the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Improving Durability of Turbine Components through Trenched Film Cooling and Contoured Endwalls—University of Texas at Austin

Background

Gas turbine operation utilizing coal-derived high hydrogen fuels (synthesis gas, or syngas) requires new cooling configurations for turbine components. The use of syngas is likely to lead to degraded cooling performance resulting from rougher surfaces and partial blockage of film cooling holes. In this project the University of Texas at Austin (UT) in cooperation with The Pennsylvania State University (Penn State) will investigate the development of new film cooling and endwall cooling designs for maximum performance when subjected to high levels of contaminant depositions.

This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers. Both are managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high hydrogen content fuels derived from coal that is clean, efficient, and cost-effective; minimizes carbon dioxide (CO_2) emissions; and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

Wind tunnel facilities at Penn State and UT have been specifically designed to simulate film cooling of turbine vanes, blades, and endwalls. These facilities incorporate equipment that simulates the deposition of contaminants in the turbine by using molten wax particles to simulate the molten contaminant particles that occur at actual engine conditions. The wax particles used in the test facilities are sized appropriately to simulate the inertial behavior of particles that exist in engine conditions. The use of wax also allows for the simulation of the liquid-to-solid phase change that is essential to the primary deposition mechanism.

UT will be focusing on the performance of shallow trench film cooling configurations for various positions on the suction and pressure sides of a simulated vane with active deposition. Meanwhile, Penn State will be investigating the effect of active deposition on various endwall cooling configurations. Preliminary results show that deposition could be simulated dynamically using wax and that the effects of deposition could be quantified using infrared thermography. New endwall and vane surface film cooling configurations will be developed to minimize deposition and maximize cooling performance under contaminated conditions.

CONTACTS

Richard A. Dennis
Technology Manager, Turbines
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4515
richard.dennis@netl.doe.gov

Robin Ames
Project Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304- 285-0978
robin.ames@netl.doe.gov

David G. Bogard
Principal Investigator
University of Texas at Austin
Department of Mechanical Engineering
1 University Station C2200
Austin, TX 78712
512-471-3128
dbogard@mail.utexas.edu

PARTNERS

Pennsylvania State University

PROJECT DURATION

Start Date	**End Date**
10/01/2010	09/30/2013

COST

Total Project Value

$627,802

DOE/Non-DOE Share

$500,000 / $127,802

AWARD NUMBER

FE0005540

U.S. DEPARTMENT OF ENERGY

Goals and Objectives

The primary goal of this project is to develop new film cooling configurations specifically designed to mitigate the effects of depositions that cause significant degradation of turbine engine cooling performance. A specific focus is the development of trench and crater film cooling configurations that will operate successfully despite the heavy deposition of contaminants expected to occur when using syngas. These new film cooling designs will significantly improve the durability of gas turbines operating with syngas fuels. Project objectives are as follows:

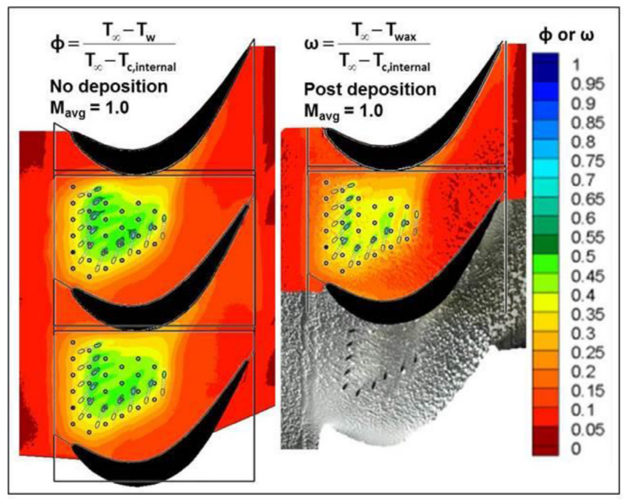
- Use a high conductivity, matched Biot number, model vane to evaluate the performance of simulated thermal barrier coating (TBC) with and without film cooling.
- Further develop the simulation of contaminant depositions to obtain more realistic deposits on simulated turbine vanes and endwalls.
- Perform deposition studies on a contoured endwall model.
- Measure aero-thermal boundary layers for flat and contoured endwalls.

Accomplishments

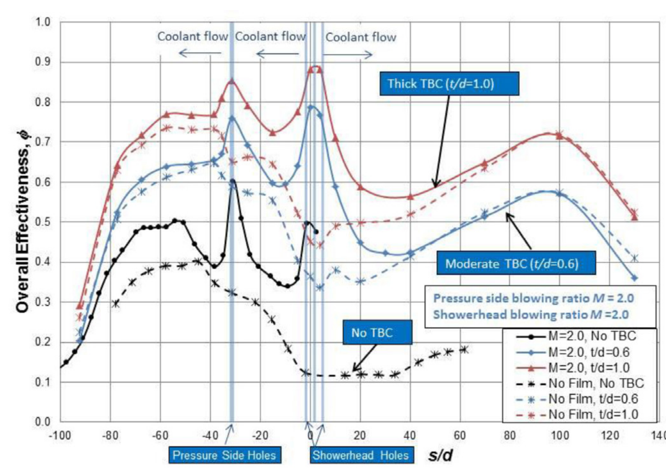
- Completed experimental simulation of a turbine vane with TBC. Measurements were made with a matched Biot number conducting model to obtain overall effectiveness with and without film cooling on the pressure side of the vane.
- Completed experiments where contaminant depositions on the leading edge and pressure side of a turbine vane with TBC were simulated using a unique molten wax spray technique. Results showed that the contaminant deposition acted as an insulating layer on the TBC surface, therefore decreasing the vane metal temperature.
- Results from the previous year showed that relatively thick TBC, with a thickness to hole diameter ratio of t/d = 1.0, caused a dramatic increase in overall cooling effectiveness. An important part of this year's work was to evaluate a moderate thickness TBC with thickness t/d = 0.6, i.e. 40% thinner than the TBC of FY2012. Although the overall cooling effectiveness was lower with the moderate thickness TBC, the cooling due to TBC still has a dominating effect.
- Measurements of temperature, velocity, and total pressure loss were taken in the wake of the turbine vane for cases with and without deposition, as well as with and without film cooling. Deposition was simulated using our unique molten wax spray technique. Results showed film cooling has a negligible effect on the velocity deficit and pressure loss in the wake, while deposition has a significant effect.
- Experiments measuring overall effectiveness of a matched Biot number flat endwall model have been conducted for film cooling only, as well as internal impingement cooling plus film cooling.
- Experiments with impingement were completed at two impingement heights representing the range of heights that will occur with the contoured endwall and in an engine.
- A one-dimensional analysis used to calculate the overall effectiveness based on results from impingement alone and film alone had good agreement at low blowing ratios, and reasonable agreement at high blowing ratios.
- Additional thermocouples were installed on the backside of the endwall, which were used to derive values for internal heat transfer coefficient.
- Deposition was dynamically simulated on the flat endwall. Internal endwall temperatures were measured to be higher with deposition, indicating an increase in heat transfer coefficient due to roughness effects.

Benefits

This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. The new turbine cooling designs developed in this project will extend component life, leading to reduced costs.



Effectiveness contours and corresponding deposition photographs at M_{avg}= 1.0 with no deposition and post deposition.



The combined cooling effects of TBC (Thermal Barrier Coating) and film cooling are shown in the distributions of overall cooling effectiveness, ϕ, presented here for no TBC, moderate thickness TBC, and thick TBC.