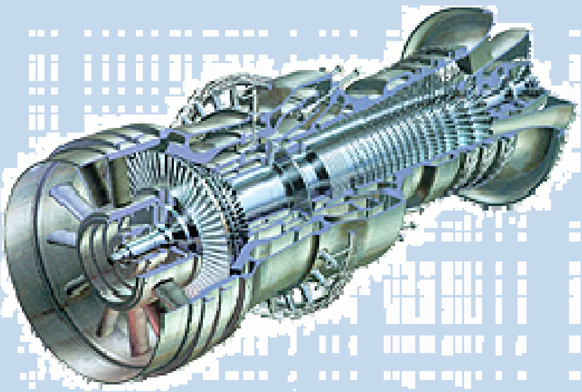
Deposition of Alternative (Syngas) Fuels on Turbine Blades with Film Cooling



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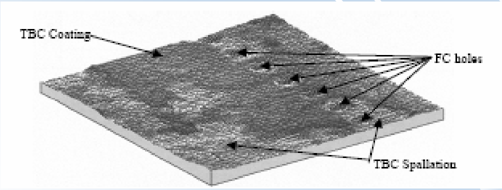
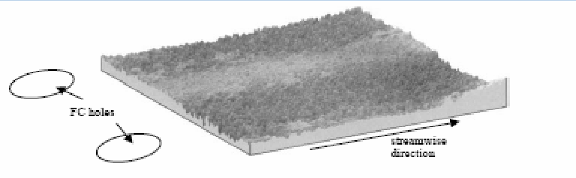
ACERC

Motivation

- Alternate fuels (e.g. coal, petcoke, and biomass) are being considered to produce syngas fuels to replace natural gas in power turbines
- Despite gas cleanup, small levels of airborne particulate (e.g. 0.1 ppmw) produce significant quantities (e.g. 2 tons) of ingested material in a large utility power plant during an 8000 hour operating year
- Previous studies of deposits from “dirty fuels” (e.g. Wenglarz et al., Wright et al., Patnaik et al., etc…) were conducted in the 1980s, before the advent of G and H class machines with…
  - Higher firing temperatures (1400C)
  - Broader use of EB and APS TBCs
  - Heavier reliance on innovative film cooling strategies
- The impact of depositing synfuel contaminants may present unforeseen viability issues for modern high performance turbines. For example…



Spallation near a film cooling hole



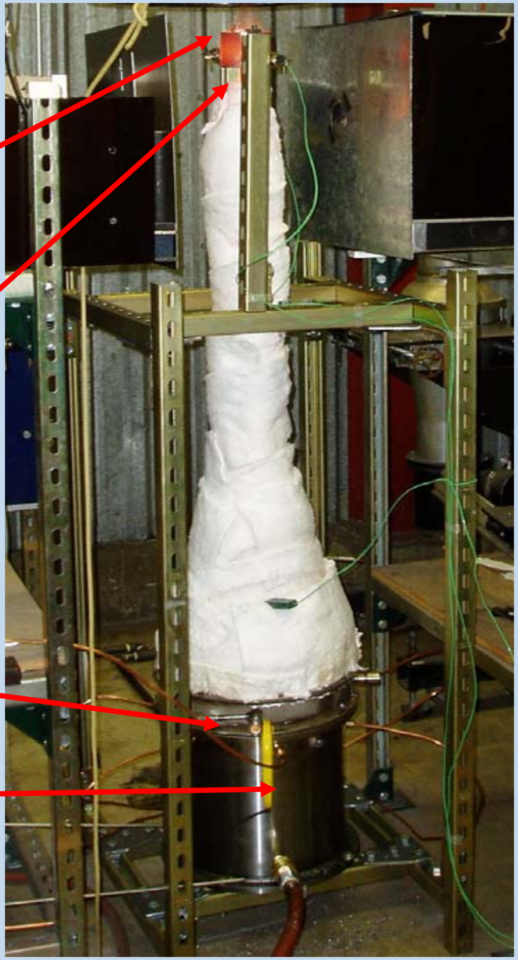
“Furrows” downstream of a film cooling hole

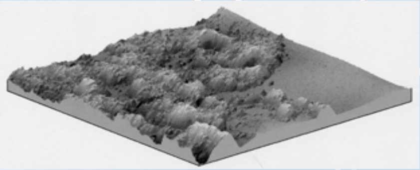
Deposits in the mouth of a film cooling hole

Turbine Accelerated Deposition Facility (TADF) Operating Principles

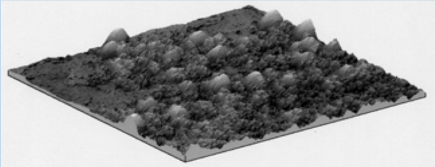
- **OBJECTIVE**: Characterize "engine-like" deposits in a laboratory/research setting

- Match critical design parameters:
  - Turbine coupons with TBC coatings
    - Co-based superalloy + MCrAlY + TBC
  - Combustor exit temperature and velocity
    - T_{exit} = 1150C
    - V_{exit} = 200 m/s (Mach = 0.31)
  - Controlled environment for combustion
    - Natural gas premixed burner
  - Fuel ash particulate size, phase, and constituents.



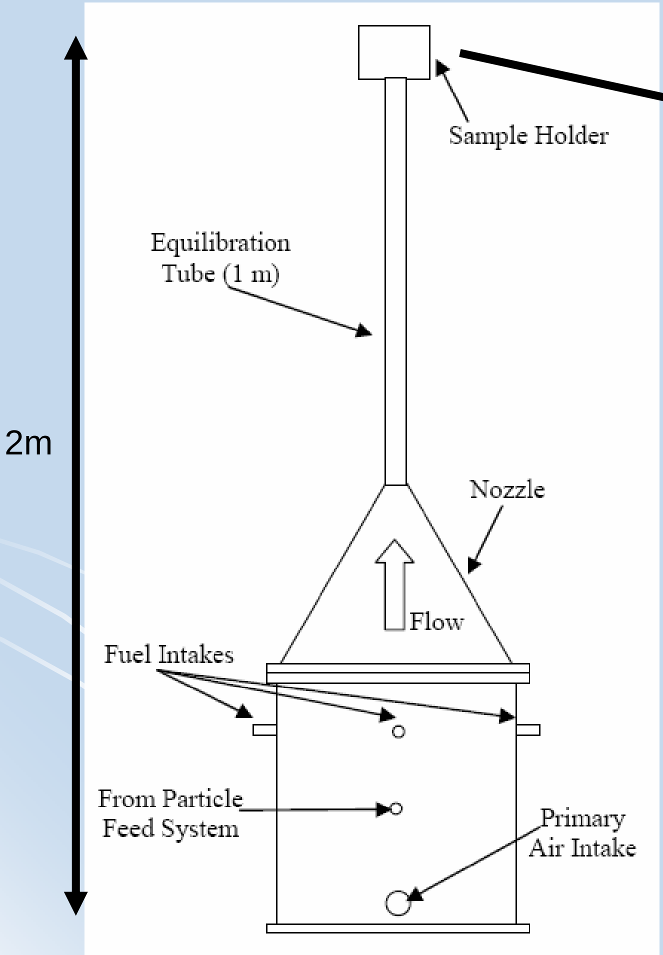


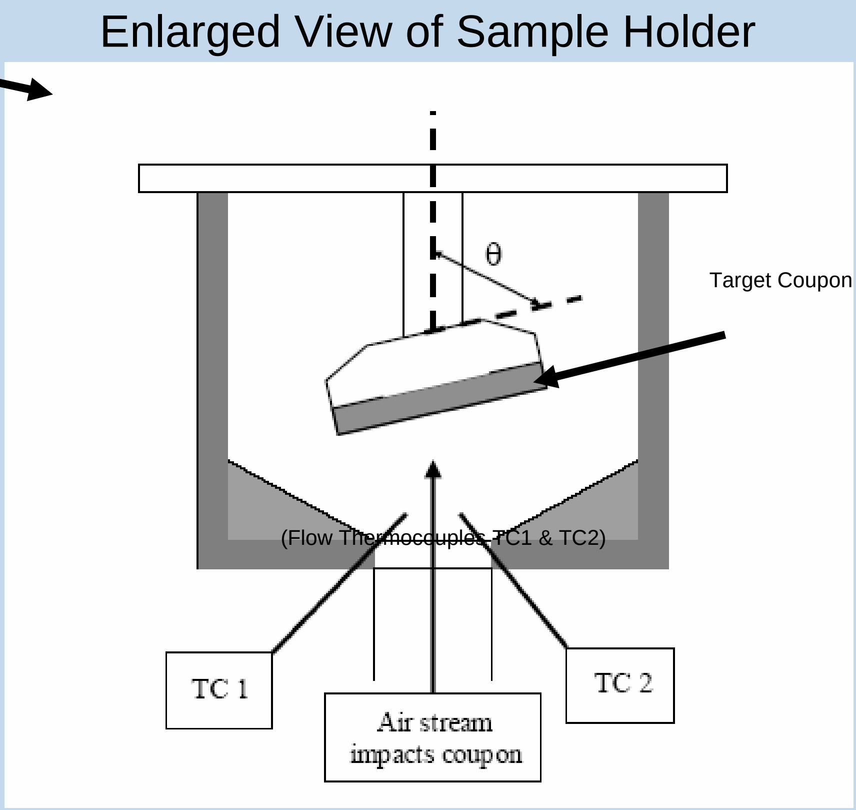
Surface map of deposits from 1st stage turbine blade with 25,000 hours service



Surface map of deposits in TADF with 60 ppmw for 4 hours

Schematic of Turbine Accelerated Deposition Facility (TADF) at BYU





(Jensen et al. IGTI 2004 in Vienna
Paper #GT2004-53324.)

Coupons obtained from industrial partners, including oxidation resistant coating and thermal barrier coating (TBC)

TADF Operation

- Test Duration
  - To simulate long periods of time, the net particulate loading (ppmw-hr) is matched:

For example:

A real gas turbine can experience 0.02 ppmw for 8000 hrs (~1 year):

0.02 ppmw * 8000 hrs = 160 ppmw-hr net particulate loading

To simulate with a 4 hour test: 160 ppmw-hr / 4 hrs = 40 ppmw

  - Jensen et al (2004) showed that accelerated deposition was similar to industrial deposition in: surface roughness, thickness, structure, and composition

- Available Fuels
  - Coal fly ash
  - Petroleum coke ash
  - Biomass ash
    - Straw
    - Sawdust
- Size ~ 2-10 μm

Coal

Straw

Petcoke

Sawdust

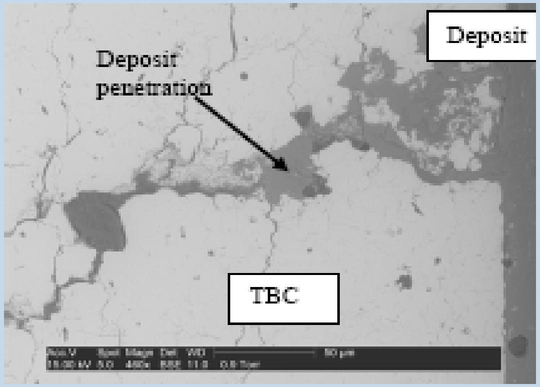
Measurements and Analyses

- Deposit physical features
- Deposition rate
- Surface topology
- Deposit structure
- Elemental composition
  - Bulk deposit
  - Deposits in TBC vertical segmentation cracks
  - Near spallation events
- Effective thermal conductivity
- Convective heat transfer coefficient (i.e., Stanton number)

Bulk Deposit Analysis

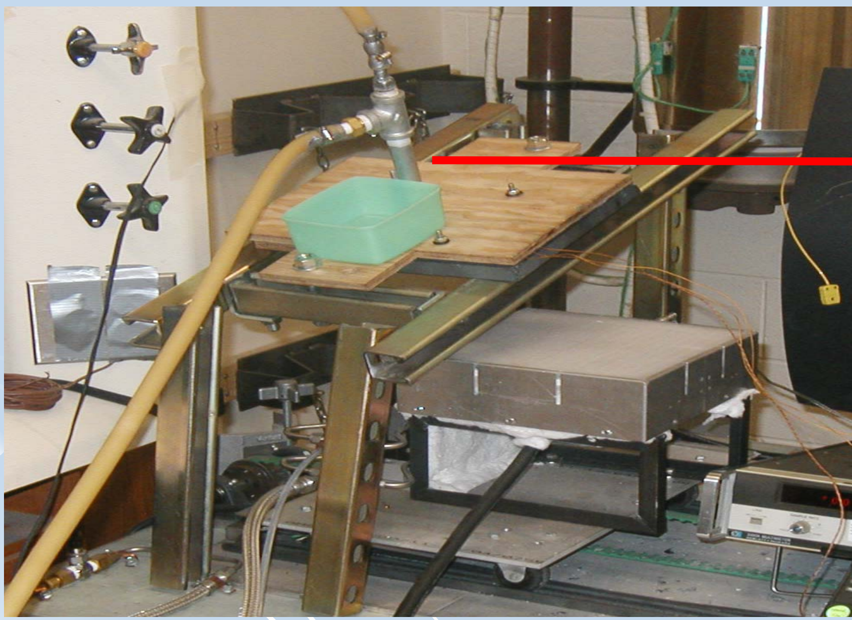
Element	Coal	Petcoke	Straw	Sawdust
Na	5.8	3.5	4.4	5.6
Mg	4.1	1.8	2.6	7.7
Al	18.9	12.5	3.2	7.8
Si	45.3	55.0	42.6	31.8
P	1.84	0.0	6.6	0.9
S	0.9	0.0	2.0	0.9
Cl	0.0	0.0	6.7	0.0
K	2.0	1.9	15.9	4.6
Ca	11.6	6.8	7.6	34.3
Ti	1.8	1.1	3.6	0.8
V	0.0	2.2	0.0	0.0
Cr	0.0	0.3	1.2	0.0
Mn	0.0	0.0	0.0	1.8
Fe	7.8	14.5	0.0	3.8
Ni	0.0	0.5	0.0	0.0

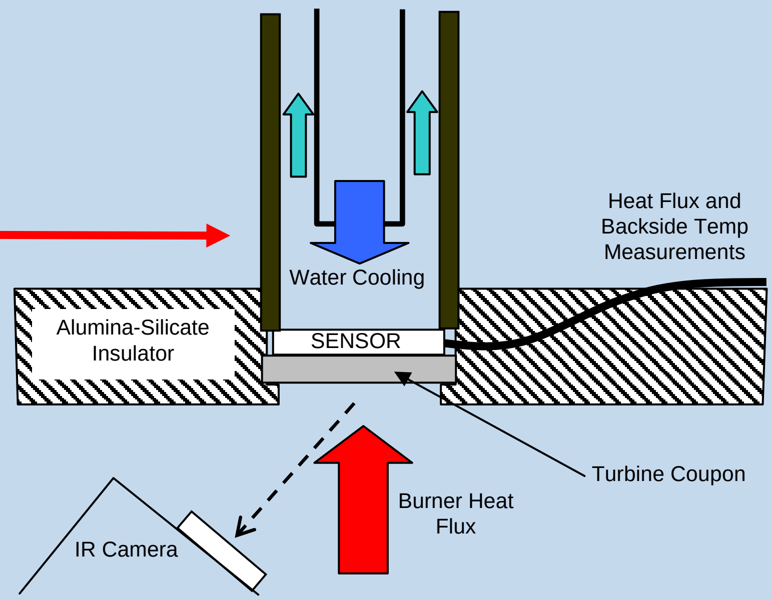
Ash Penetration Into TBC



Thermal Conductivity Measurements

Goal: Measure change in effective thermal conductivity due to deposit





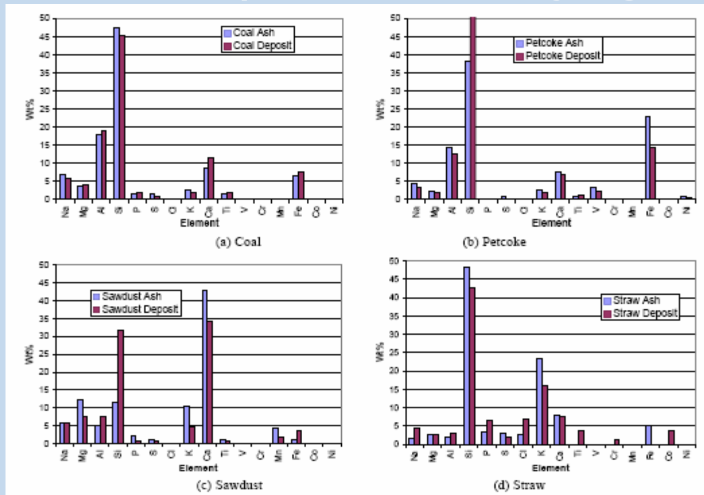
Measurements:

- Burner-side temperature with IR camera
- Cool-side heat flux and temperature with thermocouples and heat flux sensor

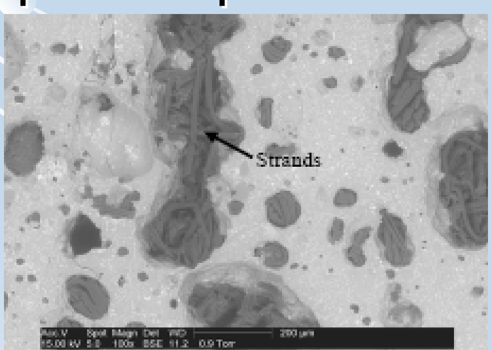
Technical Results to Date

(uncooled coupons)

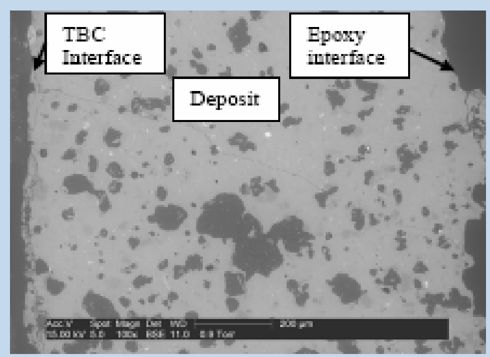
- Compare deposit composition to syngas flyash composition



- Compare deposit cross sections with ESEM



Petroleum coke flyash deposit



Coal flyash deposit

Project Summary

- Deposits in accelerated facility (4 hrs) match accumulated deposits in industrial facilities (8000-25,000 hrs)
- Synfuel deposits generated to date show fuel-type dependence
  - Composition is fuel-type dependent
    - Enhanced deposition of unique elements (e.g., Fe for petcoke, Ca for sawdust)
    - Deposition in TBC cracks has different composition than deposit on surface
  - Physical structure is also fuel-type dependent
    - Strands detected in voids in petcoke flyash deposit
- Making progress on thermal conductivity measurement
- Redesign of facility for cooled coupons is underway
- Work on deposits around film cooling holes will start in year two