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A Preliminary Study on the Mixed Convection Heat Transfer in a Horizontal Pipe

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1. Introduction

Mixed convection phenomena have applications in heat exchangers designed for viscous liquids, pipelines used for transporting oil, and heat exchangers for gas flows and have been investigated for numerical study [1]. The experimental studies on the topic are rare due to the limited practical uses. The definitions on the buoyancy coefficient that represent the relative influence of the forced and the natural convection are different by scholars.

When the fluid passes through a horizontal heated pipe, the secondary flow patterns of the flows moving upward along inner wall and downward through the centerline of the pipe, appear. Two symmetric counter-rotating, spiraling axial flows around the vertical centerline and the heat transfer of the bottom is higher due to the unstable stratification [2].

This study is preliminary experiments for laminar and turbulent mixed convection for horizontal pipe geometries. The diameter of the pipe was 0.026m and lengths were ranging from 0.03m to 0.50m varying the Reynolds number.

Experiments were carried out using a copper sulfate electroplating system was adopted for mass transfer based on the analogy concept.

2. Previous study

The researches on the mixed convection of vertical pipes were many investigated, however that of the horizontal pipes were not extendedly studied. Existing studies simply Graetz solution is compared with the mixed convection region. And then it only presents the graph of increased Nusselt number as buoyancy effects. Therefore that is all that the study of mixed convection has been carried out existing between natural convection and forced convection. In many researches are buoyancy effects about dimensionless length, even though it is defined starting length of buoyancy effect was different by scholars.

Ou and Cheng[3] investigated that the classical Graetz problem with natural convection effect in isthermally cooled or heated horizontal tubes is approached by a numerical method using large Prandtl number assumption. The Nusselt number results are compared against the experimental data and the agreement is found to be satisfactory. And they measured the profile of velocity and temperature as axial flow that is approached by a numerical method.

Hishida et al.[2] presented for the developing primary and secondary velocity profiles, developing temperature fields, local wall shear stress, and local and average Nusselt number which reveal how the developing flow and heat transfer in the entrance region are affected by the secondary flow due to buoyancy forces.

Table I: Test matrix.

Pr	*D*(*m*)	Gr_D	Ra_D	*L(m)*	*Re*
2094	0.026	1.4×10^6	3.0×10^9	0.03	71, 141, 211, 422, 565, 708, 844, 112, 1270
				0.05	
				0.06	
				0.10	
				0.20	
				0.30	
				0.50	


Fig. 1 The experimental equipment.

Coutier and Greif[4] experimental and theoretical studied mixed convection phenomena when the wall was cooled. The form in cross section of isotherm and streamline was coarse in the bottom, while the top was dense. This is same with flip it over cross section when the wall heated. And they found that every shape and size is depends on heated section length.

3. Experiments

3.1 Mass transfer method using analogy concept

Mass transfer rates were measured instead of the heat transfer rates as the analogy between heat and mass transfer can be applied when the boundary conditions are of same type. Measurements were made using the limiting electrolysis current technique with a cupric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system [6].

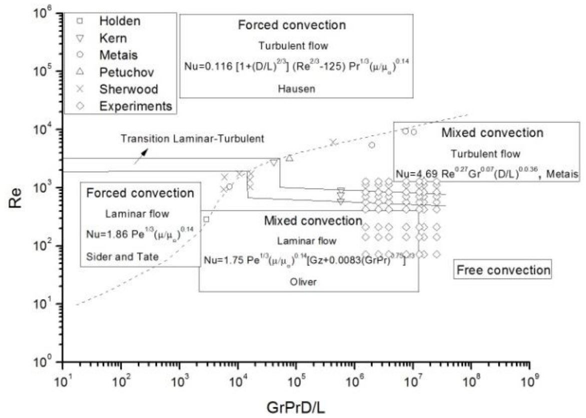

Fig. 2 Redrawn flow regime map in horizontal pipe[5].

3.2 Test matrix and apparatus

Table 1 presents the test matrix. Prandtl number was 2,094 and Rayleigh number was 3.0×10^9. The length of cathodes was varied from 0.03*m* to 0.50*m* and varying the Reynolds number from 71 to 1270 for the laminar mixed convection.

Fig. 1 shows the experimental equipments. Fluid from the upstream reservoir through the test section and then go to downstream reservoir eventually flows into the sink source. In order to prevent flow perturbation, the flow is controlled by the head difference of upstream and downstream reservoirs and the flow rate is measured by the electromagnetic flow meter. An anode was located at the center of cathode.

4. Results and discussion

Fig.2 is the redrawn flow regime map of Ghajar and Tam [5], and the current experimental region is added. Top left region is forced convection region and bottom right region is natural convection region. Horizontal lines denote transition lines, which separate laminar region in bottom and turbulent region in the top. The mixed convection region is indicated by the dashed line. The current experimental region is located in the laminar and transition mixed convection region.

Fig. 3 shows the experimental results together with the forced convection heat transfer correlation. The Nusselt number increases due to the mixed convection can be easily seen. With small length pipes, the Nusselt number was always higher than those of forced convection for low Reynolds number, which agrees with previous study for the buoyancy effects. However with the pipe length more than 0.30m, the Nusselt number increase no more, indicates that the limited Nusselt number value existed when the heated section length increase the fluid temperature was equal to wall temperature.

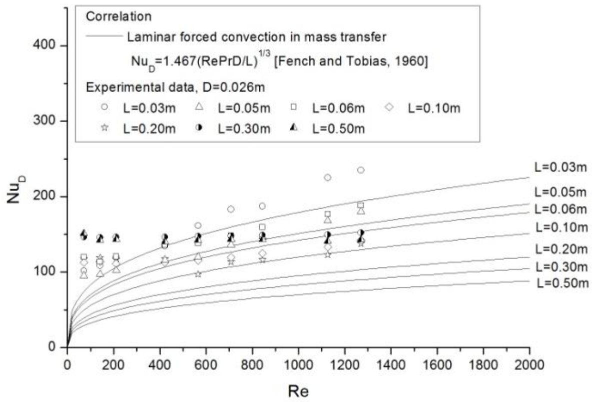

Fig. 3 Compared with forced convection correlation and experiemental results.

5. Conclusions

Mixed convection mass transfers inside horizontal pipe were investigated for the pipe of various lengths with varying Reynolds number. Current results belong to laminar mixed convection and transition mixed convection. In all of heated section length, the heat transfer rates were higher than correlation for the forced convection on low Reynolds number. With the heated section length of more than 0.30m, the heat transfer rates does not affect of the Nusselt number value. It represents that buoyancy effect does not enhancement Nusselt number when the length of heated section

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