OPEN ACCESS
ISSN: 2249-6645

International
Journal
Of Modern Engineering Research (IJMER)

A New Methodology To Estimate Unknown Parameter From Fin Heat Transfer

S.Sandeep[1],Prof N.Jeevan Kumar[2],A.Harish Kumar[3]

[1](M .Tech Thermal Engineering ,CMR college of Engineering &Technology, Hyderabad. Email:sabbani.sandeep01@gmail.com)

[2](Professor & HOD, Department of Mechanical Engineering, CMR Technical Campus, Kadlakoya (V), Medchal Road, Hyderabad 501401, mechhod.cmrec@gmail.com)

[3](Associate Professor, Department of Mechanical Engineering, CMR Technical Campus, Kadlakoya (V), Medchal Road, Hyderabad 501401, harishkumarakuthota@gmail.com)

Abstract:- *Natural convection heat transfer and fluid flow is an important phenomenon in daily life and engineering applications such as building heating and cooling applications, renewable energy sources, cooling of electronic equipment, heat exchangers and computer cooling technologies. Natural convection fin heat transfer is essential to design a heat transfer equipment to enhance heat transfer for various applications.Placing the fin increases the surface area thereby increasing the heat transfer. The present study investigates the estimation of convective heat transfer from the temperature distribution obtained by performing steady state experiments in a fin.*

The fin contains an aluminum base plate of size 120x150x8mm and a steel plate which is placed at the center of the aluminium base. A heater is provided beneath the surface of the base. Base plate contains six calibrated thermocouples and fin contains twelve calibrated thermocouples. The base plate is aluminium and it acts a lumped system. The base plate is maintained at a constant temperature during steady state experiments. The present study now becomes inverse problem wherein the temperature is known and convective heat transfer is unknown. The estimation is done by minimizing the error between the experimental temperature and simulated temperature. Simulated temperature is obtained using forward model. The present work is solved as one dimensional heat transfer from fin. Finite difference method is used to obtain temperature of the fin and is called as forward model. Grid independence study is carried out to find the optimum space for simulation purpose. Genetic algorithm is used as inverse model to minimize the error between experiments and simulation to estimate the unknown convective heat transfer coefficient.

Keywords:- *Fin, Convective Heat Transfer, Genetic Algorithm, Lumped System, Forward Model, Grid*

I. INTRODUCTION

Conventional methods of temperature measurement can be used for various thermal measurements to study heat transfer characteristics of a thermal system. In certain conditions there are limitationsassociated with the thermocouple and hence to study the heat transfer rate one should know the temperature information. For example in re-entry of space vehicle due to irreversible conversion of kinetic energy into heat energy the temperature of the surface is high and thermocouple cannot be used to measure temperature. The only way to find out heat flux on the surface of the vehicle is to use inverse heat transfer by getting the temperature information inside the space vehicle. Another example is of moving boundary layer between solid and liquid in case of cooling of molten metal where temperature cannot be measured with thermocouple.

This research aims atdeveloping new concepts to find out various thermo physical parameters like convective heat transfer coefficient, emissivity, thermal conductivity, thermal diffusivity etc. Such an attempt is made in this paper wherein unknown heat transfer coefficient is estimated from the known temperature information obtained from experiments.

$\{R^2=\sum_{k=0}^{n}\binom{n}{k}\left(T_{simulated}-T_{experimental}\right)^2\}$

II. INVERSE MODEL

Inverse problems are faced almost in every branch of science including thermal engineering. Following are some of the major fields where inverse method is extensively used to solve problems which are seemingly unsolvable if tried with analytical method.

- Estimation of temperatures at moving interfaces like liquid boundary layer during cooling of molten metals.
- Thermal stresses developed in outer surface of space vehicle during reentry where temperature measurement using thermocouples is not possible.

One of the major drawbacks associated with inverse problems is their sensitivity towards random errors. Inverse problem becomes difficult if number of parameters to be estimated is large in number. Also it is found that complexity of mathematical model determines difficulties to be faced in estimation. So our aim is not only to estimate given parameters but also to choose model with least computational cost. It is very important to note that any numerical model should be independent of step size. Grid independence study is performed in way that the optimum grid which can compromise computational time and grid size. Following are generalized steps involved in a Forward Model:

1. Develop mathematical model using ordinary differential equation (ODE)/ partial differential equation (PDE).
2. Discretize given equation using finite difference method.
3. Assume the unknown thermophysical properties/ boundary conditions and obtain temperature.

The Inverse Model is as follows:

1. Incorporate suitable inverse model. In this case, it is minimization of error between simulation and experiments. Minimization can be done using following methods

a. Conjugate Gradient Method
b. Levenberg Marquardt Algorithm
c. Genetic algorithms
d. Simulated Annealing

A lot of gradient and stochastic based methods are available but very important algorithms are reported here. However gradient based method has some limitations which are listed below:

- It is trapped in local minima instead of global minima.
- It cannot incorporate any information about the variance of measurement.
- It lacks to accept prior information about the unknown estimates.

The general approach of an inverse problem is represented in the schematic given in Fig. 1. The forward model contains the governing equation in terms of ODE or PDE. For an assumed value of input, the forward model is solved to get Z(x) and in heat transfer it is temperature/temperature distribution. When experiments are performed temperature is the output and error minimization is done using L2 Norm. Furthermore, the error is minimized for various values of unknown input parameters using suitable inverse model.

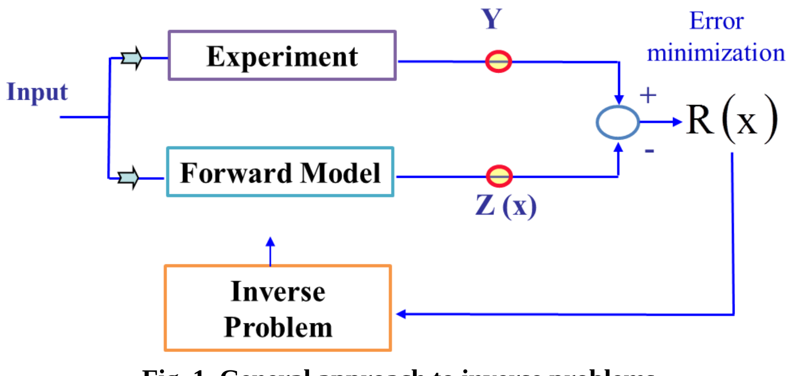

Fig. 1. General approach to inverse problems

III. EXPERIMENTAL PROCEDURE

As shown in Fig.1, the mild steel fin with dimensions *150×250×4mm* mounted on aluminium base plate with dimensions *120x150x8mm* acts as a constant base to the fin. 12 holes along the length of fin and 6 holes across the width of baseplate have been drilled to place thermocouples (k type). Beneath the plate heater is provided to heat the base plate. The bottom of the heater is insulated by glass wool to avoid heat flowing downside.

Heat flux is supplied to the base plate with the help of DC power supply. The base plate is heated and it maintains constant temperature once it reaches steady state. Conduction heat transfer takes place in the fin and the fin is also convecting. The fin is highly polished to avoid radiation. The fin is allowed to reach steady state and the experiment is performed for4 to 5 hrs. The steady state is reached by means of convection and the temperature distribution is recorded using data logger. This becomes an inverse problem wherein temperature is known and heat transfer coefficient is unknown. Fig. 2 shows the experimental setup of the fin. Fig. 3 shows the temperature distribution for various base temperatures. Experiments have been performed for three different base temperatures.

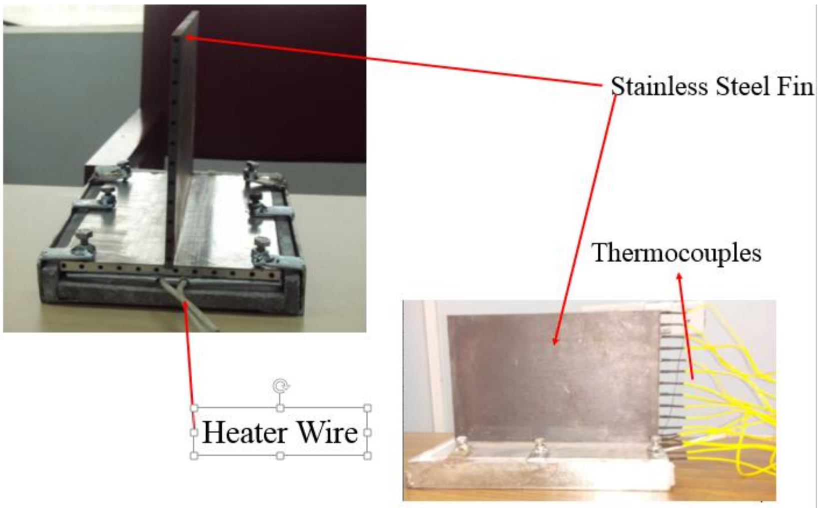

Fig. 2. Experimental Setup

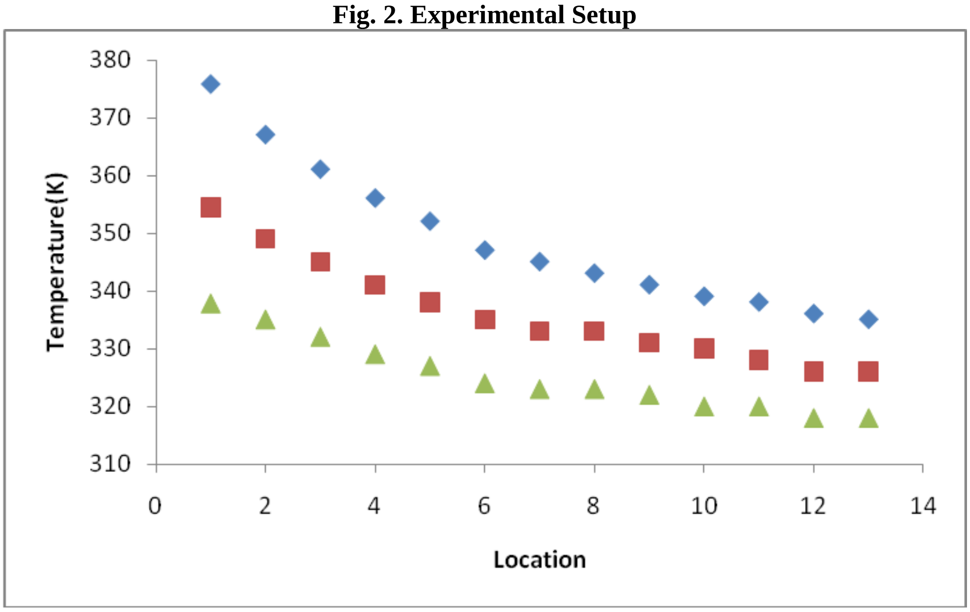

Fig. 3. Experimental Observations

IV. FORWARD MODEL AND VALIDATION

Presently, the aim is to calculate heat transfer coefficient (h) for a given temperature distribution of fin. The governing equation of the fin is given as

$$kA\left(\frac{d^2T}{dx^2}\right)\Delta x = hPdx(T - T_\infty) \quad .....(1)$$

Where,

T = Temperature in K

T_∞ = Ambient temperature

k = Thermal conductivity of fin material

A = Area of cross section of fin = $t \times b$

t = Thickness of fin (4mm)

b = Width of fin (250mm)

P = Perimeter of fin = $2(t + b)$

Δx = *Elemental length*

Above equation can be written in the form of non-dimensional parameters and it is given as

$$\frac{d^2\theta}{d\xi^2} = m^2 l^2 \theta \qquad \text{.....(2)}$$

Where, $\theta = non-dimensional\ temperature = \frac{T-T_\infty}{T_\circ - T_\infty}$,

$\xi = non\ dimensional\ distance = x/L$

$$m = \sqrt{hP/_{kA}}$$

Boundary conditions of the fin are

At x = 0, θ = 1

x = L, $\frac{d\theta}{dx} = 0$

V.GRID INDEPENDENCE STUDY

Grid independence study is performed to eliminate/reduce the influence of the number of grids/grid size for computation purpose. For various grids the tip temperature has been found out to vary between 0.4635 and 0.466. In order to compromise on accuracy and computational cost further calculations have been made for the grid size of 13.

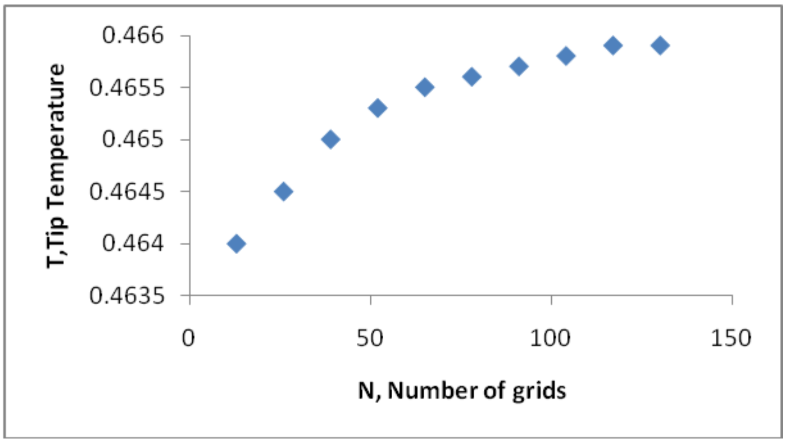

Fig. 4. Variation of tip temperature with respect to number of grids

Equation 2 is solved to get temperature distribution along the fin. Fig. 5 represents the temperature distribution for an assumed value of h = 7.75W/m^{2}K

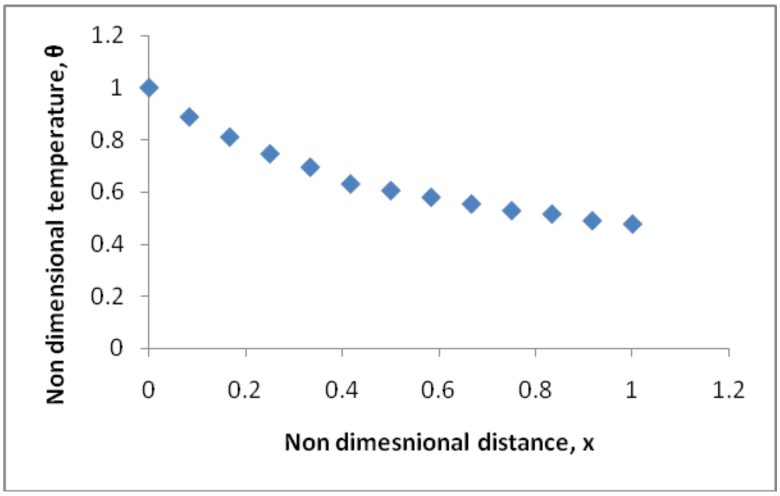

Fig. 5. Temperature distribution for the non-dimensional location(h=7.75 W/m^{2}K)

To get the temperature distribution of the fin the following parameters have been considered:

No. of nodes, M=13; L= 0.150 m; k = 45 W/m-k; t=0.004 m; b=0.250 m; h = 7.75 W/m^{2}K;

VI. RESULTS AND DISCUSSION

A simple L2Norm calculation has been done for different values of heat transfer coefficient and such an exercise is reported in Fig 6. The experimental temperature is considered for a base temperature of 354.5 K. From Fig. 6 it is observed that the heat transfer coefficient of 6.75 W/m^{2}K shows least residual. Similarly, one can follow the same procedure to estimate heat transfer coefficient for various base temperatures.

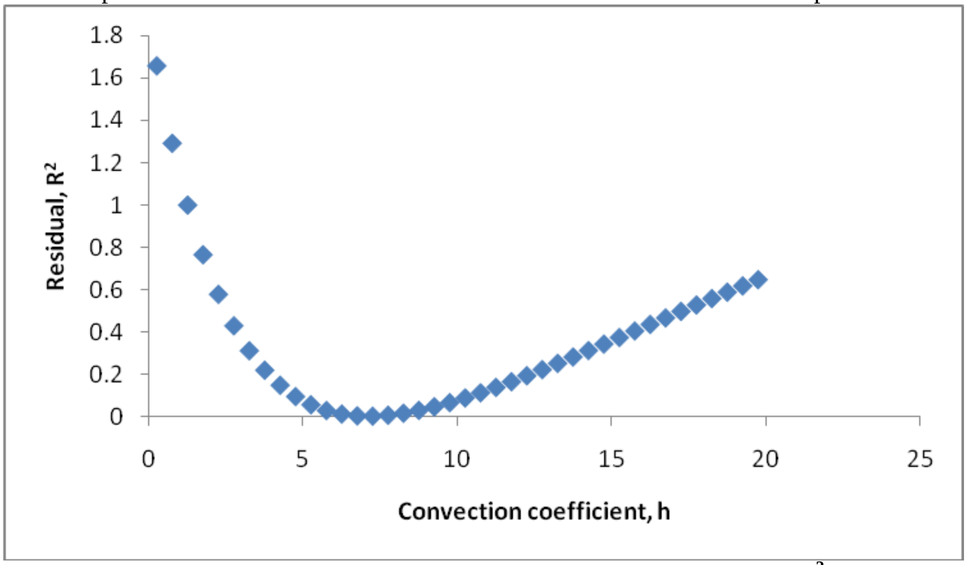

Fig. 6.Residual v/s convective heat transfer coefficient h W/m^{2}K

TheResidual Function used here is$R^2 = \sum_{k=0}^{n} \binom{n}{k} \left(T_{simulated} - T_{experimental}\right)^2$

GENETIC ALGORITHM

Heat transfer coefficient is also estimated using stochastic based algorithm and one such algorithm is Genetic algorithm (or GA). It is a search technique used in computing to find true or approximate solutions to optimization and search problems. Genetic algorithms are implemented as a computer simulation in which a population of abstract representations of candidate solutionsto an optimization problem evolves toward better solutions. In general solutions are represented in binary form as strings of 0s and 1s, but other encodings can be used.

Genetic algorithm tool available in Matlab is also used as an inverse model for the present work. Convective heat transfer coefficient has been estimated for different values of base temperature and

Table 1: Retrieved value of convective heat transfer coefficient using GA

S. No.	T_{base}(K)	$h_{retrieved}$(W/m^{2}K)
1	375.75	7.111
2	354.50	6.669
3	337.75	6.739

It is interesting to note that the value of h is dependent on base temperature which is in agreement with the fact that convection heat transfer increases with respect to the fin surface temperature

VII.CONCLUSIONS

Steady state in-house fin heat transfer experiments have been carried out in still air (natural convection) and temperatures have been recorded. Forward model has been developed using Finite Difference method. Grid independence study is carried out to fix number of grids for the computation purpose. Convective heat transfer coefficient has been estimated for different base temperatures using Least Squares Method and Genetic Algorithm. The results were found satisfactory and agree very well with literature.

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