NATURAL CONVECTION HEAT TRANSFER THROUGH SEMICIRCULAR STAGGERED PROMOTER MOUNTED ON VERTICAL PLATE

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Abstract A new enhancing technique is developed for free convection adjacent to a vertical heated plate. To enhance heat transfer, semicircular-shaped plates of which the edges faced upstream, are attached to a vertical plate in a staggered layout. These plates work not only as an extended surface but also as a heat transfer promoter. The overall heat transfer coefficients of the above enhanced surface are measured and compared with a non treated flat surface, a conventional vertical plate finned surface, and V-shaped plate. Results show that the heat transfer performance achieved for the present experimental surface and V-shaped of Misumi-Kitamura is almost similar. The measured heat transfer coefficient is about 6.5% higher than that of a conventional vertical finned surface with the same total surface area and fin height.

Key Words: *Natural convection, Diverter plate, Heat transfer enhancement*

INTRODUCTION

Natural convection heat transfer from vertical surfaces with large-scale surface roughness elements is encountered in several technological applications. The practical interest is the dissipation of heat from electronic devices, where component performance and reliability are strongly dependent on operating temperature. Natural convection represents an inherently reliable cooling process. In other applications where the heat-dissipating surface is normally smooth, it requires enhancing the surface to achieve the desired temperature level or rate of heat transfer. The traditional solution is to add vertical fins. Further, it should be noted that vertical fins are basically, inapplicable to the heat transfer enhancement of a tall, vertical plate. This is due to the fact that the boundary layer developed over the tall plate becomes very thick, while the fins should be much higher than the boundary layer thickness in order to obtain an appreciable improvement of the heat transfer. However, such high fins are no longer practical. In order to dispose of these restrictions inherent in finned surfaces and to realize a compact but high performance heat transfer plate, a technique that increases the heat transfer rate itself should be developed.

A number of previous works have engaged in heat transfer enhancement of natural convection. Among these works, some is to install roughness element on the heat transfer surface. Heya, et al.(1982) examined heat transfer enhancement on roughness elements mounted on horizontal cylinders and used both air and water as working fluids. They observed no appreciable heat transfer coefficients. The same results was observed by Fujii et al.(1973). Bhavnani and Bergles(1990) investigated the heat transfer around two-dimensional rectangular ribs of height 3.6 to 6.35 mm attached horizontally on a vertical plate. They reported that the overall heat transfer coefficients of the ribbed surface became 7 to 40% smaller than those for a smooth plate of equal projected area.

The above result suggests that roughness elements placed in a natural convection boundary layer work as a flow retarder rather than a heat transfer promoter. Misumi and Kitamura(1993) investigated heat transfer on V-shaped plates of which the edges faced upstream, were attached to a vertical plate in a staggered layout and used water as a working fluid. They compared their results with a nontreated flat surface and a conventional finned surface. They reported that the highest heat transfer performance achieved for V-shaped plate was 40% higher than that of a conventional finned surface with the same total surface area and fin height. The present study with semicircular promoter has been considered on the basis of the fact that the natural convection heat transfer increases with the increase of heat transfer area. Obviously, the heat transfer surface area is more in semi-circular promoter than a V-shaped promoter.

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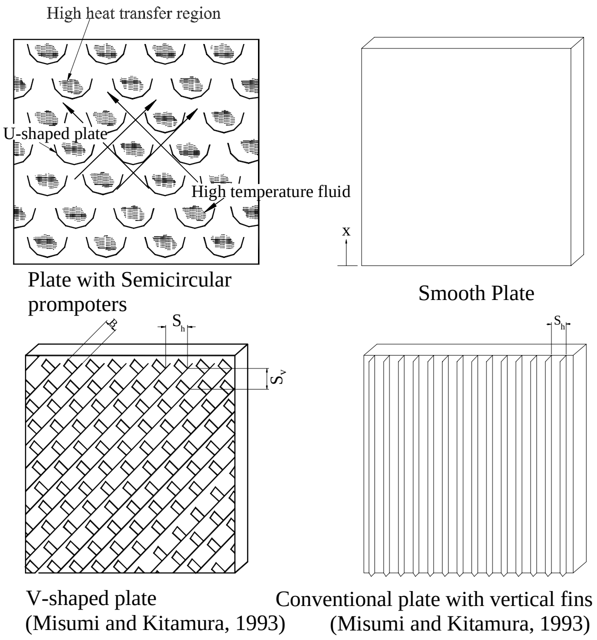
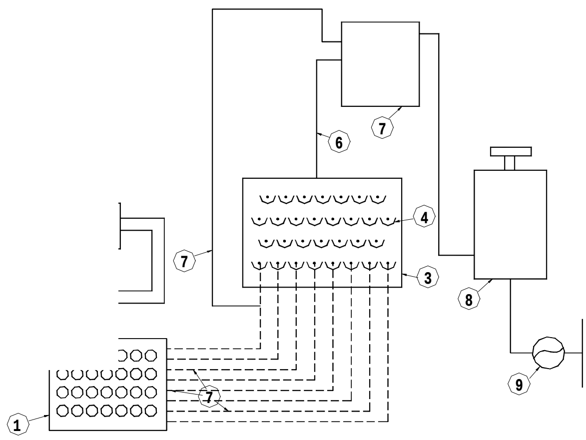


Fig. 1 Different Types of Test Plates

EXPERIMENT

The test plate is made of vertical plate with semicircular promoters as shown in Fig. 1. The smooth plate is made of a 2 mm thick, 280 mm wide and 240 mm high copper plate. To compare the heat transfer performance, the height and total surface area of promoters are the same as those of vee shaped promoters [Misumi, T, and Kitamura, K., 1993]. The semicircular promoters utilized in the experiment are made of a 1 mm thick copper plate and their dimensions are as follows: horizontal pitch S_h =40 mm, vertical pitch S_v =40 mm, Length B =20 mm, and height H =10 mm. The Nichrome wire heaters are glued to the back of the test plate. The double-adhesive tapes electrically insulated the copper plate from the heaters. The heaters are divided into four heating sections, each sections is heated by an independent a.c. power supply. By adjustment of the electrical input to each heating section, the surface temperatures of the plate are maintained almost uniform. An acrylic resin plate of 10 mm thick is installed on the back of the heaters to support the test plate. Styrofoam thermal insulation of 20 mm thick is also glued to the back of the acrylic plate to prevent conduction heat loss through the acrylic plate to the ambient plate. Forty six chromel-alumel thermocouples are spot welded on the back of the copper plate to measure the temperatures. They are distributed densely near the promoters to confirm the uniformity of the surface temperatures. The test plate is placed vertically in the large water tank of 600x 600 mm^2 cross-sectional area and 900 mm depth. The schematic diagram of the experimental set up is shown in Fig. 2. Water at room temperature is used as the test fluid. The experiments are conducted under temperature differences between the plate and the ambient water of ΔT = 2.5, 3.5, 5.0, 6.0 and 7.5 K. The maximum temperature deviation against the average temperature of the test plate is kept to less than 0.5 K even for the case of ΔT =7.5 K. This confirms the temperature uniformity of the test plate.



1. Thermocouple Selector Switch
2. Thermocouples
3. Base Plate (vertical)
4. Semicircular Promoter
5. Digital Temperautre Reader
6. Heater Wire
7. Switch Box with Voltmeter and Ameter
8. Power Regulator
9. A. C. Power Source

Fig. 2 Schematic Diagram of The Experimental Setup

RESULTS AND DISCUSSION

In the present study both the local and overall heat transfer coefficients are calculated. The local heat transfer coefficient is calculated from the energy input through the electric means in each four individual heating section. The overall heat transfer coefficient is also calculated from the total heat input to the heater following the equation below:

$$h_m = Q/A_b(T_w-T_f) \quad (1)$$

where, Q: total heat input to heaters, A_b: surface area of the base plate, and T_f: ambient temperature of the fluid. The overall heat transfer coefficient of vertical plate with semicircular staggered promoter is compared with that of V-shaped plate (Misumi and Kitamura, 1993) and vertical flat plate (Misumi and Kitamura, 1993) as shown in Fig. 3. The overall heat transfer coefficients for the semicircular diverted plate is higher than conventional vertical fin plate and the values are very close to V-shaped promoter. The main principle of the present study is to increase heat transfer by redirecting the high temperature fluid towards both sides of the promoter and will introduce the low temperature ambient fluid into the down stream region of the promoter. This aim has satisfied strongly in case of V-shaped promoter, but in semicircular promoter there is a possibility to form stagnant fluid region. In former one the there is less change to form stagnant fluid region, because the sharp edge of the V always redirect the fluid and helps to renew the boundary layer. The ratio of the heat transfer coefficient between semicircular promoter and vertical fin (Misumi and Kitamuara, 1993) to flat vertical plate is 2.11 and 1.92, respectively. On the other hand the ratio of total heat transfer surface area between semicircular promoter with its base smooth plate and vertical fin with its base smooth plate (Misumi and Kitamuara, 1993) to flat vertical plate is 2.0 times for both plates. It is obvious from these results that the ratio of the heat transfer enhancement exceed the ratio of the surface area particularly in semicircular promoter.

In order to assess the performance of the heat transfer plates, the local as well as the overall heat transfer characteristics should be investigated. In the experiments, the test plate has been divided into four heating sections, thus, the local heat transfer coefficient for each section are measured from the electrical to the heater as follows:

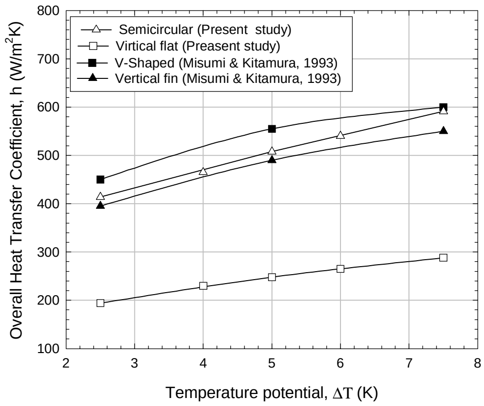
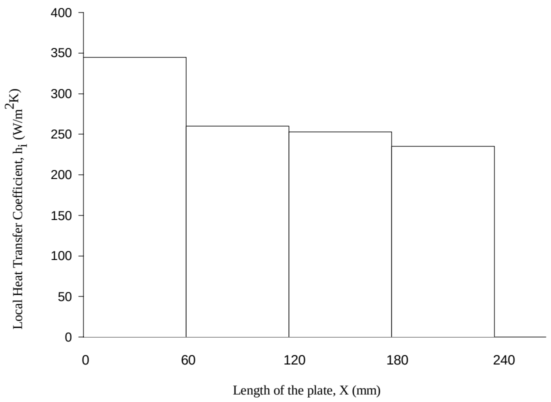
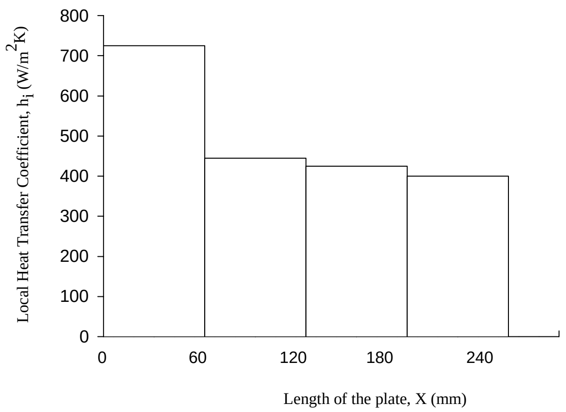


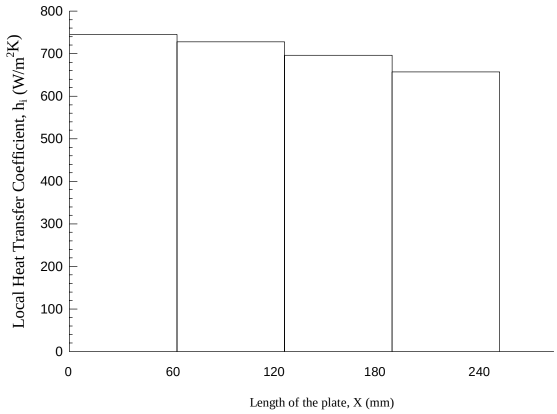
Figure 3: Comperison of Heat Transfer Coefficient



(a) Vertical Smooth Plate



(b) Vertical Fin plate (Misumi and Kitamura, 1993)



(c) Vertical Plate with Semicircular Promoter

Fig. 4 Local Heat Transfer Coefficient

$$h_i = Q_i/A_i(T_w - T_f) \qquad (2)$$

where h_i, Q_i, A_i stand for the local heat transfer coefficient, the transferred heat and the surface area of the i th heating section, respectively The typical results of the local heat transfer coefficients thus obtained are shown in Fig. 4 for the case of ΔT = 5K. Here, the height of the fins and the promoters is kept equal to 10 mm, and thus, the effective surface areas are identical for both plates. Fig. 4(a) demonstrates that the heat transfer coefficient of the smooth plate is the smallest among the three plates at every heating section. The local heat transfer coefficients at the bottom heating section from 0 to 60 mm are almost the same between the vertical fins and the semicircular promoters as shown in Figs. 4(b) and (c). However, the variation of these coefficients with the vertical distance differs somewhat between the two. The result for the experimental plate demonstrates that the local heat transfer coefficients far downstream of the plate are maintained almost as high as that at the bottom of the plate. On the other hand, the result for the conventional plate shows a marked decrease in the local heat transfer coefficients in the vertical direction. Such reduction is caused by the development of the boundary layers over the base plate and the vertical fins, and is inevitable in the conventional plate. Meanwhile, the promoters renew the boundary layers developed over the base plate and realize high heat transfer regions behind them. In light of these facts, the advantages of the plate are obvious.

CONCLUSION

Introducing promoters i. e., extended surface in the staggered form is an enhancing technique for natural convection from a vertical plate. The technique is based on the idea that the heat transfer of natural convection can be promoted by redirecting the high temperature fluids from the vicinity of the heated plate and by introducing low temperature ambient fluids into the near wall region. Semicircular plates attached on the vertical plate are proposed as heat transfer promoters that could enable such fluid motion.

The experimental result reveals that semicircular staggered promoters mounted on a vertical plate provides the following advantages when compared to conventional one.

1. Heat transfer enhancement will be high in semicircular promoter with same height and surface area of vertical fins.

2. Heat transfer coefficient can be increased even in the down stream section of the vertical plate with the promoter used in this experiment.

3. When compared the heat transfer coefficient of semicircular promoters with that of V-shaped promoter, it is noted that the former one provides less heat transfer. Due to higher surface area of semicircular promoter at the leading edge than to V-shaped sharped edge, there is higher possibility of stagnant fluid region formation and consequently less ability for redirecting the hot fluid. This reveals that rebuilding of boundary layer is very important in natural convection.

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