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Final Report

The Impact of Separated Flow on Heat and Mass Transfer

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Introduction

An investigation of the effect of flow separation on heat and mass transfer has been completed. This research, sponsored by the Department of Energy (contract number: DE-FG02-87ER13800) provided enhanced understanding of fundamental mechanisms governing important heat and mass transfer flow processes. This report summarizes the work conducted under the project.

Early studies conducted in the laboratory showed enhancement in heat transfer near the base of a cylinder projecting from a surface. Some of the surprising results included the significantly increased heat and mass transfer in the lower regions of the horse shoe vortex stretching around the cylinder both on the cylinder surface and on the base from which it protrudes. Figures 1 and 2 show the heat and mass transfer distribution along a cylinder and on the base around the cylinder. These show significant increases in mass transfer due not only due to the main vortex, but also due to the inner vortex on the cylinder and on the base itself.

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The program considered the influence of vortices on a single cylinder and arrays of cylinders as would be present in a pin fin system, for example in the trailing edge region of a turbine blade or in small heat exchanger ducts. Consideration of both active and passive endwalls and active and passive cylinders showed the interaction of the heat and mass transfer between the cylinders and the walls. Measurements included flow visualization of the vortex structure and local distributions of mass transfer on a cylinder. Other studies were made with square cylinders at various angles of orientation. The enhancement of heat transfer on a square cylinder is shown in figure 3.

Different arrangements of cylinders, arrays of in-line and staggered, were studied. Significant advantages were found for staggered array in comparison to the in-line array in terms of increased heat transfer for a given pressure drop. Figures 4 and 5 provide information on this flow structure with an array of stepped fins as could be used in a pin fin heat exchanger.

We analyzed the heat and mass transfer through single holes and an array of short holes. These required a complex experimental design for measurements within the holes. The results give strong indications of the separation and reattachment of the flow entering such holes as well as the interacting flow between holes. Figures 6 and 7 show a sketch of the flow geometry and some of the mass transfer results.

Heat transfer measurements were conducted on flow of a jet onto concave and convex cylindrical surfaces. Examples of flow visualization are shown in figures 8

and 9 for flow towards concave and convex surfaces, respectively. Note that the concave surface provides a recirculation of the flow so that some of the spent air from the jet re-enters into the flow.

The program included the development of a complex and accurate system for measuring local distribution of mass transfer which can generally be converted to corresponding heat transfer situations. The technique has been refined to a high degree and provided considerable new knowledge on flow and heat transfer situations of great interest in a number of energy conversion devices, including heat exchangers, gas turbines, solar energy systems and general heat transfer systems.

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Fig. 1 - Distribution of Sherwood Number Along the Cylinder

Fig. 2 - Contours of Mass Transfer Coefficient on the Endwall

Fig. 3 - Mass Transfer Distribution On the Sides of a Square Cylinder Near the End Wall

Three Dimensional Flow Pattern Over The Stepped Fin

Figure 4

Endwall Flow Pattern of the Stepped Pin-Fin Array
(SP1 : 1st, 2nd, 3rd, 4th, and 5th Row, $Re_{d,ave} = 18,000$)

Figure 5

$S = 4.76 \text{ mm}$
 $P/S = 3.0$
 $t/S = 1.43$
 $L/S = 16.8 (\pm 8.4)$
 $L_n/S = 10.5 (\pm 5.25)$

Fig. 6 - Schematic of Multiple Two Dimensional Slits

2-D Multi-Slit Flow

2-D Multi-Slit Flow

Fig. 7 - Mass Transfer Distribution on a Rib Between Two Adjacent Slits

Figure 8

Interaction of the 10 mm jet with
the spent flow for $Y/d=12$ on CCV

Figure 9

Interaction of the 10 mm jet with
the CVX surface for $Y/d=12$

Fig. 10 Effect of excitation frequency on the vortex structure of a jet.
 $u_j^0 = 8 \text{ m/s}$, $Re_j = 10,000$.