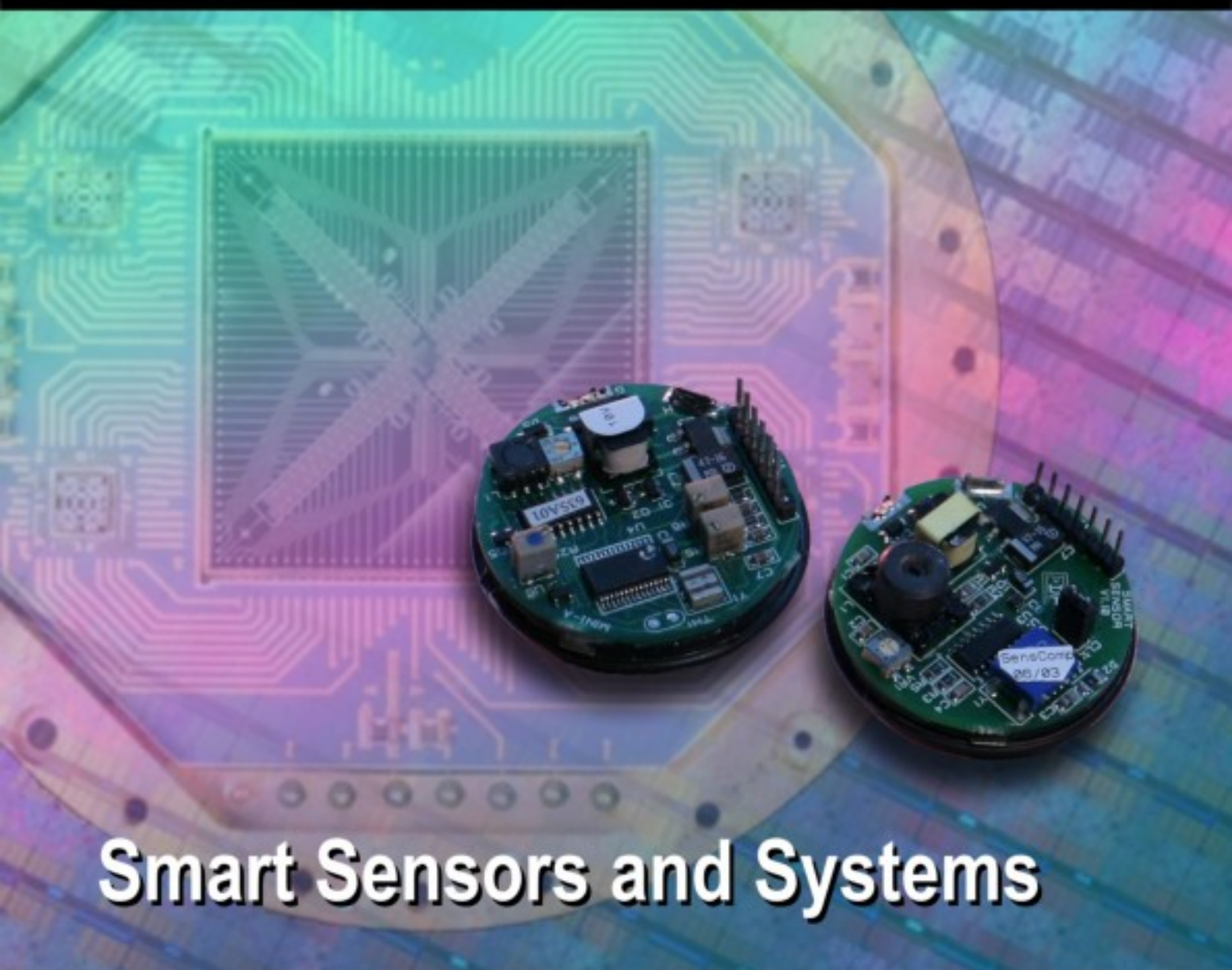


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## The Effect on Pressure Drop across Control Valve for Two Phase Flow (Air-Water)

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**Abstract:** Two-phase flow of water-air mixture through a pneumatic control valve for varying openings and varying ratios of flow rates was studied. The pressure drop increased with air-water ratio and the degree of variation depended on the valve opening. The friction factor decreases with Reynolds number and was also a function of valve opening. Two phase multiplier was correlated to Lockhart-Martinelli parameter and was decreasing as found in literature. Valve characteristics in terms of lift and fraction of maximum flow with quality as parameter showed that air water ratio drastically changed the characteristics. *Copyright © 2009 IFSA.*

**Keywords:** Control valve, Lockhart-martenelli parameter, Air-water system, Quality

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### 1. Introduction

Two phase flow is an important area applicable to petrochemical and allied industries. Simultaneous gas and liquid flow occurs in many types of industrial equipments, such as high pressure boilers, condensers, thermal hydraulic circuits of nuclear power stations, refrigeration equipment, evaporators and many other parts of chemical and process plants. Fundamental research in multiphase flows has been mainly directed towards the gas-liquid studies at low pressure.

The dispersions of the two phases in flow conduits depend on the flow rate of each phase, the flow properties and the geometry. The particular way the two phases are dispersed is termed the flow pattern or flow regime varies from one flow to another. These variations often make the two-phase flow study, such as pressure drop and heat transfer characteristics difficult to obtain and in most cases

are not as reliable as for single-phase. However, the design of many an industrial component necessitates the reasonable estimation of these two-phase parameters. Valve characteristics for two phase flow have not received any attention because of its complexity.

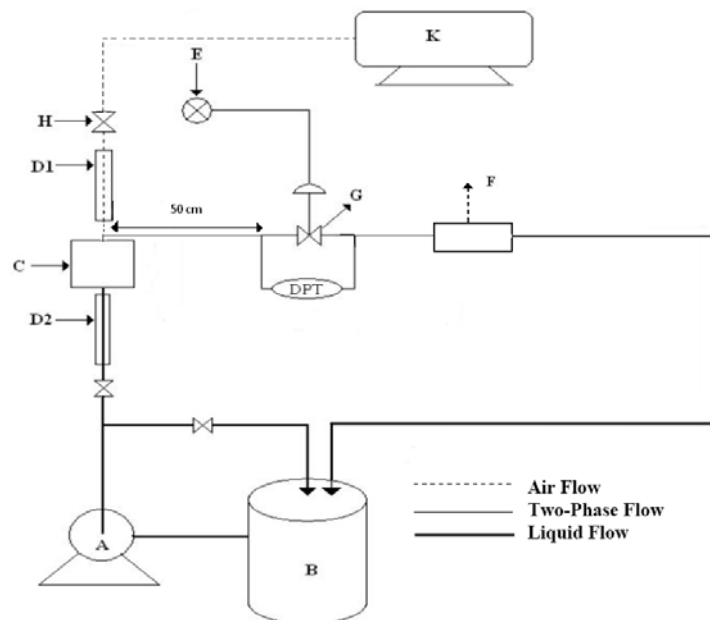
Lockhart and Martinelli [3] made the first detailed analysis in 1949 (Lockhart, 1949). Awwad. A, R. C. Xim, Z. F. Dong. et al. [5], Govier and Omer [10], were successors in this field. They concentrated on developing the flow pattern model for horizontal, inclined and vertical pipes. They have considered the following parameters:

- The operational variables (volumetric flow rate)
- Physical properties of the fluids (density and viscosity)
- Geometric variables of the system (diameter and length of the pipe).

Rani Hemamalini and Sundaram [1] studied experimentally the effect on pressure drop across horizontal pipe and control valve for air/water two-phase flow.

## 2. Experimental Procedure and Set Up

Fig. 1 shows the experimental set-up. A control valve is used as a test section. A calming section of 50 cm is provided to nullify the end effects developed during the experiment. The liquid is metered through Krone-Marshall magnetic flow meter (C). Purified air from an Ingersol Rand compressor through a 0 to  $2.027 \times 10^5$  Pa pressure regulators is metered through a non-return valve (H) using a PLACKA Rotameter. The pressure drop across the valve is measured with Honeywell differential pressure transducer (DPT). An electro pneumatic converter (E) is used to actuate the normally open pneumatic control valve.



**Fig. 1.** Experimental set-up of Coil in Series with Control Valve.

A	Pump	F	Gas vent
B	Storage Tank (Liquid)	G	Control valve (1/2" equal percentage)
C	Magnetic flow meter	H	Non-Return valve
D1	Rotameter (air )	K	Compressor
D2	Rotameter (Liquid)		
E	I/P converter		

Experiments were carried out with pure liquid and mixture of air and liquid with valve openings of 25, 50, 75, and 100 percent. The pressure was measured for different ratios. The liquid and air ratio varied from 50-150 LPH and 25-75 LPH respectively.

## 2.1. Single Phase Flow (Liquid Flow)

The friction factor for valve section is estimated from the measured pressure drop and corresponding flow velocity, using equations (1), (2) and (3).

$$NRe = \frac{\rho_1 V_1 D}{\mu_1} \quad (1)$$

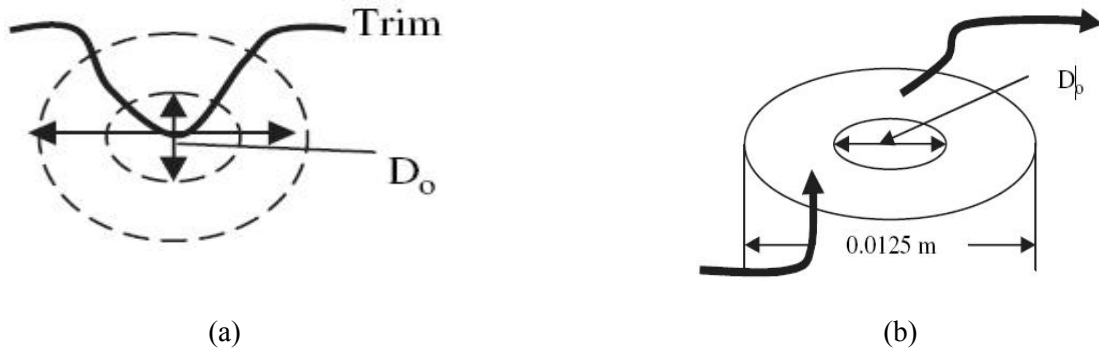
$$f_v = \frac{\Delta P_v}{2 \rho_1 V_1^2} (D_e) \quad (2)$$

$$f = a NRe^m, \quad (3)$$

where, the equivalent diameter,  $D_e$  for valve is determined based on the geometry of the control valve.

## 2.2. Definition of Equivalent Diameter for Valve Opening

The valve assembly was dismantled and the orifice opening and trim configuration was measured for different lift positions. The maximum valve opening was 0.125 m. Fig. 2 shows the details of stem contour and opening. For the valve section based on valve opening, an equivalent diameter was determined defined by Eq. (3).



**Fig. 2.** (a) Definition of Equivalent Diameter, (b) Flow through Valve.

Equivalent diameter  $d_e = 4 \times$  hydraulic radius, where

$$D_e = 4 \left( \frac{\frac{\pi}{4} (0.0125^2 - D_o^2)}{\pi (0.0125 + D_o)} \right) \quad (4)$$

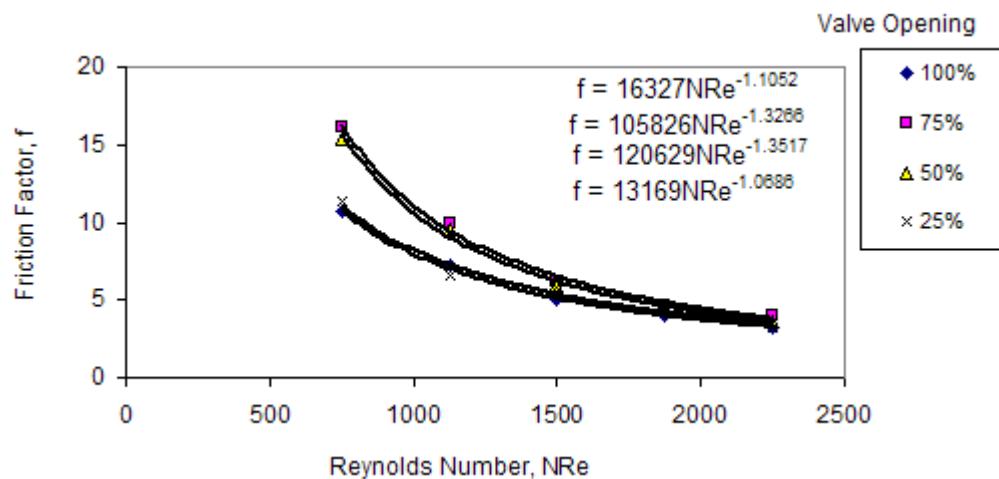
$$D_e = 0.0125 - D_o$$

The value of equivalent diameter for various lifts is given in Table 1. Fig. 3 shows the graph for friction factor vs Reynolds number for water in the valve section for different valve openings. The data was fitted to equation (3)

$$f = aNRe^m$$

**Table 1.** Equivalent Diameters for valve opening.

Percentage of Lift	Orifice Diameter ( $D_0$ ) in m	Equivalent Diameter ( $D_e$ ) in m
100	0	0.0125
75	0.0094	0.0031
50	0.0063	0.0063
25	0.0031	0.0094



**Fig. 3.** Friction Factor vs Reynolds Number for Water in the Valve Section.

The values of constants of Eq. (3)  $a$  and  $m$  for pure liquid and valve section are given in Table 2. A single graph could not be obtained due to valve geometry.

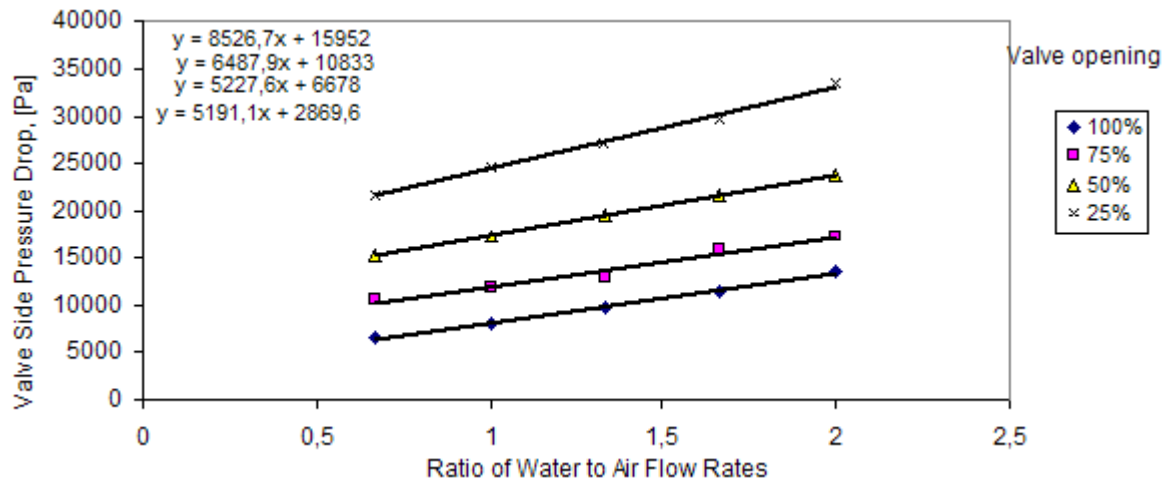
**Table 2.** Constants for Eq. (3) for various valves opening for valve section.

Constants	Valve opening (%)			
	25	50	75	100
$a$	16327	105826	12629	13169
$m$	-1.152	-1.3266	-1.3517	-1.0686

### 2.3. Two-Phase Flow (Pressure Drop vs $Q_l/Q_a$ )

The measured pressure drop across control valve for different liquid to air ratios ( $Q_l/Q_a$ ) are plotted and shown in Fig. 4. It is observed that maximum pressure drop is 33.3 KPa for 25 % valve opening and decreases as the valve opening increases.





**Fig. 4.** Effect of Pressure Drop in Valve section for Different Valve Opening for Water at Air Flow Rate of 75 lph.

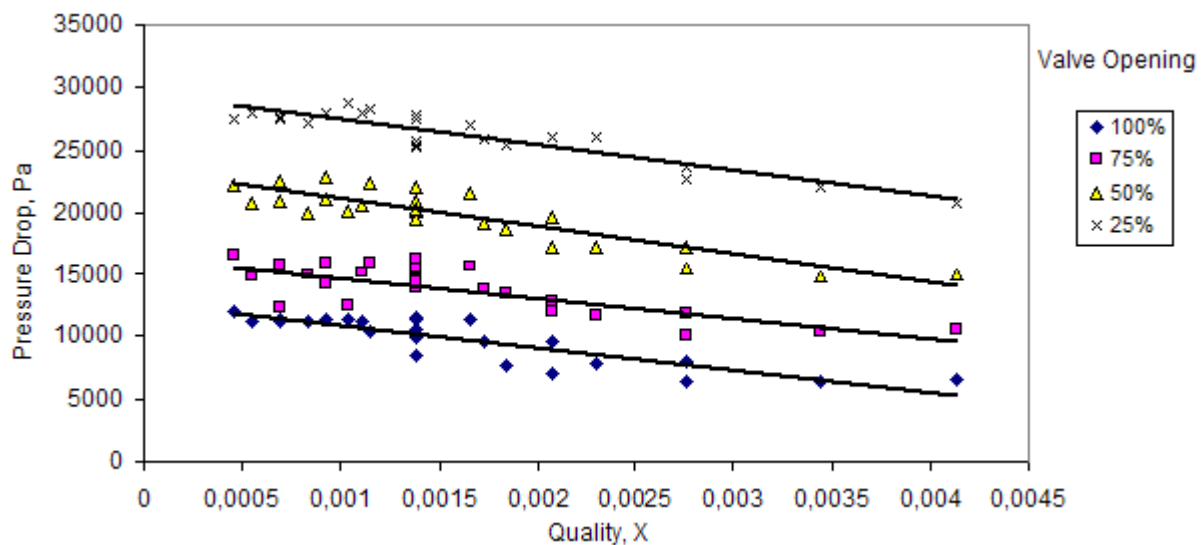
## 2.4. Pressure Drop vs Quality (X)

The term quality  $X$  defines the fraction of dispersed phase (flow rate of air/ (flow rate of liquid+ flow rate of air)) in two-phase flow and can be estimated using Eq. (5).

$$X = \frac{1}{\left(1 + \frac{\rho_1 Q_1}{\rho_2 Q_2}\right)} \quad (5)$$

The experimentally measured pressure drop variation with quality,  $X$  is shown in Fig. 5. The pressure drop varies linearly with flow rate as seen in Fig. 5.

The maximum pressure drop across valve is 28.5 KPa at constant quality of 0.0012. The variation of pressure drop with quality,  $X$  is in agreement with literature [2].



**Fig. 5.** Two phase Pressure Drop Vs Quality for Valve Section (Water).

## 2.5. Two-Phase Multiplier vs Quality X

Another relationship useful in two-phase studies is the two-phase multiplier given by Eq. (6) and (7)

$$\phi_g = \frac{(dp/dz)_{TP}}{(dp/dz)_g} \quad (6)$$

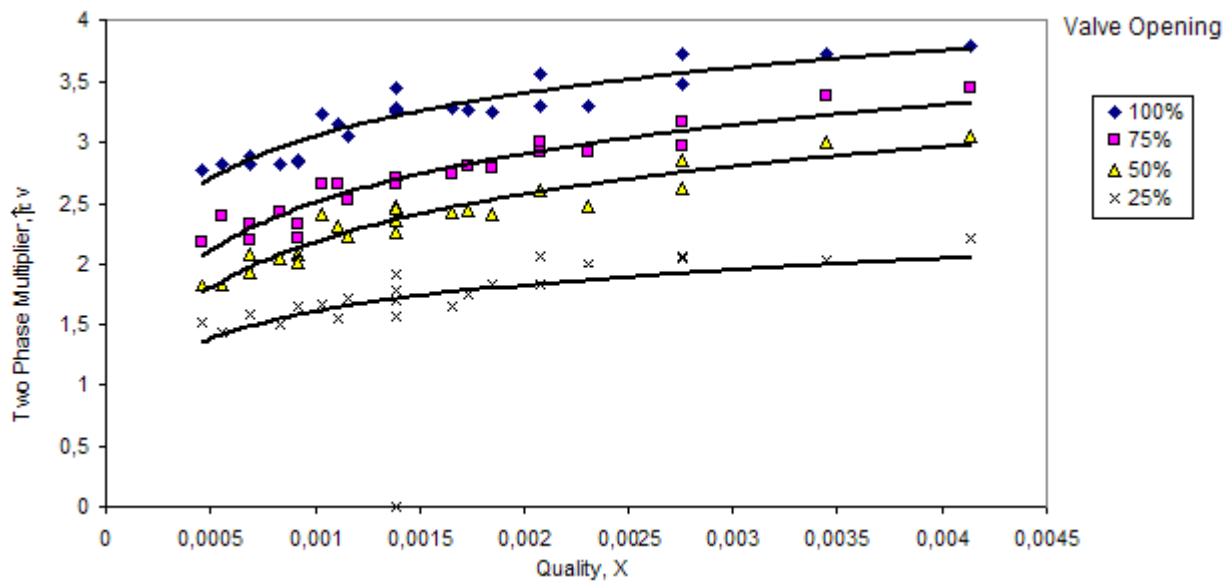
$$\phi_l = \frac{(dp/dz)_{TP}}{(dp/dz)_l} \quad (7)$$

The two-phase multiplier is defined as the ratio of pressure drop for two-phase flow to single phase for gas ( $\phi_g$ ) or liquid ( $\phi_l$ ) as given by the Eq. (6) & (7). The pressure drop for single phase in the denominator of Eq. (6) & (7) is given from Eq. (8) and Eq. (9) from pure fluid friction factors.

$$\left(\frac{dp}{dz}\right)_l = 2f_l \rho_l V_l^2 / D \quad (8)$$

$$\left(\frac{dp}{dz}\right)_g = 2f_g \rho_g V_g^2 / D \quad (9)$$

The  $\phi_l$  obtained experimentally is plotted against quality and is shown in Fig. 6. The two-phase multiplier increases with quality in agreement with literature [3].



**Fig. 6.** Two-phase multiplier vs quality for valve section.

## 2.6. Relation Between Two Phase Multiplier and Lockhart–Martinelli (L–M) Parameter

A method of predicting pressure drop in two-phase flow from the studies on one of the single phase has been suggested [4] in terms of L–M parameter  $X_{tt}$  defined by Eqs. (10) and (11).

$$X_u^2 = \left[ \frac{(1-X)}{X} \right]^{2-m} \left( \frac{\rho_a}{\rho_1} \right) \left( \frac{\mu_1}{\mu_a} \right)^m, \quad (10)$$

where “m” is the value obtained for single phase flow from the relation Eq. (3). The two-phase multiplier  $\Phi_1$  is related to L–M parameters by the Eq. (9):

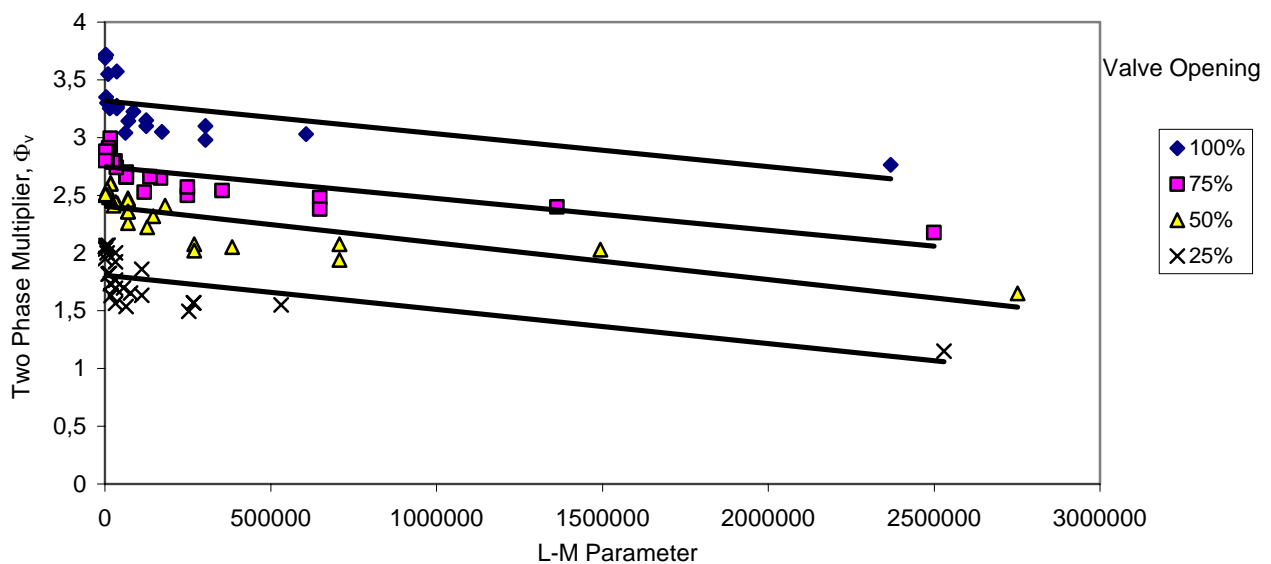
$$\phi_1^2 = \frac{\Delta P_{1Pf}}{\Delta P_1} = 1 + \frac{C}{X_u} + \frac{1}{X_u^2} \quad (11)$$

Fig. 7 presents  $\Phi_1$  vs  $X_{tt}$  graphically for valve section. The two-phase multiplier is observed to decrease with increase in Lockart–Martinelli parameter ( $X_{tt}$ ). The relationship given by Eq. (9) is fitted by regression analysis and the value of C is estimated and is given in Table 3.

Thus the two-phase multiplier can be used to predict the pressure drop across control valve section for different gas-liquid ratios studied.

**Table 3.**

Valve opening (%)	Valve section
25	248
50	425
75	414
100	398

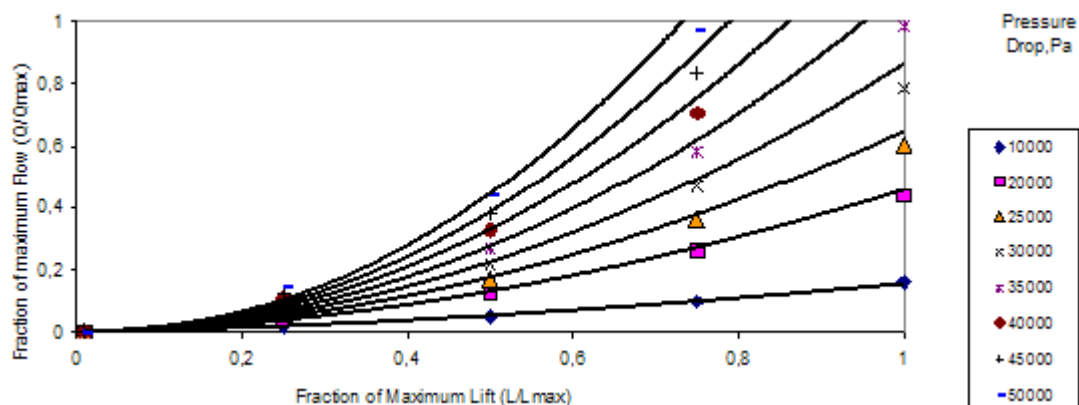


**Fig. 7.** Variation of two-phase multiplier vs L–M parameter for valve section.

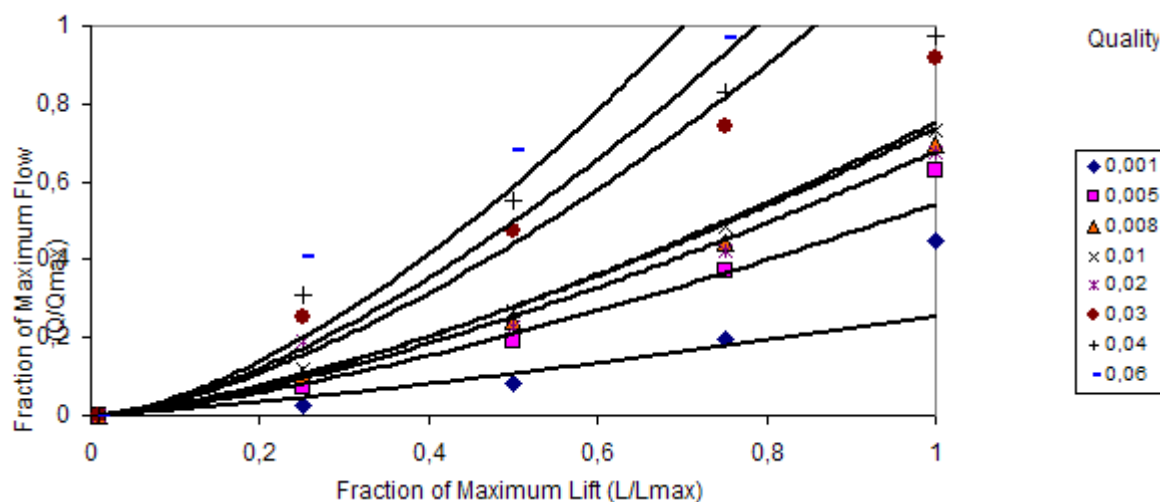
## 2.7. Valve Characteristics

The installed characteristics of the valve are plots fraction of maximum flow rate vs the fraction of valve opening at different pressure drop across the control valve. These plots are useful to determine the suitability of the valve in process design. Fig. (8) shows the characteristics for constant quality of 0.001 and Fig. (9) at constant pressure drop of 1 KPa. It is seen that for a quality of 0.001 the

maximum permissible pressure drop is 3.0 KPa and for a constant pressure drop of 1KPa the maximum permissible quality is 0.02 for full range of operation.



**Fig. 8.** Valve characteristics at constant quality of 0.001.



**Fig. 9.** Valve characteristics at constant pressure drop of 1000Pa.

### 3. Conclusions

Two-phase flow through control valve has been studied for different quality. Pressure drop has been related to quality. Two-phase multiplier and L–M parameter correlation is found to be in good agreement with the literature. The installed characteristics of the valve are represented for different quality and pressure drop. The study has been specific to the experimental set-up used in this work. The correlations especially between two-phase multiplier based on liquid phase and L–M parameter will be useful in design of control valves for two-phase flow. The study enables one to predict the required pressure drop information from the data for single-phase flow through valve. The valve used being an equal percentage valve; the correlation can be extended to other types of valves such as linear and quick opening by appropriate definition of equivalent diameter for valve opening. The valve characteristics in terms of pressure drop and quality clearly indicates the maximum value, which the specific control valve can accommodate for proper utilization of the valve. These correlations can be tried for other types and size of valves also and their useful range be established.

## Nomenclature

C - Cfactor in Eq. (11)  
 D - diameter of pipe, m  
 De - equivalent diameter of valve opening, m  
 Do - orifice diameter, m  
 F - friction factor  
 L - valve stem position (or lift) m exponent  
 Qa - air flow rate, m<sup>3</sup>/s  
 Ql - liquid flow rate, m<sup>3</sup>/s  
 NRe - Reynolds number  
 V - velocity of flow, m/s  
 X - quality

## Greek symbols

$\rho$  - density of liquid/gas, kg/m<sup>3</sup>  
 $\mu$  - dynamic viscosity liquid/gas, Ns/m<sup>2</sup>  
 $\Delta P$  - pressure drop, Pa  
 $\chi^2_{tt}$  - Lockhart–Martinelli (L–M) parameter  
 $\Phi_1$  - two-phase multiplier based on pure liquids Eqs. (7a) and (12)  
 $\Phi_a$  - two-phase multiplier based on pure gases Eq. (7b)

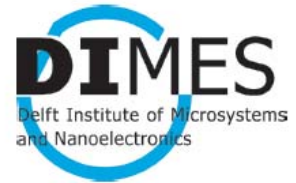
## Subscripts

a - air  
 l - liquid, water  
 v - valve section  
 TPF - two-phase flow

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# Smart Sensor Systems '09

April 20 - April 23, 2009



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## Guide for Contributors

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*Sensors & Transducers Journal* (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, some special sponsored and conference issues published annually.

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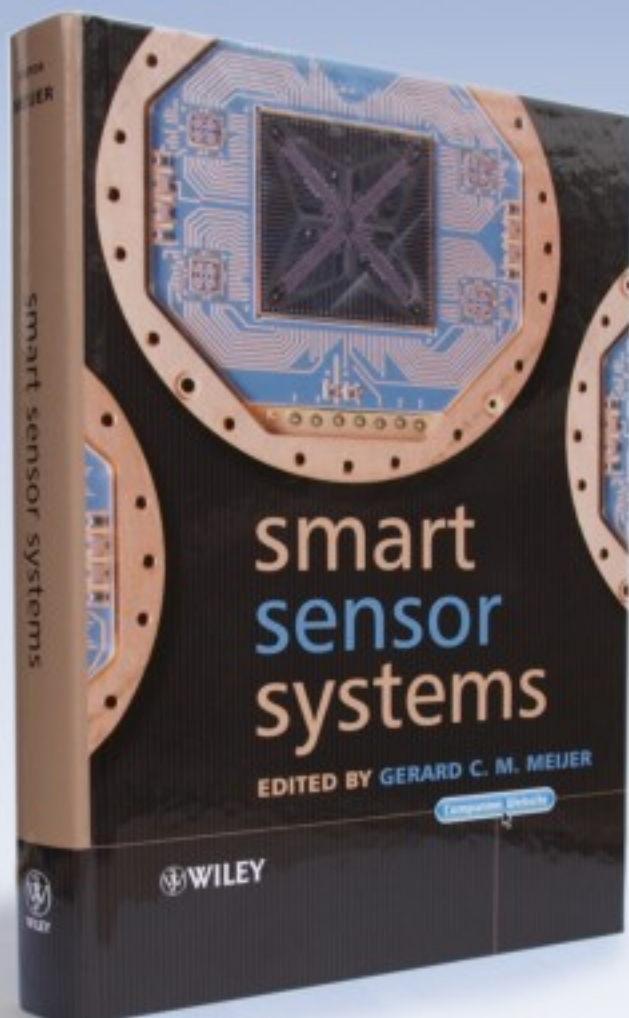
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