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Thermal Analysis of Pin Fin using Different Materials and Forms

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Abstract: ***The purpose of this paper is to study the thermal performance of pin fin. The main aim of this study is to find out the most effective fin from a series of selected fins of different materials and geometries. Trials were conducted for varying Reynolds number and results were found out respectively for each fin.***

Keywords: Pin fin, Reynolds number, Nusselt number**,** *Prandtl* number, Convective heat transfer coefficient, Efficiency, Effectiveness

1. Introduction

An extended surface (also known as a combined conduction-convection system or a fin) is a solid within which heat transfer by conduction is assumed to be one dimensional, while heat is also transferred by convection from the surface in a direction transverse to that of conduction.

Fins are used to increase the heat transfer rate from surface to the surrounding fluid . Familiar examples are the circumferential fins around the cylinder of motor cycle engine & pin fins attached to the condenser tubes at the back of domestic refrigerator. In present pin-fins are normally used in different shapes & sizes depending upon its applications.

It is obvious that a fin surface sticks out from the primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one moves out along the fin. The design of the fins therefore required knowledge of the temperature distribution in the fin.

Fins are quite often found in industry, especially in heat exchanger industry as in finned tubes of double-pipe, shell-and-tube and compact heat exchangers. As an example, fins are used in air cooled finned tube heat exchangers like car radiators and heat rejection devices.

Moreover, fins are also utilized in cooling of large heat flux electronic devices as well as in cooling of gas turbine blades. Fins are also used in thermal storage heat exchanger systems including phase change materials. To the best knowledge of the, fins as passive elements for enhancing heat transfer rates

Figure 1: Practical use of Fins

Fins are classified according to the following criteria:
- Geometrical design of the fin.
- Fins arrangements.
- Number of fluidic reservoirs interacting with the fin
- Location of the fin base with respect to the solid boundary.
- Composition of the fin.

According to design aspects, fins can have simple designs, such as rectangular, triangular, parabolic, annular, and pin rod fins. On the other hand, fin design can be complicated such as spiral fin. In addition, fins can have simple network as in finned tubes heat exchangers. Moreover, fins can be further classified based on the fact whether they interact thermally with a single fluid reservoir or with two different fluid reservoirs. In addition, fins can be attached to the surface as in the works or they may have roots in the heated/cooled walls. Finally, fins can be solid or they can be porous or permeable.

2. Experimental Setup

A fin of circular cross section in fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to the axis. One end of the fin projects outside the duct and is heated by a heater. Temperature measured at five points along the length of the fin. The air flow rate is measured by an orifice meter fitted on the delivery side of the blower. Current and voltage is measured by ammeter and voltmeter respectively which is fitted on the control panel. Dimmerstat is also mounted on control panel which is used to vary the heat input to the base of fin.

A block of 48 mm diameter and 50 mm length is provided to mount the fin. The block is threaded internally, while the fin is threaded externally at one end for easy removal and fitting of different fins. Nichrome wire heater is fitted on the block.

Following are the main components of setup:

A. Duct
The duct is rectangular shaped of dimension140mm x90mm cross section.Length of duct is 400 mm.The material used for duct manufacturing is Mild Steel

B. Blower
The blower used operates on 1 HP motor

C. Heater
The heater used is a nichrome wire heater of 50 mm diameter and 50 mm length.

D. Manometer
The manometer used is water manometer of specification 250-0-250

E. Fin
Fins of various materials are used with standard dimension of 12.7 mm diameter and 130 mm length. Five thermocouples of K type are fitted on the length of fin for temperature measurement at 32 mm interval. Thermocouple arrangement is shown in fig.2

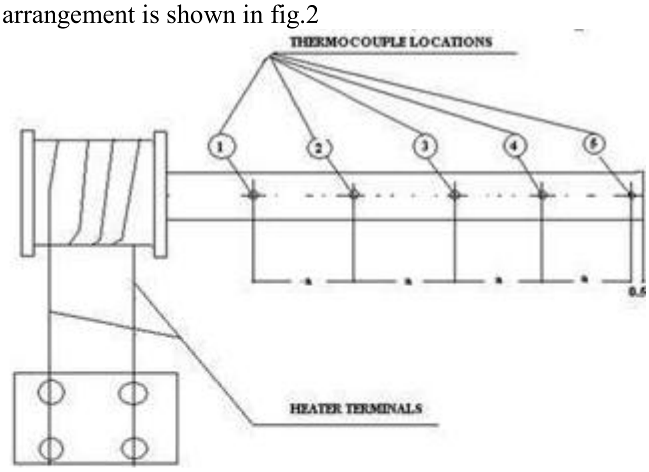


Figure 2: Thermocouple Arrangement on Fin

Figure 3: Experimental Setup

3. Experimental Procedure

To study the temperature distribution along the length of a pin fin forced convection, the procedure is as follows:
1) Insert the required find and make proper connections.
2) Switch on the main supply
3) Start heating the fin by switching ON the heater
4) Adjust dimmer stat voltage equal to 80 volts.
5) Start the blower and adjust the difference of level in the manometer with the help of gate valve.
6) Wait for 20 minutes and adjust the voltage to 60 volts.
7) Wait to obtain the steady state condition.
8) Note down the thermocouple readings (1) to (5) at a time interval of 5-10 minutes.
9) When the steady state is reached, record the final reading (1) to (5).
10) Repeat the same experiment with different manometer readings.
11) Remove the fin when it is cooled.

4. Precautions

1) See that the dimmer stat is at zero position before switching ON the heater.
2) Operate the changeover switch of temperature indicator, gently.
3) Be sure that the steady state is reached before taking the final reading.

Table 1: Nomenclature

ρ-Density of air
D-Diameter of pin fin
μ-Dynamic viscosity
C_p-Specific heat
K_a-Thermal conductivity of air
T_{amb}-Ambient Temperature
Nu-Nusselt Number
V_{mf}-Velocity of air at mean film temperature
Δha-Height of air column
Qa-Flow of air
Va-Velocity of air through duct
T_s-Average surface temperature of fin
T_{mf}-Mean film temperature
Q_{act}-Actual heat transfer rate through fin
Q_{max}-Maximum heat transfer rate through fin
η-Efficiency of pin fin
ε-Effectiveness of fin
Re- Reynolds number
Pr- Prandtl number
h- heat transfer coefficient
Δh_w-Height of air column

V. Governing Equations

Various governing equations used in the experiment are as follows:

For forced convection,

$Nu = 0.615\,(R_e)^{0.466}$ .. $40 < R_e < 4000$

$Nu = 0.174\,(R_e)^{0.618}$ .. $4000 < R_e < 40000$

Where, Nusselt Number: $Nu = \frac{h \times Lc}{ka}$ (1.1)

Reynolds Number: $R_e = \frac{\rho \times Vmf \times D}{\mu}$ (1.2)

Prandtl Number: $P_r = \frac{Cp \times \mu}{KAir}$ (1.3)

Tm = Average fin temperature

$= \frac{(T1+T2+T3+T4+T5)}{5}$ (1.4)

$\Delta T = T_1 - T_{amb}$

A. Mean Film Temperature:

$T_{mF} = \frac{(Tm + TF)}{2}$ (1.5)

Mass Flow Rate Of Air:

$Q_a = \frac{cd \times a1 \times a2 \times \sqrt{2 \times g \times (\Delta ha)}}{\sqrt{(a1^2 - a2^2)}}$ (1.6)

Velocity Of Air Through Duct:

$V_a = \frac{Qa}{Duct\frac{c}{s}area}$ (1.7)

B. Mean Film Velocity:

$V_{mf} = Va \times \frac{(Tmf+273)}{(Ts+273)}$ (1.8)

$Nu = 0.683 \times Re^{0.466} \times Pr^{0.33}$ (1.9)

C. Heat Transfer Coefficient:

$h = \frac{Nu \times Ka}{d}$ (2.0)

Actual Heat Transfer:

$Q_{act} = \sqrt{hPkA} \times (T1 - Tamb) \times x\tanh(ml)$ (2.1)

Maximum Possible Heat Transfer:

$Q_{max} = h \times (\pi \times d \times l) \times (T1 - Tamb)$ (2.2)

D. Efficiency:

$\eta\% = \frac{Qact}{Qmax} \times 100$ (2.3)

Effectiveness Of Heat Transfer:

$\varepsilon = \frac{Qwith\ fin}{Qwithout\ fin}$ (2.4)

5. Observation

1) Diameter of the orifice = 14mm.
2) Diameter of the delivery pipe = 32mm
3) Coefficient of discharge (or orifice meter) Cd= 0.62.
4) Thermal conductivity of fin material (Brass) = 110w/m ^{0}C.
5) Thermal conductivity of fin material (Aluminium) = 220w/m ^{0}C
6) Thermal conductivity of fin material (MS) = 54w/m ^{0}C
7) Temperature indicator = 0 – 300 ^{0}C with compensation of ambient temperature up to 50^{0}C.
8) Dimmerstat for heat input control 230V, 2 Amps.
9) Heater suitable for mounting at the fin end outside the duct =150 watts (Band type)
10) Voltmeter = 0-500V.
11) Ammeter =0-5Amps.
12) Ambient Temperature $T_6 = T_f = 27^0C$
13) Voltage (V) = 60 V
14) Current (I) = 0.17 A

Table 2: Observation Table

Sr. No	Type of Fins	Fin Temperatures				
		T_1 (^{0}C)	T_2 (^{0}C)	T_3 (^{0}C)	T_4 (^{0}C)	T_5 (^{0}C)
1	Brass	121	106	98	96	90
2	Brass With Holes	112	99	91	89	81
3	Brass With Knurls	122	106	97	95	87
4	Aluminium	121	110	108	108	99
5	MS	111	72	55	48	42

obtained at an interval of 5 minutes. Following are the final readings obtained for various fins for Δh_w=80mm

6. Results

Below are the results calculated from the observations :

Table 3: Result of Observation

Sr No	*Material*	$\Delta h_{w\,(cm)}$	R_e	ε	η
1	Brass	80	207.143	32.643	79.726
		60	177.737	33.035	80.683
		40	144.62	33.592	82.043
		20	102.024	34.485	84.223
2	Brass with knurling	80	207.351	32.646	79.733
		60	179.006	33.056	80.732
		40	145.337	33.605	82.075
		20	102.262	34.492	84.242
3	Brass with holes	80	209.099	32.672	70.642
		60	178.351	33.045	71.447
		40	145.087	33.601	72.689
		20	102.389	34.495	74.583
4	Aluminium	80	205.386	36.337	88.746
		60	176.59	36.588	89.359
		40	143.49	36.93	90.195
		20	101.039	37.471	91.518

Based on the results obtained by conducting tests on various fins, results were obtained which we have represented graphically.

A. Brass Fin:

Overlapping Graph Of Efficiency(η), Effectiveness(ε), Vs Reynolds Number(Re):

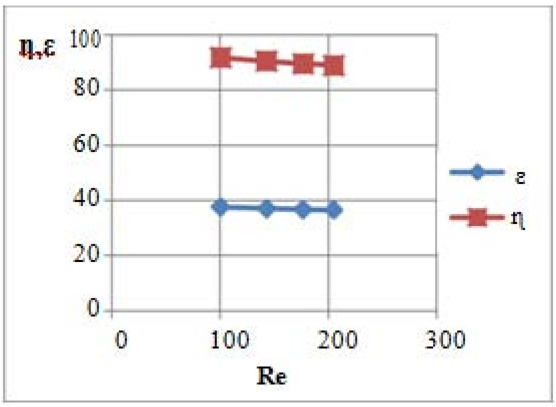


Figure 4: Brass Fin

B. Brass Fin with Knurling:

Overlapping Graph Of Efficiency(η), Effectiveness(ε), Vs Reynolds Number(Re):

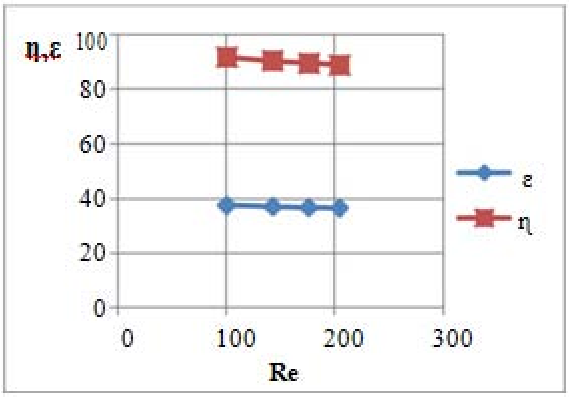
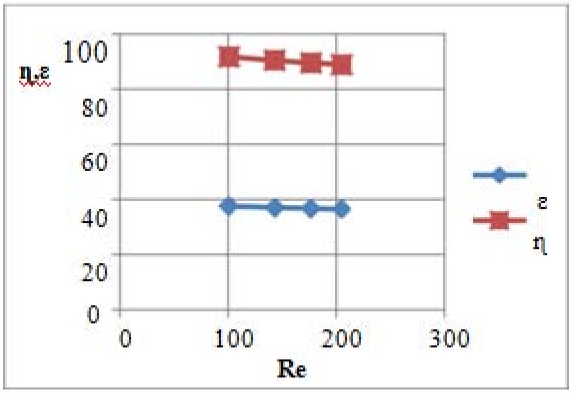


Figure 5: Brass Fin with Knurling

C. Brass Fin with Holes:



Overlapping Graph Of Efficiency (η), Effectiveness(ε), Vs Reynolds Number(Re):

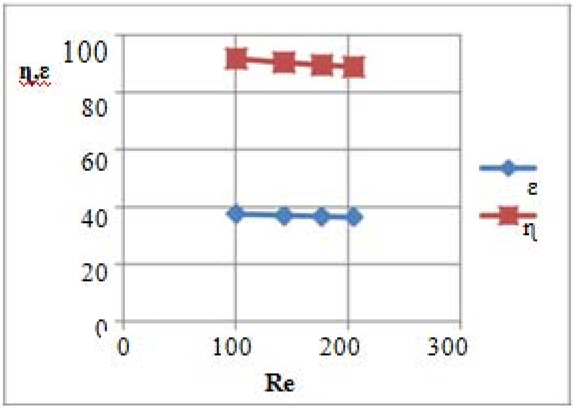


Figure 6: Brass Fin with Holes

D. Aluminium Fin:

Overlapping Graph Of Efficiency (η), Effectiveness(ε),Vs

Reynolds Number(Re):

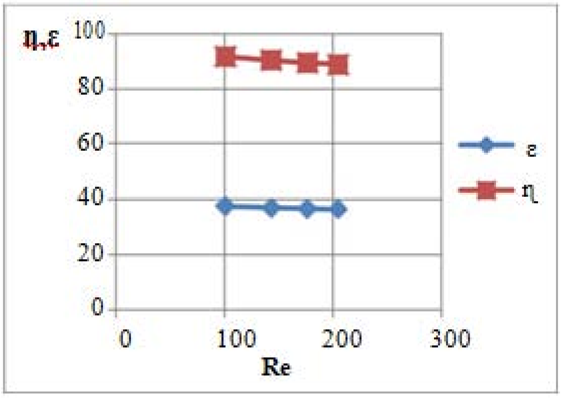


Figure 7: Aluminium Fin

7. Conclusion

So from the above result obtained, we can conclude that as Reynolds number increases, the efficiency and effectiveness of the pin fin decreases. While material wise Aluminium is the most effective material.

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