CHARACTERISTICS OF DISCHARGE COEFFICIENT IN INDUSTRIAL BURNER APPLICATIONS

By

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ABSTRACT

Experimental investigation is made to determine discharge coefficient of different types of burners used in industrial combustion applications. Tests were carried out to study the influence of burner geometry and flow variables, such as Reynolds number, porosity, length/diameter ratio and number of holes on discharge coefficient. Results have shown reasonable agreement when compared with data done by other researchers. Tests were carried out at Sudan University of Science and Technology-College of Engineering.

الملخص:

التحقيق التجريبي لإيجاد معاملِ التصريف للمشاعل المختلفةِ التي تستعمل في تطبيقاتِ الاحتراق الصناعيةِ. الاختبارات نُفّذتْ لدِراسَة تأثيرِ هندسةِ المشعلِ ومتغيّراتَ السريان، مثل عددِ رينولدز، مسامية، طول/نسبة قطرٍ، وعدد الفتحاتِ، على معاملِ التصريفِ. أظهرت النتائج توافقية معقولة عندما قُورنتْ بالبياناتِ المعمولة من باحثين آخرين. تم أجراء الجزء التطبيقي في كلية الهندسة في جامعة السودان للعلوم والتكنولوجيا.

INTRODUCTION

There is a tendency of operating the combustion zone at lower equivalence ratio in order to reduce flame temperature, improve the temperature pattern and to reduce the combustion pollutants level at the exit of the combustion system. This necessitates a substantial increase of the air admitted to the combustion zone. There is a little information on C_d for multi–holes orifice plate normal to the flow direction specially grid plate with L/D ratio less than 0.3. Systems are suggested to be rapid mixing burners for combustion in industrial applications, which could reduce the combustion pollutant to level similar to the fully premixed systems (Aldabbagh, 1988).

Although industrial combustion engines contribution to total air pollution is very small compared to other types of heat engines (petrol, diesel, and coal fired), increase demand and utilization in different applications make them significant source of pollution.

Aldabbagh, and Andrews, (1983) showed that flame stabilizer geometry has a major influence on combustion efficiency and flame stability but less influence on NO_x.

Therefore, it is necessary to know burner pressure drop and hence pressure loss coefficient in order to design burner pressure drop at specific Mach number.

The present work investigates pressure loss characteristics for different types of burner by studying the use of these constructions in a number of different contexts to reduce flow non-uniformities in ducts, for boundary layer control applications, and as a mean of conveniently simulating the pressure drop characteristics of some other more complex component in a mock up of a real system. Knowledge of the flow characteristics of squared edged orifices of small diameters is important in a number of applications, such as fluid power engineering, pneumatics techniques of metrology and fluidics.

Experimental Equipment:

A schematic layout of the test rig, built at Sudan University of Science and Technology-College of Engineering, is shown in (Fig. 1). The system used to provide the air consists of a blower driven by an electric motor. A venturi meter was positioned at a distance to allow for fully developed flow and consequently accurate flow metering.

A manometer is used to measure the venturi static and differential pressure and static pressure loss. The temperatures of air at inlet and of the venturi and of the air upstream burner are measured by sensor thermocouples. Different type of burners has been tested to evaluate the geometric effect on pressure loss coefficient. (Fig.2) showed Venturi flow meter used in the present investigation, the fluid is accelerated through a converging cone of angle 15-20° and the pressure difference between the upstream side of the cone and the throat is measured and provides the signal for the rate of flow.

Theoretical Approach:

Calculation of Air Mass Flow: Air mass flow rate was calculated according to British Standard B.S. 1042. The basic equation of the mass flow rate is given by:

$$\dot{m} = C_D Z E \varepsilon A(2\rho\Delta P)^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where C_D = Discharge Coefficient

Z = Correction factor

ε = Expansibility factor, B. S. 1042[10]. expressed as

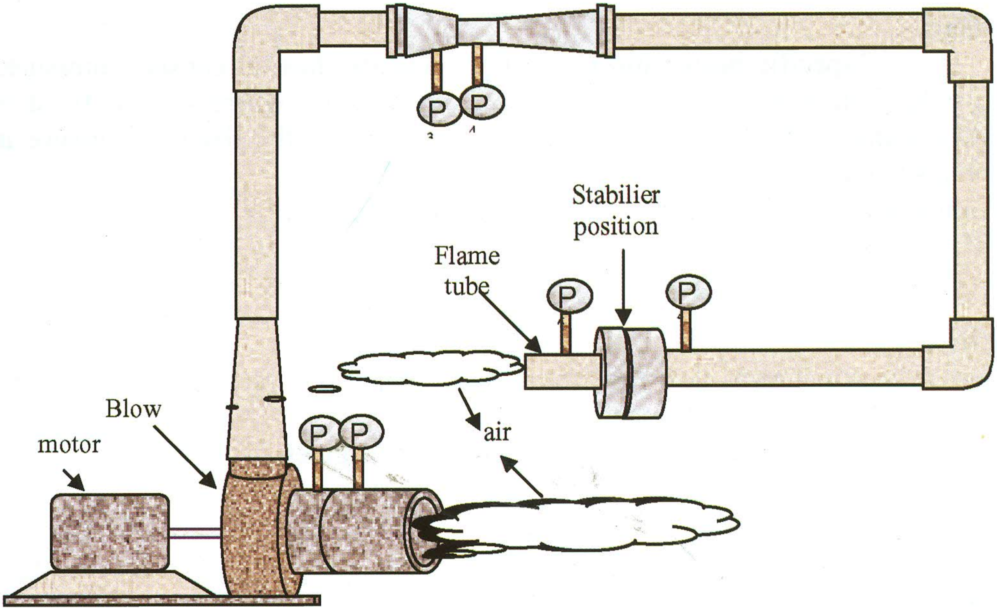

Fig. (1): General Layout of the Test rig

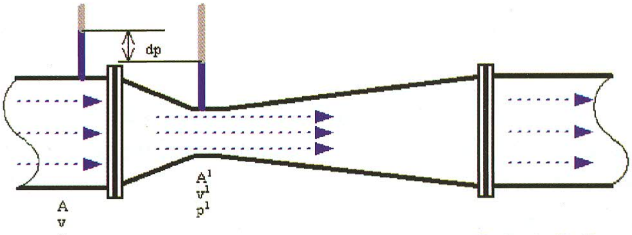

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Fig. (2): Venturi Flow Meter

$$\varepsilon = \left\{\left(\frac{\gamma^{\frac{2}{\gamma}}}{\gamma - 1}\right)\left(\frac{1 - s^2}{1 - s^2 r^{\frac{2}{\gamma}}}\right)\left(\frac{1 - r^{\frac{\gamma-1}{\gamma}}}{1 - r}\right)\right\}^{\frac{1}{2}} \quad \text{.............(4-2)}$$

where:

γ = specific heats ratio C_p/C_v, C_p = Specific heat at constant pressure, C_v = Specific heat at constant volume, $E = 1/(1-s^2)^{0.5}$ where $s = (d/D)^2$, d = throat diameter, m, D = pipe diameter, m, r = Ratio of the absolute pressure at the upstream tapping to that at the venturi throat.

From equation (1) Discharge Coefficient can be calculated: B. S. 1042:

$$C_D = \frac{\dot{m}}{A_2(2\rho\,\Delta P)^{0.5}} \quad \text{.......... ....} \quad (2)$$

Where:

$\dot{m}$ = actual mass flow rate from venturi meter, ρ = inlet density kg/m^3, A_2 = open area, C_D = overall discharge coefficient.

Pressure drop as percentage of upstream pressure is given by:

$$\frac{\Delta P_{12}}{P}\% = \frac{(h_{1s} - h_{2s}) \times \rho_w \times g \times 100}{P_a + \rho_w \times g \times h_{1T}} \quad \text{.......... ....} \quad (3)$$

$$\frac{\Delta P}{P}\% = \frac{\Delta P \times 100}{P_a + \Delta P} \quad \text{.......... ....} \quad (4)$$

Where:

h = pressure in H_2O, ΔP = pressure loss, ρ_w = water density kg/m^3, g = gravimetric acceleration (m/s^2), Δh = pressure difference in m H_2O, P_a = atmospheric pressure in N/m^2.

Equation (2) and (4) may be combined to get:

$$\frac{\Delta P}{P} = \frac{\gamma}{2}\left(\frac{M}{C_D} \times \frac{A_1}{A_2}\right)^2 \quad \text{.......... ....} \quad (5)$$

Correction of the Pressure Drop to Reference Mach number:

The pressure drop is a function of Mach no. (1). It is useful to correct the measured pressure drop of the stabilizer to the standard Mach no. of 0.0467 (M_{ref}) B. S. 1042[10].

$$\left(\frac{\Delta P}{P}\right)_{corr} = \left(\frac{\Delta P}{P}\right)_{meas} \times \left(\frac{M_{ref}}{M_{meas}}\right)^2 \qquad \text{.......... ....} \quad (6)$$

EXPERIMENTAL RESULTS

From a general standpoint variables that can influence the pressure loss coefficient or discharge coefficient C_D values for different types of burners are:

(a) Density, Viscosity and Velocity of fluid.
(b) Diameter of the pipe and orifice.
(c) Compressibility of fluid.
(d) Roughness of the pipe.
(e) Wall thickness/diameter, L/D ratio for the orifice.
(f) Number of holes.

Reynolds number includes the variables in (a). The variable in (b) are covered by the porosity, m, or, the percentage pressure drop.

The effect of compressibility has being allowed by the use of expansibility factor given by B.S. 1042.

Therefore discharge coefficient can be correlated by:

C_d = f(Re, m, t/D, L/D, no. of holes)

Since most piping system will have reasonable internal roughness. Hence the larger the pipe the smaller the relative roughness, for which the term t/D vanishes, therefore the functional variation for C_d can be deduced to:

C_d = f(Re, m, L/D, no. of holes)

Influence of Reynolds Number: (Fig. 3 and 4) show the variation of discharge coefficient with Reynolds number, Re, for Re greater than 8000 for different percentage pressure loss burners. In this region the effect of (Reynolds number was found to be insignificant, which supported by flow studies, Smith, W.A.J., (1991), of the discharge characteristics of sharp-edged orifices. Some small effect might be expected for long orifices where the reattached flow loss is dominant but no significant effect was noted in the present work.

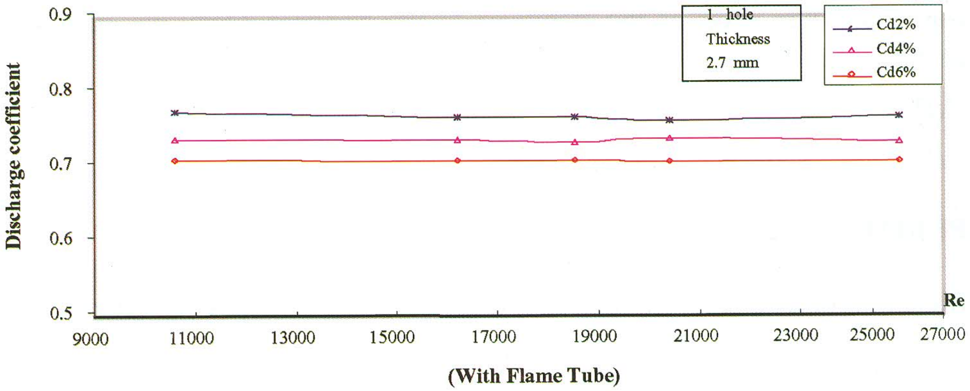

Fig. (3): Discharge Coefficient VS Reynolds Number for Different Pressure loss Burner

Influence of Porosity: The variations of discharge coefficient with porosity are shown (Fig. 5 and 6) for different types of burners. The results show that values of discharge coefficient are increased with increase in porosity and this can be explained by dependence of pressure recovery distance on area ratio results in improving discharge coefficient values.

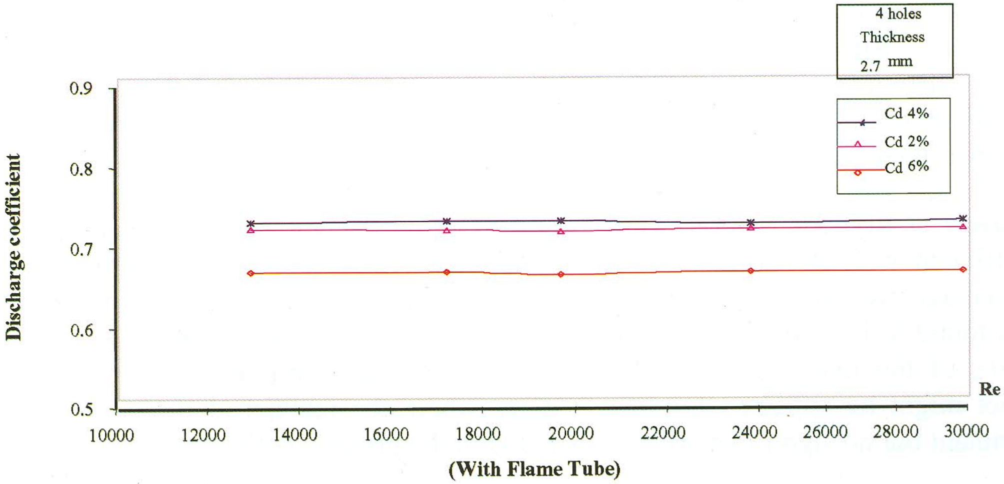

Fig. (4): Discharge Coefficient VS Reynolds Number for Different Pressure Loss Burner

Influence of Pressure Loss: Pressure loss can be shown to be related to area ratio by the following equation:

$$\frac{\Delta P}{P} = 0.5\frac{u^2}{C_D^2}\frac{1}{RT}\left[\frac{A_1}{A_2}\right]^2$$

Where, A1/A2 is the combustor area to burner area ratio, C_D discharge coefficient.

Therefore an opposite trend can be seen in (Fig. 7) which shows that the higher the pressure loss the lower the discharge coefficient and this due to the inverse proportionality of pressure loss with area ratio. This is supported by the theoretical data plotted on the same graph based on sharp-edged orifice plate.

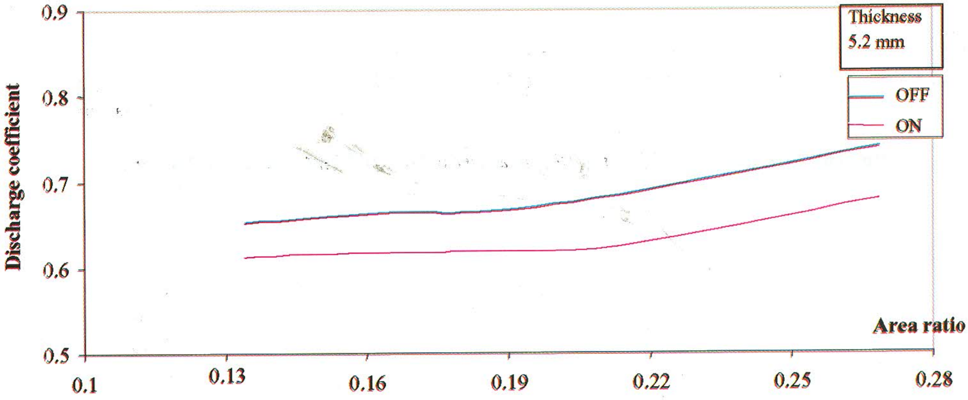

Fig. (5): Discharge Coefficient VS Area Ratio when Combustor Tube (ON) and (OFF)

Influence of Wall Thickness/Diameter (L/D) Ratio:

Another important non-dimensional parameter beside the porosity is the L/D ratio, which can be formed from the basic dimensions and it is a convenient specification of the orifice geometry.

The influence of L/D ratio is shown in (Fig.8) for the same number of holes. The results are plotted together with data based on the same area ratio which obtained from, (Smith, C. F., 1982), and showed a reasonable agreement.

In both figures there is a trend of increase in discharge coefficient with increase in L/D ratio.

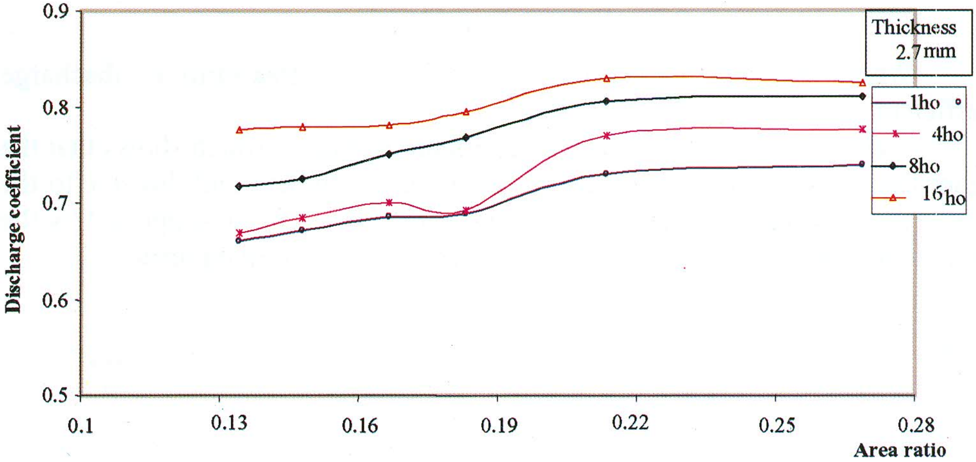

Fig. (6): Discharge Coefficient VS Area Ratio for Different Types of Burners

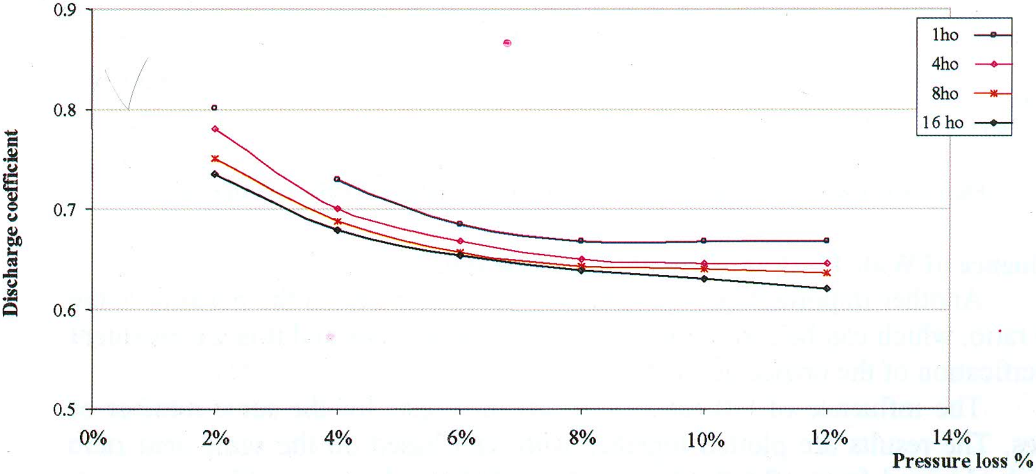

Fig. (7): Discharge coefficient VS Pressure Loss, for Different Types of Burners

Influence of Number of Holes:

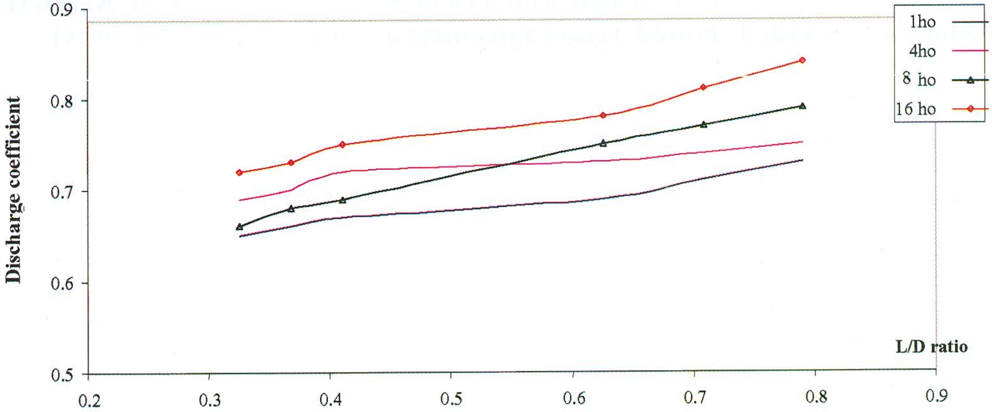

Fig. (8) Discharge coefficient VS L/D Ratio for the Same Area Ratio

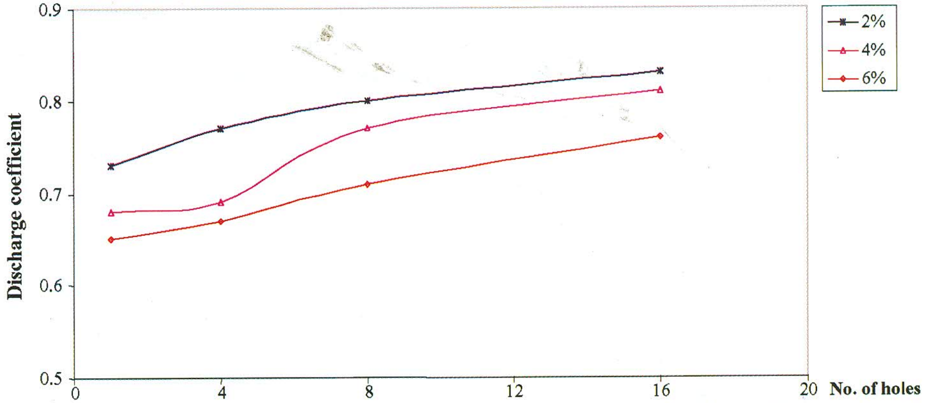

Fig. (9): Discharge coefficient VS Different Number of Holes for Different Pressure loss Burners

(Fig.9) shows the variation of discharge coefficient with number of holes for different burner pressure drop. It shows a trend of increasing discharge coefficient values with increase in number of holes. The larger recirculation zone may explain this for the lower number of holes causing an abstraction to the flow, results in lower discharge coefficient values.

COMPARISON OF RESULTS

Results have been compared with data done by, (Al-dabbagh, N. A. and G. E. Andrews, 1988) and showed a good agreement as illustration in (Fig. 10-14).

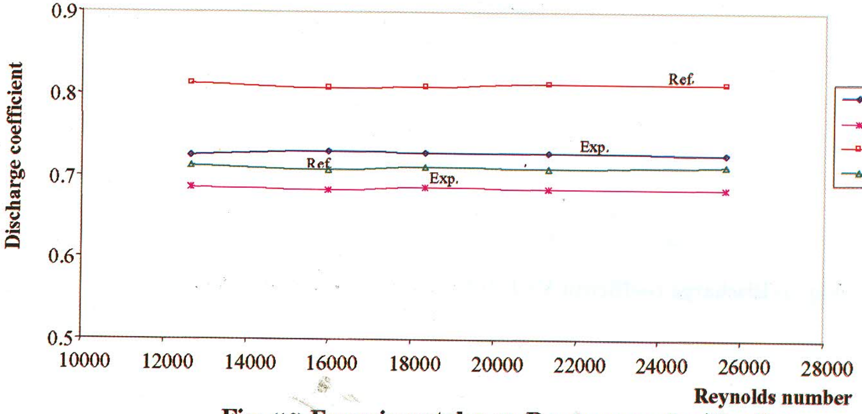

Fig. (10) **Experimental C_d Vs Re-compared with others**

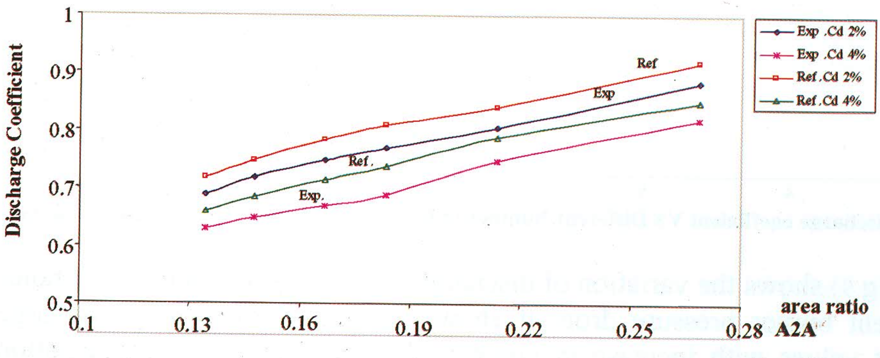

Fig. (11): **Experimental C_d Vs A_2/A_1 compared with others**

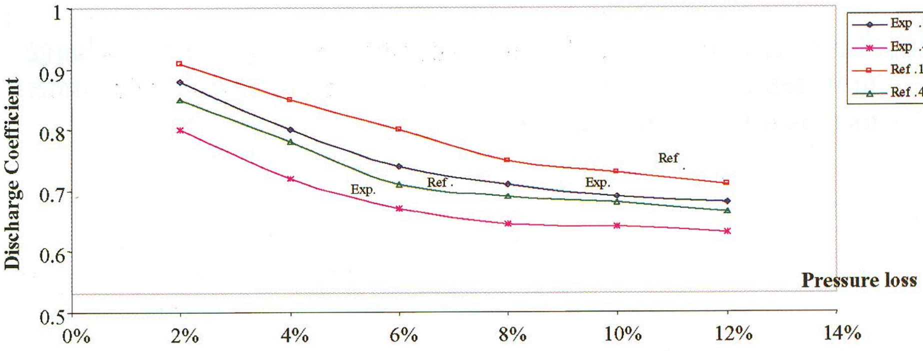

Fig. (12): Experimental C_d Vs press. loss compared with others

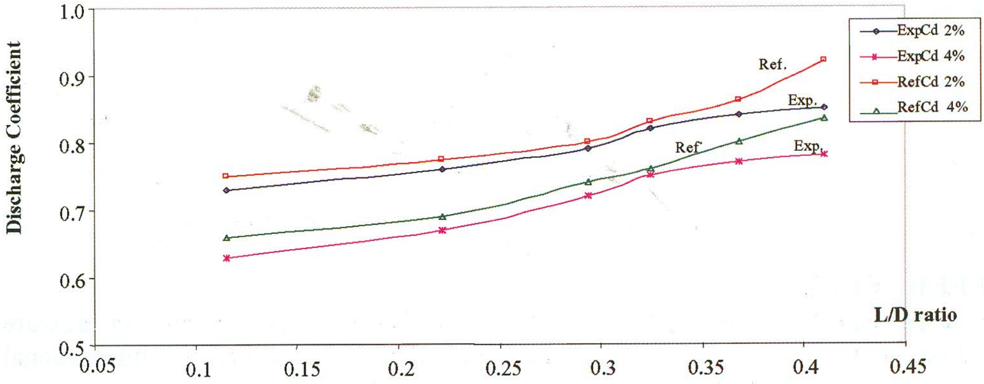

Fig. (13): Experimental C_d Vs L/D compared with others

CONCLUSIONS

- Discharge coefficient of different types of perforated plats used as a burner have been measured and showed a reasonable agreement when compared with data obtained by other researchers.
- Reynolds number has no significant influence on discharge coefficient in the region where Re, higher that 8000 especially for the lower pressure loss burner.

- Discharge coefficient values increased for higher area ratio for the same L/D ratio.
- For the same area ratio and the same number of holes the discharge coefficient increased with increase in L/D ratio and the influence of number of holes increases as L/D ratio increases.

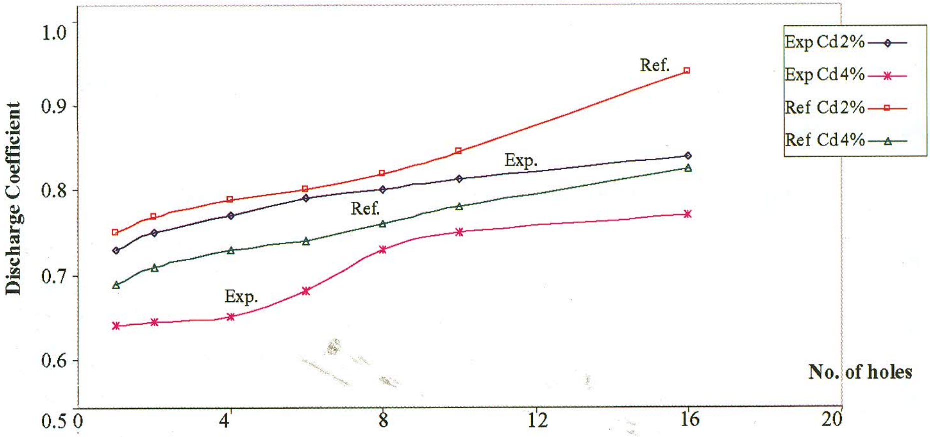

Fig. (14): Experimental C_d Vs no. of holes compared with others

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