Ash Fouling Free Regenerative Air Preheater for Deep Cyclic Operation

(DE-FE0031757)

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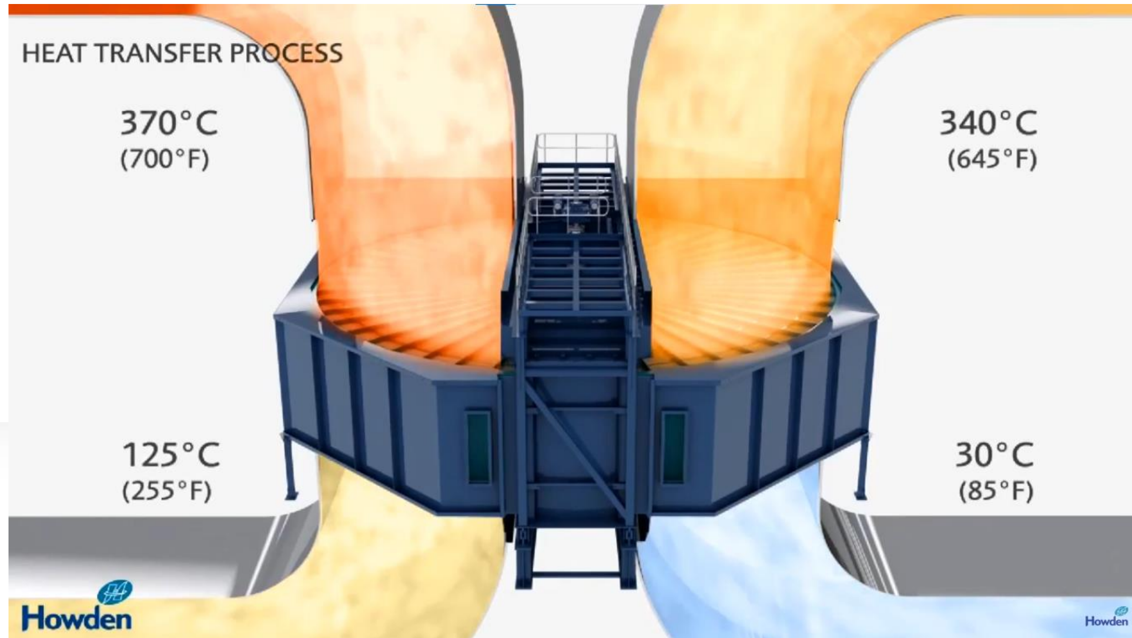
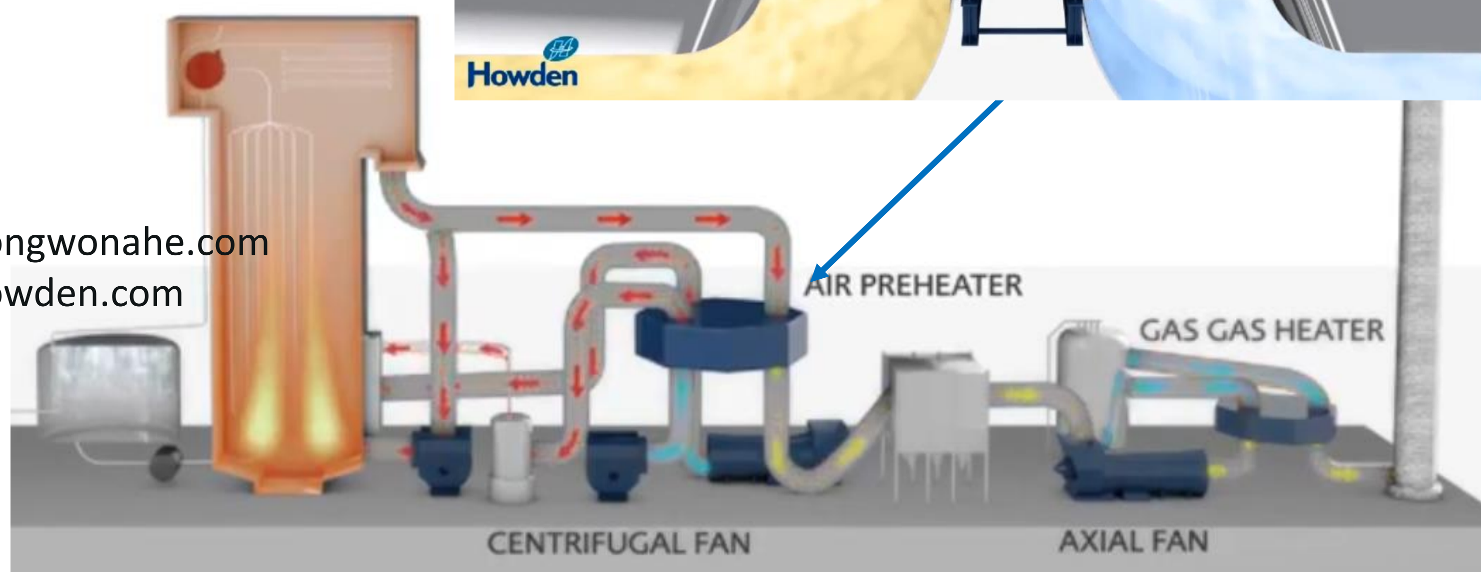
Outline

- Background and CAER Approach
- Ash Collection and Mechanism for Ash Fouling
- CAER Pilot APH
- Unit Assembly and Installation
- Conclusion

Background - Regenerative Air Preheater





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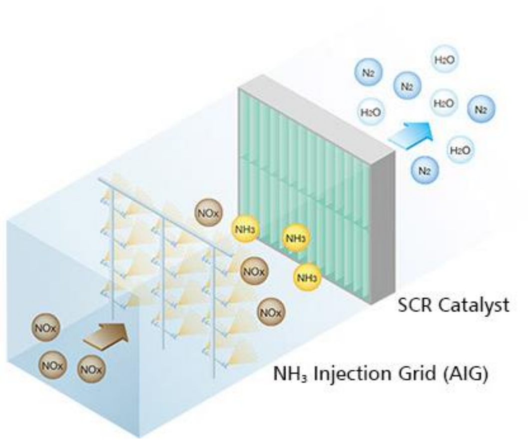
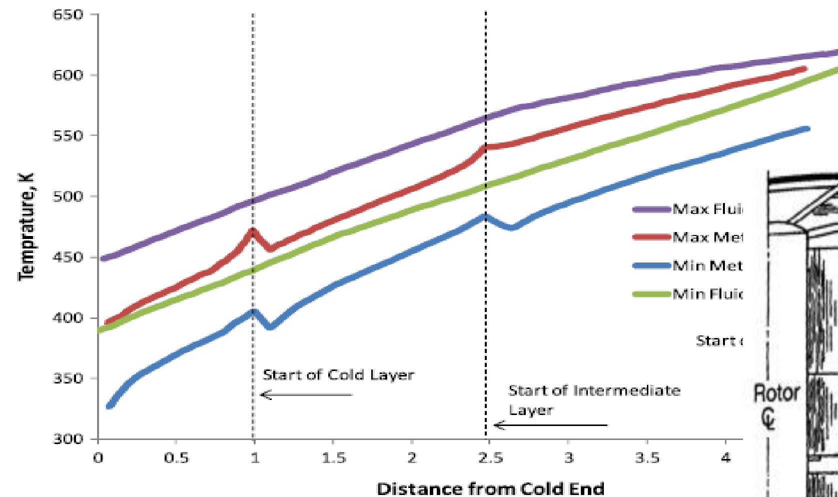
Ash Fouling Problem in Air Preheater During Cyclic Operation

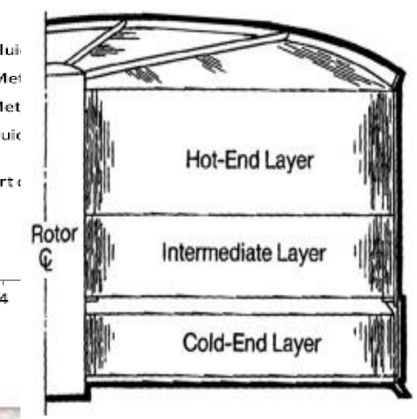


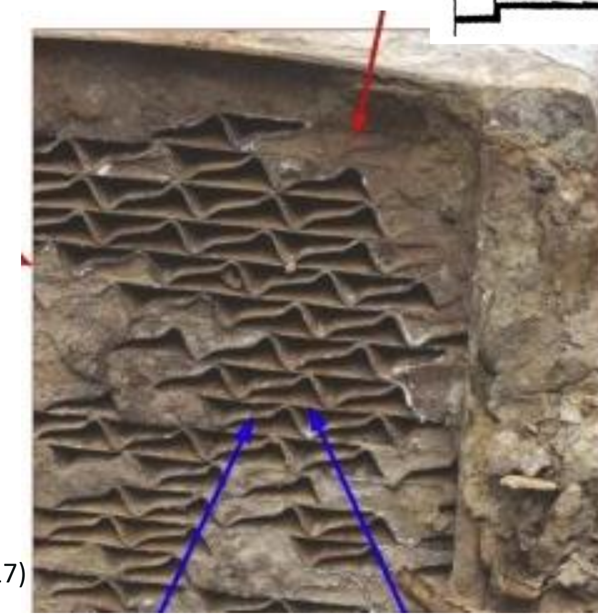
https://power.mhi.com/

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$NH_3 + SO_3 + H_2O \leftrightarrow NH_4HSO_4$$





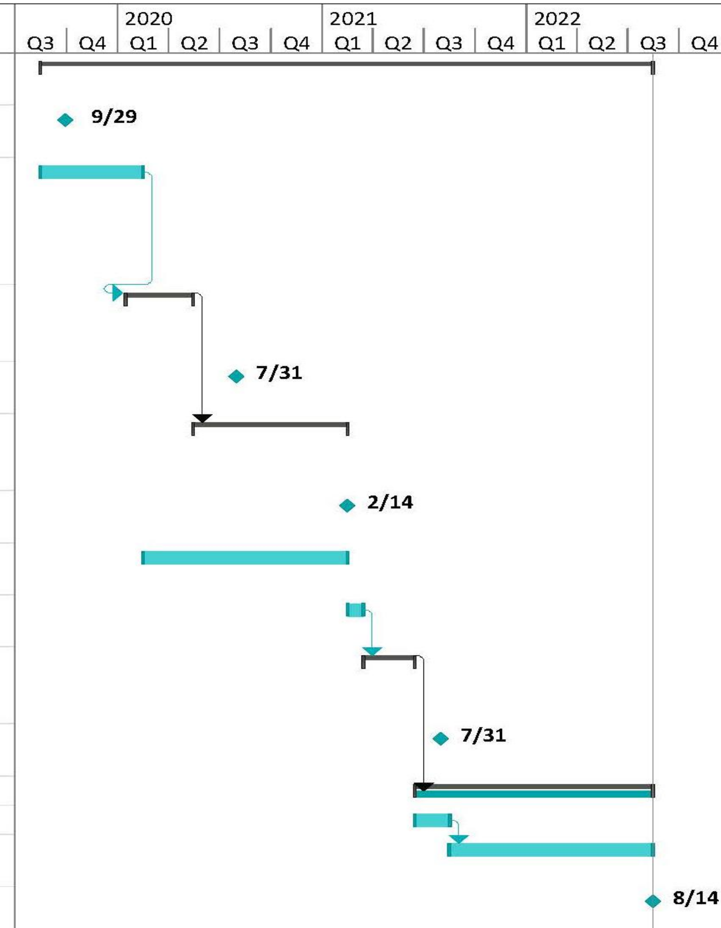


Chen et al. Appl Term Eng 113, 25 (2017)

Project Overview

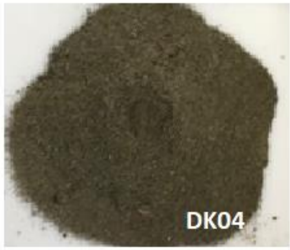
- **Objective:** Develop a in-situ ash cleaning technology
- **Project Start Date:** August, 2019
- **Scheduled Duration:** 3 years
- **Two Budget Period:** $2,500,482
- **Project Partners:**
  - LG&E and KU
  - BDDB

ID	Task Name	Start	Finish
1	1 Project Management and Planning	8/15/19	8/14/22
2	*1.1 Project Kickoff Meeting Held*	*9/29/19*	*9/29/19*
3	2 Information Collection for 1) Unit 3 Operating Conditions Anticipated for 2021 and 2022, and 2) Ash Property and ABS	8/15/19	2/14/20
4	3 Process Design Package, Risk Analysis and Tie-in Requirement	1/15/20	5/14/20
5	*3.1 Completed Process Design Package*	*7/31/20*	*7/31/20*
6	4 Procurement, Fabrication, Shipping and Installation of Bench-scale	5/15/20	2/14/21
7	*4.1 Air Preheater Installed*	*2/14/21*	*2/14/21*
8	5 Test Condition Selection and Data Analysis Plan	2/15/20	2/14/21
9	6 Operational Procedure and Safety Protocol	2/15/21	3/14/21
10	7 Process and Balance of Plant Testing, Start-up, and Commissioning	3/15/21	6/14/21
11	*7.1 Air Preheater Commissioned*	*7/31/21*	*7/31/21*
12	8 Test Campaign	6/15/21	8/14/22
13	8.1 Parametric Study	6/15/21	8/16/21
14	8.2 Long-term Verification Test and	8/16/21	8/14/22
15	*8.3 Test Campaign Complete*	*8/14/22*	*8/14/22*



Information/Ash Sample Gathering

Sample Location at EW Brown Station (APH)	Physical Characteristics	Sample Description
Air heater gas cold side (gas outlet)	Dark grey particles, mainly in a loose form (fine particles) or partially aggregated in bigger structures.	Solid ash around the perimeter and on top of some of the braces near the air heater.
Air heater gas cold side (gas outlet)	Dark grey particles. Mainly in a loose form, mixed with a large and crispy structures	This sample was collected from the ductwork under the air heater.
Air heater gas hot side (gas inlet)	Mixture of brown to yellowish fine particles. Mainly in a fine powder form.	Sample from ash that was laying in piles on the air heater basket on 3-1 side.



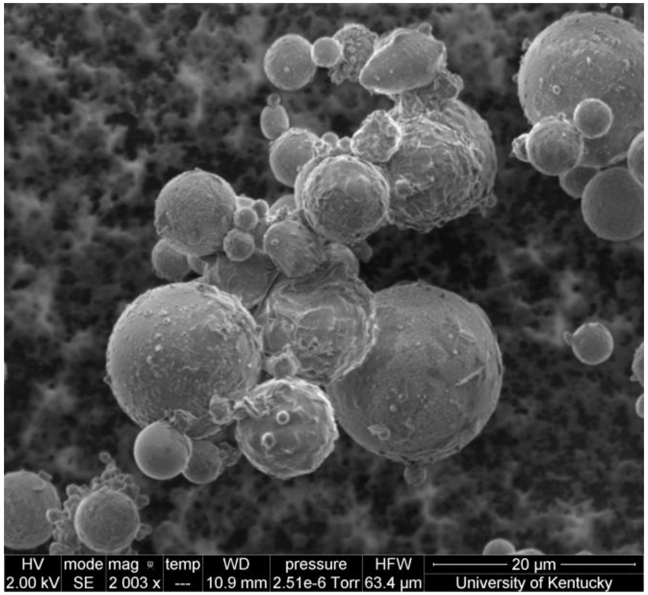
Chemical Analysis and Mechanism Determination on the APH Ash Deposits

1. ***Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM-EDS):*** Morphology and surface analysis (quantitative analysis)
2. ***X-ray fluorescence (XRF):*** Elemental analysis and mineralogy in order to ash composition, element contents, and mineral composition (e.g. silica, alumina, ferrous, calcium oxides).
3. ***Ammonia Extraction, pH measurement and Ion chromatography (IC):*** sulfates (SO_4^{2-}), sulfites (SO_3^{2-}), chlorides (Cl^-), fluorates, carbonates and intermediates (cation and anion analysis)
4. ***X-ray Diffraction (XRD):*** Rietveld refinement (phase determination, crystallography)
5. ***Thermal Gravimetric Analysis & Differential Scanning Calorimetry (TGA/DSC) accompanied by Mass Spectroscopy (MS):***

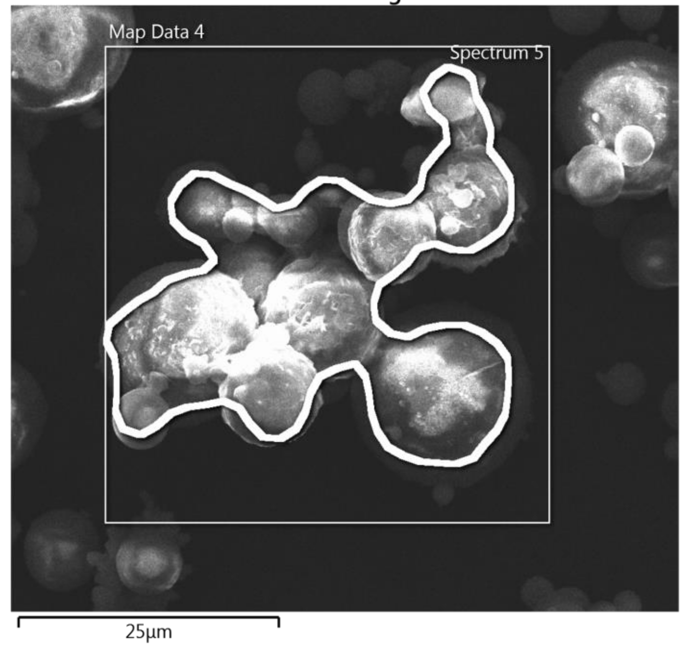
- Thermal decomposition and volatilization properties
- Reaction kinetics determination via analysis of the derivative TG curves (DTG analysis)

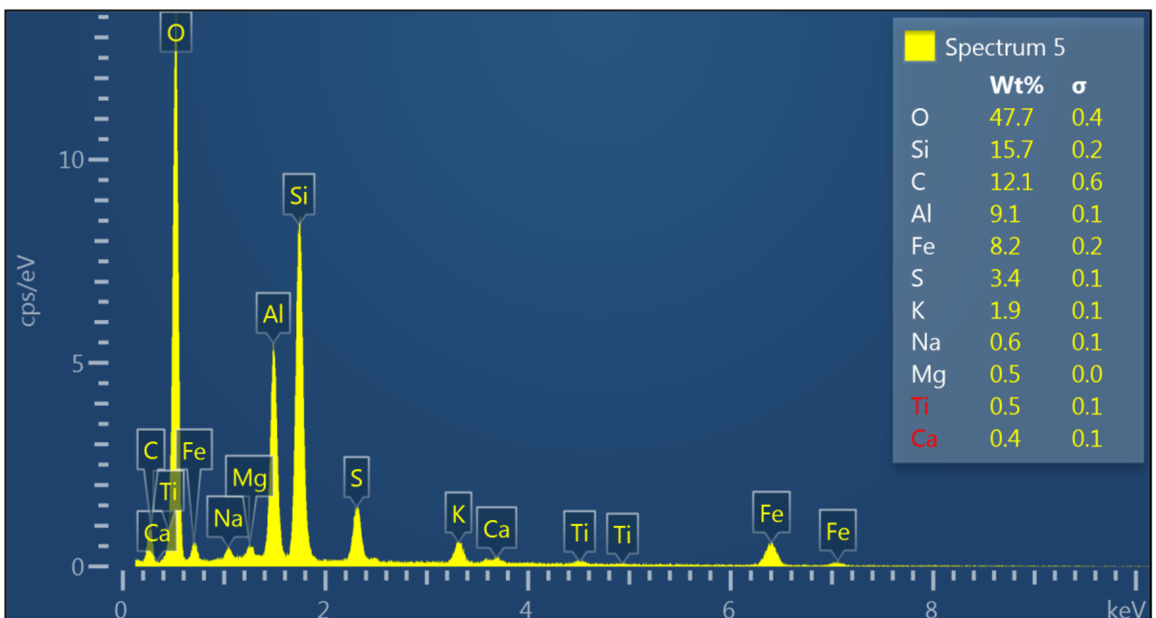
Sample ID: *DK_02*

Sample Location: *Air preheater cold side (gas outlet)*



Electron Image 4





- Large number of ash particles on the surface of larger particles. Most of the particles are mainly round.
- Mainly oxygen, silicon and carbon content exists on the surface of the larger particles.

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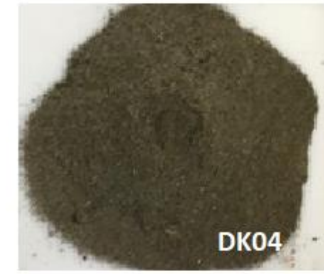
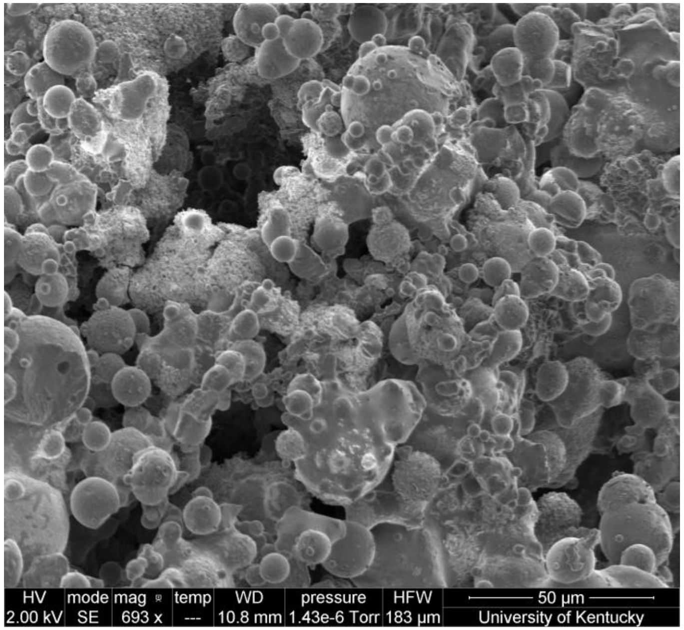
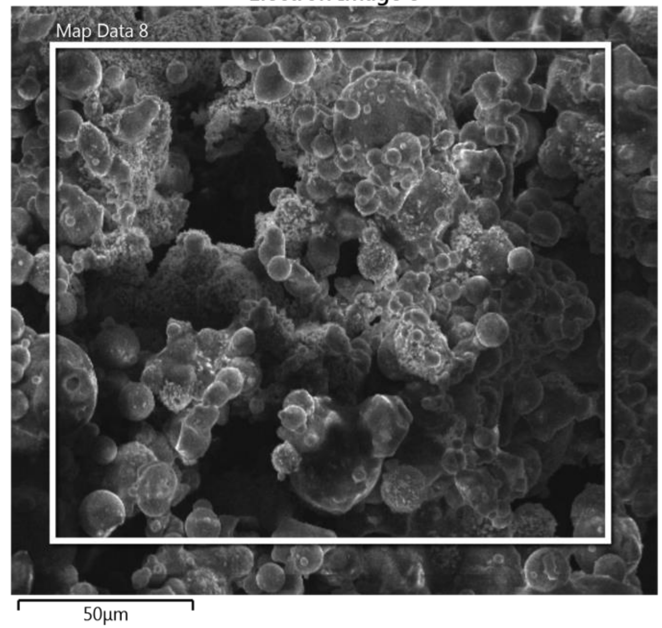
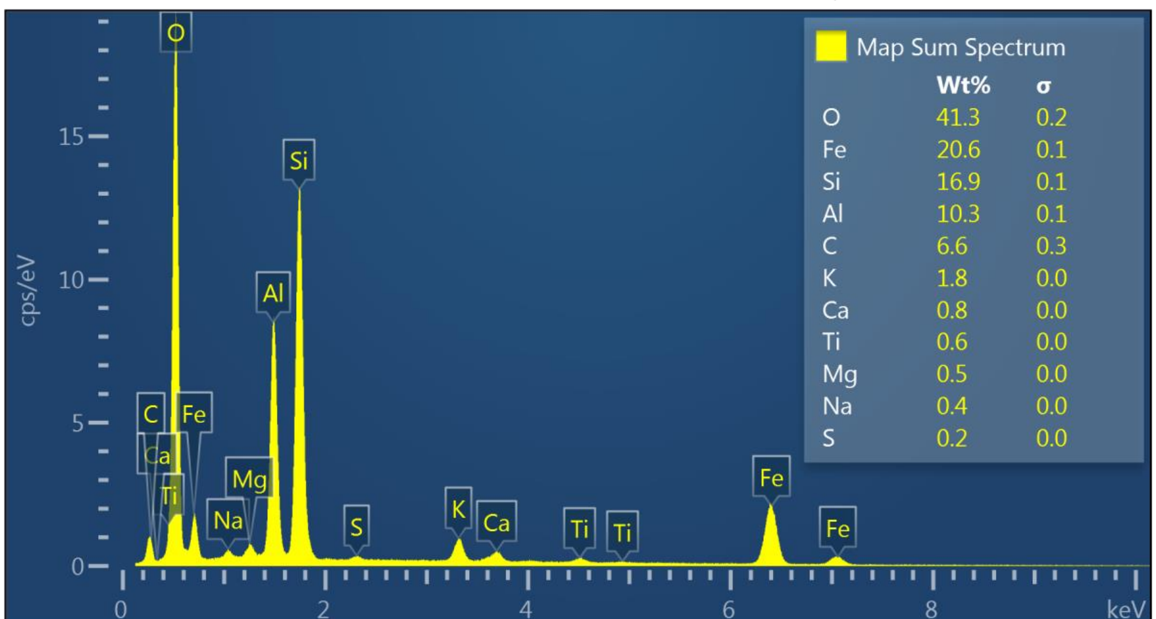
Sample ID: *DK_04*
Sample Location: *Air preheater hot side (gas inlet)*





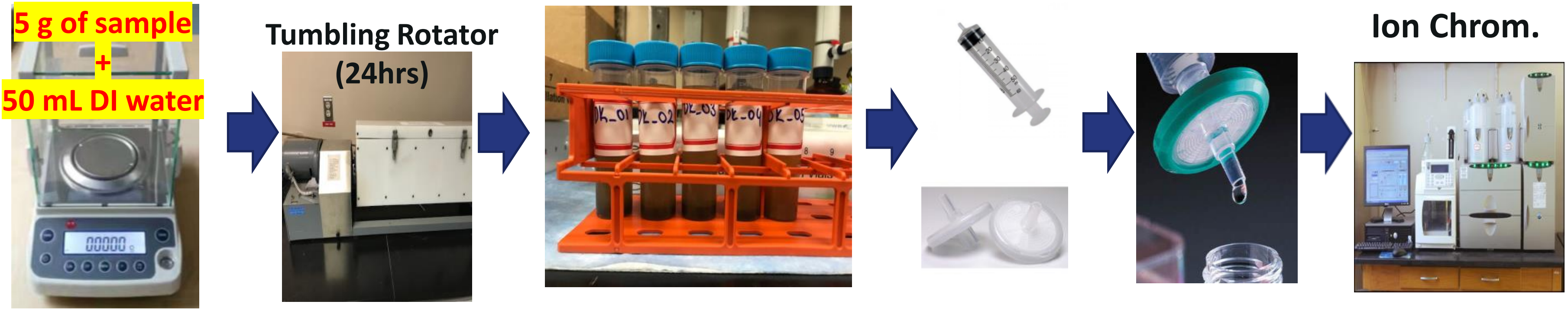
Electron Image 8

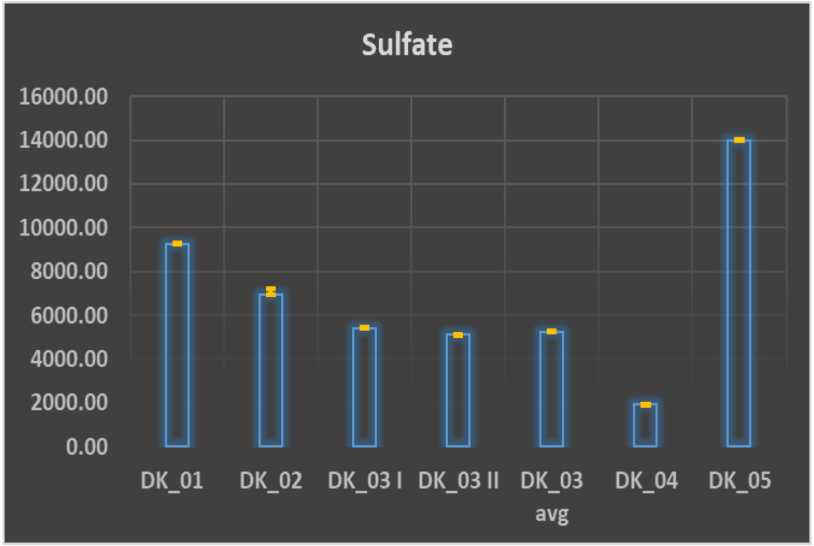


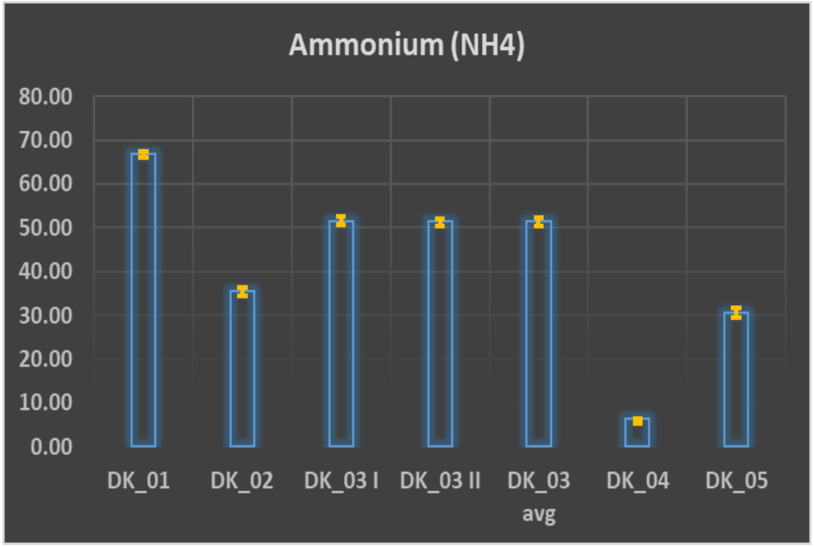


- Contrary to the microstructure of deposits from the cold side of the APH (gas outlet), here the particles are more aggregated.
- The ash is rough and clustered together due to the higher temperature conditions. The surface of the larger structures is mainly composed of iron, oxygen and silicon.

Ammonia Extraction







DK05 (hot side):

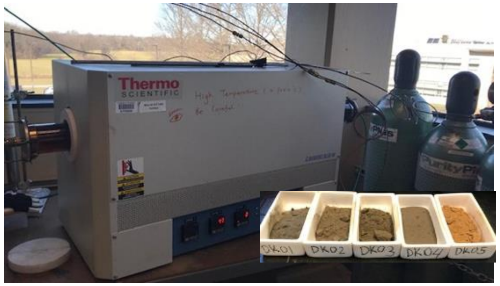
- The highest amount of Sulfates, 13997 ppm (In accordance with XRD)
- Intermediate amount of Ammonia, 30.61 ppm

DK01 (cold side):

- The highest amount of Ammonia, 66.91 ppm
- The second highest amount of Sulfates (after DK05), 9254 ppm

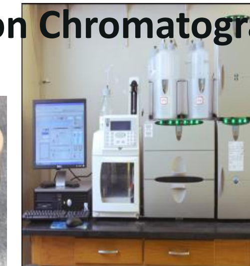
T. Townsend , J. Schert, T. Vinson. Development of a Standard Operating Procedure for Analysis of Ammonia Concentrations in Coal Fly Ash, 2015 http://ftp.fdot.gov/file/d/FTP/FDOT%20LTS/CO/research/Completed_Proj/Summary_SMO/FDOT-BDV31-977-10-rpt.pdf

Proof-of-Concept using Furnace Heating

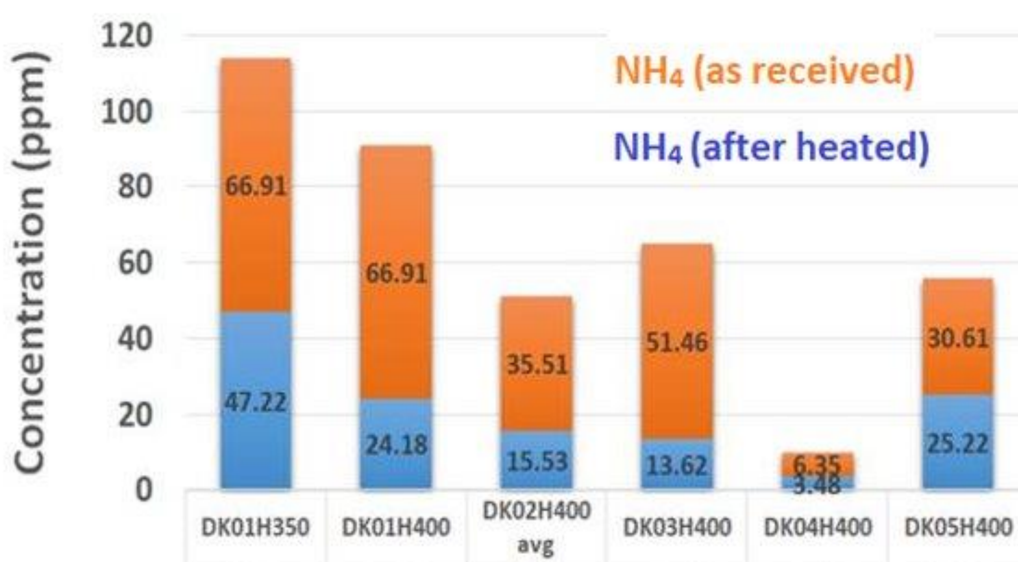


Tumbling rotator (24hrs)

Ion Chromatography

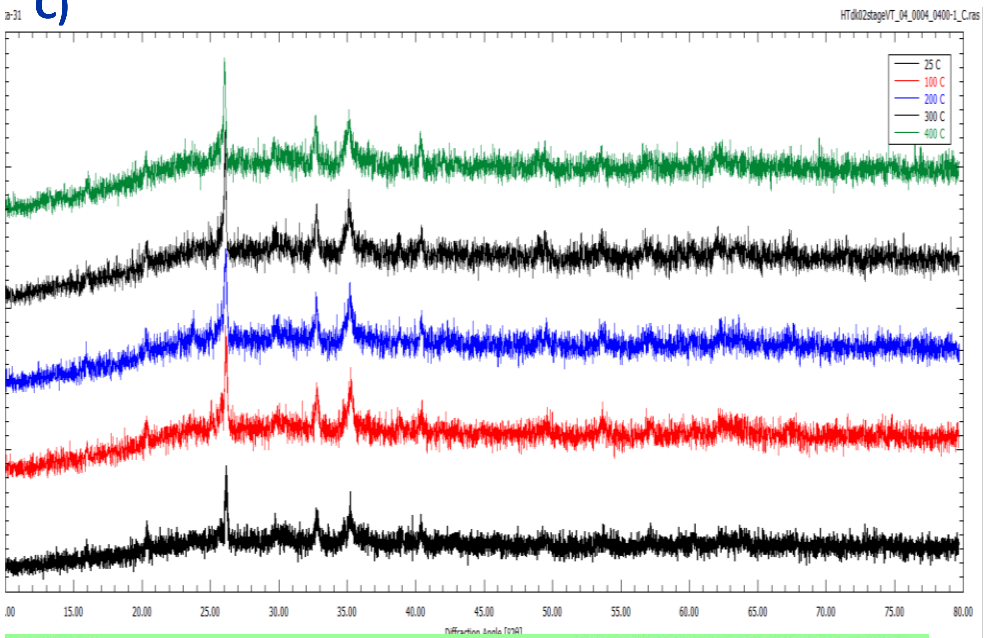


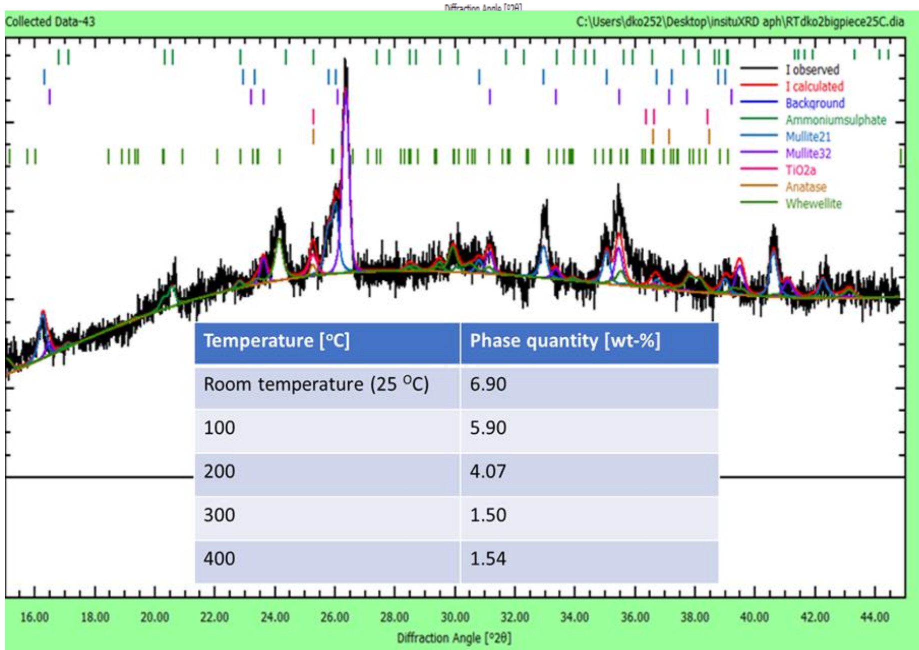
NH_4 before & after furnace: 350 °C and 400 °C



	DK01H350	DK01H400	DK02H400 avg	DK03H400	DK04H400	DK05H400
NH_4 (as received)	66.91	66.91	35.51	51.46	6.35	30.61
NH_4 (after heated)	47.22	24.18	15.53	13.62	3.48	25.22

Conformation with In-situ High Temperature XRD (25˚C-400˚C)



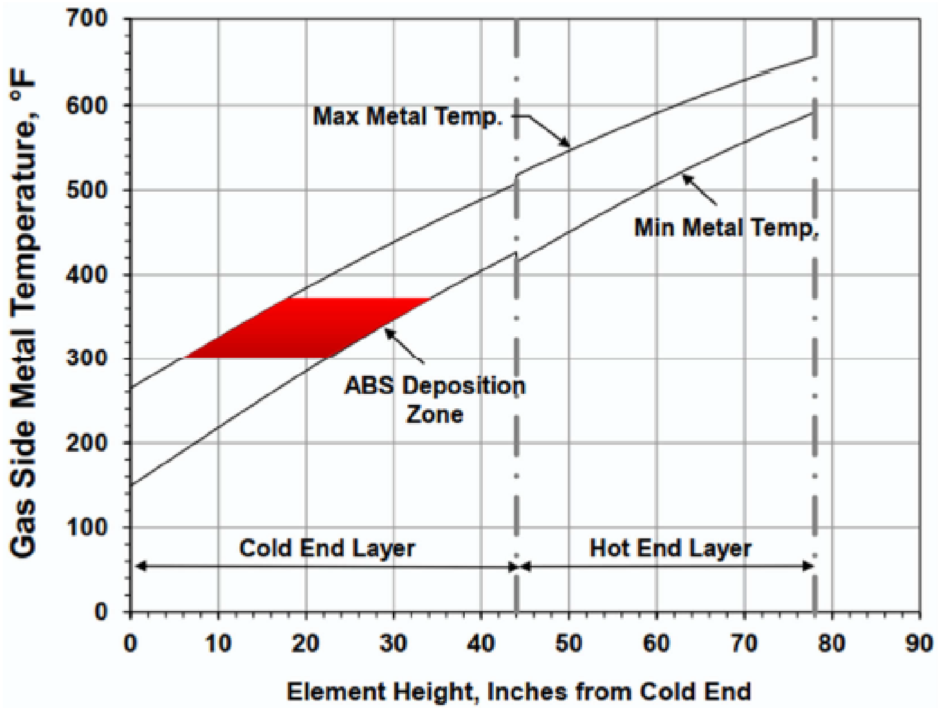


Temperature [°C]	Phase quantity [wt-%]
Room temperature (25 °C)	6.90
100	5.90
200	4.07
300	1.50
400	1.54

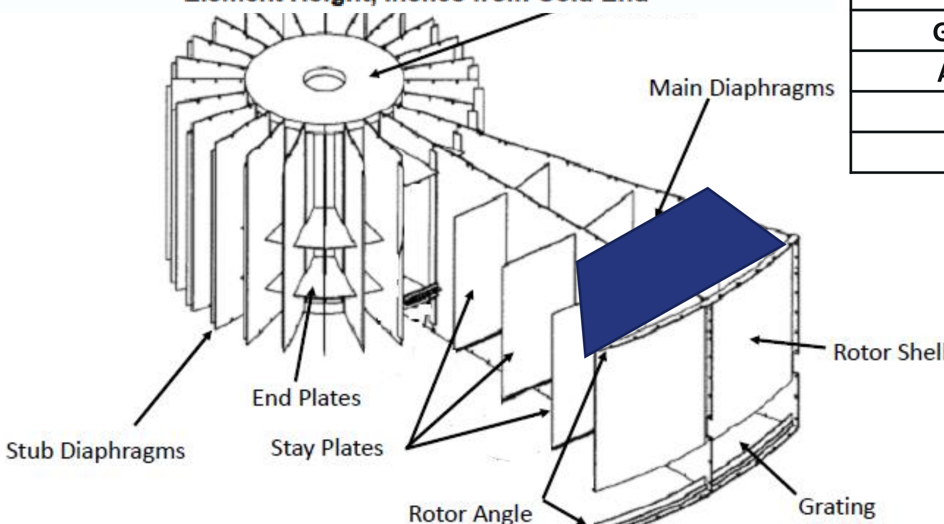
ABS melting point: 147°C
AS melting point: 235 °C
ABS decomposition: 308-419°C
AS decomposition: 213-308°C

- Between the temperatures of 200 °C and 400 °C, NH_4-sulfates formations are melting and partially decomposing or reacting with alkali metals and alkaline oxides and, thus new phases are formed.

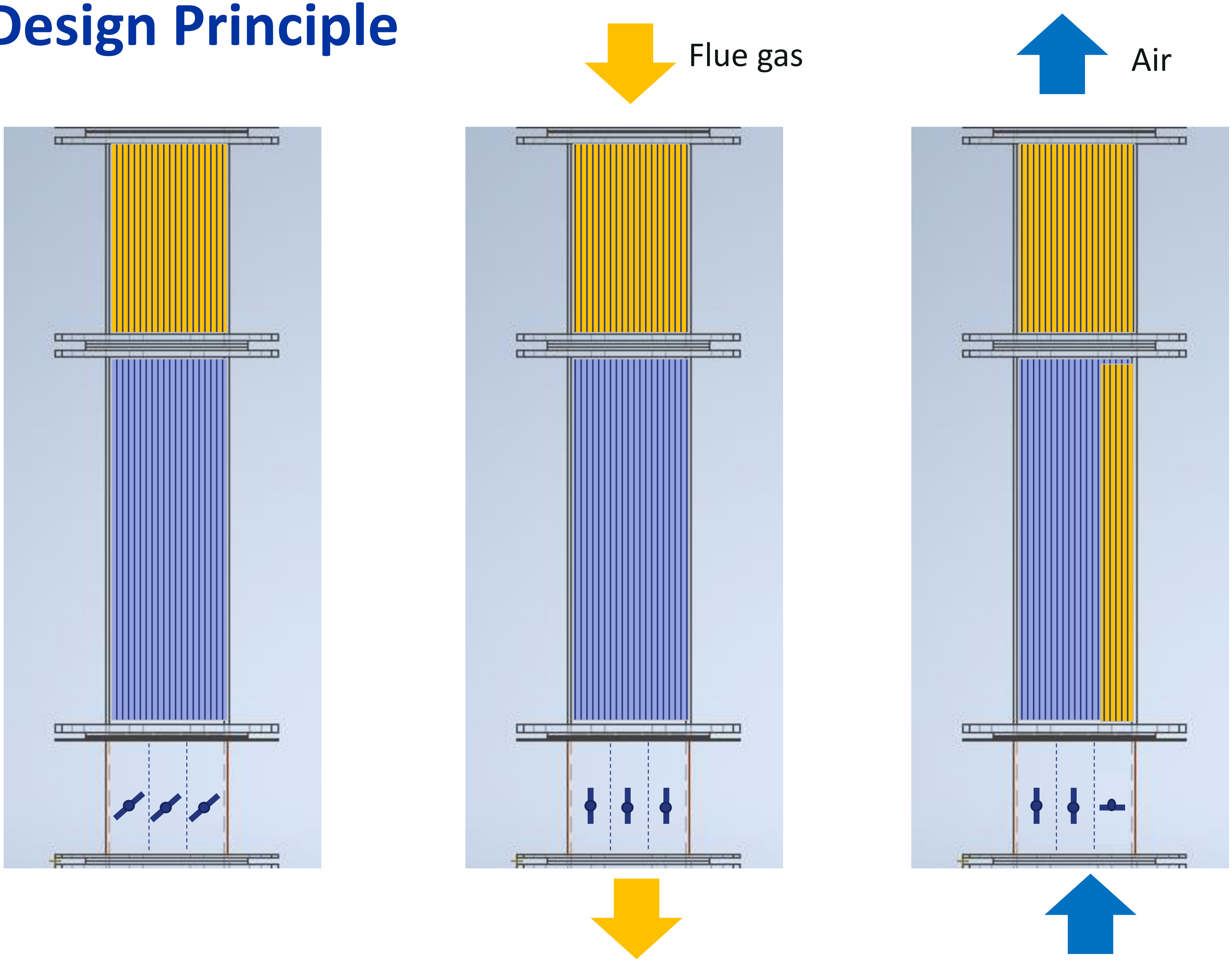
CAER Technology for In-situ Cleaning



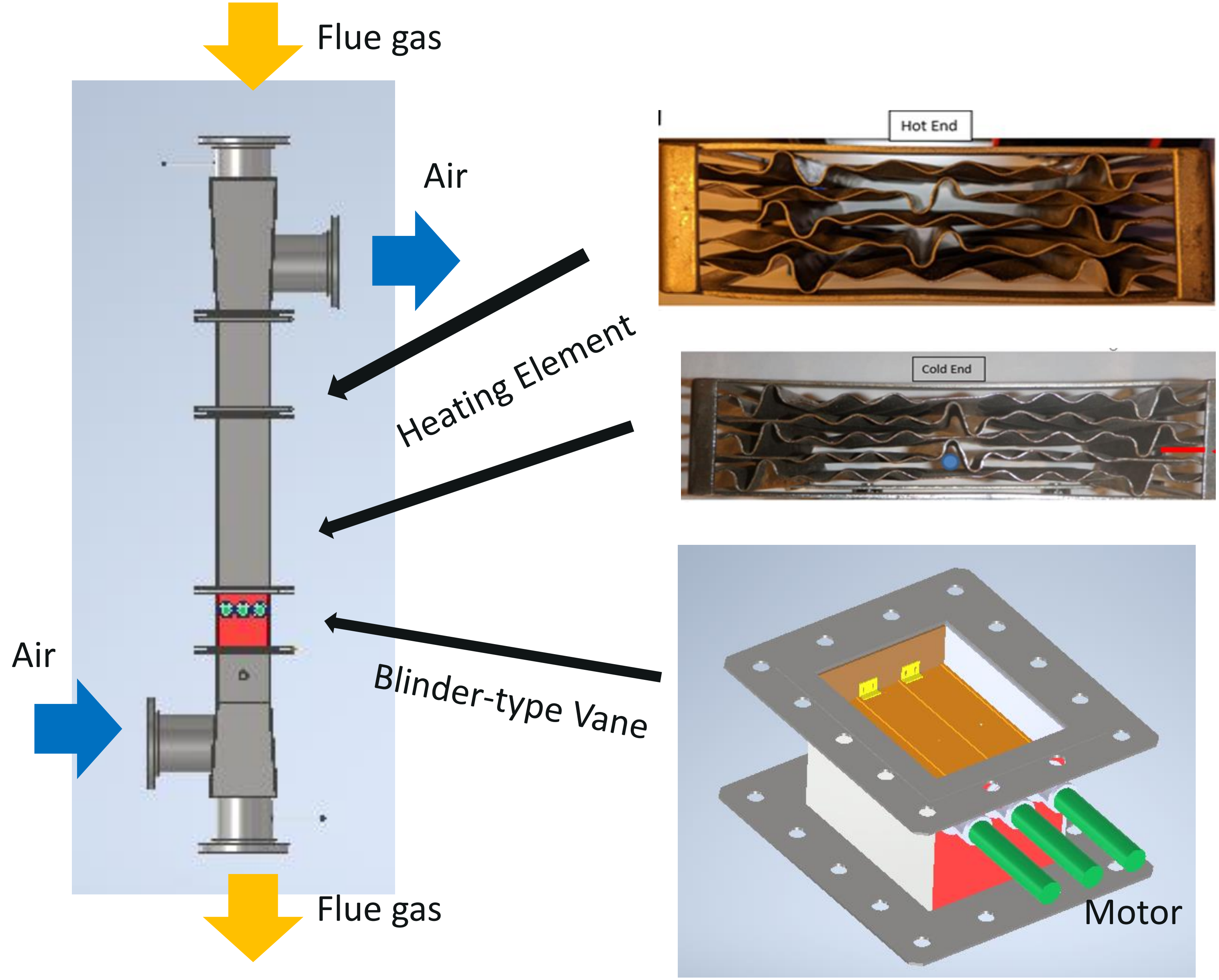
Switching Regenerator	IU	U.S.	Predicted
Gas entering temperature/℃	371.1	700.0F	700F
Gas leaving temperature/℃	148.9	300.0F	239F
Gas flow rate/lbs/hr		3000.0	3000
Air leaving temperature/℃	318.1	604.6F	605F
Air entering temperature/℃	30.0	86.0F	86F
Air flow rate/lbs/hr		2857.0	2857
Gas velocity/m/s	15.0	49.2ft/s	47.3ft/s
Air velocity/m/s	7.4		
Width/m	0.3	10.0"	10”
Length/m	0.3	10.0"	~7.2”
Height/m	1.7	68.0"	40”
Gas flowing time/s	24.0		
Air flowing time/s	24.0		
Gas-side dP*			2.0
Air-side dP*			1.5



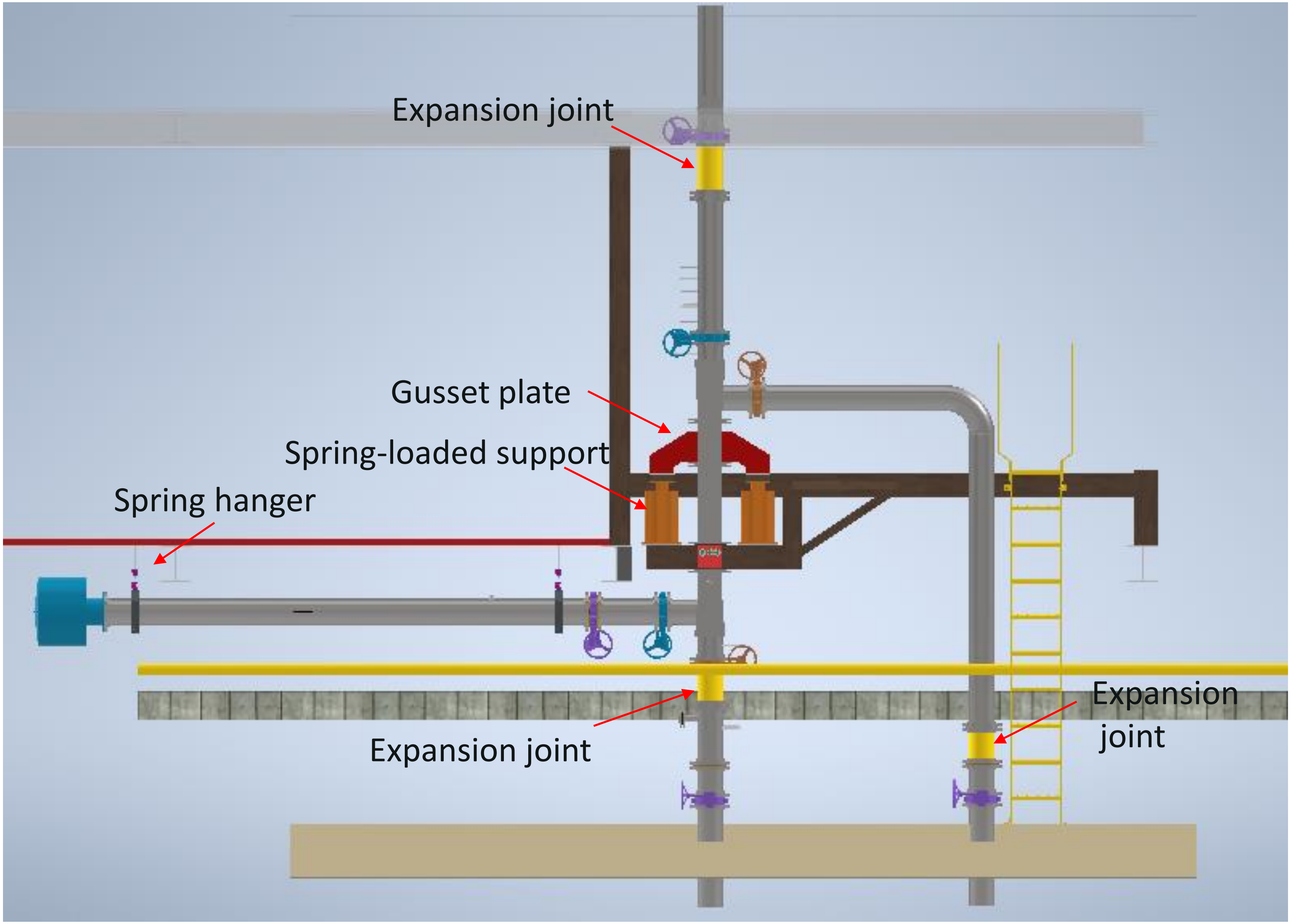
Design Principle



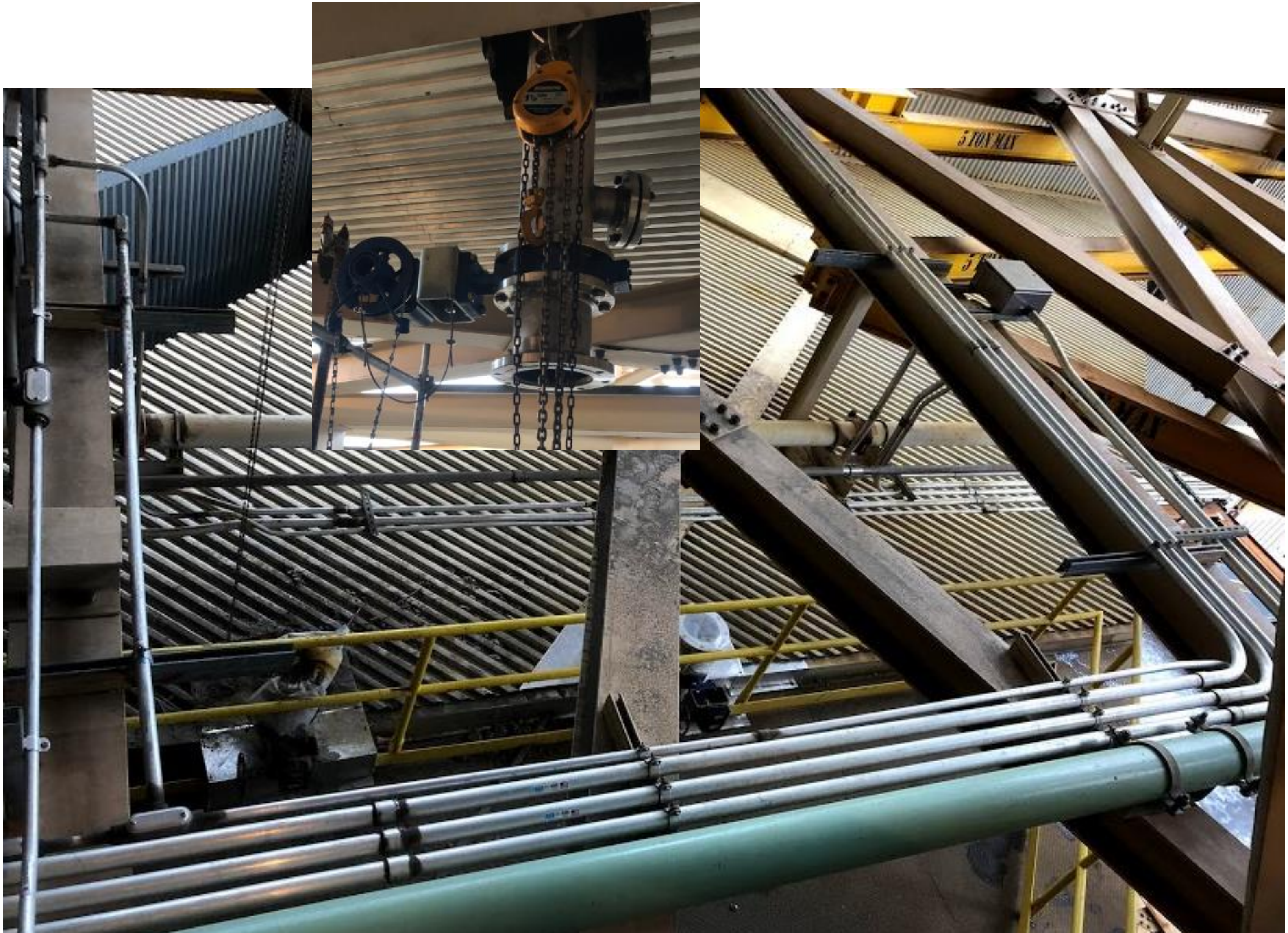
A Close Look at the Pilot APH Built at CAER



On-site Installation



Existing Structure and Tie-in at Host Site



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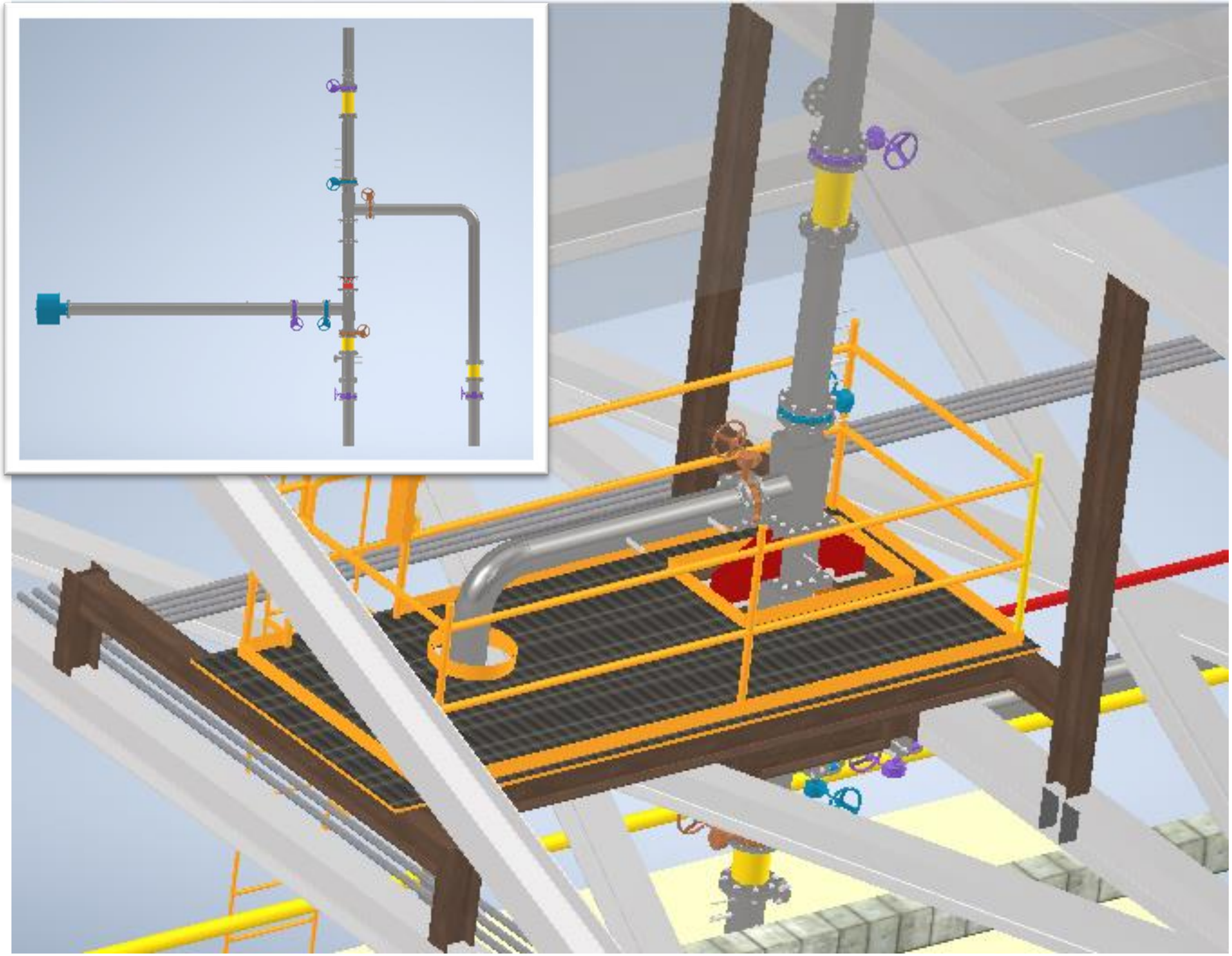
Overlook of Pilot APH after Installation



Conclusions

- The cold end ash was found to have a much higher content of ammonia-sulfates compared to the hot side.
- The transition and weight loss around 300 °C unveils the start of the decomposition process of NH_4-sulfates (e.g. ABS, NH_4HSO_4). The total thermal decomposition of the NH_4-sulfates takes place around 380-500 °C. Also, the kinetic analysis (weight loss rate) via TGA indicates the activation energy was 110 kJ/mol or 26.3 kcal/mol.
- After the heat treatment experiments up to 350 °C and 400 °C , the ash collected is in loose form and breakable.
- The pilot APH fabrication complete and ready for installation at EW Brown Station.

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