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Performance of Heat Pipe Heat Exchanger under Natural Convection

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Abstract

To evaluate the thermal performance of a heat pipe heat exchanger (HPHE) under natural convection by adopting thermal resistance approach. The model evaluates the rate of heat transport across evaporator system of the HPHE under natural convection. The model will computes various thermal resistances of the heat pipe at the external surface of evaporator as well as the internal surface of the heat pipe based on the correlations available in the literature. The rate of heat transport will be calculated by converting the model into a computer program, whose solution is based on an iterative procedure.

Key Words: Inclined Heat Pipe, Natural Convection, Nusselt Number, Heat Transfer

INTRODUCTION

Thermal systems are commonly associated with different types of heat exchangers, based on sensible heat transfer, latent heat transfer and mixed mode of these two types. These include shell and tube type, cross flow heat exchangers, evaporators, condensers, and heat pipe heat exchangers, etc. The motivation for using heat pipe heat exchangers is to obtain high exchanger compactness in given box-volume having weight limitations. Energy systems manufacturers normally offer the base systems, which are used in a variety of engineering applications. For conversion of these base systems into a complete one, the manufacturers normally depend upon the local vendors for procurement of accessories including heat exchangers, which may not be optimally designed. Since these heat exchangers are to be adopted in a new configuration and layout, therefore, even well designed heat exchangers in a particular configuration are subject to change in effectiveness. To enhance the effectiveness of the sensible heat exchangers, one may look for a variety of solutions in the given situation. One of the solutions may be increasing the surface area of heat transfer, which increases the size of the heat exchanger, whereas, the other solution may be increasing the flow rates of the fluids involved, which results in more pressure drops of the fluids. The first option needs more space, whereas, the second may not be permitted by virtue of design implications. In the recent past, heat pipe heat exchangers (HPHE) have been used in various thermal systems for improving their effectiveness. Most of the studies on these exchangers are limited to forced convection but a little work has been reported in the natural convection conditions. Therefore, the present work aims at conducting research on heat pipe heat exchangers under natural convection conditios.

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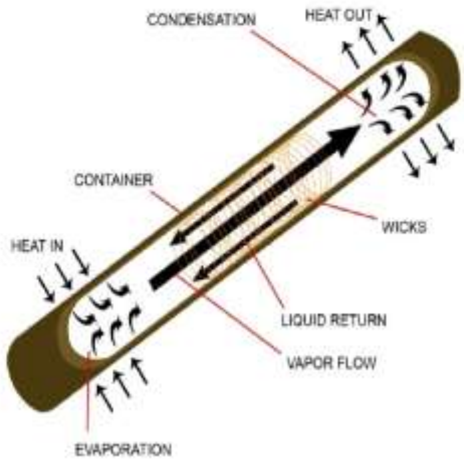

Fig.1.1 Heat pipe

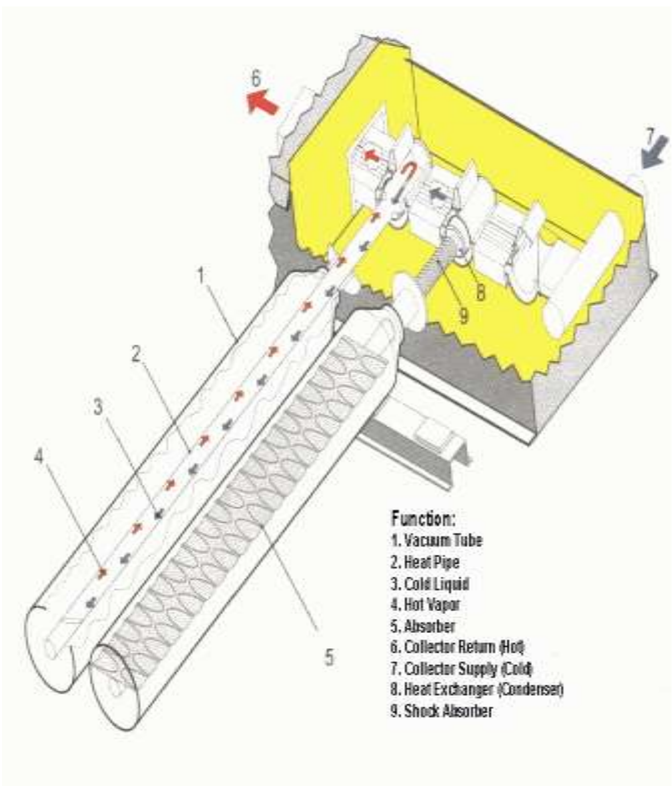

Fig.1.2 The Titanium Nitride Oxide coated absorber fin transfers heat to the condenser via a heat pipe

LITERATURE REVIEW

An overview of research work carried out in the area of fundamental studies on heat pipe and its applications, general empirical correlations under forced & natural convection, modeling of heat pipe heat exchangers (HPHE), experimental studies, and applications of HPHE. This survey has been carried out with the following objective:

a) To identify some of the important design aspects of heat pipe heat exchangers.

b) To identify the correlations for heat transfer, which can be used in the present study.

Liu and Wang (1)

Have reported A new thermal storage system, a heat pipe heat exchanger with latent heat storage, is reported. The new system may operate in three basic different operation modes, the charging only, the discharging only and the simultaneous charging/discharging modes, which makes the system suitable for various time and/or weather dependent energy systems. In this part of the paper, the basic structure, the working principle and the design concept are briefly introduced. Extensive experimental results are presented of the charging only and discharging only operations, and the effects of the inlet temperature and the flow rate of the cold/ hot water were also investigated. The results show that the heat exchanger performs the designed functions very well and can both store and release the thermal energy efficiently

Roul et al. (2)

have reported An experimental investigation of natural convection heat transfer in heated vertical ducts dissipating heat from the internal surface is presented. The ducts are open-ended and circular in cross section. The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. Heat transfer experiment is carried out for four different channels of 45mm. internal diameter and 3.8mm thickness with length varying from 450mm to 850mm. Ratios of length to diameter of the channel are taken as L/D = 10, 12.22, 15.56, and 18.89. Wall heat fluxes are maintained at q// = 250 to 3341 W/m2. The studies are also carried out on intensified channels of the same geometrical sizes with the discrete rings of rectangular section. Thickness of the rings are taken as t = 2.0, 3.0, 3.8mm; step size (s) of the rings are varying from 75mm to 283.3mm and the other ratios are taken as: ratio s/D = 1.67 to 6.29, ratio t/D = 0.044 to 0.084 and ratio s / t = 19.74 to 141.65. A systematic experimental database for the local steady state natural convection heat transfer behaviour is obtained. The effects of L/D ratio and wall heating condition on local steady-state heat transfer phenomena are studied. The effects of ring thickness and ring spacing on heat transfer behaviour are observed. The present experimental data is compared with the existing theoretical and experimental results for the cases of vertical smooth tubes and also for tubes with discrete rings.

Naveen et al. (3)

have reported Free convection heat transfer for an inclined steel pipe of 55^0 was carried out for different heat inputs .The experiments were carried on specially developed facility to perform constant heat flux and the temperatures were measured by thermocouples. The electrical input to the heater was controlled by dimmer stat and is measured by wattmeter. The experiments are carried for Gr number; the effects of inclination and Gr number on the temperature distribution were investigated. The average Nusselt numbers (Nu) were estimated along the tube length. The experimental heat transfer co-efficient was calculated from Nu number. The aim of project was concentrated on optimizing the Design (D/L RATIO) of inclined heated steel pipe for different heat input. Further by using the boundary condition of different heat input flow of steel pipe, analysis for copper pipe is carried out through CFD and L/D ratio of inclined heated copper pipe for different heat input was finalized

Totala and Shimpi (4)

have reported The present experimental study deals with natural convection through vertical cylinder .The experimental set up is designed and used to study the natural convection phenomenon from vertical cylinder in terms of average heat transfer coefficient. Also practical local heat transfer coefficient along the length of cylinder is determined experimentally and is compared with theoretical value obtained by using appropriate governing equations .The set up consist of brass cylinder of length 450mm and outside diameter 32mm with air as a working fluid. The results indicate the temperature variation along the length of cylinder and the comparative study of theoretically and practically obtain local heat transfer coefficient.

EXPERIMENTAL TECHNIQUE

To make an experimental setup of Heat pipe heat exchanger and arrange a single heat pipe with a setup in which we can rotate heat pipe in different - different angles and use a circular type vacuum tube as insulating materials.

Use as a Working Fluids**" Water, Ethanol, Methanol and Acetone"**

The surface heat transfer coefficient of a system transferring heat by natural convection depends on the shape, dimensions and orientation of the body, the temperature difference between the hot body and the surrounding fluid and fluid properties like κ, μ, ρ etc. The dependence of 'h' on all the above mentioned parameters is generally expressed in terms of non-dimensional groups, as follows:

hL / k is called the Nusselt Number (Nu),

$\mathbf{gL^3\beta\Delta T / \nu^2}$ is called the Grashoff Number (Gr) and,

$\mathbf{\mu C_p / k}$ is called the Prandtl Number

$$\mathbf{hL / k = gL^3\beta\Delta T / \nu^2 = \mu C_p / k}$$

A and **n** are constants depending on the shape and orientation of the heat transferring surface.
L is a characteristic dimension of the surface,
κ is the thermal conductivity of the fluid,
ν is the kinematic viscosity of the fluid,
μ is the dynamic viscosity of the fluid,
$\mathbf{C_p}$ is the specific heat of the fluid,
β is the coefficient of volumetric expansion of the fluid,
g is the acceleration due to gravity at the place of experiment,
$\mathbf{\Delta T = T_s - T_a}$
For a cylinder losing heat by natural convection

$$\mathbf{Nu = hL / k = 0.59\,(Gr.Pr)^{0.25}, \text{ for } 10^4 < Gr.Pr < 10^9}$$

$$\mathbf{Nu = hL / k = 0.59\,(Gr.Pr)^{1/3}, \text{ for } 10^9 < Gr.Pr < 10^{12}}$$

Here L is the length of cylinder and h_{th} is theoretical heat transfer coefficient.
All the properties of the fluid are evaluated at the mean film temperature (T_f)

When a hot body is kept in a still atmosphere, heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the hot body gets heated, rises up due to the decrease in its density and the cold surrounding fluid rushes in to take its place. The process is continuous and heat transfer takes place due to the relative motion of hot and cold particles. The heat transfer coefficient is given by:

$$\mathbf{h = q / A_s (T_s - T_a)}$$

Here,

h = Average surface heat transfer coefficient.

q = Heat transfer rate.

$\mathbf{A_s}$ = Area of heat transferring surface

$\mathbf{T_s}$ = Average surface temperature (°C),

$\mathbf{T_a}$ =Ambient temperature in the duct (°C)

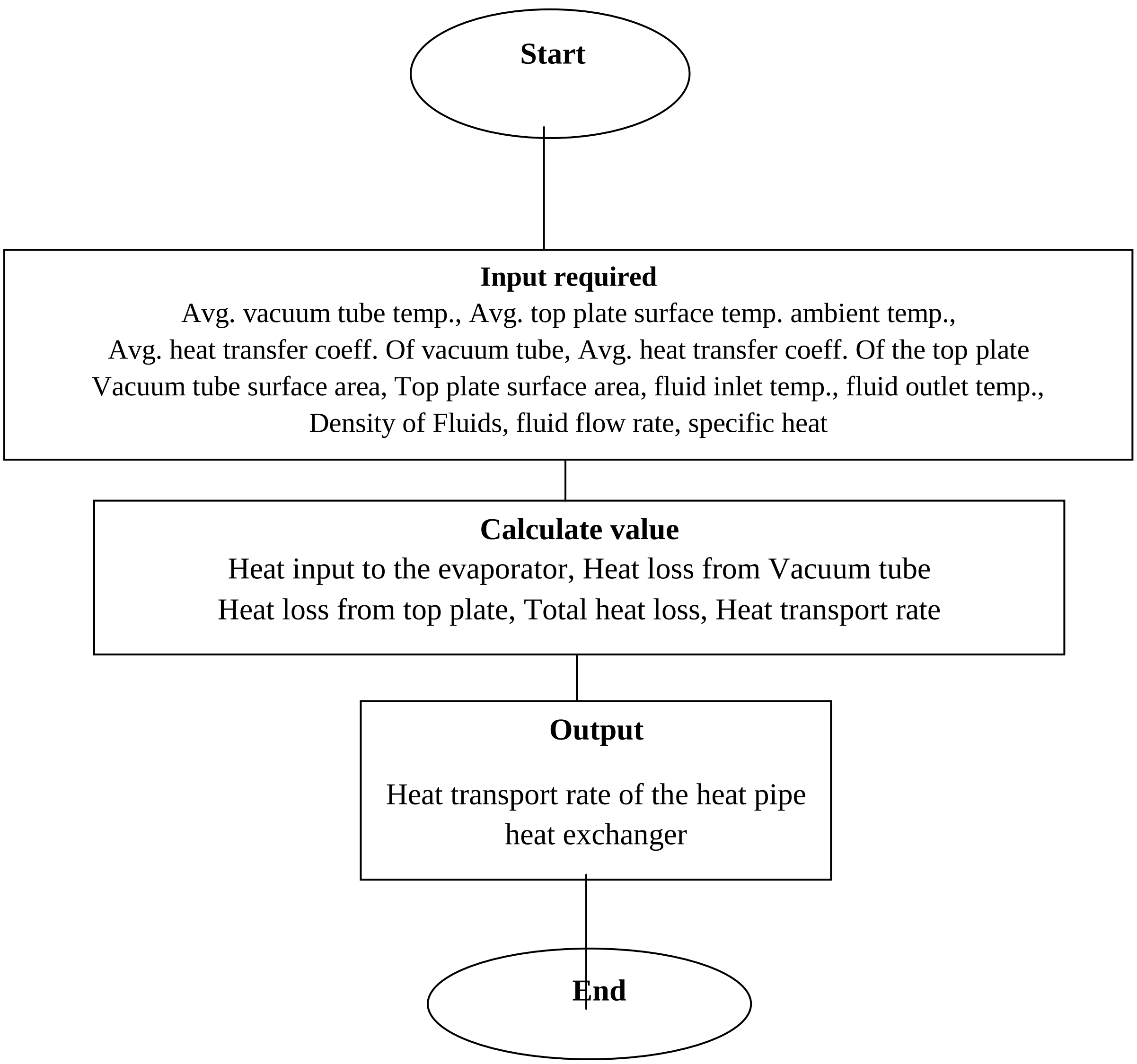

Figure 1.3 Problem formulation

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