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TO INVESTIGATE THE PERFORMANCE OF RECTANGULAR FIN ARRAY WITHIN A TRIANGULAR ENCLOSURE

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Abstract - *Heat transfer within the enclosures has been turned out to be a one of the prime functional areas of investigation due to its prominent engineering applications ranging from nuclear reactors to solar panels, domestic heating and building insulation cavities. The present analysis deals with an experimental investigation for the performance of a system consisting of a heated rectangular finned base plate within a horizontally oriented and air filled triangular enclosure in natural convection dominated region at a wide range of Rayleigh number (2997770 to 5548480) for different fin array distance (10 mm to 24 mm) and fin spacing values (26 mm to 65 mm). The system is arranged in such a way that the vertical side of the enclosure is insulated, base side is heated uniformly while its inclined side is cooled isothermally. The attachment of fins always results to the heat transfer enhancement as compared to the bare base plate during the experiments. Important parameters affecting system performance (convective heat transfer coefficient and fin effectiveness) are noticed as Rayleigh number (Ra), fin spacing (S) and fin array distance (D). The convective heat transfer coefficient (h) is reported to increase with increasing Rayleigh number while diminished system performance is noticed with increased values of fin array distance. Fin spacing is found as the most critical parameter affecting system performance. The results gave an optimum fin spacing at which the best system performance (highest convection heat transfer coefficient and finned surface effectiveness) is achieved.*

***Key Words*: Rectangular Fin, Heat Transfer, Convection , Prandtl number (Pr), Rayleigh number (Ra).**

1. INTRODUCTION

Heat is defined as energy under transmission from one medium or object to another by the virtue of temperature gradient between them. There are three basic modes of heat transfer- conduction, convection and radiation. Convection relates to the transfer of heat by means of motion of the molecules in the fluid. Convection may cause a related phenomenon called advection, in which mass or heat is transported by the currents or motion in the fluid.

Natural convection is a type of heat transfer involving the heat transfer due to density difference and a body force without application of any external source. Fluid flow generated by any external source creates forced convection. Forced convection is generally more efficient than free convection because of faster velocity of flow currents. Various dimensionless numbers involved in the study of natural convection are Grash of number, Prandtl number, Rayleigh number and Nusselt number. As per definitions, the Grash of number is directly proportional to temperature difference between the hot and cold parallel plates and Rayleigh number is defined as the product of Grash of and Prandtl numbers. number shows the relationship between buoyancy and viscosity within the fluid while Prandtl number is the relation between momentum diffusivity and thermal diffusivity. We can say that the temperature difference imposed between the parallel hot and cold walls must exceed a certain finite value for significant convective heat transfer between the plates. The Rayleigh number at this instant is known as critical Rayleigh number. So Convection cells are the cellular flow consisting of counter rotating two dimensional cells. They occur in plane horizontal layer of fluid heated from below due to density difference and Buoyancy (gravity) is responsible for these convection cells. Bénard cells come in to the picture above critical Rayleigh number **[1]**.

There are numerous studies in the literature regarding natural convection in enclosures. Most of the previous studies on natural convection in enclosures are related to either side heating or bottom heating. These studies are mainly focused on the investigations of heat transfer and flow profiles for fluids of different Prandtl number (Pr) at a wide range of Rayleigh number (Ra) and are conducted at various temperatures and geometries of the enclosure. There are several types of two-dimensional enclosures, which receive considerable attention. The various types of the enclosures are square, rectangular, triangle, sphere, cylinder inclined and partition. The most common case studies are the square and the rectangular enclosures, which are heated and cooled uniformly either at the two vertical or horizontal walls while the remaining two walls are thermally insulated. Regardless of the nature of the convection heat transfer process, the convective heat flux is proportional to the temperature differences. The proportionality constant, which is termed the convective heat transfer coefficient, is essential in any study of convection **[2]**. Dimensional analysis shows that in free convection the Nusselt number, Nu, which is a dimensionless heat transfer coefficient and signifies the ratio between convective and conductive heat transfer, depends on two dimensionless groups: the number and Prandtl number. The number approximates the ratio of the buoyancy force to the viscous force, and its value primarily determines the transition from laminar to turbulence occurrence, while the Prandtl number, which is a fluid property, represents the ratio between the fluid viscosity (momentum diffusivity) and thermal diffusivity. Some studies, including the present one, use the Rayleigh number instead of the number, which is simply the product of the and Prandtl numbers.

1.1 LITERATURE REVIEW

Natural convection is the motion that arises from density difference within a fluid. These differences may result from gradients in temperature, concentration or composition. Natural convection in an enclosure is the result of a complex interaction between the finite fluid system and all the walls that confine it. The complexity of this internal interaction is responsible for the diversity of flows that can exist inside the enclosure. At the same time the complexity of the phenomenon is linked to our relative inability to predict both the flow and heat transferred across the enclosure. Also, the investigation on the natural convection within the enclosures can be broadly categorized under two important headings:

i. Enclosures heated from bottom

ii. Enclosures heated from side

The problem of heat transfer due to natural convection in triangular or attic-shaped enclosures is quite widespread and has application to buildings, solar collectors and greenhouses. However, unlike rectangular, square and cylindrical enclosures, it has received relatively little attention. It should be noted that the problem has not been completely ignored; in fact many of the studies undertaken in the area have relied upon the use of computational fluid dynamics to further the understanding of the flow and heat transfer in triangular enclosures, although there are relatively few experimental studies. A comparative analysis regarding optimum parametric design for heat transfer through triangular fin array within a rectangular enclosure was carried out by Das and Dwivedi **[9]** using classical and Taguchi methodologies. The Taguchi‟s methodology was determined about 67% more effective as compare to classical one for horizontal enclosure orientation. In their computational study Akinsete and Coleman **[2]** found that for a right triangular enclosure with a cooled inclined wall, heated base and adiabatic vertical side that there was an increase in heat transfer near the apex of the heated and cooled side. In this study they observed a single convection cell as did Poulikakos and Bejan **[10]**. However, in a separate computational study Poulikakos and Bejan **[11]** found that at higher Rayleigh numbers Benard-type instability resulted in multiple cells forming in their enclosure. They found that the formation of these cells was related to the aspect ratio of the right triangular enclosure, as did Asan and Namli **[12, 13]**. Similar results were also reported in literature of Aramayo et al. **[14, 15]**. The flow behavior and presence of convection cells has also been discussed in recent times for isosceles triangular enclosures, similar to those formed by pitched roofs. Holtzman et al. **[16]** showed computationally that the flow in such enclosures was asymmetric and undertook flow visualization to validate this conclusion. A similar phenomenon was computationally observed by Ridouane et al. **[17]**. Given the large number of computational studies that have examined natural convection in triangular enclosures, there is a distinct lack of generalized correlations to predict the heat transfer in these spaces **[18–20]**. Al-Shariah and Ecevit **[21]** were perhaps the first to present a truly generalized equation for heat transfer in a triangular enclosure. In their study they examined a right triangular enclosure with one heated and one cooled side and found that the heat transfer could be expressed as a function of the Rayleigh number.

1.2 RESEARCH OBJECTIVES

In an effort to complete and extend some of the previously reported results of natural convection from sources in enclosures, two configurations have been considered in this investigation. The test rig configuration is a horizontal narrow triangular enclosure heated from bottom, cooled from the inclined top wall. Rests of the walls are assumed to be adiabatic. The configurations have applications in cooling of electronic equipment. The purpose of this portion of investigation is to address the unanswered questions from the previous investigations.

2. EXPERIMENTAL SETUP

The main aim of this experimental analysis is to investigate the effects of several influencing geometrical parameters like fin array distance, fin spacing and Rayleigh number from the rectangular fin array within an air filled triangular enclosure. In order to facilitate this investigation, total three base plates were designed and built. A number of fins with rectangular geometry with various geometrical parameters were prepared. A series of tests having in total, 37 experimental runs were undertaken. The experimental study was conducted for wide parametric ranges; fin array distance 10 mm ≤ D ≤ 24 mm, fin spacing 26 mm ≤ S ≤ 65 mm and Rayleigh number 2997770 ≤ Ra ≤ 5548480.

To enable this investigation, total 10 samples of fin arrangements, were designed and machined at Mechanical Workshop, Allen house Institute of Technology, Kanpur. Nut and bolts were used to make physical contact between the base plate and the fin surface. Aluminum was used as the material for finned base plate of constant thickness (*T'Plate*= 3 mm) due to its high thermal conductivity, low emissivity, structural strength and durability. A bare base plate was prepared for validation of the fabricated experimental test rig with the existing analytical empirical correlations in the literature. Table 3.1 shows the all possible test array combinations for the present investigation.

A test-rig was designed for measurement of natural convection heat transfer from rectangular fin array within a triangular enclosure. The detailed schematic diagrams and pictorial view of the experimental test-rig has been shown in figures . There were three main sections of the experimental setup:

a) Heating section
b) Test section
c) Cooling section

Figure-1: Pictorial View of a Fin Array Sample

During the experiments, the heater was connected with a power supply through a variable transformer to control the power input. The variable transformer was used to control the power input and hence the input heat flux and corresponding Rayleigh number were controlled. A digital multimeter with accuracy of ±0.4% for voltage as well as the resistance was used to record the output data. The surface temperature distribution of the base plate of the fin array was measured using six K- type Teflon coated chromel-alumel thermocouples are equally spaced and distributed as shown in figure. In order to facilitate the thermocouples installation within the enclosure without disturbing the heat transfer

3. RESULTS AND DISCUSSION

The effects of different important geometrical parameters on the steady state natural convection heat transfer and fin effectiveness for both horizontal and vertical enclosure orientations are discussed. In this section deals with the validation test for an experimental technique used in the present study. The validation has been done by comparing experimental results for bare plate with standard empirical correlations available in literature. In the second section, the effects of several influencing parameters on the natural convection heat transfer from rectangular fin array within a triangular enclosure are examined. The fin effectiveness as the function of different controlling parameters is reported in succeeding section. A detailed discussion regarding the impact of fin array distance (*D*), fin spacing (*S*) and Rayleigh number (*Ra*) is made.

The enclosure with heated bare plate is used for establishment of confidence level in the experimental method. The experimental results are compared with the empirical correlations recommended by V. Akinsete [2] as described in the form of equations

$$Nu \,\square\, 1.102(Gr)^{0.0535}(H / a)^{\square 1.19}$$

3.1. Heat Transfer Rate

This section includes the effects of several influencing parameters like fin array distance (*D*), fin spacing (*S*) and Rayleigh number (*Ra*) on the natural convection heat transfer from rectangular fin array within an air filled triangular enclosure.

Table -1: Tested Fin Array Combinations

Fin array combination	Fin array distance (*D*) (mm)	Fin spacing (*S*) (mm)	Number of fins (*n*)
1	10	26	10
2	10	37	7
3	10	65	4
4	17	26	10
5	17	37	7
6	17	65	4
7	24	26	10
8	24	37	7
9	24	65	4
10	-	-	Bare plate

The Nusselt number variation with fin height has been illustrated in figures for horizontally oriented triangular enclosures at different fin spacing and Rayleigh number values. As it can be seen from the graphs attained that the Nusselt number decreases continuously with increase in fin array distance for all the fin spacing and Rayleigh number values. This result can be attributed to the reduced effective surface area available for heat transfer due to reduced fin height as a result of increased fin array distance.

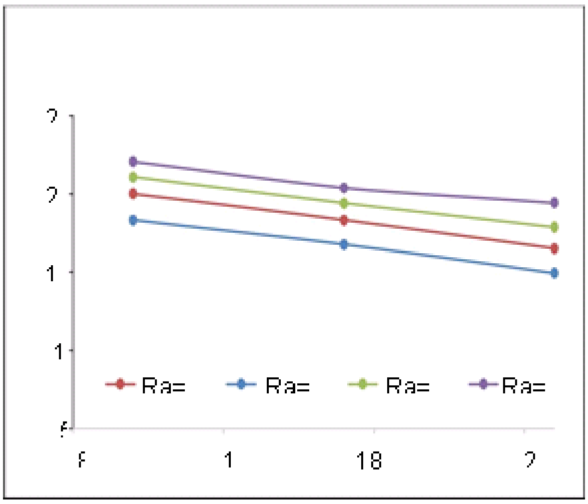

Figure 3.1: Variation of Nusselt Number with Fin Height- *S*= 26 mm

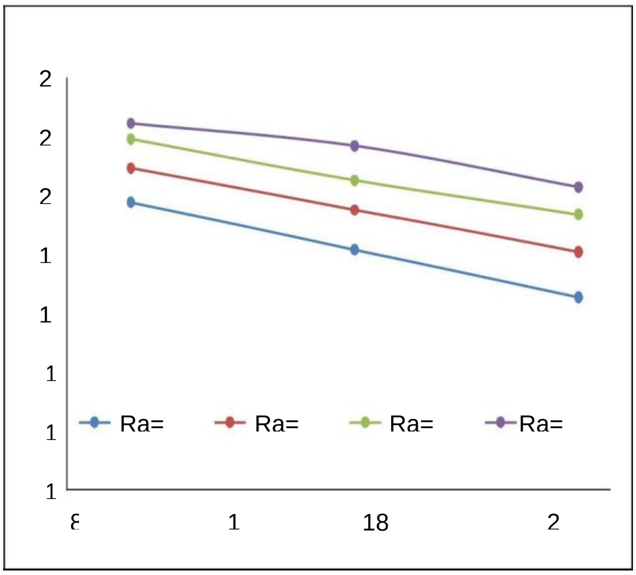

Figure 3.2: Variation of Nusselt Number with Fin Height- *S*= 37 mm

4. CONCLUSIONS

An experimental investigation regarding laminar natural convection heat transfer from heated rectangular fin arrays within a triangular enclosure was performed in order to analyse the effects of several influencing parameters on system performance. Air was used as a working fluid. Three new custom-designed test base plates were designed and fabricated to carry out the experimental analysis with various testing samples at different scales. An uncertainty analysis was carried out to check the feasibility of experimental work and the uncertainty of 9.35% was reported in the measurement of convection heat transfer. On the basis of investigation, the major concluding remarks can be highlighted as following:

- The Nusselt number is reported as a strong function of various geometrical and design parameters as fin array distance, fin spacing and Rayleigh number for any tested fin array combination for enclosure orientation considered for the study. The continuous increase in the Nusselt number with Rayleigh number is observed while with increase in fin spacing, the Nusselt number increases firstly up to a maximum value then tends to decrease. Continuous increase in fin array distance causes the reduced system performance.
- The effectiveness of the finned surface is a very strong function of fin spacing, fin array distance and Rayleigh number. The fin effectiveness decreases with increase in fin array distance and Rayleigh number respectively, while with increase in fin spacing, the fin effectiveness increases initially up to a certain value beyond which it tends to decrease. The finned surface effectiveness is always greater than 1 for each fin array configuration and enclosure orientation taken under consideration during the investigation.

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