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Planning of experimentation for performance evaluation of Porous Media Heat Exchanger

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Abstract

Latest developments in the manufacturing technology have led to development of advance lightweight materials for thermal applications [11]. For Investigation of thermal properties for such materials proper planning is desirable. On the other hand, it is recognized that there are different thermal management issues which can be minimized with proper planning in experimentation. Heat transfer through porous materials has gained significance in industrial applications based research. In this paper planning required for evaluating performance of porous material, i.e. metal foam heat exchanger, has been discussed.

Keywords: Forced Convection, Heat Exchanger, Dimensional Analysis, Calibration.

INTRODUCTION

The use of porous materials as efficient and compact heat exchangers for heat dissipation is under extensive research. The louvered fin has a same level of the surface area density as the uncompressed metal foams. However, the manufacturing process of a louvered fin is very complicated and is costly as compared to the metal foams. There is a demand to make highly efficient compact heat exchanger by using metal foams which have a high heat transfer rate and structural strength as well as a low-cost manufacturing process [1]. In the past investigations have been carried out for heat transfer in metal foams for practical applications, including compact heat exchangers. There is a need to investigate the performance of porous material heat exchanger and to obtain better results proper planning is a necessary. This paper aims to present planning required to asses' thermal performance of porous material at exchanger.

NOMENCLATURE:

A	surface area	k_s	thermal conductivity of solid
K	permeability	T	time
Cp	specific heat capacity	u	velocity
Nu	Nusselt number	X, Y, Z	Cartesian coordinates
p	pressure		Greek symbols
g	gravitational acceleration	ε	porosity
Pr	Prandtl number	μ_f	viscosity of fluid
k	thermal conductivity	ρ	density of fluid
k_f	thermal conductivity of fluid	μ	Dynamic Viscosity
K	Permeability	θ	Temperature
Re	Reynolds Number	H	Heat

PLANNING OF EXPERIMENTATION

The steps involved in planning of experimentation [2], under classical plan of experimentation for porous material heat exchanger performance assessment are discussed below:-

a) Identification of variables
b) Dimensional Analysis
c) Test envelop, test point and range
d) Selection of measuring instrument
e) Calibration of measuring instruments
f) Test data checking and rejection
g) Data analysis

Identification of variables (Dependent and Independent)[3] :

Any physical quantity which undergoes change is termed as variable. Variable which can be varied independent of other variable is known as independent variable, whereas any parameter which changer due to change in some other variable or variables is known as dependent variable.

1) Dependent variables:

The dependent variables in the process are:

a) Heat transfer Coefficient (h): Heat transfer coefficient is a quantitative characteristic of convective heat transfer between a fluid medium (a fluid) and the surface (wall) over which the fluid flows.

b) Pressure drop (Δp): it is the change in value of pressure across the two sides of a heat exchanger.

2) Independent variables: The independent variables are

I) Fluid related variables

a. Density

b. Viscosity

c. Thermal Conductivity

e. Specific Heat

f. Temperature

II) Flow related variables

a. Velocity

III) Geometry related variables

a. Porosity

b. Permeability

c. Length

d. Diameter

Measurement of variables:

The Dependent variables:

a. Heat transfer Coefficient (h): as per the model formulation.

b. Pressure drop (Δp): as per the model formulation.

The independent variables are:

I) Fluid related variables

a. Density: From Heat transfer Data book at bulk mean temperature in ^{o}C.

b. Viscosity: From Heat transfer Data book at bulk mean temperature in ^{o}C.

c. Thermal Conductivity: From Data book at bulk mean temperature in ^oC.

d. Specific Heat: From Heat transfer Data book at bulk mean temperature in ^oC.

e. Temperature: Using K Type thermocouples.

II) Flow related variables

Velocity:

a. Cold Fluid (Air): velocity is measured using LUTRON Anemometer.

b. Hot Fluid (Water): Kept Constant.

III) Geometry related variables

a. Porosity: As specified by the manufacturer (ERG Aerospace).

b. Permeability: Calculated.

c. Tube length: Constant.

d. Tube diameter: Constant.

Dimensional Analysis :

Buckingham Pi theorem is used to perform dimensional analysis. The following procedure was adopted to determine the dimensionless parameters, i.e. π terms: (1) list the corresponding parameters; (2) apply the M, L, T, H, θ, system; (3) list the dimensions of all the parameters; form the π terms [2].

Table 1. List of variables, notation and their dimensions [2].

Sr. No.	variables	symbols	units	M.L.T.H.θ
1	Heat Transfer Coefficient	h	Wm^2K	$HL^{-2}\theta^{-1}T^{-1}$
2	Thermal conductivity	k	kg/m^3	$Hl^{-1}T^{-1}\theta^{-1}$
3	Dynamic viscosity	μ	kg/ms	$ML^{-1}T^{-1}$
4	Density of fluid	ρ	kg/m^3	ML^{-3}
5	Specific heat of fluid	Cp	Kj/kg-K	$HM^{-1}\theta^{-1}$
6	Velocity of fluid	u	m/s	$L.T^{-1}$
7	Temperature difference	ΔT	θ	θ
8	Diameter of Tube	Dt	m	L
9	Length of tube	Lt	m	L
10	Permeability of Foam	k_f	m^2	L^2
11	Porosity of Foam	φf	--	$M^0L^0T^0\theta^0H^0$
12	Hydraulic Diameter	Dh	m	L
13	Pressure	p	N/m^2	$ML^{-1}T^{-2}$

List of Pi terms:

Table 2. List of Pi Term

Sr. No.	Pi Term	Sr. No.	Pi Term
1	π1=hL/k=Nusselt Number	5	$\pi 5 = k_f / D^2$=Geometry(Fixed)
2	π2=μCp/k=Prandtl Number	6	π6=φ= Porosity (Fixed)
3	π3=ρuD/μ=Reynolds Number	7	π7=Dh/D =Geometry (Fixed)
4	π4=L/D=Geometry (Fixed)	8	$\pi 8 = \rho D^2 \Delta P / \mu^2$ =Pressure Function

The heat transfer coefficient, h, is given by:

$$N_u = f \quad (Pr, Re, \frac{L}{D}, \frac{k_f}{D^2}, \varphi, \frac{Dh}{D}, \frac{\Delta p \rho D^2}{\mu^2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Out of our 8 Pi-terms, one and eight are the dependent terms (i.e. output), while 2-7 are independent terms, (details available in Table 2).

The test envelop, test point and range [2]:

The tests envelop for independent and dependent variables are shown in table 2.

Table 2. The test envelop, test point and range for independent and dependent variables.

Group	Definition	Test Point	Test Envelope	Range	Test Sequence
π1	Nusselt Number	142.488696, 188.442271, 229.22841, 266.126202, 298.450532	142.488696-298.450532	h=475.556024-1096.8057 L=.01m K=0.0267-0.0294	Random
π2	Reynolds Number	3219.85374, 4274.97085, 5211.78849, 6048.2141, 6796.55241	3219.85374-6796.55241	ρ=1.177-1.042 u=.5-1.3 μ=0.00001846-0.00002013	Random
π3	Prandtl Number	0.6948427, 0.69212956, 0.69059573, 0.68948673	0.6948427-0.68948673	Cp=1005-1007	Random
π4, π5, π6, π7	Geometry	Constant	Constant	Constant	--
π8	Pressure Drop	9,9.2,9.5, 9.7,9.9	9-9.9	Fixed	Random

Fabrication of Experimental setup :

The proposed experimental setup used in this study is shown in Fig. 1. The facility consists of the following major parts: test section, a duct, a pressure loss measurement section, an inclined manometer, a blower, a velocity measurement section with a digital anemometer, heated section, water circulation pump. A square duct is used for the test arrangement. The air velocity was controlled with a fan and regulator. Air was used as a cold fluid in the canal. Water was used as a hot fluid for heat exchanger. Water is heated with an electric heater. Water temperature is controlled with a temperature controller. A pump is used to maintain water circulation. In the experiments, cold-hot fluids input/output temperatures and the temperatures of hot fluid inlet and outlet tubes carrying hot fluid are measured with thermocouples. The inlet (Tc,in) and outlet (Tc,out) temperatures of the cold fluid (air) were determined from the points where the stream starts and from the duct axis. The hot fluid inlet temperature is heat exchangers inlet temperature to the tubes whereas the hot fluid outlet temperature is heat exchangers outlet temperature from the tubes [3]. The experimental data is used for calculations and plotting graphs which help determining the heat transfer performance.

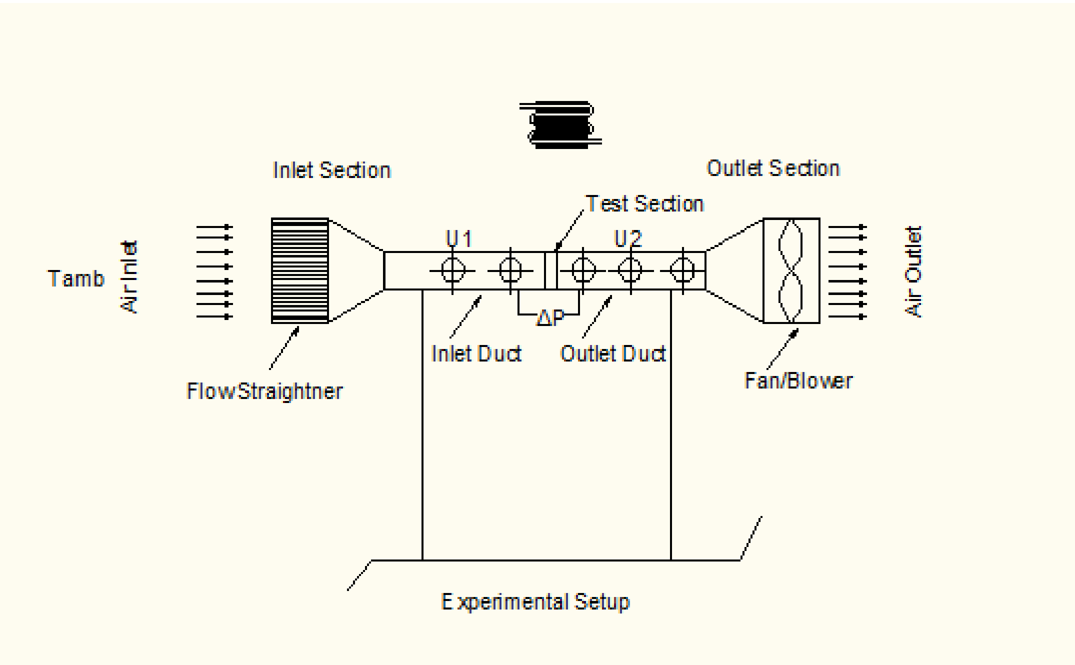

Figure 1. Proposed experimental setup

Selection of measuring instrument:

The measuring instruments are selected so as to measure the variables in the Calibration of measuring instrument. The measuring instruments to be used are thermocouple with temperature indicator, Anemometer, Inclined manometer and rotameter.

Calibration of measuring instruments

For proper experimentation, the calibration of various measuring instruments is very essential. The calibration of measuring instruments is carried out using replica method.

Trial experimentation:

After selection and calibration of measuring instruments as per the required test envelope, trial experimentation is performed. Trial experimentation gives initial set of readings to check the values of variables.

Data checking and rejection

Test data checking should be done by using replication technique, statistical method of setting up rejection standards shall be used for rejection.

Modification in experimental setup

After trial experimentation, the modifications if any are carried out in the experimental setup.

Experimentation

After modifying the experimental setup as per the requirements, the final experimentation is performed to obtain the final set of readings.

Observation table (sample)

The test observations are recorded in the observation table for further processing. The observation table used for recording the experimental data is shown below.

Sr. No.	Cold Fluid temperature		Hot Fluid temperature		Cold Fluid Velocity	Hot Fluid Velocity	Pressure drop
	T_{ci} °C	T_{co} °C	T_{hi} °C	T_{ho} °C	$u_{cold\ fluid}$ (m/s)	$u_{hot\ fluid}$ (m/s)	Δp (N/m^2)
1	25	26	30	29	0.5	0.5	0.0002

FORMULATION OF MODEL [4-6]

It is necessary to correlate quantitatively various independent and dependent terms involved in this complex phenomenon. The model representing the behavior of dependent pi term π1 with respect to various independent pi terms can be obtained as under;[7]-[8]

$$\pi_1 = k1x(\pi\, 1)^{a1}x(\pi\, 2)^{b1}x(\pi\, 3)^{c1}x(\pi\, 4)^{d1}\, b1x(\pi\, 5)^{e1}x(\pi\, 6)^{f1} \ldots\ldots\ldots\ldots \text{(ii)}$$

Taking log on the both sides of equation for π1

$$\text{Log } \pi 1 = \text{Log } K1 \times a \text{ Log } \pi 1 \times b \text{ Log } \pi 2 \times c \text{ Log } \pi 3 \times d \text{ Log } \pi 4 \times e \text{ Log } \pi 5 \times f \text{ Log } \pi 6 \ldots \text{(iii)}$$

Let, Z = log π1, K = log k1, A = log π 1, B = log π 2, C =log π 3, D = log π 4, E = log π 5, F=log π 6 Putting the values in equations 4, the same can be written as

$$Z = K + a \times A + b \times B + c \times C + d \times D + e \times E \ldots\ldots\ldots \text{(iv)}$$

Equation (iv) is a regression equation of Z on A, B, C, D and E in a dimensional co-ordinate system .

Thus, Model formulation is necessary to correlate quantitatively various independent and dependent terms involved in the phenomenon. This correlation is nothing but a mathematical model as a design tool for such situation [9].

RESULT ANALYSIS

Some form of analysis must be performed on all experimental data. The analysis may be a simple verbal appraisal of the test results, or it may take the form of a complex theoretical analysis of the errors involved in the experiment and matching of the data with fundamental physical principles. Even new principles may be developed in order to explain some unusual phenomenon. We will consider the analysis of data to determine errors, precision, and general validity of experimental measurements.

CONCLUSION

In this study, planning of experimentation for performance analysis of Porous Media Heat Exchanger is summarized.

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