Mist/Steam Cooling for Advanced Turbine Systems

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Abstract

With the recent adoptions of closed-loop steam cooling by two major gas turbine manufacturers for their heavy-frame Advanced Turbine Systems (ATS), a major part of external air-film cooling load will be replaced by internal steam cooling. With the availability of steam from the bottom cycle of a heavy-frame ATS, mist/steam cooling has been introduced by this research group as a potential means to significantly enhance turbine airfoils' internal cooling effectiveness.

Basically, the concept of using mist/steam cooling to enhance cooling effectiveness is based on the following features: (a) latent heat of evaporation, (b) increased specific heat, (c) steeper temperature gradient near the wall, (d) lower bulk temperature, (e) increased flow mixing induced by steam-particle interactions and particle dynamics, and (f) additional momentum and mass transfer induced by evaporation of liquid droplets on/near the wall.

As a first step, an experimental system under low pressure (1.5 bar) and low heat flux conditions, instead of high pressure and high heat flux conditions as in a real gas turbine environment, was set up in the laboratory at Clemson University. Four test conditions were performed: a horizontal tube, a 180° curved tube, impingement jests on a flat surface, and impingement jets on a curved surface. The arithmetic mean mist diameter (d_{10}) was about 3-6 μm in most cases.

The results in the heated horizontal tube show that an average enhancement of 100% with the highest local heat transfer enhancement of 200% is achieved with 5% mist. When the test section is mildly heated, an interesting wall temperature distribution is observed; the wall temperature increases first, then decreases, and finally increases again. A three-stage heat transfer model with transition boiling, unstable liquid fragment evaporation, and dry-wall mist cooling, has been proposed and has shown some success in predicting the wall temperature of the mist/steam flow.

The PDPA measurements have facilitated better understanding and interpreting of the droplet dynamics and heat transfer mechanisms.

The results in the 180° tube bend show that the outer wall of the test section always exhibits a higher heat transfer enhancement than the inner wall heat transfer due to the effect of centrifugal force. The highest enhancement occurs at a location on the outer wall about 45° downstream of the inlet of the test section. Generally, only a small number of droplets can survive the 180° turn and be present in the downstream straight section. The overall cooling enhancement of the mist/steam flow ranges from 40% to 300%.

Studies on the confined slot jet impingement cooling show that heat transfer enhancement from 100% to 400% was achieved in the stagnation area by employing about 1.5% of the mist. Efforts have also been made to reveal the enhancement mechanism. The heat transfer enhancement decreased with the wall temperature and increased with the mist concentration. This study has shed light on how to generate appropriate droplet sizes to achieve effective droplet transportation. Preliminary analysis was performed, and extending present results to a higher temperature and higher pressure environment looks promising.

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