the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Environmental Considerations and Cooling Strategies for Vane Leading Edges in a Syngas Environment—University of North Dakota

Background

Cooling airfoil leading edges of modern first stage gas turbine vanes presents a considerable challenge due to the aggressive heat transfer environment and efficiency penalties related to turbine hot gas path cooling. This environment is made more complex when natural gas is replaced by high hydrogen fuels (HHF) such as synthesis gas (syngas) derived from coal gasification with higher expected levels of impurities. In this project the University of North Dakota (UND) and The Ohio State University (OSU) will explore technology opportunities to improve the reliability of HHF gas turbines by analyzing the effects of free-stream turbulence level, geometry, deposition, and cooling on the heat load experienced by turbine vane leading edges.

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

This collaborative effort studying technologies important to the reliability of HHF gas turbines has been structured utilizing three phases.

Phase I: Leading Edge Model Development and Experimental Validation

The initial task for OSU's turbine reacting flow rig (TuRFR) facility will be to determine if the deposition mechanism for faired cylinders is similar to deposition for turbine vanes. If this approach is feasible, then the relative impact of leading edge diameter on deposition can be investigated using varying diameter cylinders instead of vanes. The deposition measurements will then be made and sent to UND for surface modeling. During Phase I, UND will study the response of turbulence approaching large cylindrical stagnation regions, the associated heat transfer augmentation, and boundary layer development on the cylinder's surface. Additionally, UND will begin the development of candidate internal cooling geometries for cooling a region of a turbine vane's leading edge.

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PARTNERS

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PROJECT DURATION

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

COST

Total Project Value
$624,999

DOE/Non-DOE Share
$499,999/$125,000

AWARD NUMBER

FE0004588

Phase II: Experimental Deposition and Roughness Study

OSU will utilize the TuRFR facility, modified to generate higher levels of turbulence, to study the influence of turbulence on deposition rates in turbines. These results will be used to improve predictive modeling and made available to UND for heat transfer measurements. UND will use surfaces generated by OSU as part of their leading edge heat transfer and boundary layer studies. UND will also develop and test candidate internal cooling schemes for large regions on a turbine vane's leading edge.

Phase III: Mitigation of Deposition Using Downstream Full Coverage Film Cooling

OSU will use faired (rounded to reduce drag) cylinders to explore various film cooling designs to assess their effectiveness at reducing deposition. Actual turbine vane geometry will be used to explore the influence of select film cooling patterns on deposition. UND will investigate the combined influence of turbulence and realistic roughness on film cooling effectiveness and surface heat transfer. As a basis of comparison, they will initially look at the influence of turbulence on film cooling effectiveness and heat transfer for selected full coverage geometries.

Goals and Objectives

The primary goal of this study is to investigate methods to mitigate the adverse effect of deposition on the life and operability of turbine nozzles. The conceptual approach will develop methods for internally cooled leading-edge regions to minimize the possibility of clogging while utilizing spent cooling air to cool and protect downstream surfaces from deposition buildup. Deposition rates will be investigated on varying-diameter leading edge regions with and without high turbulence levels while considering the mitigating influence of full coverage film cooling geometries on pressure surface deposition. This focus will lead to a greater understanding concerning the influence of varying turbulence conditions and realistic roughness on full coverage film cooling schemes. The project will also investigate stagnation region heat transfer and boundary layer development with a range of elevated turbulence levels with and without realistic roughness surfaces generated from the deposition tests.

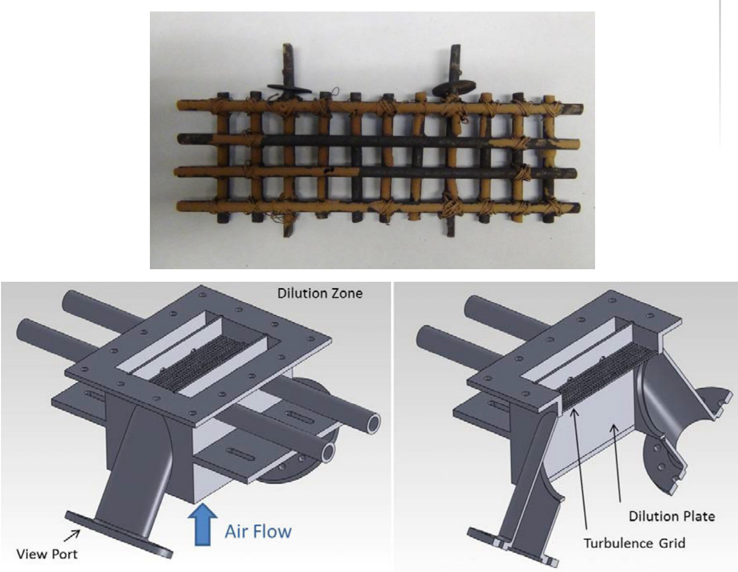

Figure 2. Grid (top) and facility installation drawings (bottom) showing grid installation in deposition facility. Elevated turbulence results in increased particulate deposition.

Accomplishments

UND accomplishments:

- Completed stagnation region heat transfer measurements for both cylinders using the six existing turbulence conditions.
- Designed and built a new smaller combustor simulator to generate turbulence intensities in excess of 20 percent. UND is currently documenting its turbulence characteristics.
- Initiated work on developing two full coverage film cooling geometries including a 30-slot. Preliminary computational fluid dynamics (CFD) studies have been conducted on the slot and discussions have been initiated with industry to help define the shaped hole geometry.
- Initiated work on developing test surfaces for cylinder approach flow turbulence measurements and cylinder surface boundary layer measurements.

OSU accomplishments:

- Conducted CFD studies of particle trajectories for faired cylinders.
- Modified TuRFR rig to accommodate a range of leading edge cylinders.
- Developed a dilution zone design in order to generate elevated turbulence levels.
- Conducted computational modeling showing the influence of transpiration on surface deposition.
- Conducted preliminary deposition tests on the impact of pressure surface film cooling on deposition.
- Documented freestream turbulence levels with and without turbulence grid.
- Documented increase in deposition rate with increasing turbulence level.
- Designed and fabricated film slot into new nozzle guide vane test section.
- Documented reduction in deposition with film cooling.

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. Understanding heat transfer and surface deposition mechanisms on turbine leading edges will allow development of innovative designs leading to increased reliability in turbines subjected to a syngas environment.

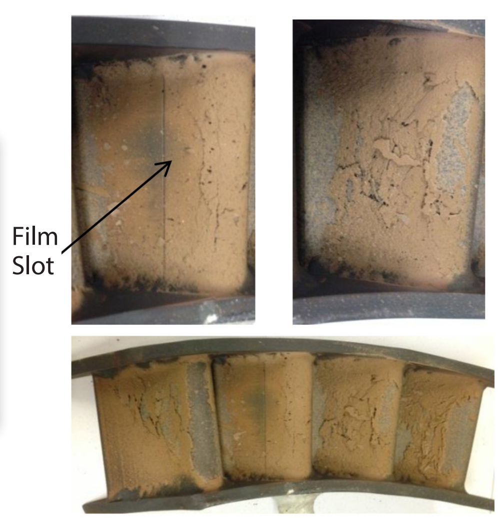

Figure 1. Deposit measurements on nozzle guide vane for slot film cooling (left); no film cooling (right).