EFFECT OF INITIAL COOLANT CONDITIONS ON TRANSPIRATION COOLING ON CURVED SURFACES

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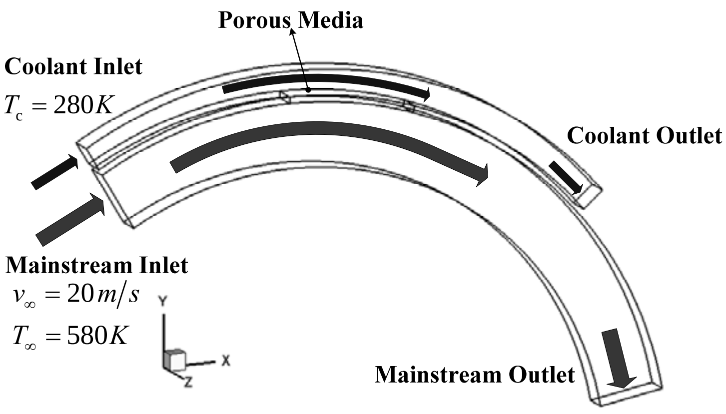
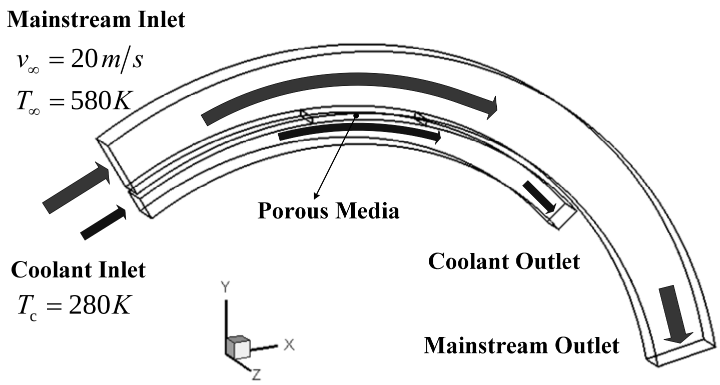
The high thermal loads in gas turbines significantly limit the turbine performance. The gas turbine inlet temperature for the next generation turbines already exceeds 2000 K, while the maximum temperatures of advanced super alloys is just 1400 K [e.g. Wang, J. H. et al. 2004]. Transpiration cooling is one of the most efficient cooling techniques to prevent surface damage from very hot gas streams and is well recognized as a possible means for cooling gas turbine combustion chamber and blades. Almost all the studies on transpiration cooling have used the plenum-coolant-feeding model to simplify the numerical simulations. However, this model does not accurately represent the real flow conditions in gas turbine internal cooling structures in practical application. The effect of the coolant side heat transfer enhancement on the transpiration cooling effectiveness was concluded in the work performed by von Wolfersdorf [2005] using a theoretical analysis of a one-dimensional flat plate. In addition, the blade curvature is also very important when modeling transpiration cooling of turbine blades.

This work presents a numerical investigation of the influence of the initial coolant conditions, such as the coolant velocities and flow directions in the internal coolant channels, on the transpiration cooling over a wide range of transpiration injection rates and mainstream inlet velocities on convex and concave surfaces such as shown in Figure 1. The results are then compared with these of the plenum model.



(a) Transpiration on a concave surface



(b) Transpiration on a convex surface

Figure 1. Schematic of mathematical models with coolant channels

The three-dimensional numerical simulations were conducted in present study. The main stream flow was calculated by solving the Navier-Stokes equations RNG *κ-ε* turbulence model. The Brinkman-Forchheimer extended Darcy equation was used to model the coolant flow through the porous media.

$$\nabla(\rho_f \varepsilon u) = -\nabla P + \nabla(\rho_f \mu u) - \frac{\mu_f}{K}\varepsilon^2 u - \varepsilon^3 \frac{\rho_f F}{\sqrt{K}}|u|u \qquad (1)$$

The permeability, *K*, and the inertia coefficient, *F*, were given by Ergun [1952]:

$$K = \frac{d_p{}^2 \cdot \varepsilon^3}{150(1-\varepsilon)^2}, \quad F = \frac{1.75}{\sqrt{150}\varepsilon^{3/2}} \qquad (2)$$

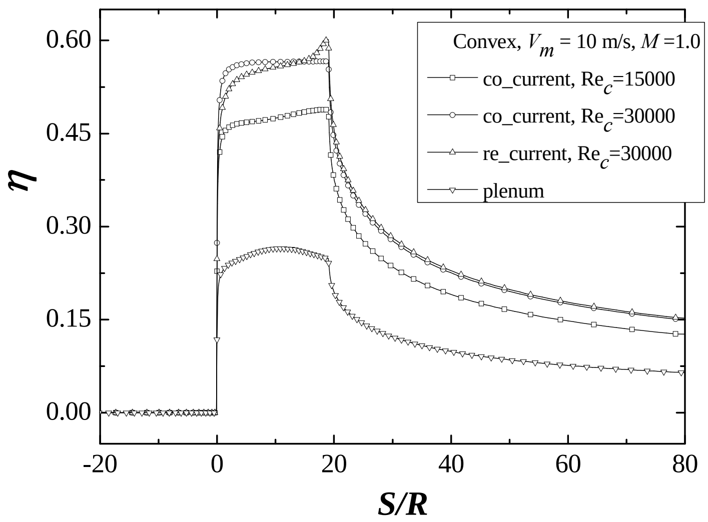
The energy equation within the porous zone based on the local thermal equilibrium model between the porous media and the local fluid flow was given by:

$$\nabla\left(\rho_f c_{pf} \varepsilon u T_f\right) = \nabla\left(\left(\lambda_m + \lambda_d\right)\nabla T_f\right) + \frac{\varepsilon^2 \mu_f}{K}u^2 + \frac{\varepsilon^3 \rho_f F}{\sqrt{K}}|u|u^2 \qquad (3)$$

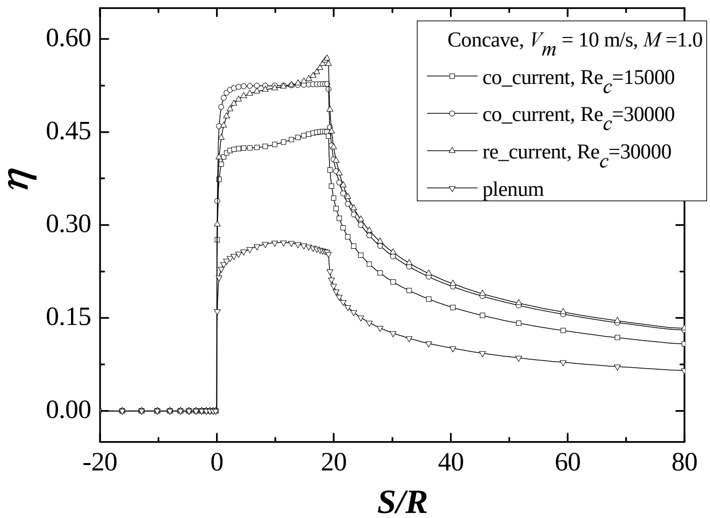
The effective thermal conductivity for the porous media with consideration of the thermal dispersion was based on the work of Hunt, M. L., and Tien, C. L. [1988]:

$$\frac{\lambda_m}{\lambda_f} = \left(1-\sqrt{1-\varepsilon}\right) + \frac{2\sqrt{1-\varepsilon}}{1-\sigma B}\left[\frac{(1-\sigma)B}{(1-\sigma B)^2}\ln\left(\frac{1}{\sigma B}\right) - \frac{B+1}{2} - \frac{B-1}{1-\sigma B}\right] \qquad (4)$$

$$B = 1.25\left(\frac{1-\varepsilon}{\varepsilon}\right)^{\frac{10}{9}}, \quad \sigma = \frac{\lambda_f}{\lambda_s} \qquad (5)$$



(a) Transpiration cooling effectiveness on the convex surface



(b) Transpiration effectiveness on the concave surface

Figure 2. Cooling effectiveness variations along the centerline of curved surfaces

CONCLUSION

The predicted results (Figure 2) show that the transpiration cooling effectivenesses are much higher for the coolant-channel model both on convex and concave surfaces than for the coolant-plenum model. For the coolant-channel model, the cooling effectiveness was improved by the enhancement of convection heat transfer on the coolant side due to the increase coolant inlet velocity. In addition, the coolant flow directions (in the same or opposite direction to the mainstream) also strongly affected the transpiration cooling effectiveness on both the convex and concave surfaces.

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