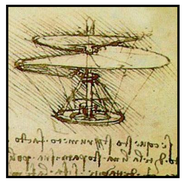

Ash Deposition on Nozzle Guide Vanes

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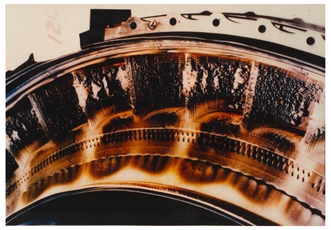
Background

Growing dependency on crude oil for locomotion and power generation is on a constant rise. However, prices keep rising and supply keeps shrinking. New technology that enables us to liquefy and gasify coal into useable fuel for gas turbines is a promising alternative.

Coal ash is a widely available and relatively cheap fuel source. Unfortunately, it also contains particulate that can damage turbomachinery. Ash deposition in the hot sections of a turbine engine can weaken performance over time, and may potentially cause catastrophic failure.

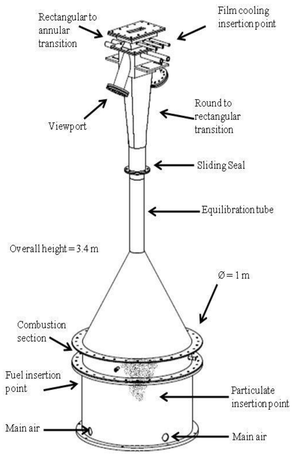


Ash Deposition on Nozzle Guide Vanes Dunn et al. (1996)

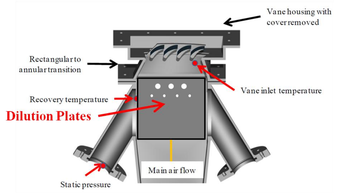
Experimental Facility: TuRFR

The OSU deposition cascade facility (Turbine Reacting Flow Rig or TuRFR) is designed with a natural gas burning combustor and metered particulate injection. The facility can operate at gas temperatures up to 1200C, equivalent to F-class engine hardware. Various coal ash samples (bituminous, lignite and sub-bituminous) are used as particulate. The TuRFR accommodates the positioning of multiple passages of actual engine hardware at the combustor exit.

- The facility has the capability to provide coolant for internal and film cooling. An external heater allows for the regulation of the coolant's temperature if necessary.
- The main ash injection site is in the combustion section to create external deposition on the test articles. It is also possible to inject ash through the cooling lines to study internal deposition in the test articles.
- A dilution zone has also been designed with interchangeable side plates to create different pattern factors and turbulence levels.
- Lower and upper portions of the TuRFR are joined at the sliding seal which allows the facility to smoothly undergo thermal expansion.

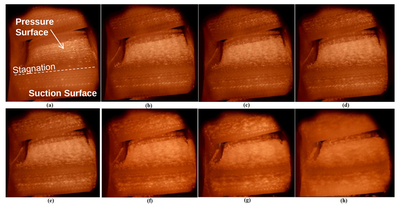


TuRFR Schematic

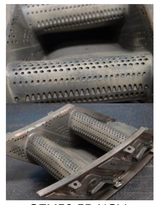


TuRFR Upper Portion

Deposition on Nozzle Guide Vanes: Transient Results



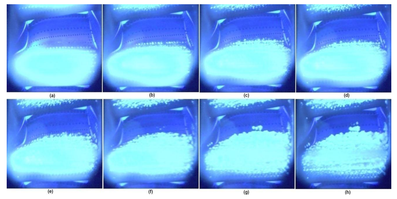
Development of JBPS Deposit, Large Stokes Number, without Film Cooling, 292 g injected: (a) + 1 min (b) +2 min (c) +3 min (d) +5 min (e) +7 min (f) +13 min (g) +20 min (h) +30 min



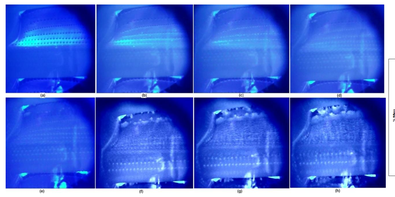
CFM56-5B NGV

Statistical Values for JBPS Fly Ash (microns)

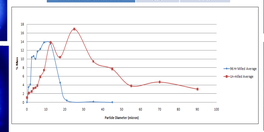
	96 hours	Un-milled
Mean Diameter	6.8	24.4
Modal Diameter	8.2	27.0
Median Diameter	5.9	17.6



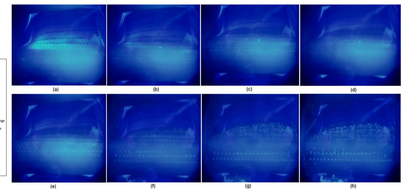
Development of JBPS Deposit, Large Stokes Number, with Film Cooling, 163 g injected: (a) + 1 min (b) +2 min (c) +4 min (d) +5 min (e) +7 min (f) +13 min (g) +20 min (h) +30 min



Development of JBPS Deposit, Small Stokes Number, without Film Cooling, 256 g injected: (a) + 1 min (b) +2 min (c) +4 min (d) +5 min (e) +7 min (f) +13 min (g) +20 min (h) +30 min



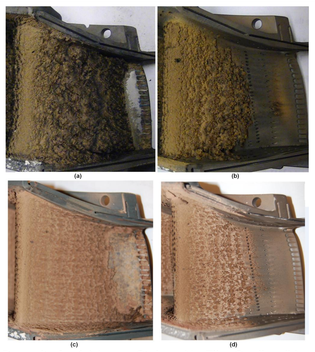
Averaged Particle Size Distributions for JBPS Coal Fly Ash



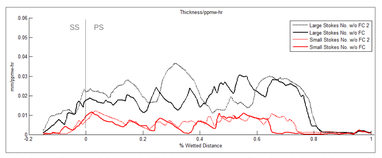
Development of JBPS Deposit, Small Stokes Number, with Film Cooling, 195 g injected: (a) + 1 min (b) +2 min (c) +3 min (d) +5 min (e) +7 min (f) +13 min (g) +20 min (h) +30 min

- In the tests with no cooling, ash deposition begins in the cooling holes downstream of the stagnation region and slowly moves upstream. Large Stokes number tests show faster accumulation and much thicker deposits.
- In tests with 9% film cooling, deposit formation begins in the stagnation region, inside the cooling holes. Deposits grow thicker and expand downstream, up to 60% chord, on the pressure surface throughout the test. Again, large Stokes number tests develop thicker deposits.

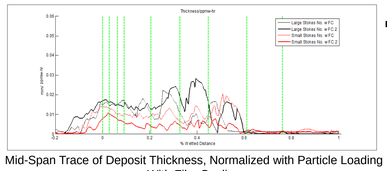
Deposition on Nozzle Guide Vanes: Simulation Results



Deposits for (a) Large Stokes, No Film Cooling (b) Large Stokes w/ Film Cooling (c) Small Stokes No Film Cooling (d) Small Stokes w/ Film Cooling Tests



Mid-Span Trace of Deposit Thickness, Normalized with Particle Loading No Film Cooling

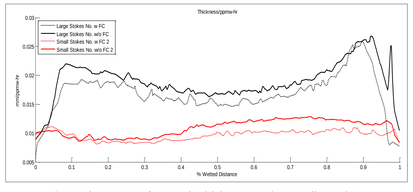


Mid-Span Trace of Deposit Thickness, Normalized with Particle Loading With Film Cooling

Deposit thickness distribution data of the deposits was acquired from laser scans

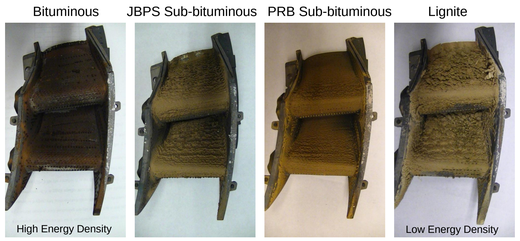
- Mid-span traces of the deposits were normalized by the particle loading for each individual test to account for variations of ash injected.
- The traces for the cooled cases indicate a periodicity of the deposit peaks with respect to the film cooling rows. Spacing between peaks is consistent to the cooling row spacing.

- Tests with the un-milled ash display thick deposits with large scale structures. Low Stokes test show thinner accumulations with small scale deposition.
- Film cooling also reduced the accumulation amount by reducing the area covered by ash. It also adds periodic roughness with respect to the film cooling rows.



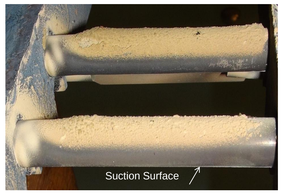
Spanwise Trace of Deposit Thickness at the Leading Edge

Deposition on NGVs: Different Ash Types



Different ashes deposit differently on the vane's surface. Bituminous ash which is the highest rank coal ash and has the highest melting temperature generates the thinnest deposits. Lignite accumulated the largest deposits due to its lower melting point. The molten ash particles have a higher probability of sticking.

Modeling NGV LE Deposition with Faired Cylinders



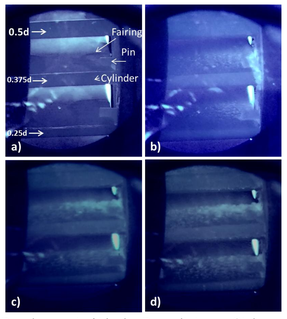
Cyl.	Conditions	Vane
0.5	LE Dia. (in)	0.75
Yes	Internal Cooling	No
No	Film Cooling	No
2000	Flow Temp (°F)	1975
0.8	Mass flow (lbm/s)	0.8
Lignite	Ash Type	JBPS
Large	Stokes	Small

Cylinder design to simulate NGVs:

- Diameters available: 0.25, 0.375, 0.5
- Fairing to reduce unsteady flow features
- Internal cooling possible
- Film cooling, with modification, possible

Under certain conditions deposition on the cylinders mimic that of an actual NGV

- Deposition diminishes to zero towards the suction side.
- Roughness is similar to a vane with no cooling.
- Transient results show deposition begins on the pressure surface.



Development of Lignite Deposit, Large Stokes Number, No Cooling: (a) 0 min, (b)+2 min, (c) +4 min, (d) +10 min after ash injection

Current/Future Work

Current and future research includes

- Increasing film cooling from 9% to 12% on the CFM56 NGV
- Internal deposition on cooled vanes
- Determine validity of modeling NGV LE with faired cylinders
- Study effect of pattern factor and turbulence level on deposition
- Validate CFD by using a less complex NGV model