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On Heat Transfer Correlation of Vertical Parallel Plates in Free Convection

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Abstract

Natural convection heat transfer from vertical parallel plates was investigated experimentally. A set of nine different parallel plate sizes were tested. Square parallel plates with sides of 100 mm, 150 mm and 200 mm were used to examine the convection heat transfer rate for plate separation distance of 10 mm, 30 mm and 50 mm respectively. Power inputs were supplied to each arrangement in order to generate temperature difference between the plates The results of this study have shown that the convective heat dissipation rate from these vertical parallel plates depends on geometric parameters, temperature excess and as well as separation distances between the plates. A new correlation has been presented on the basis of the experimental conditions of this study. These correlation equations were compared with some established data. Results seem to correlate in some sense most previous work.

***Keyword**: Heat transfer, natural convection, vertical parallel plates*

1. Introduction

Natural convection heat transfer and fluid flow in vertical parallel plate channels are relevant to a wide range of heat exchange applications such as cooling of electronic equipment, fin-tube baseboard heaters, transformer, and power supplies with the constraints normally being the space and the temperature for a given heat duty.

The first study on laminar natural convection between vertical parallel plates date back to 1942 when Elenbaas (1942) did theoretical and experimental analysis on natural convection between isothermal parallel plates. Levy *et al*. (1971) carried out experiments to confirm the analytical study conducted previously in 1971 by transient cooling of 6.35 mm thick aluminium plates with dimensions of 305 mm × 381 mm for inter-plate spacing ranging from 6.25 to 25.4 mm. Aung *et al*. (1972) conducted experimental and numerical studies on developing laminar free convection between vertical flat plates with asymmetric heating Pittman *et al*. (1999) conducted an experimental study of heat transfer by laminar natural convection between an electrically heated vertical plate with dimension 90 mm × 79 mm to both Newtonian and non-Newtonian fluids with the conditions of constant surface heat flux.

Fujii *et al*. (1996) performed numerical and experimental studies on natural convection heat transfer to air from an array of vertical parallel plates with protruding and discrete heat sources. Sparrow and Bahrami did experimental investigations on natural convection from vertical parallel plates for three types of hydrodynamic boundary conditions along the edges namely, fully open to ambient, blockage along one of the edge gaps and blockage along both the edges (Fujii et.al, 1996). Wirtz and Stutzman (1982) conducted experimental studies on free convection of air between vertical parallel plates for the case of uniform and symmetric heat flux.

2. Experimental Set Up And Procedures

Three pairs of different sized plates had been designed for the experiment. The plates' materials were selected to be pure copper due its high thermal conductivity (0.401 W/mK at 27ºC) besides having good structural strength and durability. First pair of plates consists of 200 × 200 mm square copper plates. The second set of plates were copper square plates with sides of 150 mm. Lastly, the third set were two vertical square copper plates with sides equal to 100 mm.

The designed plate rig is illustrated in Figure 1 where each plate was attached with a heater rated for 300W, AC. In order to minimize the backward heat flow from the heater, chipboard fiber glass wool and as well as polystyrene were used as insulation. An outer cover was constructed from wood to insulate the system. Wood was chosen as the outer cover material due to its high insulation quality (thermal conductivity, k ~ 0.14 W/mK) and ease to manufacture to the required shape.

In order to study free convection between two vertical plates, a free convection chamber was first designed and constructed. The overall dimensions of the chamber or framework are 1.5 m × 1.5 m × 2.5 m and the material selected was wood again due to the easiness of construction and as well as to minimize conduction of heat from copper plates to the frame. The frame was then covered by mosquito net and care must be exercised to make sure that the free convection chamber did not allow air to cross its boundary in turn to isolate the experiment from external disturbances. Figure 2 shows the zoomed view of the experimental setup.

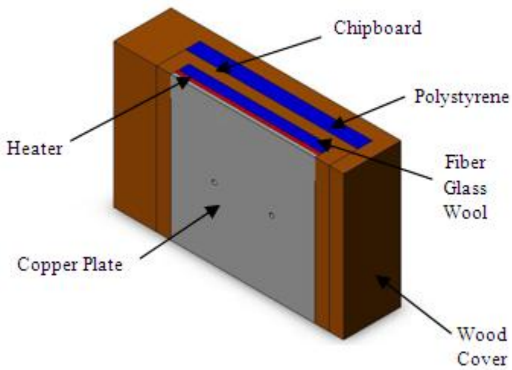

Figure. 1 Designed plate rig

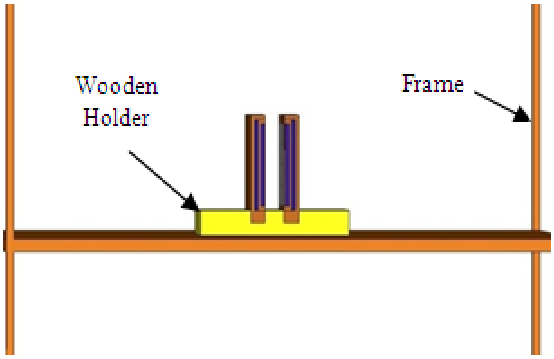

Figure. 2 Zoomed view of overall experimental rig

3. Uncertainty Analysis

The uncertainty analysis for the natural convective heat transfer coefficient can be computed by using root-sum-squares method (Holman, 2001). In the present study, the systematic errors were eliminated by calibration of thermocouples and as well as taking account the zero error of the multi-meters. Hence, the uncertainty analysis in this study was only dealt with the random errors caused by instruments' measurement accuracies. As a result, the measurements of the uncertainties of the heat transfer between two vertical parallel plates were dominated by the random errors of temperature measurements, input power measurement, and plates' geometries.

The maximum uncertainty interval is mainly contributed by the lowest instrumentation accuracy of the experiment, which is the temperature excess for the present work (Holman, 2001). The largest uncertainty of the convection heat transfer coefficient is associated with plate dimension of 100 mm × 100 mm × 2.5 mm with plate spacing of 10 mm at 6.92 %. The present work uncertainty is relatively good and comparative with Wirtz and Stutzman (1982), and Chen *et al.* (2006) with 5 % and 5 % respectively.

4. Results And Discussion

Figures 3 t0 5 show the comparison between the present work and correlation equations proposed by Elenbaas (1942) and Wirtz and Stutzman (1982) respectively.

Figure 3 illustrates the correlation equation suggested by Elenbaas (1971) for symmetrically heated parallel plates with isothermal surface conditions compared with data of present work which consist of 100 mm, 150 mm, and 200 mm square plates with plate spacing of 10 mm respectively. The suggested correlation does not correlate the generalized data of present work. There are two factors may be identified as being responsible for these large deviations. One of these is inaccurate assumption in the present work's data reduction procedure and the other relates to the validity of $\frac{S}{L}Ra_s$ as a sufficient correlation parameter at small interplate spacing.

Another factor, which must remain conjectural for the present is that the large deviations are somehow related to the inadequacy of $\frac{S}{L}Ra_s$ as a correlating parameter when S/L is small. As the spacing decreases, the frictional resistance encountered by the fluid moving vertically through the channel proper necessarily increases. As a consequence, there will be a decrease in the flow entering the bottom of the channel and an increase in the flow passing through the open gaps at the lateral edges. When these edge flows are significant, the system cannot be regarded as a two-dimensional parallel plate channel, and it is the parallel plate channel analysis that yields $\frac{S}{L}Ra_s$ as the correlating parameter. Rather, a three-dimensional model must be used and such a model would yield an additional geometrical parameter (Holman, 2001). In other words, the large deviations in Figure 3 are caused by the invalid correlating parameter, $\frac{S}{L}Ra_s$.

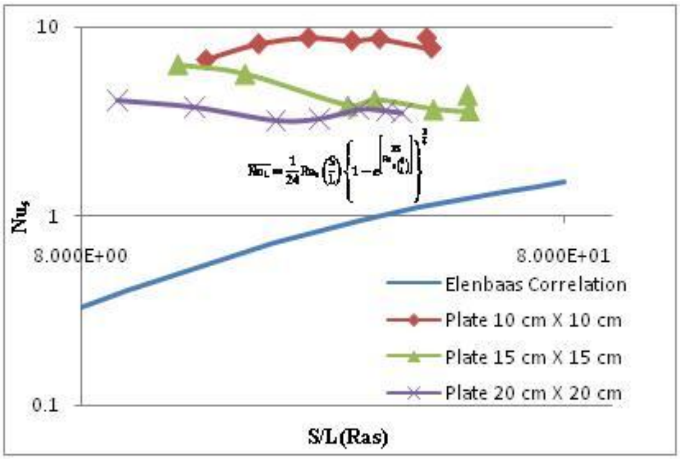

Figure. 3 Comparison of present work for plate spacing of 10 mm with the correlation equation proposed by Elenbaas [2]

Figure 4 demonstrates the correlation equation suggested by Elenbaas (1942) for symmetrically heated parallel plates with isothermal surface conditions compared with data of present work which include the square plates with sides of 100 mm, 150 mm and 200 mm and all with interspacing of 30 mm. The deviations are rather small and these results show that the test apparatus is credible and can be used to investigate the natural convection heat transfer from vertical parallel plates with plate spacing of 30 mm.

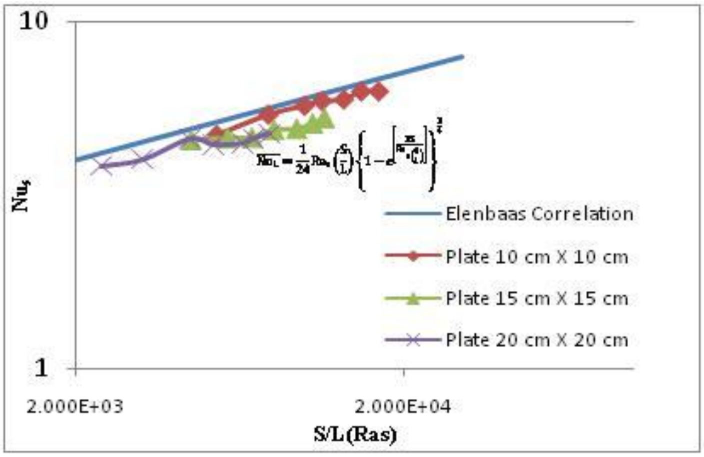

Figure. 4 Comparison of present work for plate spacing of 30 mm with the correlation equation proposed by Elenbaas (1942)

Figure 5 shows the correlation equation suggested by Elenbaas (1942) for symmetrically heated parallel plates with isothermal surface conditions compared with data of present work which contain the square plates with sides of 100 mm, 150 mm and 200 mm and all with plate spacing of 50 mm. From the figure, it can be seen that although the present results do not correlate with the Elenbaas's correlation curve but the results are generally scattered around the reference curve. These agreements confirm the validity of the experimental set-up, the experimental procedure, experimental calibration and the proposed assumption for investigation of natural convection heat transfer from vertical parallel plates channel with independent boundary layer development.

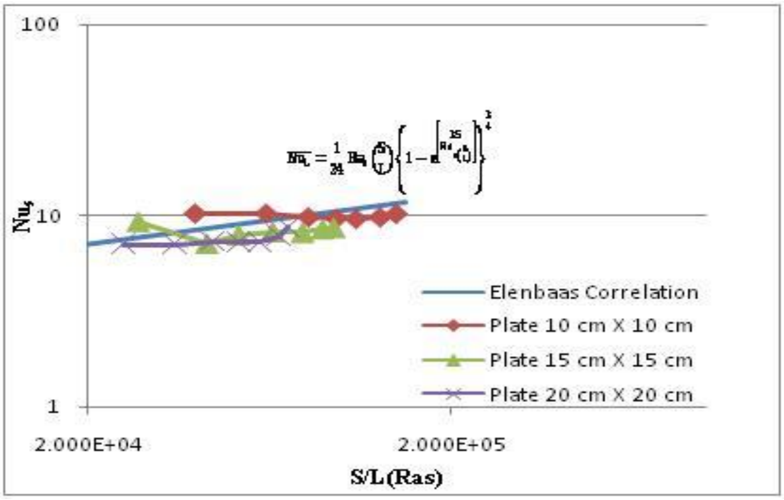

Figure. 5 Comparison of present work for plate spacing of 50 mm with the correlation equation proposed by Elenbaas (1942)

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6. Conclusion

The present work presents experimental results of natural convection heat transfer from vertical parallel plates. It can be concluded that the size of the plates, spacing between the plates, and the temperature difference between the plat surfaces and ambient air are the variables that affects the rate of convection heat transfer primarily.

As the plate spacing increases while the size of the plate decreasing (the value of $\frac{S}{L}Ra_s$ increasing) the natural convection heat transfer increases as well. This is due to for short channel and / or large spacing (large S/L), independent boundary layer development occurs at each surface and conditions correspond to those for an isolated plate in a infinite, quiescent medium and these conditions enhance the rate of natural convective heat transfer.

As for the correlation, parameter $\frac{S}{L}Ra_s$ was introduced and with experimental matching of exponential power, this correlation can be used to illustrate the relationship between the natural convection heat transfer rate and the plate spacing and as well as the plate dimension where,

$$Nu_s = 1.2762\left[Ra_s\left(\frac{S}{L}\right)\right]^{0.1643}$$

The proposed correlations provide a significant guide for prediction of natural convection heat transfer for vertically heated parallel plates with varying plate spacing.

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Nomenclatures

L	Plate length
Nu_L	Average Nusselt number
$\overline{Nu_L}$	Average Nusselt number
Ra_s	Average Rayleigh number for vertical channels
Ra_x	Local Rayleigh number
S	Plate spacing
T_s	Plate surface temperature
T_∞	Ambient temperature