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An Experimental Investigation Of Heat Transfer Characteristics In Plain And Tapered Spines

M. Krishna Prasanna[1], P. Murari[2], T. Siva Krishna[3], M.R.Ch.Sastry[4], Vamsi Krishna Salapati[5]
[1,2,3]*Assistant Professor,* [4]*Professor & HoD,* [5]*Graduate Student*
[1,2,3,4,5]*Department of Mechanical Engineering, Gudlavalleru Engineering College*
Email: prasannakrishna.268@gmail.com[1]

Abstract: In this work, experimental and numerical results of the heat transfer characteristics of the tapered spines under constant heat flux conditions are presented. An experimental set up has been used to analyze the heat transfer characteristics. The tapered spines are fabricated from cylindrical Aluminum 6061 alloy with length, base and tip diameters of 102, 12 and (4, 6, 8) mm, respectively. Experiments are performed at various Reynolds numbers in the range of 1000–5000 and various heat inputs under forced convection. An observation has been noticed that the variable heat transfer coefficient has a strong influence over the spine effectiveness.

Key words*:* Tapered spine, heat flux, Reynolds number, forced convection

1. INTRODUCTION

The term extended surface is employed to depict a very important special case involving heat transfer by conduction within a solid and heat transfer by convection from the boundaries of the solid. There are many situations that involve combined conduction convection effects, the most frequent application is one in which an extended surface is used specifically to enhance heat transfer between a solid and an adjoining fluid. Such an extended surface is termed a spine. Practically there are situations which necessitate the increase of heat transfer rate. There are three ways with in which the heat transfer rate may be increased:

- Increasing the convection coefficient ‘h’ by increasing the fluid velocity
- Increasing the convection coefficient ‘h’ by decreasing the temperature
- Increasing the heat transfer rate by increasing the surface area over which the convection occurs

In the first two cases the heat transfer rate is increased by increasing the heat transfer coefficient of the surrounding fluid. In the first case the heat transfer coefficient is increased by speeding up fluid flow by the introduction of blowers, however there are situations for which increasing h to the maximum possible value is either insufficient to obtain the required heat transfer rate or the associated prices are preventive. Moreover the second case of reducing the fluid temperature is often impractical.

The third option is the most preferable; highlighting the increase in heat transfer rate by increasing the surface area across which convection occurs. This may be done by employing spines.

2. TYPES OF SPINES

Spine is an extra surface provided over the actual component from which heat transfer to the surroundings is to be enhanced. Selection and arrangement of spines is effected by several factors. Spines come in many shapes and sizes. They can be broadly classified into

- Surface spines of constant cross-section Rectangular spines
- Spines of varying cross-section. Tapered spines.

3. GENERALIZED HEAT CONDUCTION EQUATIONS IN 3-D FOR ISOTROPIC MATERIAL:

Cartesian coordinates:

$$\frac{\partial^2 T}{\partial X^2}+\frac{\partial^2 T}{\partial Y^2}+\frac{\partial^2 T}{\partial Z^2}+\frac{q}{k}=\frac{1}{\propto}\frac{\partial T}{\partial t}$$

Cylindrical coordinates:

$$\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\left(\frac{\partial T}{\partial t}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}+\frac{\partial^2 T}{\partial Z^2}+\frac{q}{k}=\frac{1}{\propto}\frac{\partial T}{\partial t}$$

Spherical coordinates:

$$\frac{1}{r}\frac{\partial^2 (rT)}{\partial r^2}+\frac{1}{r^2 \sin\varphi}\frac{\partial}{\partial \varphi}\left(\sin\varphi\frac{\partial T}{\partial \varphi}\right)+\frac{1}{r^2 \sin^2\varphi}\frac{\partial^2 T}{\partial \phi^2}+\frac{q}{k}=\frac{1}{\propto}\frac{\partial T}{\partial t}$$

4. TYPICAL APPLICATION AREAS OF FINS ARE:

- Radiators for automobiles
- Cylinder heads Air-cooling of internal combustion engines like Scooters, motor cycles, aircraft engines, air compressors etc.
- Steam power plants economizers

- Wide variety heat exchangers which are used in different industries
- Cooling of electric motors transformers, etc.
- Cooling of electronic equipment, chips, IC boards, etc.
- Fin theory is also used to estimate error in temperature measurement while using thermometers or thermocouples.

5. CONVECTIVE HEAT TRANSFER

Convection is one of the modes of heat transfer that is possible only in the fluid medium. When a fluid flows inside a duct or over a solid body and the temperatures of the fluid and solid body are different, heat transfer between the fluid and the solid surface take place. This is because of the motion of the fluid relative to the surface. This type of heat transfer is called convection. The transfer of heat here is inseparably linked with the movement of the fluid itself. Depending up on the movement of the fluid whether it is natural or artificial, convection is classified in to Natural convection and forced convection.

5.1 Natural Convection:

There are some situations in which the fluid motion is produced due to change in density resulting from temperature gradients. The mechanism of heat transfer in these situations is called natural convection. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity to hot solid boundary become warmer (becomes less dense molecules) than the surrounding fluid resulting (high dense molecules due to low temperature). These low dense molecules of the fluid would be replaced by colder fluid resulting in what is called convection currents. These currents originate when a body force acts on a fluid in which there are density gradients. The force which induces these convection currents are called buoyancy force which is due to the density gradient within the fluid and the body force. There are many a number of correlations provided with, to study about different conditions of this natural convection. But, here in this experiment we are considered about the free convection over horizontal cylinder.

5.2 Forced Convection:

In forced convection, the fluid is forced to flow over a surface or in a tube by external means such as pump or blower. Convective heat transfer is complicated since it involves fluid motion as well as heat conduction. The convective heat transfer coefficient strongly depends on fluid properties and roughness of the solid surface and type of the fluid flow (laminar or turbulent). The flow in the boundary layer starts as smooth and streamlined which is called laminar flow. At some distance from the leading edge, the flow turns chaotic, which is called turbulent flow. Here in our experiment we are considered about the forced convection over horizontal cylinder.

6. EXPERIMENTAL SETUP:

The experimental set up consists of a simple spine which is fitted in a rectangular duct provided with a open cover over the spine. Exit end of the duct is attached to the suction end of the blower; one end of the spine is fitted to an electrical heater. A manometer is provided at the exit end of the duct to not the exit pressure of the fluid. Temperature of the spine is raised by using heater provided at the base plate, well insulated electrically and thermally to prevent heat loss and shocks. The heater is connected to an electric supply line through a wattmeter. The blower is operated only during forced convection. The base plate and spine assembly was made of aluminum (or brass) and casted together. The spine is provided with thermocouples located along the length of the spine and a thermocouple is provided to note the duct fluid temperature. Experiment is conducted on aluminum spine.

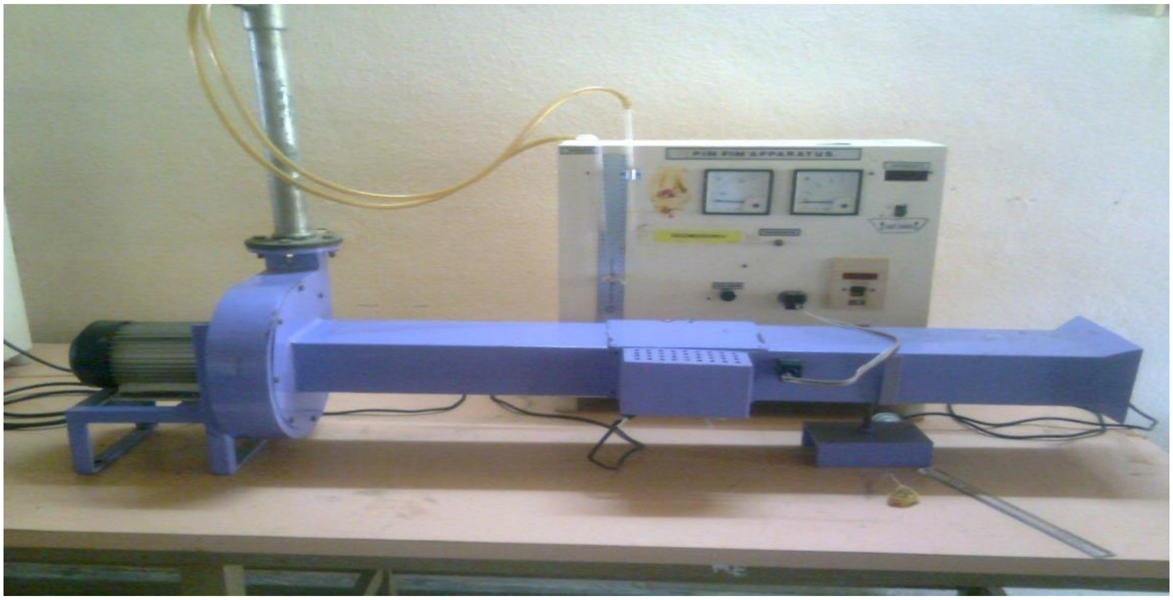


Figure 1: Experimental setup

7. EXPERIMENTAL CONDITIONS

The heat input to the spines is varied from 45 – 66 W. In forced convection, the Reynold's number is varied from 2000–5000 by regulating the flow control valve provided. Under these conditions, performance of the spines is studied.

Figure 2: Tapered spines of different Tip diameters(4,6,8mm)

8. CALCULATION FOR FORCED CONVECTION (PLAIN CYLINDRICAL FIN) For Q=45w

$$Q = C_d \frac{\pi}{4} d^2 \sqrt{2gh(\rho_w / \rho_a)} =$$

$$0.64 \times \frac{\pi}{4} \times \left(22 \times 10^{-3}\right)^2 \sqrt{2 \times 9.81 \times 0.101 \left(\frac{1000}{1.121}\right)}$$

$=0.0102\ m^3/s$.

V=Q/Duct cross sectional area = $\frac{0.01022}{0.15 \times 0.1}$

=0.6819 m/s

$V_{tmf} = \frac{v(T_{mf} + 273)}{T_f + 273} =$

$\frac{0.6819(41.79 + 273)}{33.7 + 273}$ =0.699 m/s

Re $=(V_{tmf}.D_h)/v$ = 4932.26

Nu= $0.193(Re)^{0.618}.Pr^{0.333}$

$=0.193(4932.26)^{0.618}.(0.6988)^{0.333}$

=32.9039

Nu= $\frac{hD}{K_{airA}}$

h= 76.5425 w/m^2k

m= $\sqrt{\frac{hp}{k_f A}}$

$$Q_{fin} = \sqrt{hpkA}(T - T_f)\frac{\sinh mL + \frac{h}{mk}\cosh mL}{\cosh mL + \frac{h}{mk}\sinh mL}$$

= 9.6417 w

Effectiveness of the fin $\epsilon_{fin} = \frac{Q_{fin}}{hA_b(T_b - T_a)}$

= 7.29

9. RESULTS

Performance of straight plain spine and tapered spine (circular section) at different heat inputs is studied. The obtained results are tabulated and presented graphically, and discussed in detail

Table 1: Results obtained for cylindrical spine Natural convection:[prismatic bar]

Heat input		Grasshoff number	Prandtl Number	Nusselt number	$h(w/m^2k)$	Q_{spine} (watt)	Effectivenes
Voltage (Volts)	Current (Amps)						
90	0.5	8965.6580	0.6942	4.3924	10.7980	3.34	9.62
100	0.56	9535.9193	0.6931	4.4423	11.1057	4.02	9.6
110	0.6	10180.0758	0.69212	4.496	11.3974	4.96	9.59

Table 2: Results obtained for plain cylindrical spine forced convection [prismatic bar]

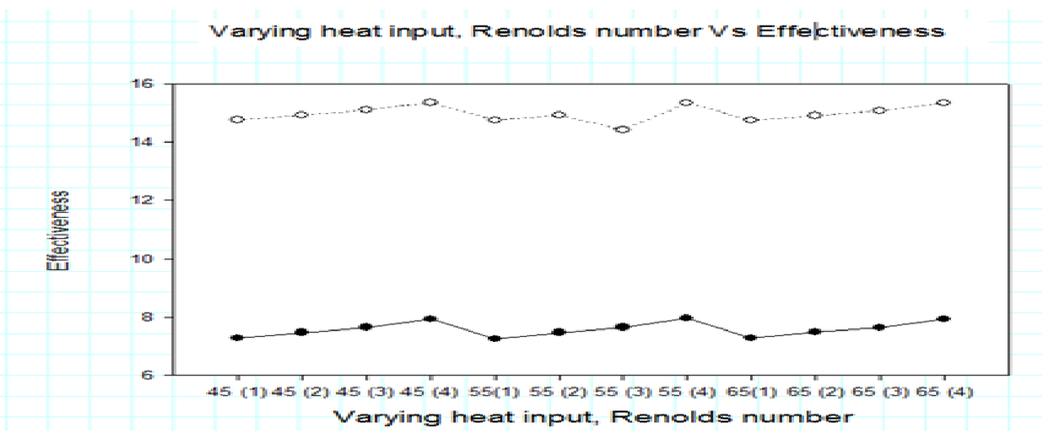
Heat input		Manometer reading H(mm)	Reynold's Number	Nusselt Number	$h(w/m^2k)$	Q_{Spine} (watts)	Effectiv eness
Voltage (Volts)	Current (Amps)						
90	0.5	101	4932.26	32.9039	76.5425	9.6417	7.29
90	0.5	75	4258.04	29.9554	69.9209	9.4078	7.47
90	0.5	50	3473.79	27.0708	63.1652	9.0001	7.65
90	0.5	25	2455.90	23.0349	53.3643	6.3301	7.94
100	0.56	101	4931.14	32.9008	78.2377	9.7555	7.25
100	0.56	75	4248.64	29.9145	69.8005	9.2772	7.47
100	0.56	50	3470.05	27.0576	63.0884	8.465	7.65
100	0.56	25	2454.40	23.0272	52.4638	6.4499	7.97
110	0.6	101	4910.22	32.8052	77.1304	13.7098	7.28
110	0.6	75	4220.83	29.7805	68.7434	13.2787	7.50
110	0.6	50	3449.49	26.9721	63.8339	12.409	7.63
110	0.6	25	2427.39	22.9034	53.823	9.0058	7.93

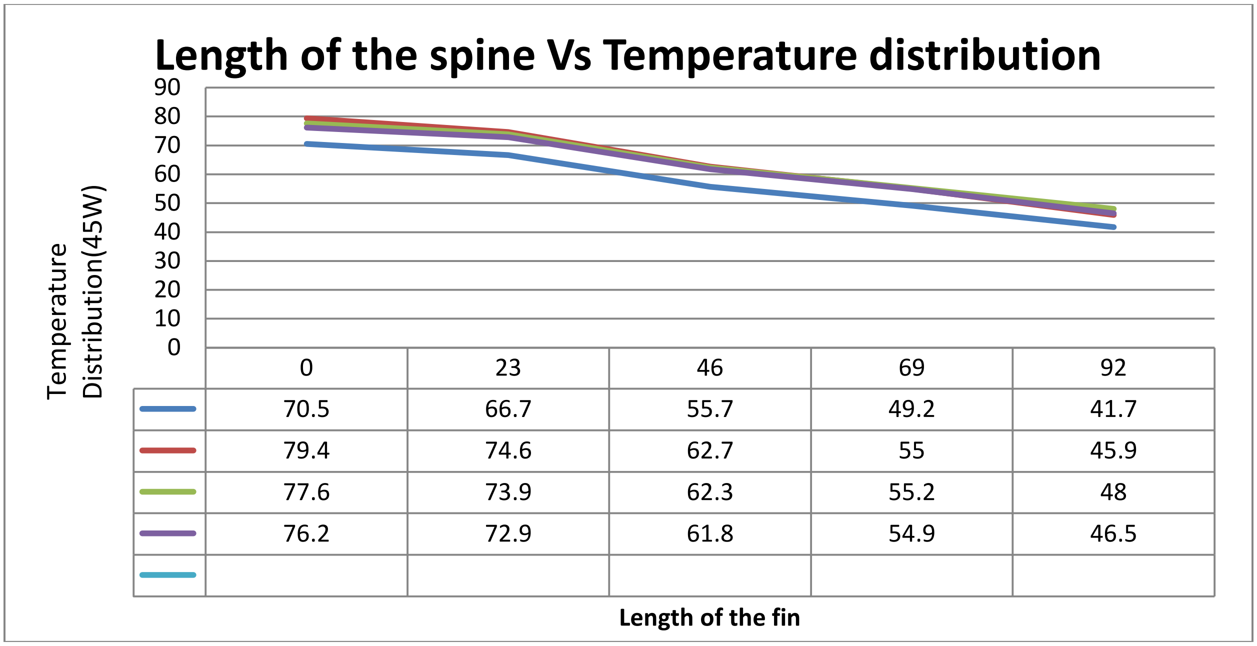
Table 3: Results obtained for tapered spine [end dia =4mm]Natural convection:

Heat input		Grasshoff number	Prandtl Number	Nusselt number	$h(w/m^2k)$	Q_{spine} (watt)	Effectiv eness
Voltage (Volts)	Current (Amps)						
90	0.5	8677.679	0.6943	4.3656	10.7504	1.8156	16.6471
100	0.56	9300.5759	0.6934	4.4218	11.0030	2.1555	16.6399
110	0.6	9419.9579	0.6923	4.4311	11.1960	2.4026	16.6296

Table 4: Results obtained for plain tapered spine [end dia = 4mm]forced convection

Heat input		Manometer reading H(mm)	Reynold's Number	Nusselt Number	h(w/m^{2}k)	Q_{Spine} (watts)	Effectiv Eness
Voltage (Volts)	Current (Amps)						
90	0.5	101	4990.8692	33.0521	76.1025	5.0461	14.7677
90	0.5	75	4291.4033	30.1073	69.4226	4.8065	14.9313
90	0.5	50	3500.1571	27.1754	62.7456	4.5661	15.1047
90	0.5	25	2486.2407	23.1737	53.0099	3.1499	15.3625
100	0.56	101	4973.23	32.9783	76.2899	6.024	14.7608
100	0.56	75	4282.9562	30.0678	69.6071	5.5464	14.9268
100	0.56	50	3497.0559	27.163	62.8082	4.7037	14.4266
100	0.56	25	2478.845	23.1382	53.1987	3.585	15.3500
110	0.6	101	4925.1272	32.773	76.7708	7.9401	14.7499
110	0.6	75	4244.5923	29.894	70.1513	7.5128	14.9122
110	0.6	50	3464.6389	27.0349	63.442	6.8304	15.0866
110	0.6	25	2449.4264	23.0022	53.8443	5.7176	15.3416





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