Pressure Drop Calculation for Perforated Solar Wall Air Conditioning System: An Analytical Approach

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Abstract-This paper is an attempt to theoretically analyse the pressure drop of air flowing in the perforated metallic solar wall air conditioning system. The pressure drop of the air conditioning system was determined at different operating modes i.e. for air heating and air cooling modes in the two cavities of the system for certain set of operating conditions. Pressure drop is a necessary parameter for possibility of flow of any fluid along the direction of flow. In the present study pressure drop of the cavity one, includes pressure drop across the face of the collector, friction pressure drop in the cavity, the buoyancy force pressure drop of the air, and the acceleration pressure drop of the air in the system. To calculate pressure drop in cavity 2, the cavity is considered as a duct with sharp 90° bend then the Bernaulli's equation is employed at the inlet and outlet of the cavity with appropriate assumptions. Thus the pressure drop in cavity 1 and 2 are found 23.718 pa and 157.2 pa respectively, which pressure drop is sufficient for flow of air in respective cavities.

Index Terms- perforated; solar wall; pressure drop; air conditioning.

1. INTRODUCTION

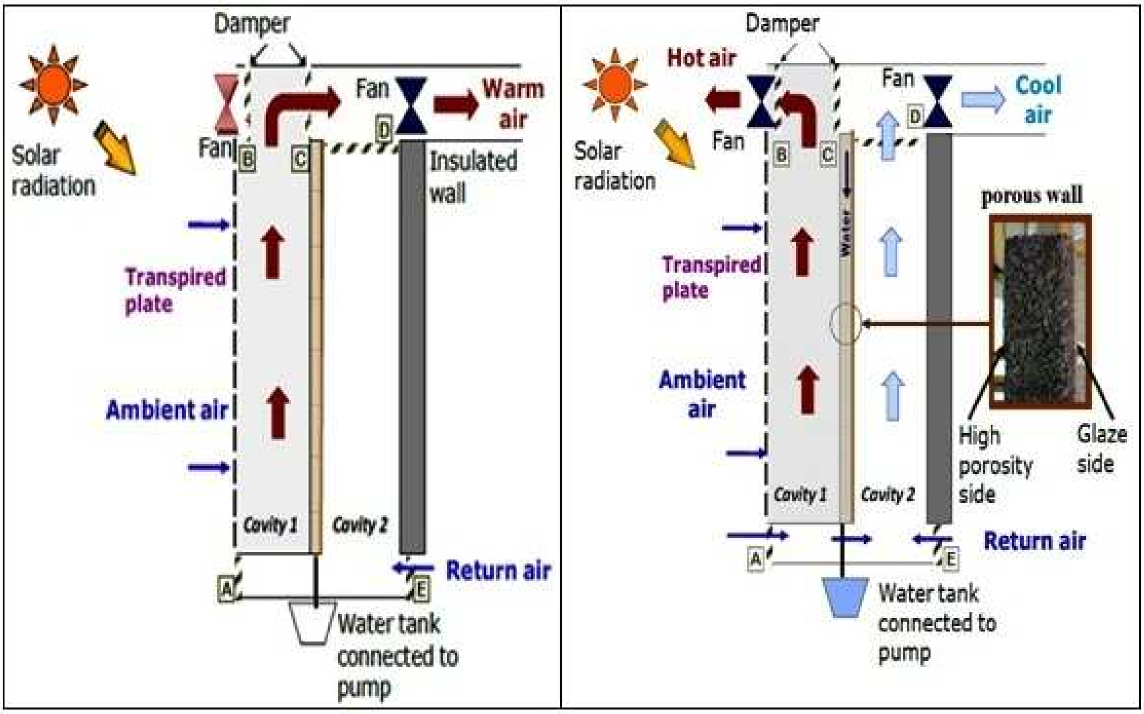
Perforated metallic solar wall (collector) systems are usually mounted on the side of the building that receives the most solar radiation available. It may be a fan-assisted system, whereby air is drawn through the holes into the cavity/passage, which absorb the heat when crossing the holes of plate as well as from the back side of the plate when moves in the cavity, and the warm air is further utilized in air conditioning processes. The basic reason for using the perforated metal plate as the solar collector is not only to absorb the solar radiation heat but also to reduce the convection heat loss. Such systems will result higher heat exchange effectives and better efficiency.

H.Y. Chan(2013)[1] proposed solar facade for space cooling using transpired solar wall. Figure 1(a) and (b) show heating and cooling modes of the facade system respectively. For the heating mode, Dampers A, B and D are closed, Fan B is switched off, and the porous wall is dry. Thus, air is drawn by Fan D through the holes and supplied to the building through Damper C. On the other hand, only Damper C is closed for the cooling mode, and the porous wall is wetted with flowing water throughout the operating period. At this time, in cavity 1, the ambient air is drawn by Fan B through the holes on the plate and exhausted through Damper B. The supply air for cavity 2 can be drawn from the ambient (through Damper A), from the return air from indoors (through Damper E) or be the mixture of both. The air is then cooled by the wall and ducted to the building through Damper D.

Kutscher (1994)[2] performed some experiments on a small test collector to predict the heat exchange effectiveness and pressure drop for the collector and noted that important parameters included air flow rate, crosswind speed, hole pitch, and hole diameter. Though many research have been carried out to study the Nusselt number correlations, heat exchange effectiveness, wind effects and temperature change, yet only few of research that involved pressure drop study in both the cavities to verify possibility of airflow in the cavities. This paper is to theoretically calculate the pressure drop in both the cavity of the system shown in figure 1.

2. ANALYTICAL PROCEDURE

In the present study the pressure drop analysis is performed for the perforated metallic solar wall air conditioning system. Operating condition is considered approximately same as specified in air conditioning application in the work of H.Y.chan[3].The properties of air at different temperatures are calculated by interpolation from the given values of properties at different temperatures from the literatures available[3,4]. Calculation of pressure drop in cavity 1 and 2 is necessary because flow of air from ambient to cavity is due to pressure drop. In further sections process of pressure drop calculation in cavities is explained.



(a) (b)

Fig.1 (a) Solar facade in space heating mode and Fig.1(b) Solar facade in space cooling mode

Table 1. Parameters used to predict static pressure in cavity 1

Suction Velocity :	0.04 m/s
Porosity:	0.84%
Height (average distance to fan)	4m
Average Density of air:	1.2 kg/m^3
Hole Diameter:	0.0012m
Kinematic Viscosity:	0.00001672 m^2/s
Cavity Depth:	0.25 m
Collector Width:	2 m
Outlet Density:	1.1575 kg/m^3
Ambient Density:	1.2469 kg/m^3
Friction Coefficient:	0.033
Air volumetric flow rate:	450m^3/hr
Fan front area:	250mm x 250mm
Hydraulic diameter of cavity:	0.44m

2.1. *Pressure Drop formulation across Collector and cavity 1*

Required power is related to the total pressure drop in the system that must be overcome by the fan including the pressure drop across the face of the collector, the friction in the cavity, the buoyancy force of the air, and the acceleration of the air in the system. View of cavity 1 is shown in figure2. Total pressure drop across the face of the perforated collector is given by:

$$\Delta P_{tot} = \Delta P_c + \Delta P_{fric} + \Delta P_{buoy} + \Delta P_{acc} \qquad \text{Eq.(1)}$$

The following equations are used to calculate the pressure drop across the perforated metallic plate:

$$\Delta P_c = 0.5\rho v_s^2 \nu \zeta \qquad \text{Eq. (2)}$$

Where $\zeta = 6.82(\frac{1-\sigma}{\sigma})^2 Re_D^{-0.236}$ and $Re_D = \frac{v_s D}{\nu\sigma}$

$$\Delta P_{fric} = \frac{fH\rho v_p^2}{2\,D_h} \qquad \text{Eq. (3)}$$

Where $v_p = \frac{v_s H}{2D_p}$ and $D_h = \frac{4(D_p \times W)}{2(D_p + W)}$

$$\Delta P_{buoy} = 0.5(\rho_o - \rho_a)gH \qquad \text{Eq. (4)}$$

The air is accelerated to the velocity at the outlet of the fan, so the acceleration head is better defined in the outlet of fan as in equation (5).

$$\Delta P_{acc} = 0.5\rho(v_{fan,out})^2 \qquad \text{Eq. (5)}$$

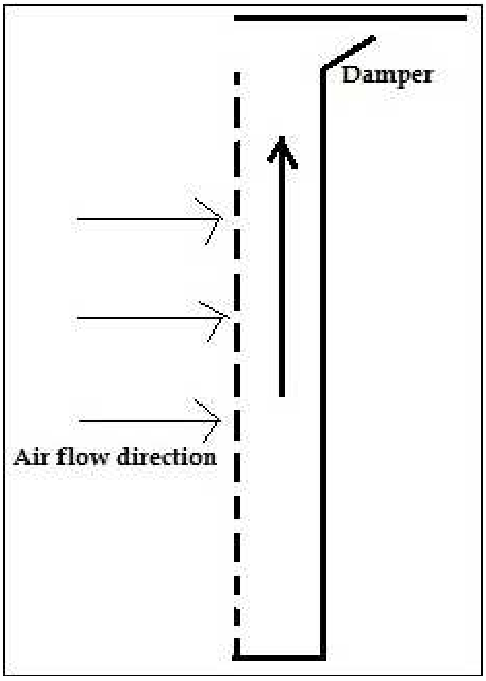


Fig 2. View of cavity 1

2.2. pressure drop calculation in cavity 1

The operating conditions are taken approximately same as the previous work of H.Y. Chan[5] as shown in table 1.From above equation (2) the pressure drop through the collector would be:

$Re_D = \frac{(0.04)(0.0012)}{(0.0084)(0.00001672)} = 341.76$

$\zeta = 6.82(341.76)^{-0.236}(\frac{1-0.0084}{0.0084})^2 = 23985.05$

$\Delta P_{coll} = \frac{(1.2)(0.04)^2(23985.05)}{2} = 23.05$ pa.

The friction as defined by equation (3) would be:

$\Delta P_{fric} = \frac{0.033\times4\times1.2\times(0.22)^2}{2\times0.44} = 0.018$

The buoyancy term action helps push flow in the direction of the fan as defined by equation (4):

$\Delta P_{buoy} = 0.5(1.1575-1.2469)\times9.81\times4 = -1.75\ pa$

Again the acceleration is given by equation (5) represent:

$\Delta P_{acc} = 0.5\times1.2\times2^2 = 2.4$ pa

Therefore the total pressure drop would become equation (1):

$\Delta P_{total} = 23.05+0.018-1.75+2.4 = 23.718$ pa.

2.3Pressure Drop formulation in cavity 2 during cooling applications

To calculate pressure drop in cavity 2, the cavity is considered as a duct with sharp 90° bend then the Bernaulli's equation is employed at the inlet and outlet of the cavity with appropriate assumptions as the flow is one directional, steady, irrotational and properties of air is not changing within the cavity (as the temperature drop is not more than $10°C$ for cooling application)[1]. The cavity is as shown in figure below. The head loss will cause the pressure to decrease in the flow direction. If the head loss is denoted by $H_{l,}$ then Bernoulli's equation can be modified to:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_l \qquad \text{Eq. (6)}$$

2.3.1Pressure loss during fluid flow

The loss in pressure during fluid flow is due to

- Fluid friction and turbulence
- Change in fluid flow cross sectional area
- Abrupt change in the fluid flow direction

2.3.1.1frictional pressure drop

When a fluid flows through a pipe or a duct, the relative velocity of the fluid at the wall of the pipe/duct will be zero, and this condition is known as a *no-slip condition*. The no-slip condition is met in most of the common fluid flow problems (however, there are special circumstances under which the no-slip condition is not satisfied). As a result of this a velocity gradient develops inside the pipe/duct beginning with zero at the wall to a maximum, normally at the axis of the conduit. The velocity profile at any cross section depends on several factors such as the type of fluid flow, condition of the walls etc. This velocity gradient gives rise to shear stresses ultimately resulting in frictional pressure drop.The Darcy-Weisbach equation[6] is one of the most commonly used equations for estimating frictional pressure drops in internal flows. This equation is given by:

$$\Delta P_{fric} = \frac{fL\rho V^2}{2\,D} \qquad \text{Eq. (7)}$$

Where f is the dimensionless friction factor, L is the length of the pipe/duct and D is the diameter in case of a circular duct and hydraulic diameter in case of a noncircular duct. The friction factor is a function of Reynolds number, ($Re_D = \frac{\rho VD}{\mu}$) and the relative surface of the pipe or duct surface in contact with the fluid. Here in this calculation the cavity area is constant therefore no need to calculate pressure loss due to Change in fluid flow cross sectional area

2.3.1.2dynamic losses in ducts

Dynamic pressure loss takes place whenever there is a change in either the velocity or direction of airflow due to the use of a variety of bends and fittings in air conditioning ducts. Some of the commonly used fittings are: enlargements, contractions, elbows, branches, dampers etc. However, exact analytical evaluation of dynamic pressure drop through actual bends and fittings is quite complex. Hence for almost all the cases, the dynamic losses are determined from experimental data and these are expressed as:

$$\Delta P_d = \frac{k\rho V^2}{2\,D} \qquad \text{Eq. (8)}$$

Where K is the dynamic loss coefficient, which is normally obtained from experiments and listed in some books in the form of chart (moody chart)[6]. Both friction and dynamic losses gives together the total pressure drop of the duct. The pressure drops across transpired collector and for cavity 2 is calculated further.

2.4. Pressure Drop calculation in cavity 2

Now for cavity 2 (figure3) applying the Bernaulli's equation at the entry and exit point of the passage 2, where 1 denotes entry and 2 denotes exit respectively in the equation. The geometry is shown in figure. Bernaulli's equation gives:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_l$$

Where H_l represents total head losses. Here friction and bending losses are considered. The parameters for cavity 2 are given in table below:

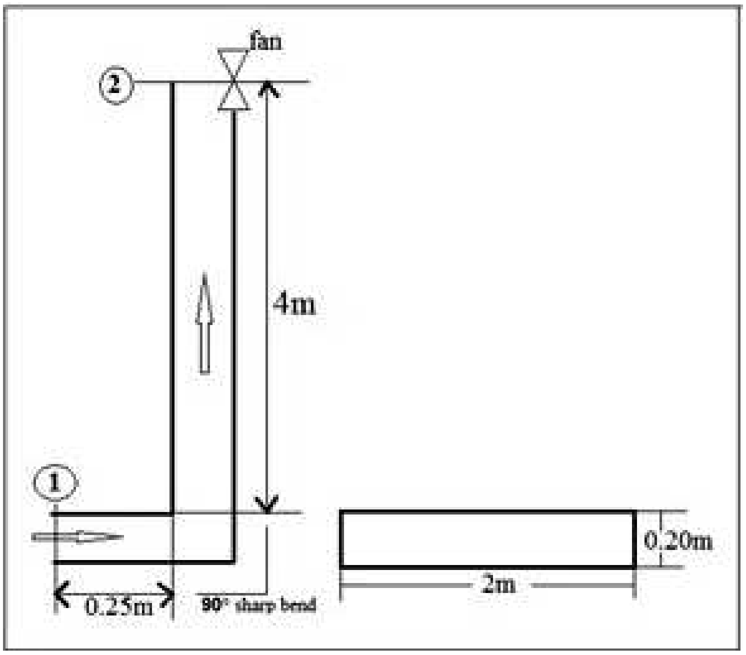


Fig.3 View of cavity 2

Table2. The parameters for cavity 2 are given in table below

Parameter	value
Height (average distance to fan)	4m
Average Density of air	1.2 kg/m^3
Passage/cavity Depth	0.20 m
Passage/cavity Width	2 m
Friction Coefficient [6]	0.05
Passage cross sectional area	2m x 0.20m
Dynamic loss co-efficient[6]	1.1
Passage/cavity air velocity	0.32m/s
Passage inlet pressure	atmospheric
Passage hydraulic diameter	0.36m

- frictional pressure drop: from equation (7):

$$\Delta P_{fric} = \frac{fL\rho V^2}{2\,D}$$

$$\Delta P_{fric} = \frac{0.05\times4\times1.2\times0.32}{2\times0.36} = 0.034 \text{ pa}$$

- Dynamic pressure drop: from equation (8):

$$\Delta P_d = \frac{k\rho V^2}{2\,D}$$

$$\Delta P_d = \frac{1.1\times1.2\times0.32^2}{2\times0.36} = 0.188 \text{ pa}$$

From solving equation (6):

$$P_1 - P_2 = (4-0)\times9.81\times4 + (0.034+0.188)$$

$$P_1 - P_2 = 157.2\, pa$$

3. THEORETICAL RESULTS

In this way pressure drop in cavity 1 and 2 is calculated. The static pressure drop in cavity 1 is approximately 24 pa which is sufficient[2] to occur the air flow in the desired direction for air conditioning similarly pressure drop in cavity 2 is approximately 157.2 pa Which shows that pressure at outlet of cavity is less than atmospheric pressure, so air will flow inside the concerned cavity and also pressure drop is enough for flow of air in the cavity 2.

4. CONCLUSION

The pressure drop has been predicted for perforated metallic solar wall air conditioning system using a simple mathematical model. Further experimental work is in progress to refine the model.

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Appendix A. Nomenclature

Nomenclature	
D	Cavity depth (m), diameter (m)
f	Friction coefficient
g	Acceleration due to gravity (m s−2)
H	Cavity height (m)
k	Dynamic loss coefficint
L	Width of perforated plate (m)
P	Pressure
Re	Reynold’s number
v	Air velocity
v_p	Passage/cavity air velocity
v_s	Suction air velocity
V_{fan}	Volume airflow rate ($m^3 hr^{-1}$)
W	Cavity width
Z	Datum head
H_l	Head loss (m)
Greek symbols	
ρ	Air density (kgm^{-3})
σ	Porocity
ν	Kinematic viscocity
ζ	Dimensionless pressure term
Subscription	
a	Ambient
acc	Acceleration
$bouy$	Buoyancy
$coll$	Collector
$fric$	Friction
h	Hydraulic
o	Output
out	Output
p	Passage