Particle Size, Gas Temperature, and Impingement Cooling Effects on High Pressure Turbine Deposition in Land Based Gas Turbines from Various Synfuels

Presented by: Jared Crosby

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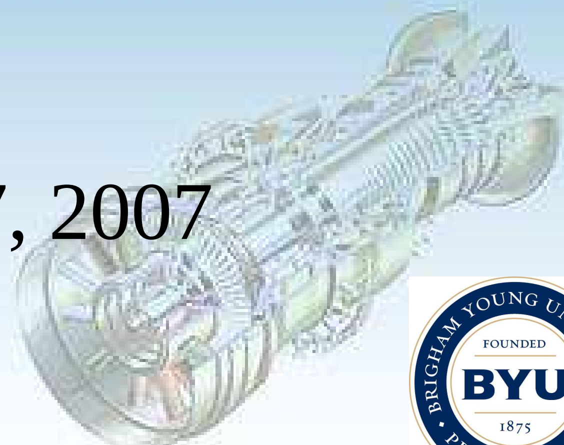

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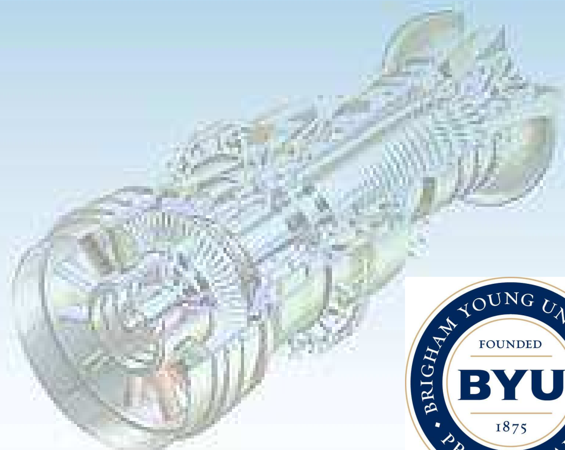

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Introduction: The Problem of Deposition

Contaminates from the air form deposits on the turbine blades:

Before…

After

A roughened surface experiences higher values of *h* than a smooth one

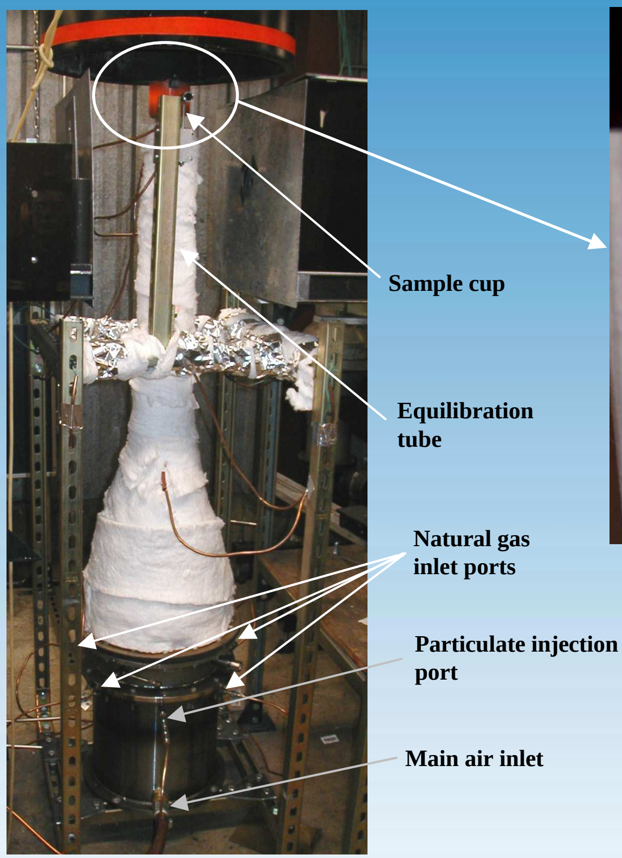
Introduction: Search for Alternative Fuels

- Due to current economic and political pressures, alternate fuels such as coal, petcoke, and biomass are being considered to produce substitute syngas fuels to replace natural gas in power turbines.
- Coal and petroleum derivative fuels are already being used at a handful of gas turbine power plants worldwide.
- Studies of potential sources of deposition from these syngas fuels necessary so adverse effects can be minimized.
- Deposition has numerous adverse results ranging from decreased engine performance to catastrophic failure of the blades.

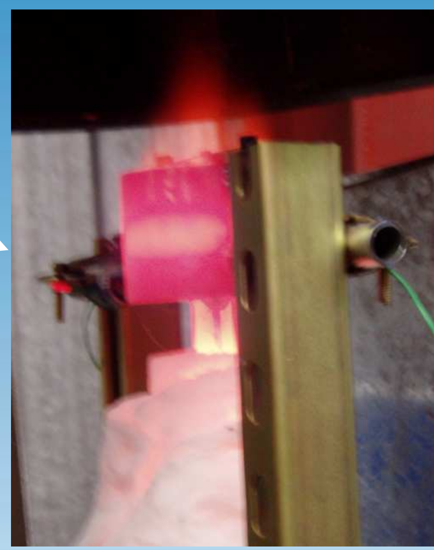
Turbine Accelerated Deposition Facility (TADF) Origins/Validation

•Real turbine blades cannot be economically obtained from industry because of the high cost of shutting down the engine

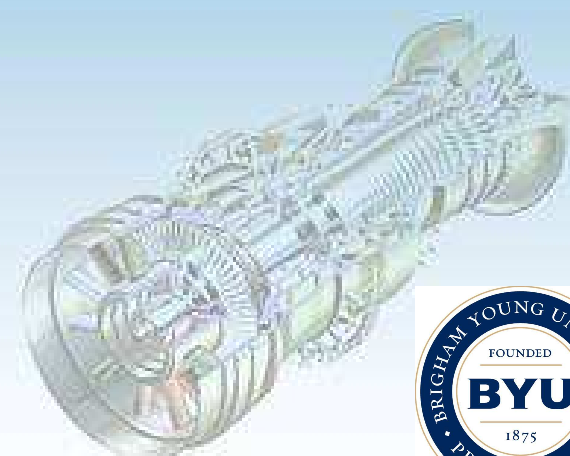
•Jensen, J.W., Squire, S.W., Bons, J.P., and Fletcher, T.H., "Simulated Land-Based Turbine Deposits Generated In An Accelerated Deposition Facility". *ASME Journal of Turbomachinery*. Vol. 127, pp. 462-470, July 2005.



TADF



End Result



Turbine Accelerated Deposition Facility (TADF) Origins/Validation

To simulate long periods of time, ppmw–hr is matched:

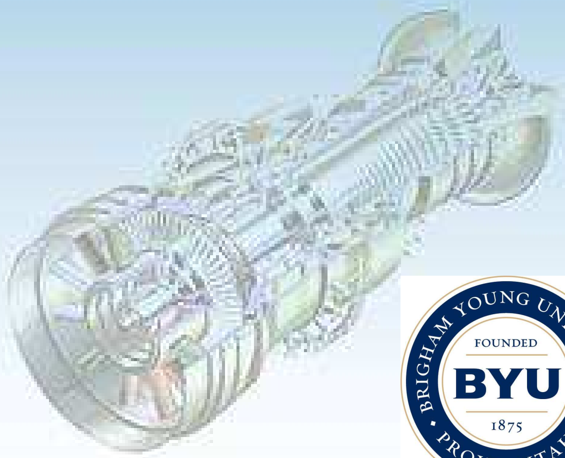
Example

A real turbine can experience 0.01-0.02ppmw for 8000hrs (~1 year):

0.01-0.02ppmw * 8000hrs = 80-160ppmw-hr

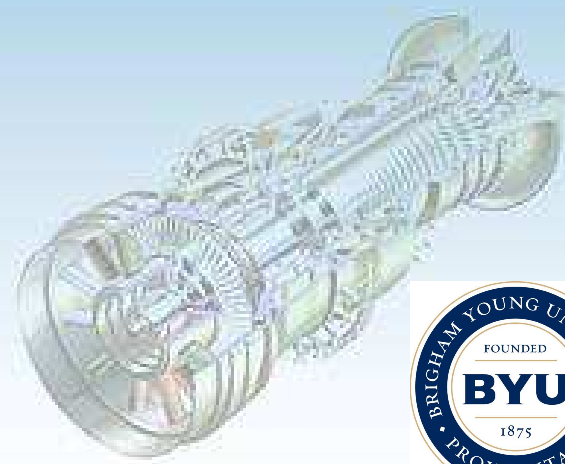
To simulate with a 4 hour test:

80-160ppmw-hr / 4hrs = <u>20-40ppmw</u>



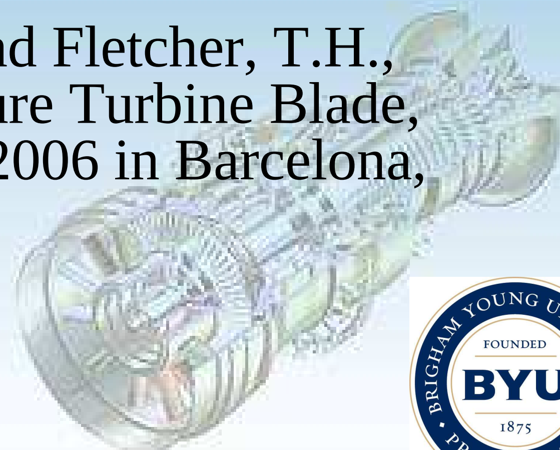
Turbine Accelerated Deposition Facility (TADF) Origins/Validation

- Jensen et al found that by matching Mach #, Exit temperature, and particle loading, simulated deposits were comparable to real hardware in all essential aspects which govern heat transfer (surface roughness, deposit thickness, structure, and elemental composition).



Turbine Accelerated Deposition Facility (TADF)
Previous Studies

- Jensen, J.W., Squire, S.W., Bons, J.P., and Fletcher, T.H., “Simulated Land-Based Turbine Deposits Generated In An Accelerated Deposition Facility”. *ASME Journal of Turbomachinery*. Vol. 127, pp. 462-470, July 2005.
- Bons, J.P., Crosby, J., Wammack, J.E., Bentley, B.I., and Fletcher, T.H., 2007, “High Pressure Turbine Deposition in Land-Based Gas Turbines with Various Synfuels,” *Journal of Engineering for Gas Turbines and Power*, Jan 2007, pp. 135-143.
- Wammack, J.E., Crosby, J., Fletcher, D., Bons, J.P., and Fletcher, T.H., 2006, “Evolution of Surface Deposits on a High Pressure Turbine Blade, Part I: Physical Characteristics,” presented at IGTI 2006 in Barcelona, Spain, May 2006, #GT2006-91246.
- Bons, J.P., Wammack, J.E., Crosby, J., Fletcher, D., and Fletcher, T.H., 2006, “Evolution of Surface Deposits on a High Pressure Turbine Blade, Part II: Convective Heat Transfer,” presented at IGTI 2006 in Barcelona, Spain, May 2006, #GT2006-91257.



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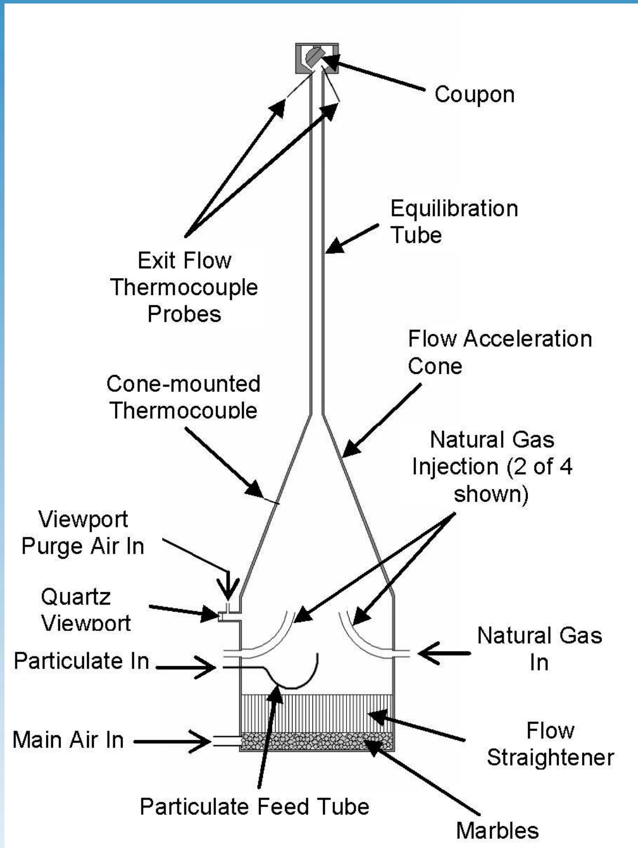
Modifications to the TADF

Before



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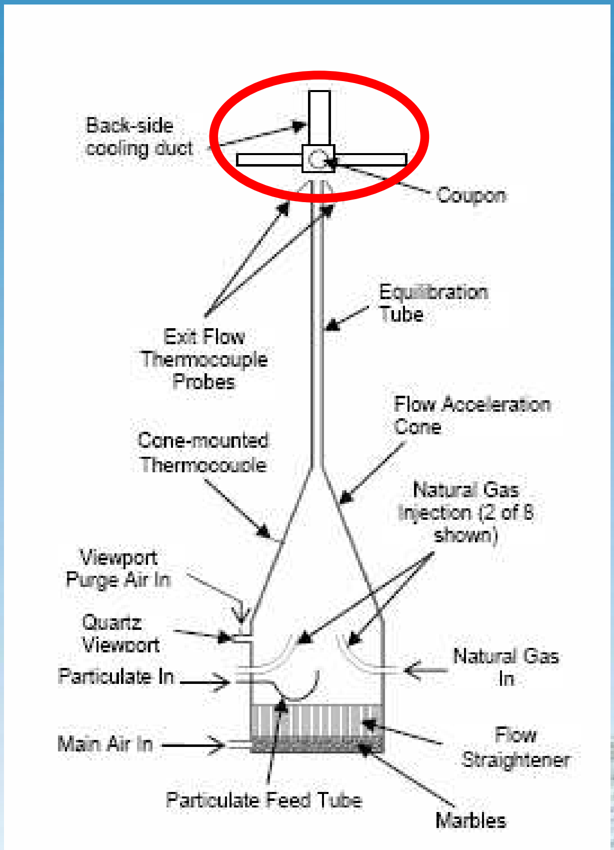
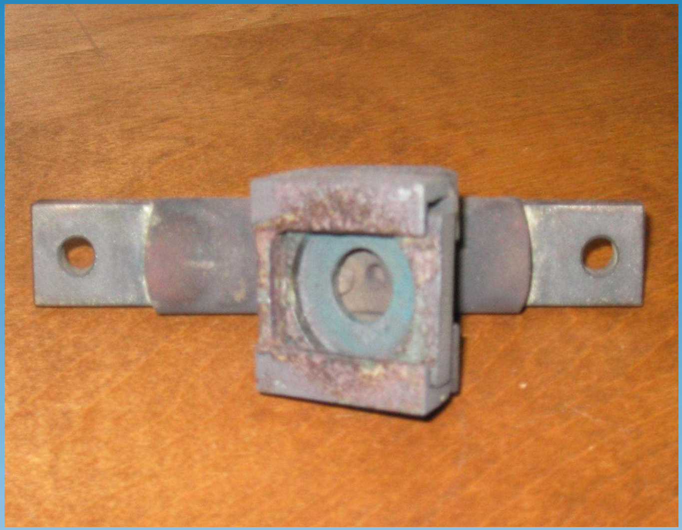
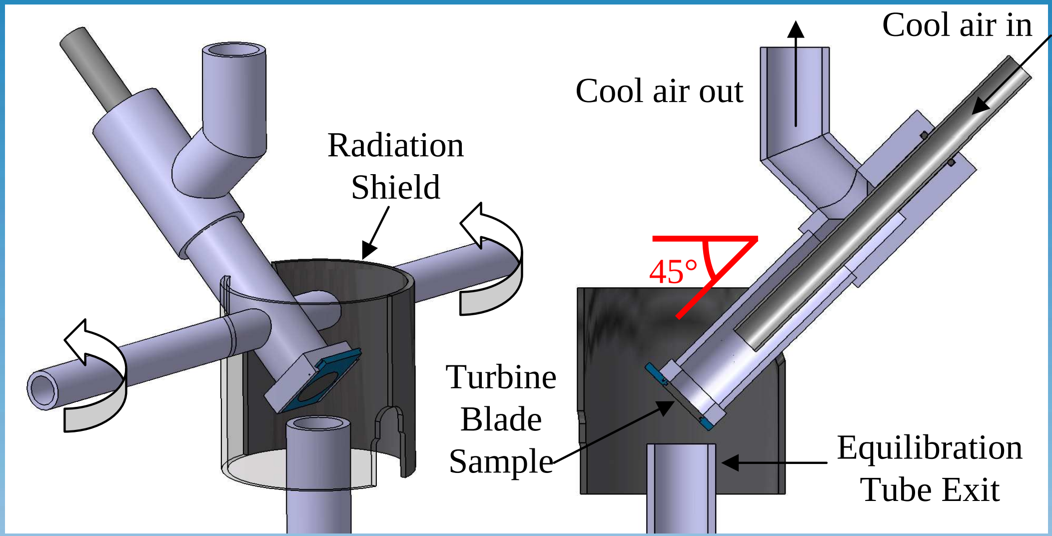


Modifications to the TADF

Before



After



- Impingement cooling more accurately simulates real engine thermal gradients
- Setup can be adapted for film cooling studies
- Optical access allows for surface temperature measurement and filming of deposit formation
- New particle feed system improved repeatability

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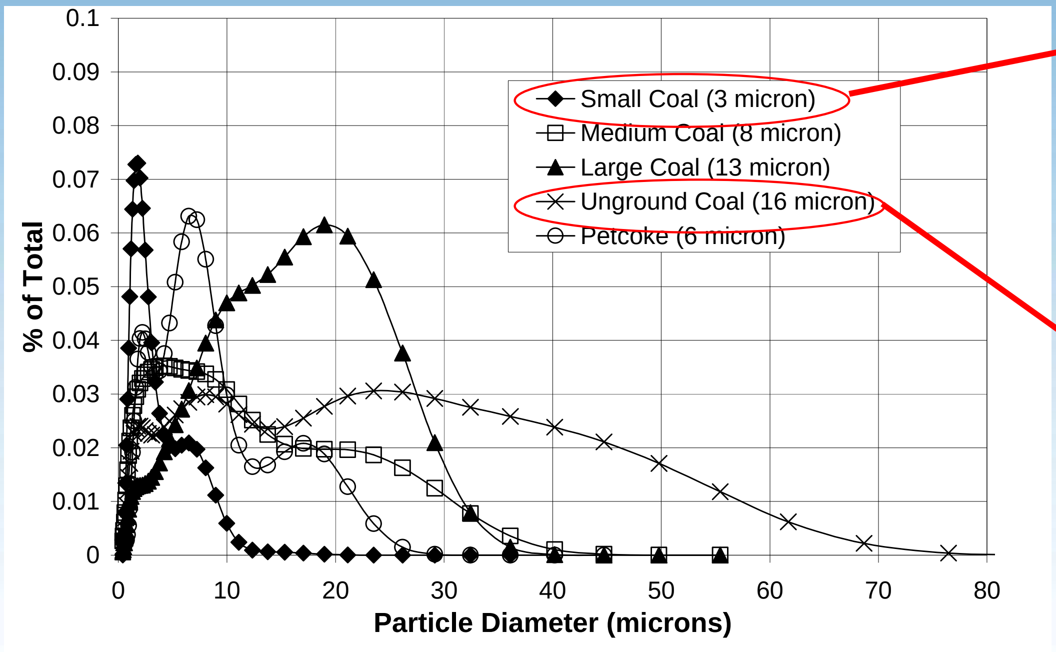
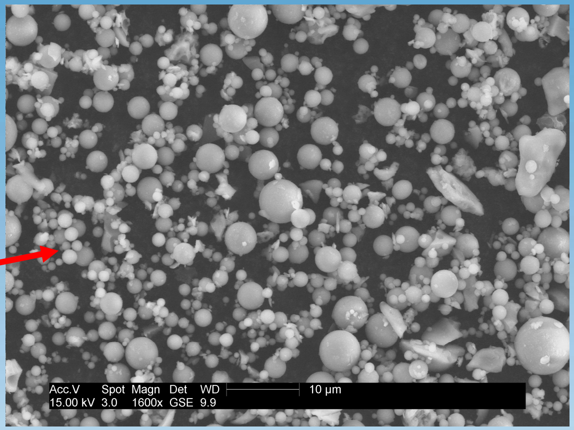
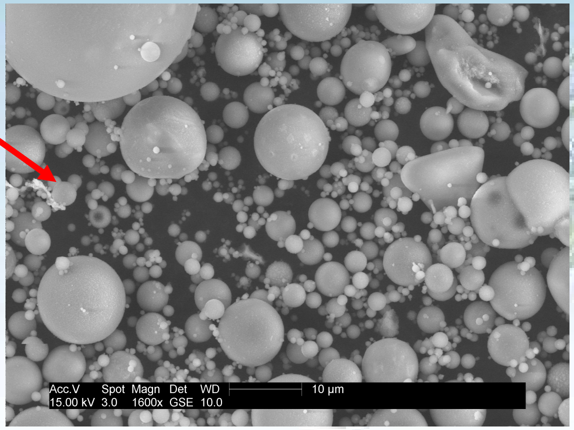
Synfuels Studied

- Subbituminous coal fly ash obtained from a power plant
- Petcoke (petroleum byproduct) boiler slag obtained from a power plant
- Synfuels mechanically ground to small particle sizes which can pass through filtration systems







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Research Conducted

- Movie
- Gas Temperature Series
  - Gas temperature was varied from 1183°C to 860°C using subbituminous coal particulate
- Particle Size Series
  - Four different particle sizes of subbituminous coal particulate were tested (from 3 to 16 μm diameter)
- Impingement Cooling Series
  - Four mass flows of coolant were tested using subbituminous coal particulate
  - Two mass flows of coolant were tested using petcoke particulate

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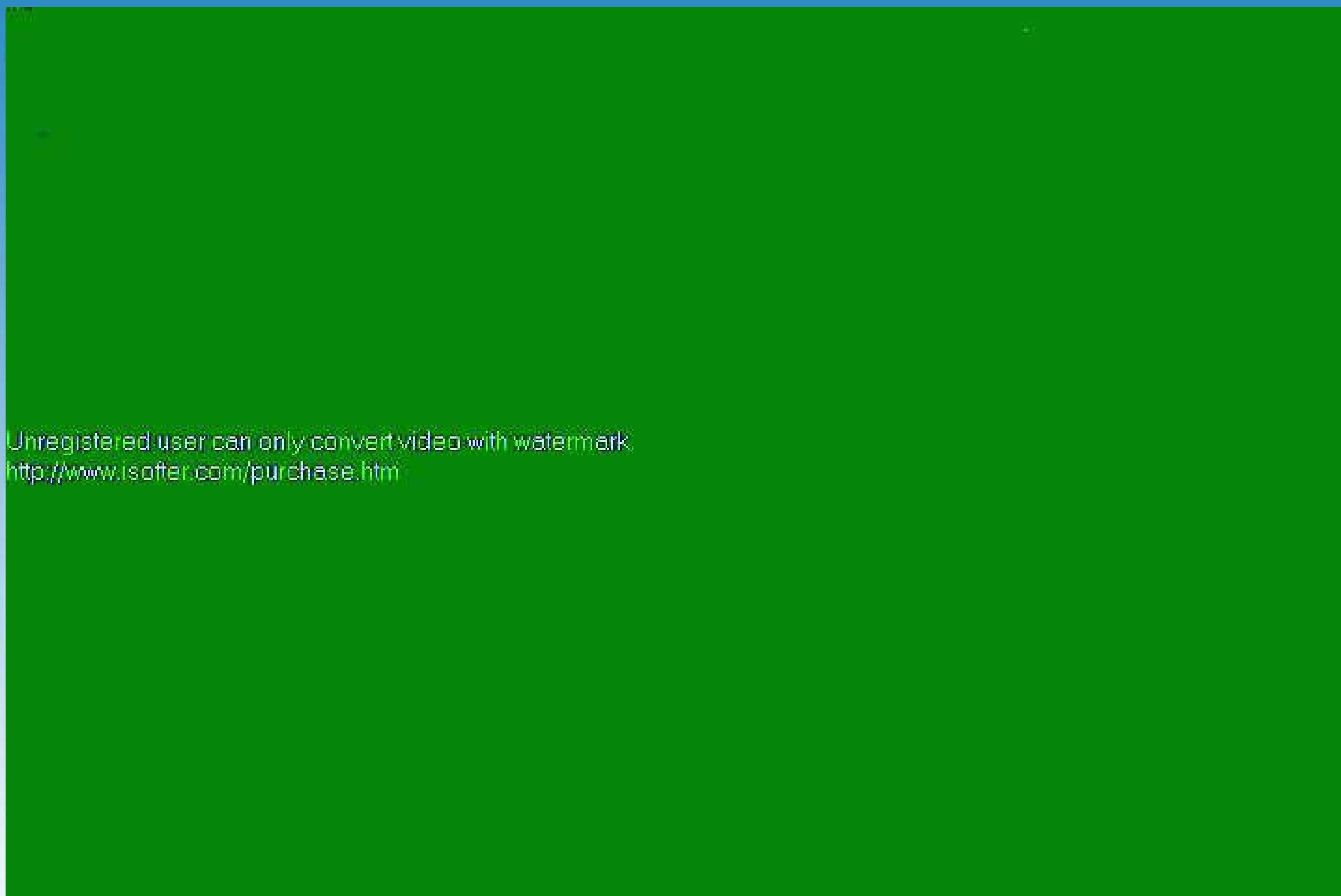
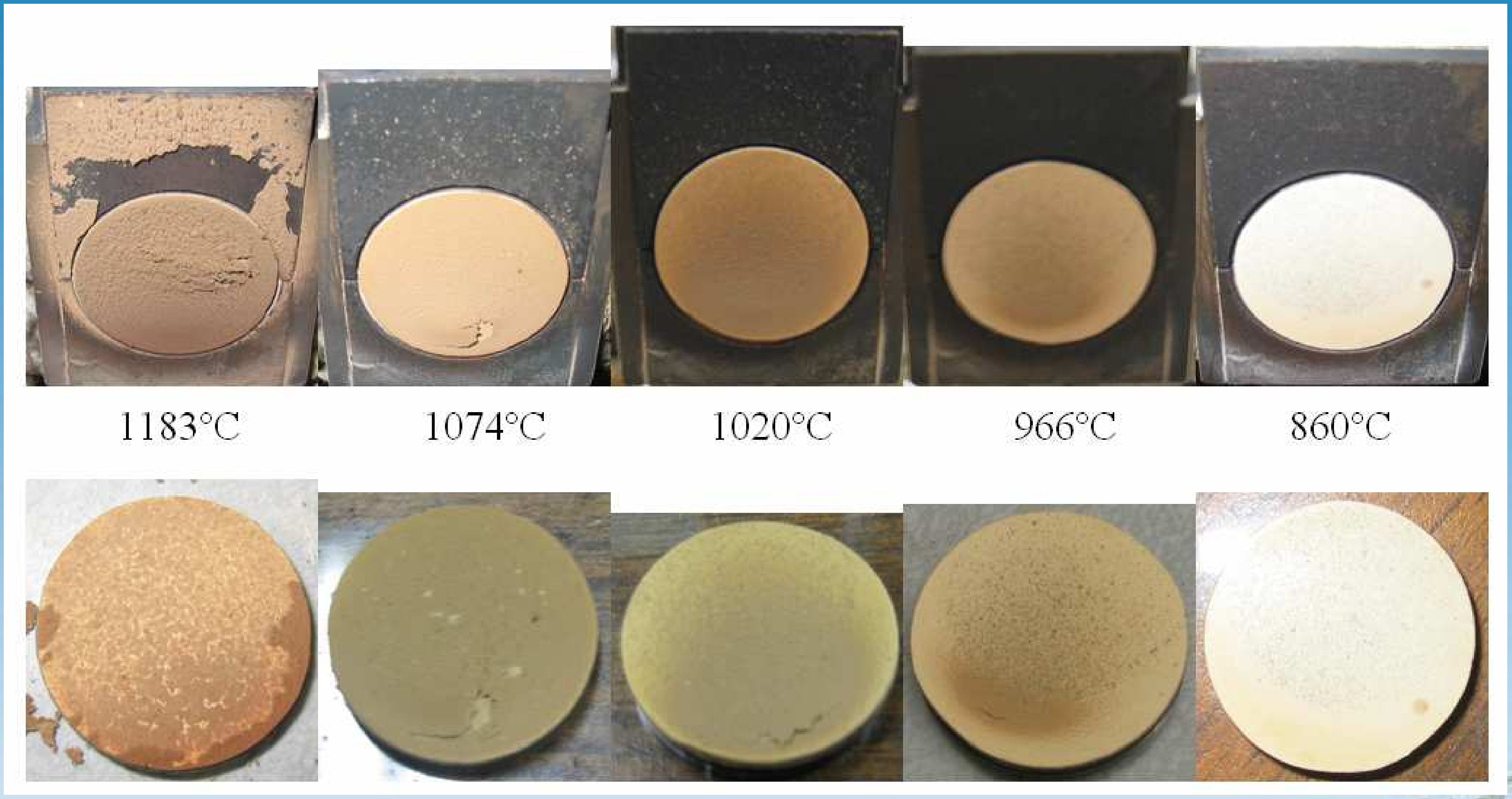
Movie


Unregistered user can only convert video with watermark
http://www.isofter.com/purchase.htm

Gas Temperature Series



Digital images of post burn coupons (top shows coupons immediately after combustor shutdown while bottom shows coupons after they have cooled to room temperature)

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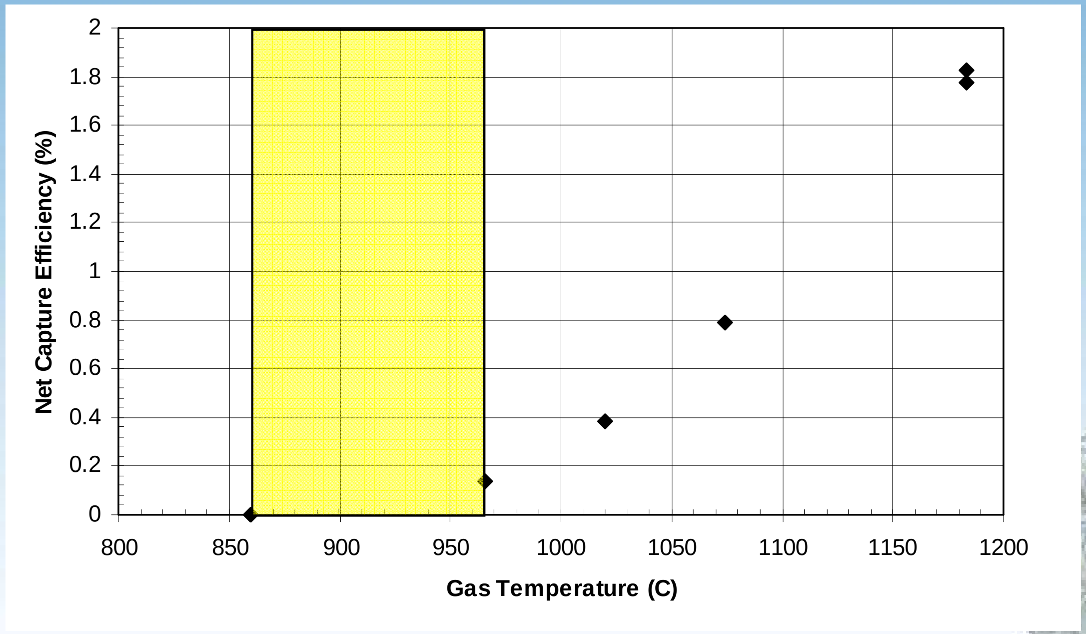
Gas Temperature Series

Table 3: Deposition results from gas temperature test series

Gas Temperature [°C]	Preburn Button Mass [g]	Button Mass Change [mg]	Separated Deposit Mass [mg]	Separated Deposit %	Net Deposit Mass [mg]	Deposition Rate [mg/cm²hr]	Net Particulate Mass [mg]	Net Capture Efficiency [%]
1183	13.66	40	100	71	140	6.91	7880	1.78
1183	13.66	40	110	73	150	7.4	8220	1.82
1074	13.64	60	0	0	60	2.96	7590	0.79
1020	13.64	30	0	0	30	1.48	7820	0.38
966	13.69	10	0	0	10	0.49	7360	0.14
860	13.62	0	0	0	0	0	7860	0

Deposition Rate =

net deposit mass divided by the exposed coupon surface area and the test duration



Net Capture Efficiency =

mg/hr of deposit divided by mg/hr of particulate added to the flow

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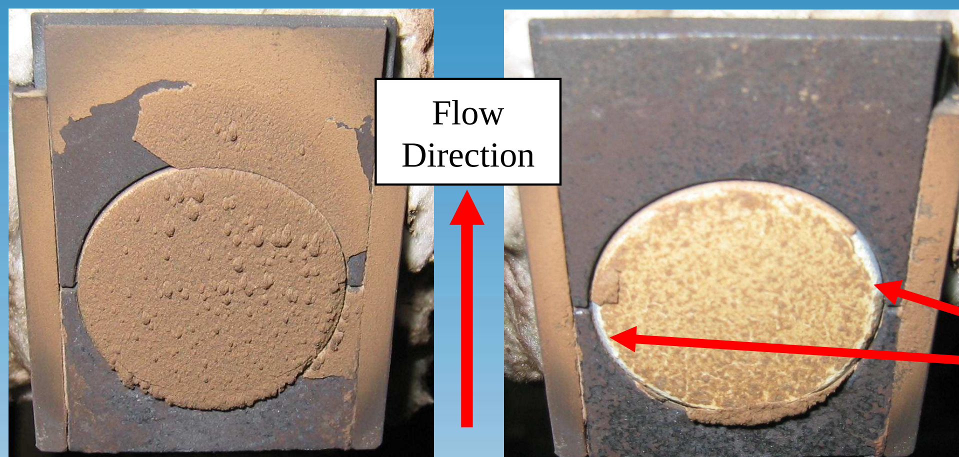
Particle Size Series



Spallation-loss of the TBC layer leaving the metal exposed

Post test images of coupon subjected to 13 μm particle size (left shows coupon immediately after combustor shutdown, right image is following cool down to room temperature)

•This test series had a 1 hour “pre-burn” prior to the 4 hour test

•The deposition rate and net capture efficiency were doubled compared to the gas temperature series test conducted at the same temperature and with the same particle size

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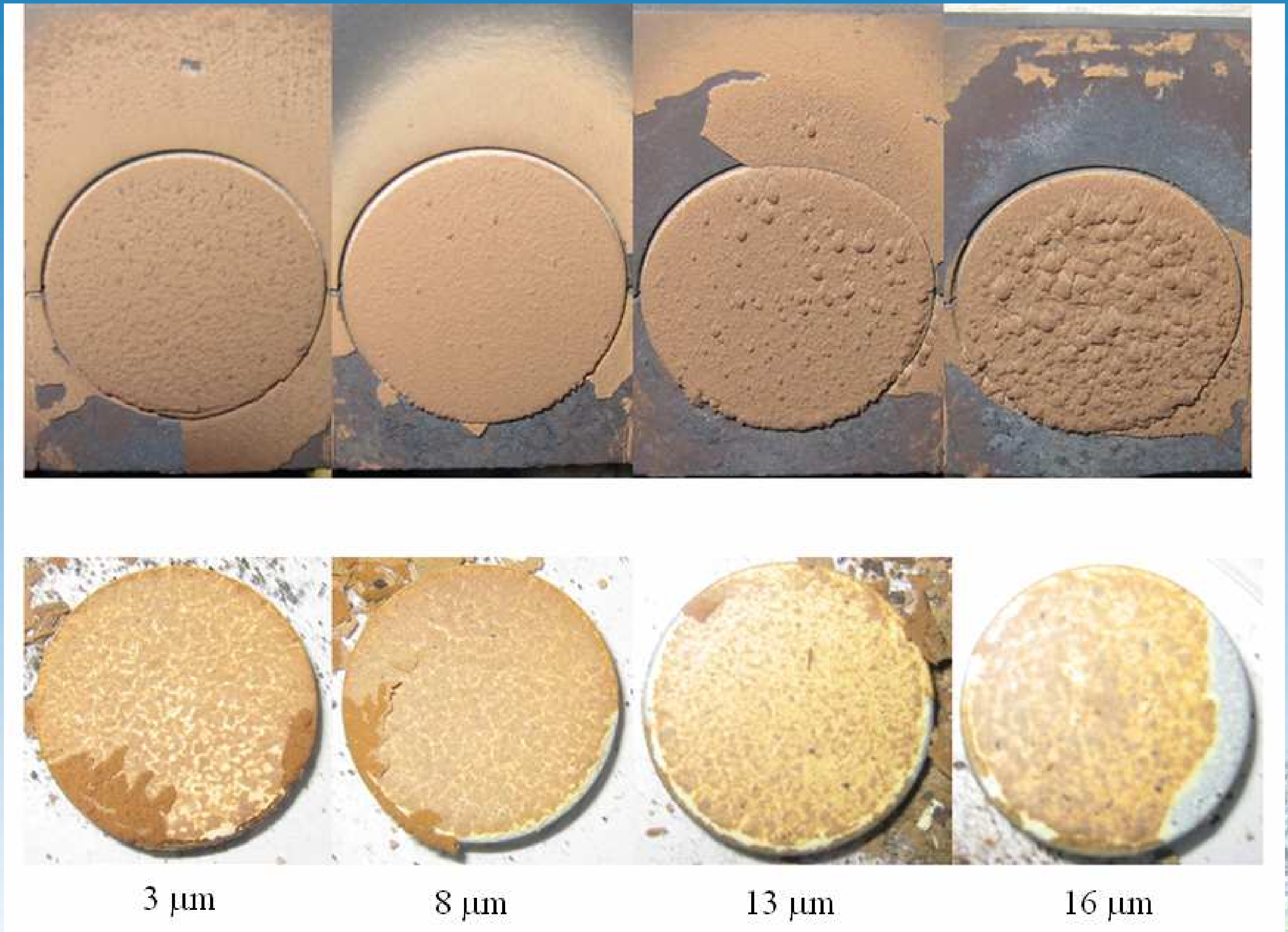
Particle Size Series

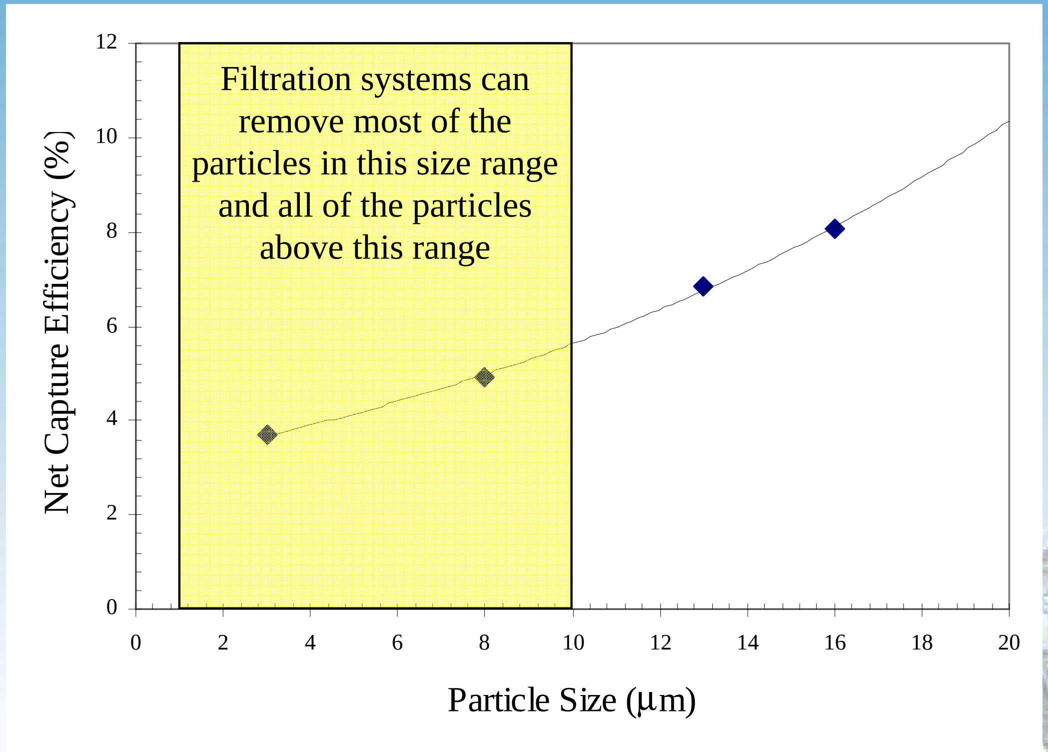


Digital images of post burn coupons (top is immediately following combustor shutdown, bottom is after cool down to room temperature)

Particle Size Series

Table 2: Deposition results from particle size test series.

Particle Size [µm]	Preburn Button Mass [g]	Button Mass Change [mg]	Separated Deposit Mass [mg]	Separated Deposit %	Net Deposit Mass [mg]	Deposition Rate [mg/cm²hr]	Net Particulate Mass added to flow [mg]	Net Capture Efficiency [%]
3	14.73	70	300	81	370	14.6	10050	3.68
8	14.88	60	450	88	510	20.13	10350	4.93
13	14.12	-10	880	101	870	34.34	12720	6.84
16	14.99	-140	1220	113	1080	42.63	13390	8.07



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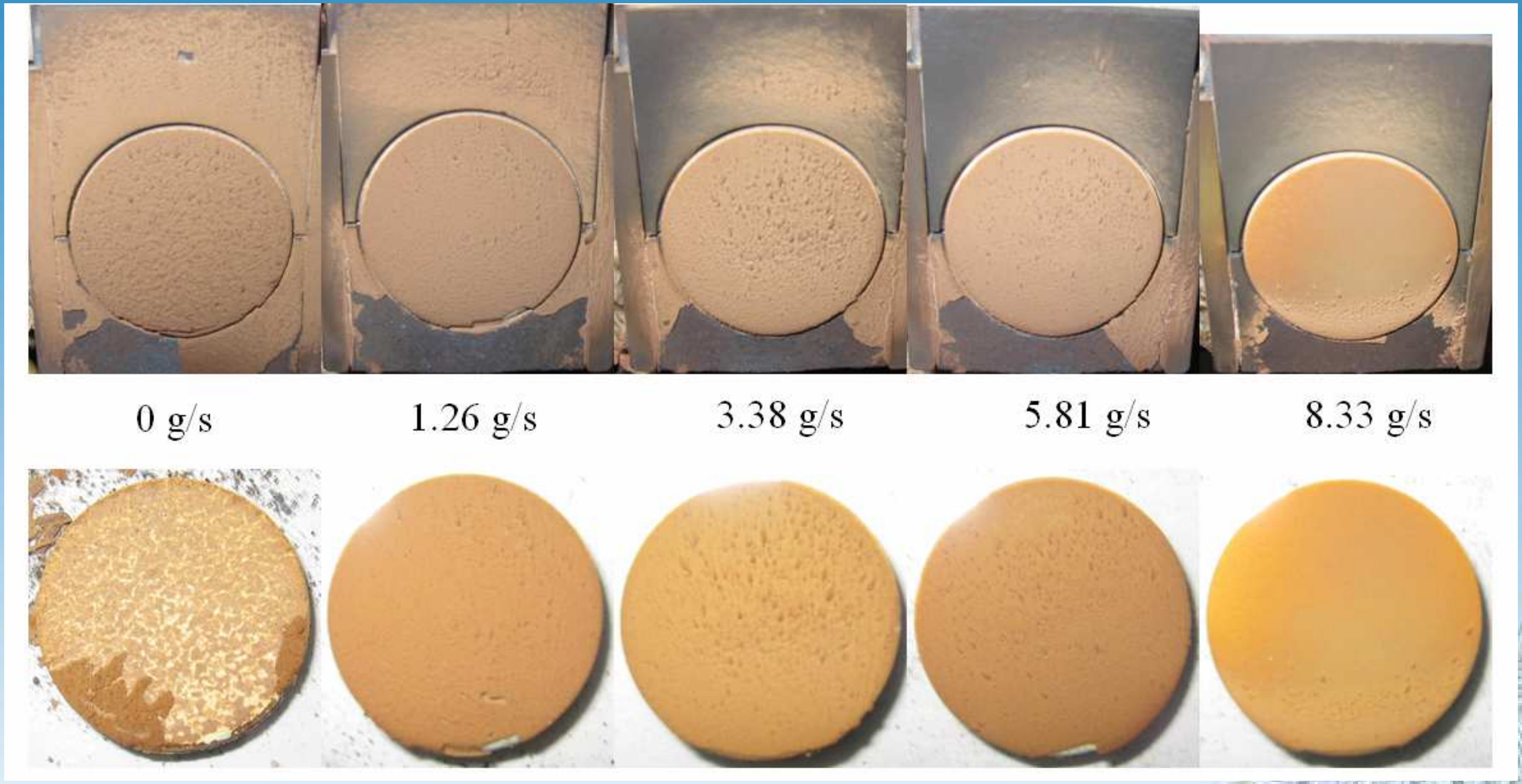
Subbituminous Coal Impingement Cooling Series



Digital images of post burn coupons (top is immediately following combustor shutdown, bottom is after cool down to room temperature)

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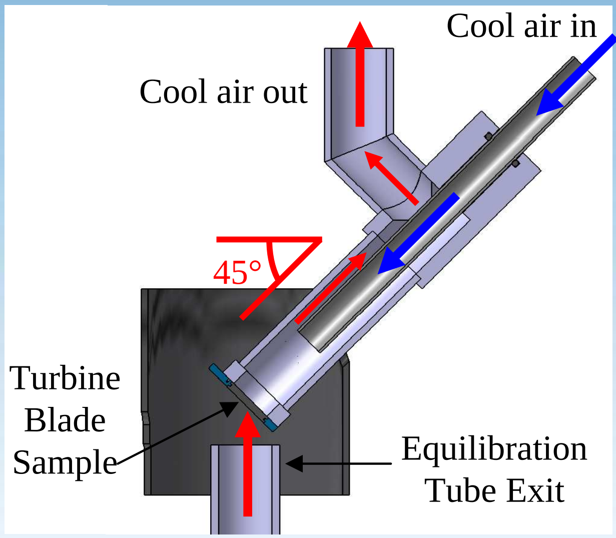
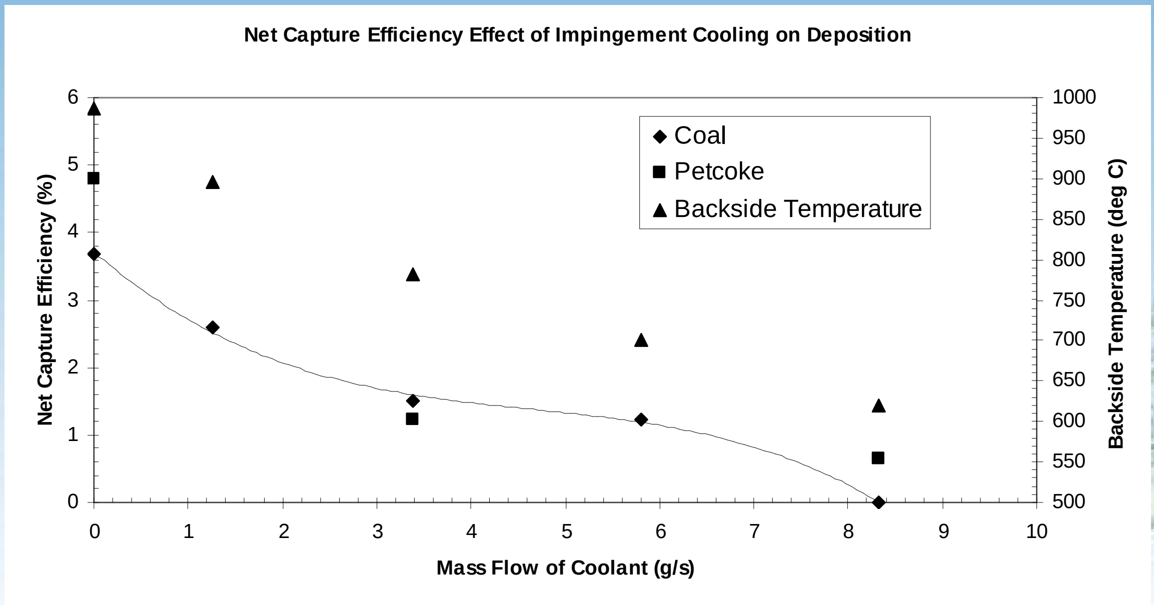
Subbituminous Coal Impingement Cooling Series

Table 4: Deposition results from impingement cooling test series using subbituminous coal

Mass flow of Coolant [g/s]	Heat Flux [kW/m²]	Preburn Button Mass [g]	Button Mass Change [mg]	Separated Deposit Mass [mg]	Separated Deposit %	Net Deposit Mass [mg]	Deposition Rate [mg/cm²hr]	Net Particulate Mass [mg]	Net Capture Efficiency [%]
0	0	14.73	70	300	81	370	14.6	10050	3.68
1.26	500.68	30.56	130	90	41	220	8.68	8480	2.59
3.38	1049.21	30.69	120	20	14	140	5.53	9270	1.51
5.81	1404.35	30.53	100	0	0	100	3.95	8120	1.23
8.33	1614.26	30.93	0	0	0	0	0	9540	0





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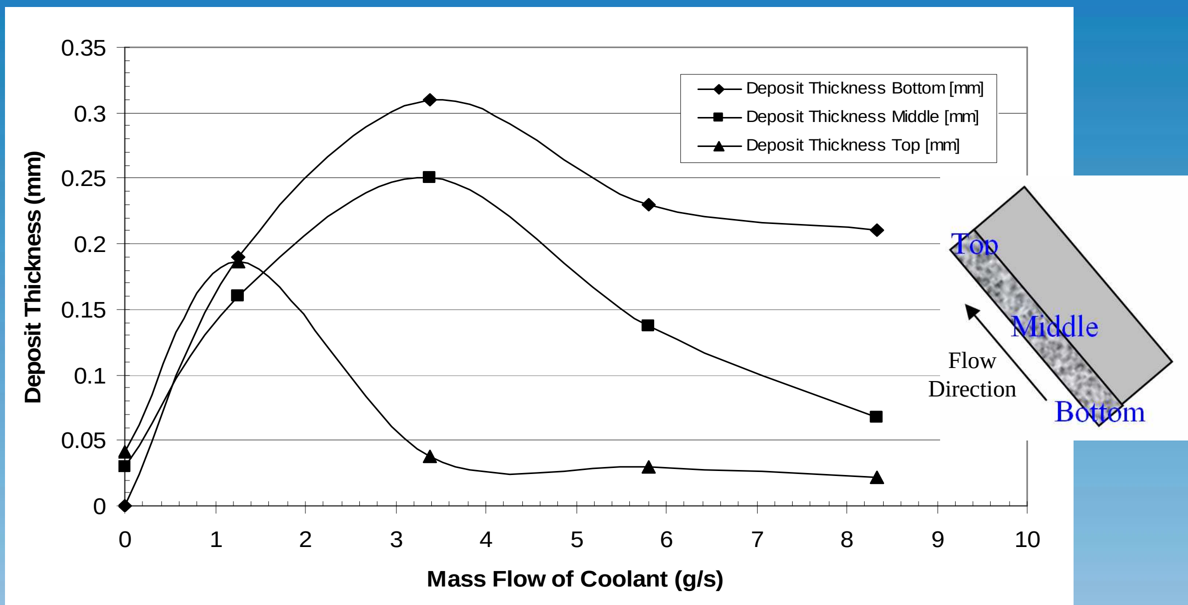
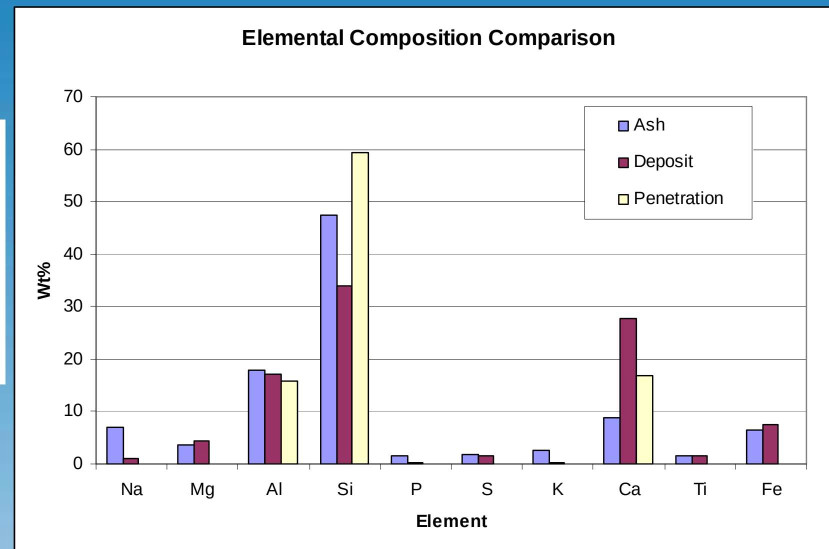
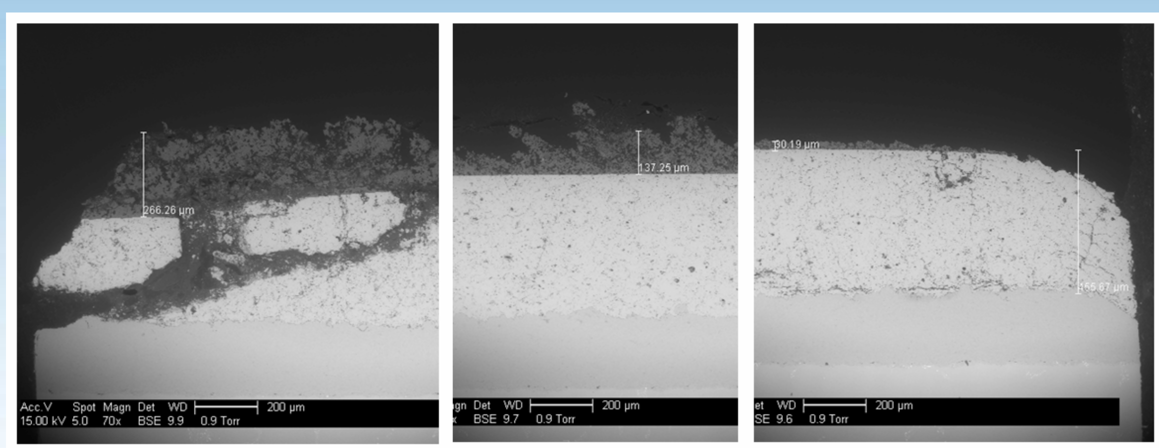
Subbituminous Coal Impingement Cooling Series ESEM Analysis





Elemental comparison of ash, deposit, and penetration for subbituminous coal impingement cooling series



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Typical image series of bottom (left), middle, and top (right) portions of 5.81 g/s coolant test sample

Conclusions

- Particle deposition rate was found to decrease with decreasing gas temperature. The threshold gas temperature for deposition using subbituminous coal was approximately 960°C. However testing with Eastern Coal found virtually no deposit at 1183°C.
- Testing with four different sizes of subbituminous coal ash particles showed greater than double the deposition rate as particle mass mean diameter was increased from 3 to 16μm.
- Ground subbituminous coal and petcoke ash particulates were used in the third and fourth test series with impingement cooling on the backside of the target coupon. Deposition rates decreased with increasing mass flow of coolant air, as expected.
- Post exposure analyses of the third test series (scanning electron microscopy and x-ray spectroscopy) show decreasing deposit thickness with increased cooling levels.

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Acknowledgements

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Questions?