HEAT TRANSFER IN A DIMPLED TWO-PASS CHANNEL

S. Acharya and F. Zhou
Mechanical Engineering Department
Louisiana State University, Baton Rouge, LA 70803

ABSTRACT

In the development of advanced turbine systems, there has been considerable effort toward increasing the turbine inlet temperature. This requires the development of more effective internal and external blade cooling strategies. In internal cooling, compressed air is circulated through ribbed serpentine passages, and discharged through the trailing edge of the blade. In recent years, efforts directed at improving internal cooling have led to concepts that include the use of inclined turbulators, vortex generators, swirl-induced cooling or screw cooling, and the use of dimpled surfaces. The present study deals with a two-pass dimpled coolant passage and investigates the effect of rotation on the mass/heat transfer from dimpled surfaces.

Dimpled surfaces have been shown to enhance surface heat transfer by a variety of investigators[1-5] and under certain conditions, they have also been shown to reduce the drag coefficient[6]. This combination of enhanced heat transfer with minimum pressure drop penalty makes dimpled surfaces attractive from a turbine blade cooling perspective. For these reasons, several investigators have explored the use of dimpled internal coolant turbine blade passages. Schukin et al.[1] studied the effects of channel geometry (converging and diverging channels) on the heat transfer downstream of a single hemispherical cavity. Chyu et al.[2] reported overall heat transfer rates that are 2.5 times greater for the dimpled surface compared to a smooth surface. Lin et al.[3] presented corresponding flow and heat transfer predictions to help explain the observed heat transfer behavior. Moon et al.[4] investigated the effect of channel height on the heat transfer and friction in a dimpled passage. Heat transfer enhancements of the order of 2.1 over smooth surfaces were reported with pressure drop penalties in the range of 1.6-2.0 over smooth surfaces. Most recently, Mahmood et al.[5] have made detailed flow and heat transfer measurements on a dimpled plate, and have identified specific vortex structures responsible for augmenting heat transfer from the downstream rims of each dimple. Heat transfer enhancements ranging from 1.8-2.4 over smooth plates were noted.

All the dimpled plate literature cited above has been done for stationary channels. In turbine blades, data under rotating conditions are of interest. Recently, Acharya and Zhou[6] reported measurement of dimpled-surface heat/mass transfer in a single pass coolant channel under conditions of rotation. This paper extends the work of Acharya and Zhou[7] and reports measurements in a two-pass coolant passage (stationary and rotating) with dimpled surfaces.

The experiments are performed in a test apparatus designed for the study of mass transfer (sublimation of naphthalene) in a two-pass internally ribbed duct. Mass transfer measurements permit the acquisition of detailed local distributions of the Sherwood number, which can then be converted to Nusselt numbers using the heat-mass transfer analogy.

The following major observations are made from this study.

- The maximum heat transfer rates are obtained downstream of the dimples. The minimum mass/heat transfer rates occur along the row containing the dimples.
- Under conditions of rotation, the dimpled surfaces appear to give enhancements of the order of 2 or greater over smooth channels. These enhancement levels are consistent with those reported in the literature for stationary dimpled surfaces.
- With rotation, a factor of 2 or greater heat transfer is observed on the dimpled trailing surface compared to the dimpled leading surface. This is consistent with that observed for rotating smooth and ribbed channels.
- The Sherwood number distributions suggest the existence of three local peaks, with the strongest peak immediately downstream of the dimples, and the weaker peaks located along the lateral edges of the dimple. These peaks appear to be related to the development of streamwise vortical structures generated from the leading edge of the dimple and the spanwise edges of the dimples.

References

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