the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Designing Turbine Endwalls for Deposition Resistance with 1,400 °C Combustor Exit Temperatures and Syngas Water Vapor Levels—The Ohio State University

Background

This University Turbine Systems Research (UTSR) project will explore a critical need for innovative turbine endwall designs that could increase turbine durability and mitigate the adverse effects of residue deposition from coal-derived synthesis gas (syngas). The Ohio State University (OSU), in cooperation with Brigham Young University (BYU), will explore modifying turbine endwall geometries through both experimental and computational components.

This project is 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. This project was competitively selected under the UTSR Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers.

Project Description

This project addresses critical turbine operability and maintainability issues in three distinct phases.

Phase I: Modeling and Experimental Validation

A deposition model will be developed and incorporated into an existing computational fluid dynamics (CFD) code capable of handling modern turbine geometries. Validation will be performed using both the OSU and BYU accelerated deposition facilities. The BYU Turbine Accelerated Deposition Facility (TADF) will

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PARTNERS

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PROJECT DURATION

Start Date	End Date
10/01/2008	03/31/2012

COST

Total Project Value
$655,270

DOE/Non-DOE Share
$475,000 / $180,270

AWARD NUMBER

NT0005055

U.S. DEPARTMENT OF ENERGY

be modified to accommodate higher firing temperatures (up to H-class engine temperatures of 1,400 degrees Celsius [°C]) and the addition of water vapor. The OSU Turbine Reacting Flow Rig (TuRFR) facility will be used to investigate deposition patterns around real film-cooled turbine hardware at engine relevant conditions. Hardware will be donated from General Electric (GE), Siemens, and Pratt & Whitney through collaborative agreements.

Phase II: CFD and Experimental Endwall Design

Various endwall design modifications will be evaluated, both experimentally and computationally, to determine their influence on deposition. BYU will perform gas temperature and fuel type test series to determine high temperature extension of deposition data.

Phase III: CFD Design Study with Cooling and Experiments with Water Vapor

BYU will explore the effect of water vapor on turbine deposition using various thermal barrier coating material systems with water vapor levels up to 15 percent to simulate levels anticipated with high hydrogen combustion. The effect of film cooling on deposition will also be studied at both BYU and OSU. Deposition models will be used to determine optimum film flow location to mitigate endwall deposition and improve material system survivability.

Goals and Objectives

The goal of this work is to develop turbine endwall geometries that both improve aerodynamic performance and reduce the potential for degradation due to deposition.

Objectives include:

- Development and validation of a deposition model.
- Evaluation of each of the design modifications for deposition resistance as well as aerodynamic and heat transfer performance.
- Determination of the effects of water vapor and film cooling on deposition, and determination of optimum film flow location to mitigate endwall deposition.

Accomplishments

- New silicon carbide components for the BYU TADF successfully demonstrated operation up to 1,400°C. The test coupon holder was also redesigned to implement a water spray backside impingement cooling that will allow it to survive at elevated temperatures.
- OSU TuRFR facility was completed. This unique facility simulates the flow field at the inlet to a modern nozzle guide vane (NGV), with gas temperatures up to 1,100 °C and Mach numbers approaching 0.1.
- Deposition studies continued with two NGV doublets donated from GE. Initial tests show a strong sensitivity to gas temperature between 1,000°C and 1,050°C. This is very near the transition temperature reported in other deposition studies. Deposits are primarily found in the leading edge and pressure surface regions. The suction surface is relatively untouched by the deposits.
- Film cooling at up to 12 percent of the main flow was shown to reduce deposition in TuRFR, though cooling holes become sites for deposit initiation.
- Four ash types were tested in TuRFR at 1,100°C. Bituminous coal has the highest ash melting temperature and lowest deposition rate. Lignite and subbituminous both deposit rapidly on leading edge and pressure surface.
- Computational deposition model was successfully implemented in three-dimensional vane geometry.
- Simulations predicted increased deposition with increasing particulate size and gas temperature, consistent with experimental observations.
- Two deposition models were compared and contrasted with experimental data. The critical viscosity model appears to have greater flexibility due to its inherent sensitivity to ash composition. This sensitivity is highly dependent on the ash melting temperature.
- Dependency of deposition on Stokes number was identified. Large particles have a more ballistic trajectory, while small particles can navigate the entire vane passage without impacting the surface.
- The first endwall redesign exhibited modest improvement in deposition rates.

Benefits

This UTSR project supports DOE's Hydrogen Turbine Program, which 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.

Figure 1. Examples of deposition issues from actual turbines, including gas turbine deposition accelerated by steam diluent injection used for NOx control (left) and failed turbine rotor platform with elevated deposition (right).

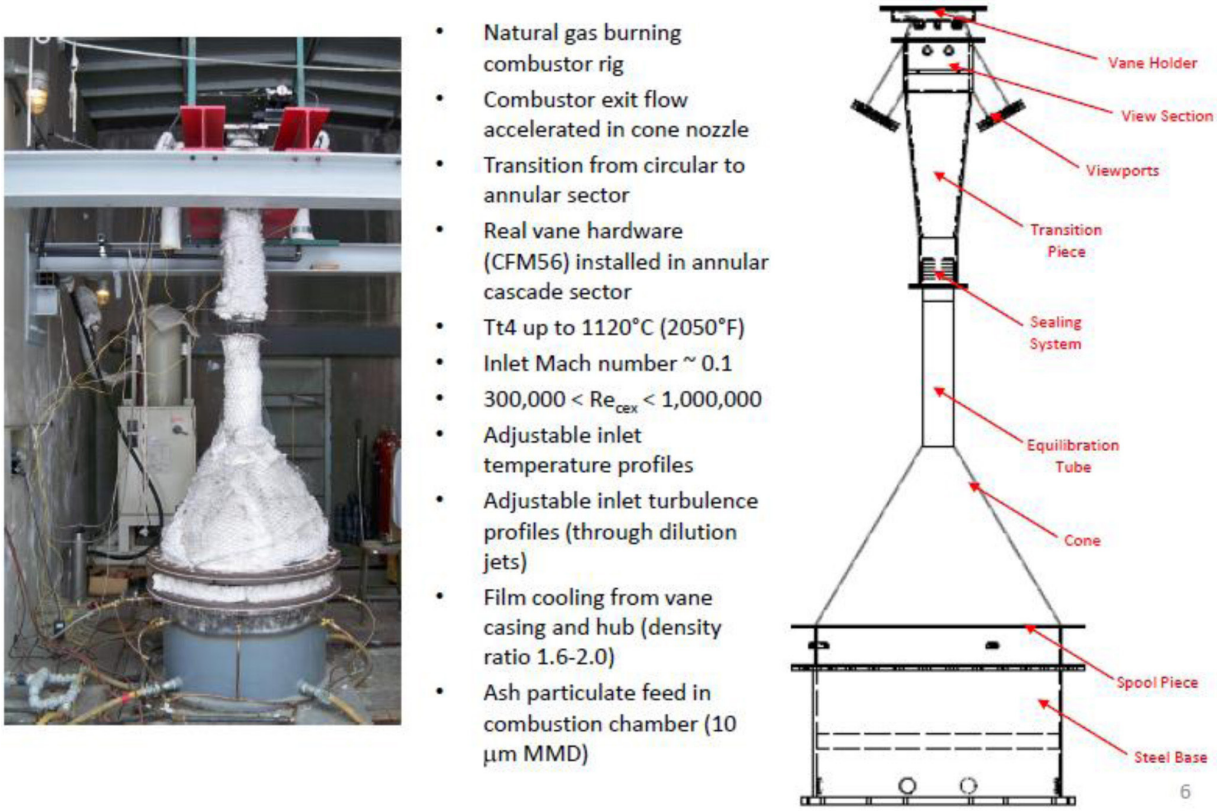

Figure 2: Photo and technical features of Ohio State University's turbine reacting flow rig .

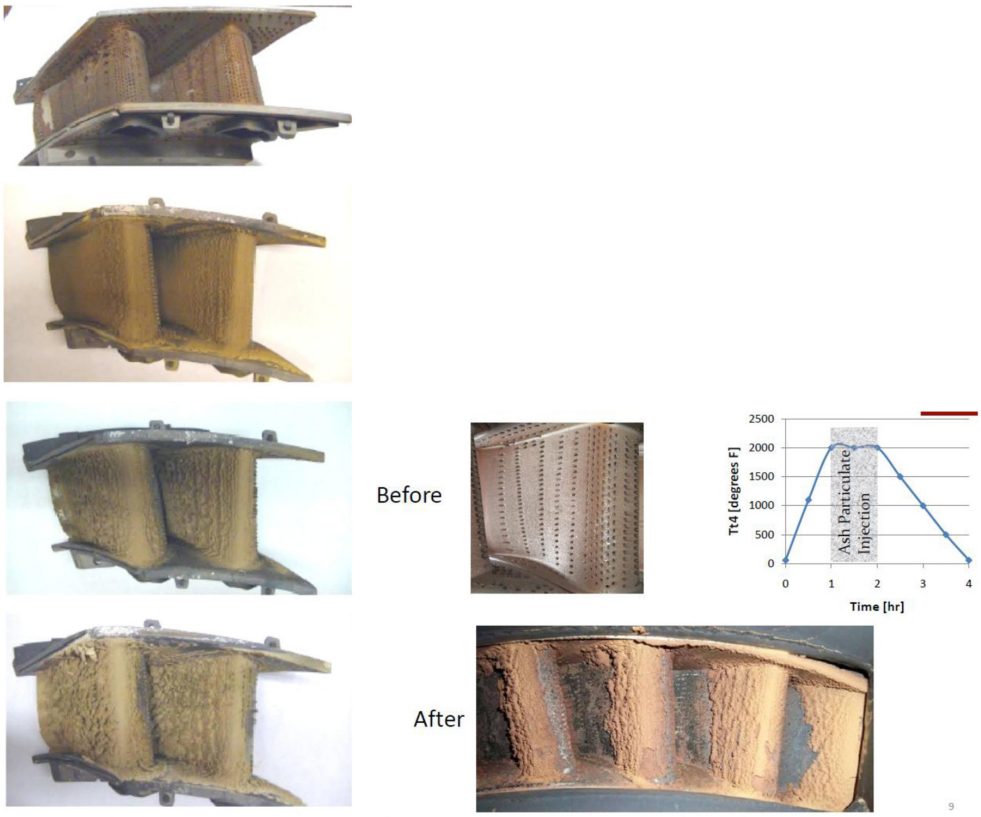

Figure 3: From the left (top to bottom) comparison of ash deposits on OSU's TuRFR test facility from (a) bituminous, (b) Powder River Basin subbituminous, (c) Jim Bridger Power Station subbituminous, and (d) lignite coal under similar test profile conditions, including a gas temperature of 1,100 °C (2,000 °F) as shown on the right.

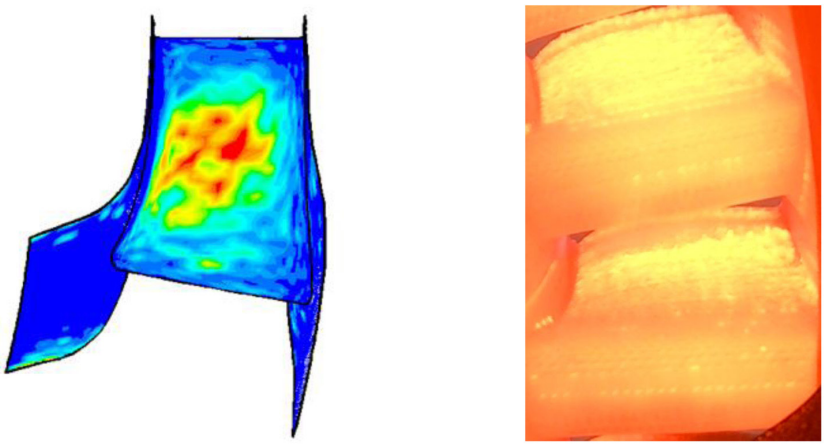

Figure 4: Comparison of (a) prediction from deposition model vs. (b) actual deposition in-process. Indicates close agreement between initial phases of deposition and model prediction before deposits become too large.