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Experimental Study of The Characteristics Of Various Type Of Fins Using Forced Convection Heat Transfer

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Abstract:

This paper investigated the heat transfer rate of various types of fins using forced convection heat transfer. The heat transfer rate of copper pin fins, copper trapezoidal fins, aluminium pin fins, aluminium trapezoidal fins are studied. The results indicated that the heat transfer rate of copper pin fins, copper trapezoidal fins are higher than the heat transfer rate of aluminium pin fins and aluminum trapezoidal fins.

Keywords: *Mixed Convection Heat Transfer, pin fins, trapezoidal fins, Reynolds number, Prandtl number, Nusselt number, Efficiency of fin, Pressure drop, friction factor, Heat Transfer Coefficient.*

1. INTRODUCTION

1.1 Fins

The fins are commonly used for increasing the heat transfer rates from the surfaces whenever it is not possible to increase the rate of rate of heat transfer either by increasing the heat transfer coefficient on the surface or by increasing the temperature difference between the surface and surrounding fluids.

The fins are commonly used on small power developing machines as engines used for scooters and motorcycles as well as small capacity compressors. They are also used in refrigerating systems for increasing heat transfer rates.

An extended surface configuration is generally classed as a

- Straight fin
- An annular fin
- A pin-fin

1.2 HEAT TRANSFER

Heat transfer is thermal energy in transit due to spatial temperature difference. Whenever there exists a temperature difference in a medium or between media, heat transfer must occur.

The heat transfer may occur in three modes,

- Conduction heat transfer
- Convection heat transfer
- Radiation heat transfer

Convection heat transfer

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heats transfer. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates.

Convection heat transfer

The convection heat transfer mode is comprised of two mechanisms. In addition to energy transfer due random molecular motion, energy is also transferred by the bulk, or macroscopic, motion of the fluid. This fluid motion is associated with the fact at any instant; large numbers of molecules are moving collectively or as aggregates. Such motion, in the presence of a temperature gradient, contributes of heat transfer.

Because of the molecules in the aggregate retain their random motion the total heat transfer is then due to a superposition of energy transport by the random motion of the molecules and by the bulk motion of the fluid. The rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling as

$$Q_{conv} = hA_s(T_s - T_\infty)$$

Where A_s is the surface area through which convection heat transfer takes place

h is the convection heat transfer coefficient in W/m^2K

T_s and T_∞ is the surface and fluid temperatures respectively.

The above expression is known as Newton's law of cooling.

It depends on the condition of boundary layer, which are influenced by surface geometry, the nature of fluid motion, and as assortment of fluid thermodynamic and transport properties.

1.3 Classification

Convective heat transfer may be classified according to the nature of the flow. They are

i. Natural convection

The natural convection is induced by the buoyancy forces, which are due to density differences caused by the temperature variations in the fluid.

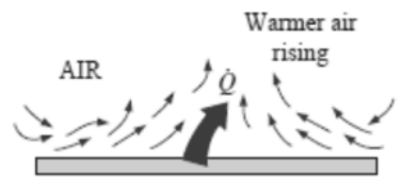

Fig 1.6 Natural convection

ii. Forced convection

When the flow is caused by the external means such as by a fan, a pump, or atmospheric winds it is called forced convection.

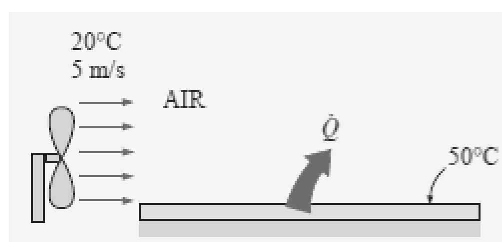

Fig 1.7 Forced convection

iii. Mixed convection

It is the combination of both free and forced convection. A process occurs when the effect of the

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buoyancy force in forced convection or the effect of forced flow in free convection becomes significant.

The heat energy being transferred is the sensible or internal thermal energy of the fluid. However, there are convection processes for which there is, in addition, latent heat exchange.

This latent heat exchange is generally associated with a phase change between the liquid and vapor states of the fluid. Two special cases of interest in this are boiling and condensation.

1.4 Forced Convection Heat Transfer

Forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or fan.

Mechanism of Forced Convection

Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate).

The rate of convection heat transfer is expressed by Newton's law of cooling:

$$q_{conv} = h\,(T_s - T_\infty)\ (W/m^2)$$

$$Q_{conv} = hA\,(T_s - T_\infty)\ (W)$$

The convective heat transfer coefficient *h* strongly depends on the fluid properties and *roughness* of the solid surface, and the type of the fluid flow (*laminar* or *turbulent*).

It is assumed that the velocity of the fluid is zero at the wall this assumption is called *no slip* condition. As a result, the heat transfer from the solid surface to the fluid layer adjacent to the surface is by pure conduction, since the fluid is motionless.

1.5 Flow over Flat Plate

The friction and heat transfer coefficient for a flat plate can be determined by solving the Conservation of mass, momentum, and energy equations (either approximately or numerically). They can also be measured experimentally.

It is found that the Nusselt number can be expressed as:

$$\text{Nu} = C\, Re^n\, Pr^n = \frac{hL}{K}$$

Where *C*, *m*, and *n* are constants and *L* is the length of the flat plate. The properties of the fluid are usually evaluated at the *film temperature* defined as:

$$T_f = \frac{Ts + T\infty}{2}$$

2. Material Selection

Generally there are two types of materials used for fins aluminium and copper. The thermal conductivity of aluminium is 225 W/mK and that of copper is 385 W/mK. The melting and boiling point of copper are 1084 ºC and 2595 ºC and that of aluminium are 658ºC and 2057 ºC.

Pure aluminium has silvery color and it has greater resistance to corrosion. It is used to deoxidizing molten irons and steel. It is used to prepare the metals from their oxides by heating a mixture of powdered aluminium and the oxides of the metal to be reduced. Its electrical resistivity is 2.669 micro ohms/cm.

Copper is reddish brown in color. Refining of the metal is usually considered to begin when copper is in blister stage, the surface of the cast material being irregular and blistered due to the generation of gases during cooling.

This copper is 99% pure and further refined in furnace by oxidation process which removes sulphur and other impurities. The excess of oxygen is removed from the metal by operation known as poling. Its electrical resistivity is 1.682 micro ohms/cm.

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3. EXPERIMENTAL SETUP

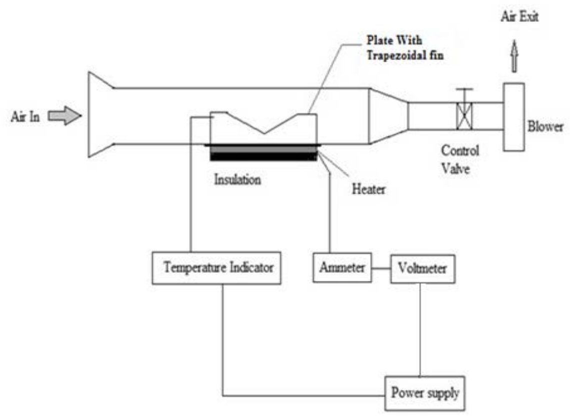

Fig. 3.1 Sketch of the experimental set up

The experimental set-up consists mainly of a nozzle, the test section, a diffuser, a flow control valve and a blower. The multipoint temperature indicator is used to measure the fin temperature, base plate temperature, and inlet and exit temperature of the air. A dimmerstat with digital voltmeter and digital ammeter is used to control the electric current supplied to the heater plate.

The test section is a rectangular duct heated at the bottom with a cross section 150 mm in width and 100 mm in height. The bottom of the heater is wounded with asbestos thread.

The unheated entrance region of the duct is 300 mm, the heated test section involving a copper plate and rectangular longitudinal fins is 127 mm. The test section consists of a 175 x 120 x 1 mm copper plate, 2 copper and 2 aluminium longitudinal fins of 1 mm thickness and 120 mm in width and 15 mm height with trapezoidal notch at the center of the fin with 20% notch area.

The another test section consists of a 175 x 120 x 1 mm aluminium plate, 2 copper and 2 aluminium longitudinal fins of 1 mm thickness and 120 mm in width and 15 mm height with trapezoidal notch at the center of the fin with 20% notch area.

The third test section consists of a 175 x 120 x 1 mm aluminium plate, 16 copper and 16 aluminium pin fins of 8 mm diameter and 25 mm in height.

The fourth test section consists of a 175 x 120 x 1 mm copper plate, 16 copper and 16 aluminium pin fins of 8 mm diameter and 25 mm in height.

Fins are attached to the plate using screw thread and rivets. The thermocouples are attached to fins to measure the fin temperature and to the base plate to measure the base plate temperature. All surfaces are carefully cleaned and polished.

A plate heater was placed under the copper plate, with a size equal to the size of the copper plate having dimensions of 175 x 120 mm. Electric current was provided to the heater plate via a variac, providing a heat flux boundary condition specified for a decide experimental case.

The test section of the rectangular duct is insulated with asbestos thread and was mounted on rigid supporting frame. The test section is attached to blower through a flow control valve. A control valve is used to control the flow rate.

The air velocity is measured with a hot-wire anemometer. All the thermocouples were attached to the fins by drilling a hole in the fins and connecting them with rigidity.

The data should be collected for different velocity, voltage drop across heater, and electric current.

Using these different values collecting from the experiment, the following parameter has to be determined. The Nusselt number for the bottom plate and the heat transfer coefficient h has to be calculated.

The experimental setup used in the evaluation of heat transfer coefficient for forced convection is

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shown in figure 3.2. The copper plate with pin fin and used in the aluminium plate with pin fin and the copper plate with trapezoidal fin and aluminium plate with trapezoidal fin convection environment is shown in figure 3.3 , 3.4 , 3.5 and 3.6 respectively.

Fig 3.2 Experimental setup

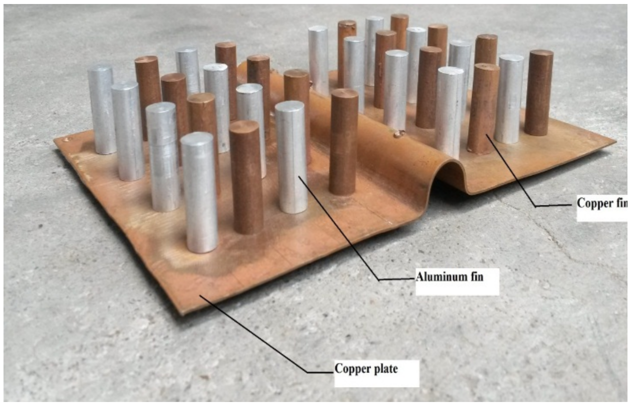

Fig 3.3 Copper plate with pin fins

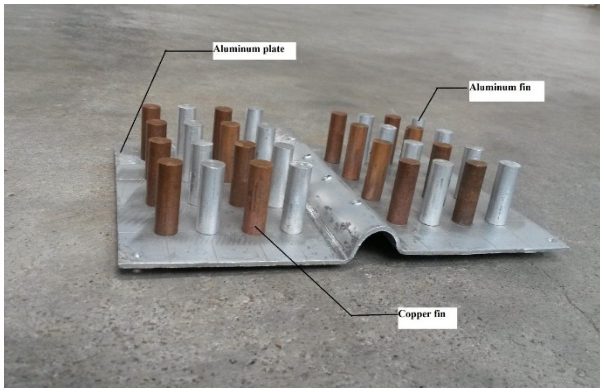

Fig 3.4 Aluminium plate with pin fins

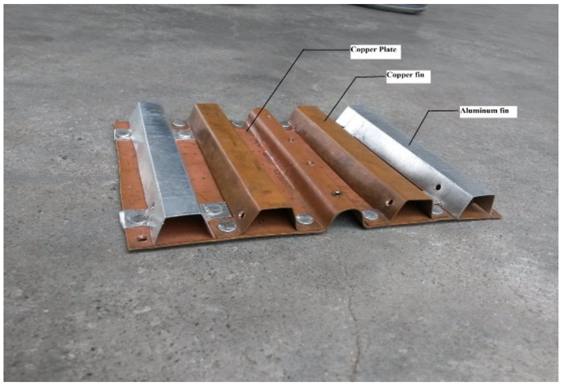

Fig 3.5 Copper plate with Trapezoidal fins

Fig 3.6 Aluminium plate with Trapezoidal fins

FORMULAE USED

- $\beta = \frac{do}{dp}$

  β- Thermal expansion

  d_0 – Diameter of orifice, m

  d_p- Diameter of pipe, m

- V_o = cd$\sqrt{2gh(\rho_m - \rho_a)/\rho_a}$ *$(\frac{1}{1-\beta})$

  V_o -Velocity of orifice

  ρ_m-Density of mamometric fluid

  ρ_a –Density of air

  c_d-Co-efficient of discharge

- $V_a = \frac{V_o*(\pi d_o^2)/4}{W*B}$

  V_a- Velocity of air in duct

W-Width of the duct, m

B-Breadth of the duct, m

- $T_s = \frac{T_1+T_2+\cdots\ldots+T_7}{7} + 273$

  Ts-Average surface temperature, ℃
- $T_\infty = T_8$ = Ambient temperature, ℃
- $T_m = \frac{T_s - T_\infty}{2}$

  Tm-Mean temperature, ℃
- Reynolds number Re

  $Re = \frac{v_a\, d_f}{\vartheta_{air}}$

  v_{air}- Velocity of air in the duct, m/s

  ϑ_{air}- Kinematic viscosity of air, m^2/s

  d_f- Diameter of fin, m
- The relationship for N_u is
- $N_u = C\, R_e^n\, P_r^{1/3}$

  P_r-Prandtl number

  Nu-Nusselt number

  Re = 0.4 to 4.0; C=0.989, n=0.33

  Re = 4.0 to 40; C=0.911, n=0.385

  Re = 40 to 4000; C=0.683, n=0.466
- $h = \frac{N_u k}{d_f}$
- $m = \sqrt{\frac{hP}{KA}}$

  P-Perimeter
- Temperature distribution is given by

  $\frac{T - T_\infty}{T_o - T_\infty} = \frac{\cosh m\,(L-x)}{\cosh m\, L}$ °C
- $T = T_\infty + (T_0 - T_\infty) * \frac{\cosh m\,(L-x)}{\cosh m\, L}$
- Effectiveness of fin = $\frac{PK}{\sqrt{hA}}$ * tanh mL
- Efficiency of fin = $\frac{\tanh mL}{mL}$
- Pressure drop $\Delta P = \frac{4flv^2}{2gd}$

  F-friction factor = $\frac{64}{R_e}$

  L-length of duct

4. RESULTS & DISCUSSION

The forced convection heat transfer with rectangular plate with trapezoidal fins and pin fins in a horizontal channel under bottom wall constant heat flux conditions has been investigated experimentally. By adjusting the flow control valve, the fluid velocity at the inlet of the duct was obtained as 1.697 m/s during the experiment. Experiments were conducted under various heat flux conditions.

Table 1

Temperature in various distances for Copper plate with pin fins

Distance of thermocouples X, m	Temperature from experiment ℃	Temperature from calculation ℃
0.015	50	49.12
0.03	47	46.35
0.06	45	44.58

Table 2

Temperature in various distances for Aluminium plate with pin fins

Distance of thermocouples X, m	Temperature from experiment ℃	Temperature from calculation ℃
0.015	41	40.52
0.03	40	39.88
0.06	39	38.72

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Table 3

Temperature in various distances for Copper plate with trapezoidal fins

Distance of thermocouples X, m	Temperature from experiment ℃	Temperature from calculation ℃
0.015	50	50.22
0.03	46	45.79
0.06	40	40.13

Table 4

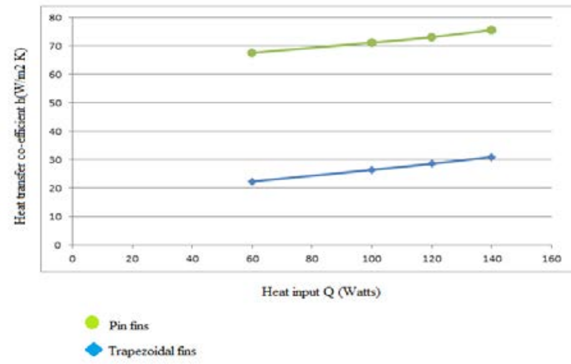
Temperature in various distances for aluminium plate with trapezoidal fins

Distance of thermocouples X, m	Temperature from experiment ℃	Temperature from calculation ℃
0.015	55	54.86
0.03	52	52.03
0.06	50	49.64

Table 5

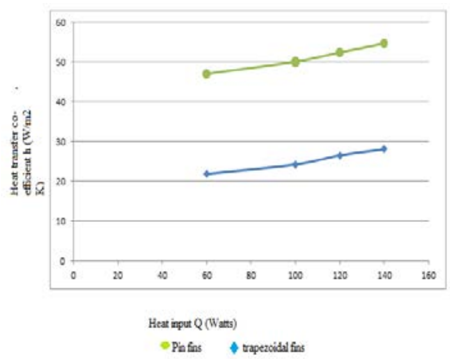
Heat transfer coefficient for various types fins

Type of fin	Heat transfer coefficient
Copper plate with pin fins	67.61
Aluminium plate with pin fins	47.05
Copper plate with trapezoidal fins	22.32
Aluminium plate with trapezoidal fins	21.897



Comparison of Heat Transfer Co-efficient for Copper plate with pin fins and Copper plate with trapezoidal fins.

The above graph indicated that the heat transfer rate of copper pin fins higher than that of copper trapezoidal fins.



Comparison of Heat Transfer Co-efficient for aluminium plate with pin fins and aluminium plate with trapezoidal fins

5. CONCLUSIONS

Forced convection heat transfer from longitudinal fins with trapezoidal notch in a horizontal rectangular channel with heat flux boundary condition at the bottom surface has been studied experimentally. Experimental results for bottom heated fin arrays have been presented for different heat input and the effect of heat transfer have been investigated. It has been determined that the average heat transfer coefficient for copper plate with trapezoidal and pin fins with fin spacing of 9 mm is more than for aluminium plate with trapezoidal and pin fins array.

Also it has been determined that the average heat transfer coefficient for copper plate with pin fins with fin spacing of 9 mm is more than for copper plate with trapezoidal fins array.

Also it has been determined that the average heat transfer coefficient for aluminium plate with pin fins with fin spacing of 9 mm is more than for aluminium plate with trapezoidal fins array.

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