Tesla-Modeling Regenerative Thermal Oxidizer

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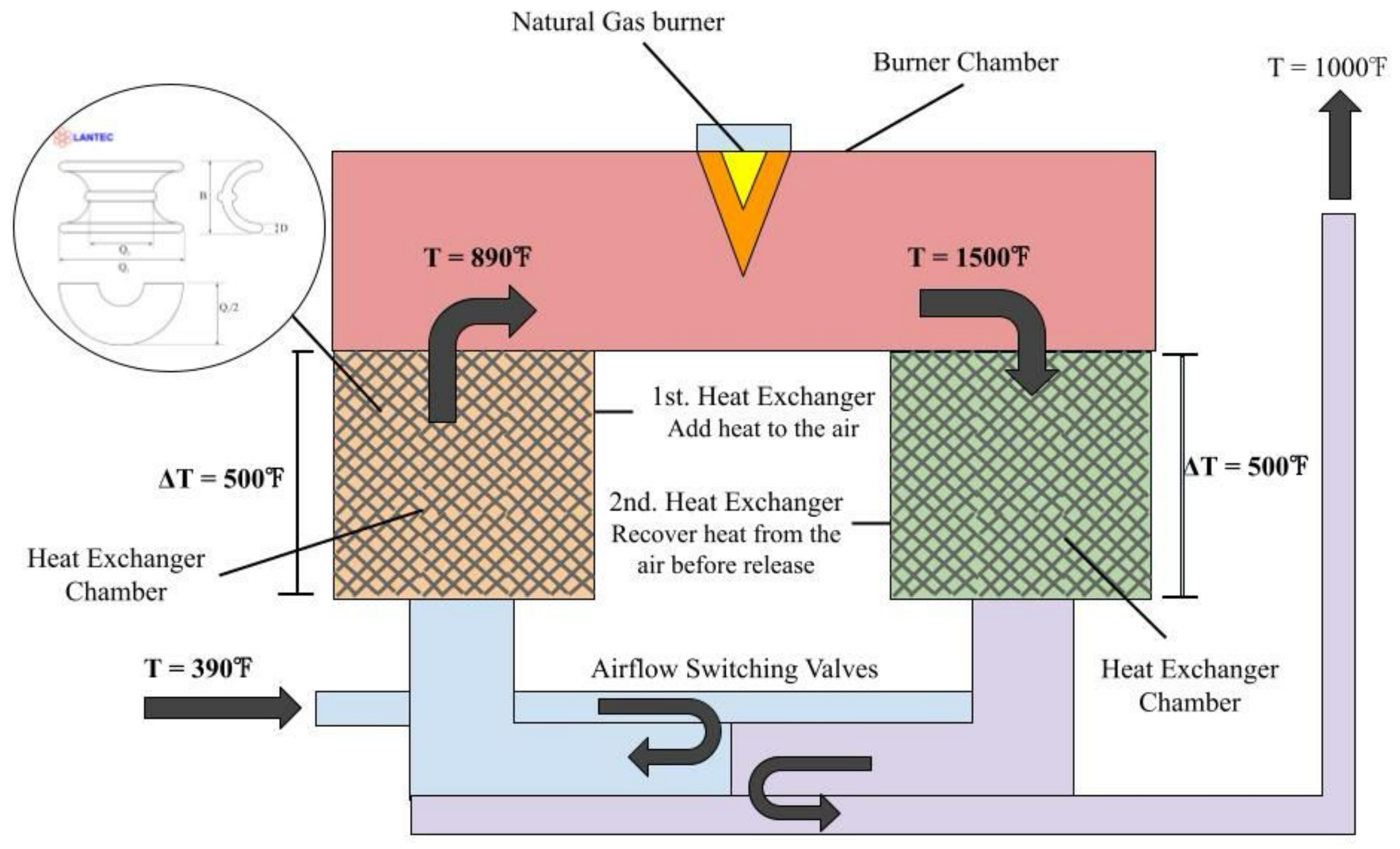
Introduction

RTO Design:



RTO Diagram

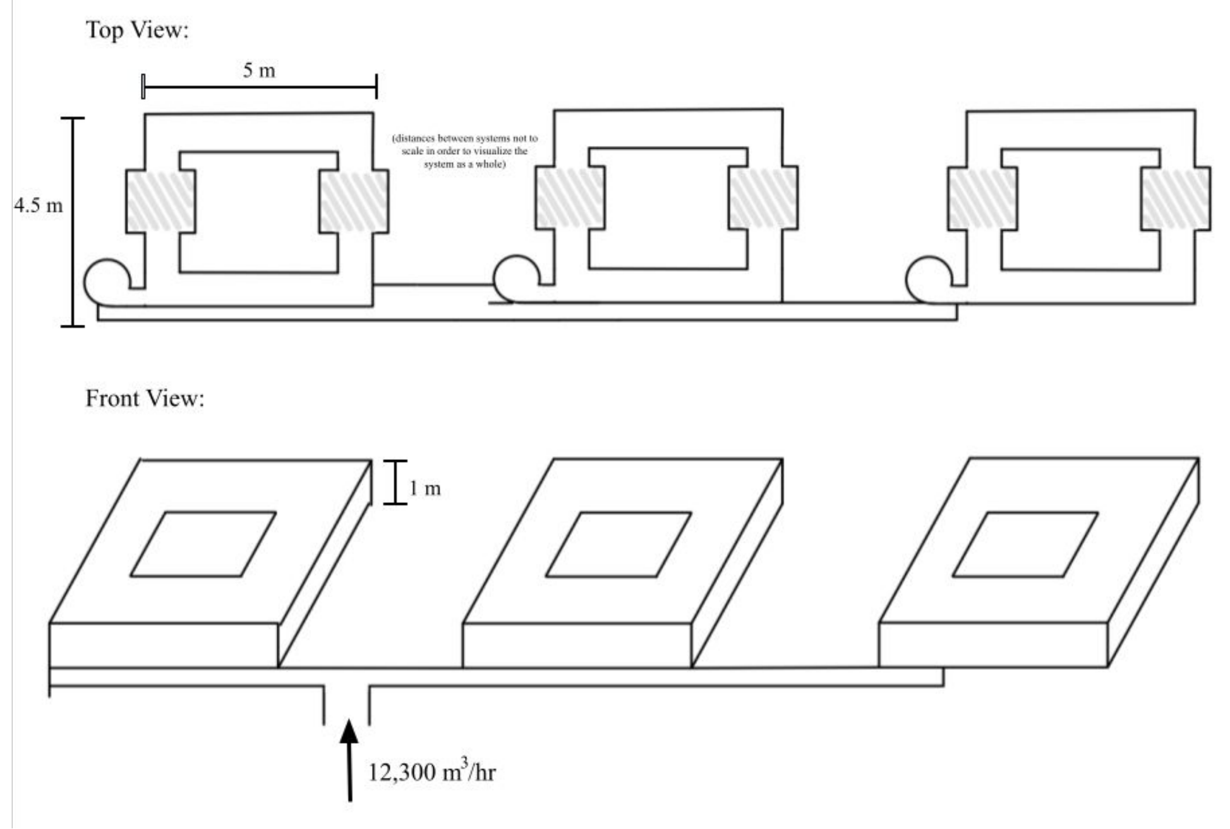
Objective

The RTO is designed to treat the exhaust gas from Tesla's paint-curing ovens by removing VOCs through high-temperature oxidation at approximately 1500°F. The system heats and processes the contaminated gas within the regenerative thermal oxidizer, which is designed to operate largely self-sufficiently aside from burner fuel input, before recirculating the cleaned gas back to the oven at a temperature suitable for continued curing operations

Key Requirements

- Processes 12,300 cubic meters of exhaust air at 390 deg F per hour
- Retrofit into current oven system
- Air must be at 1500 deg F for 0.5-1 seconds to ensure proper destruction of volatile organic compounds (VOCs)
- System must heat up from cold within 90 minutes

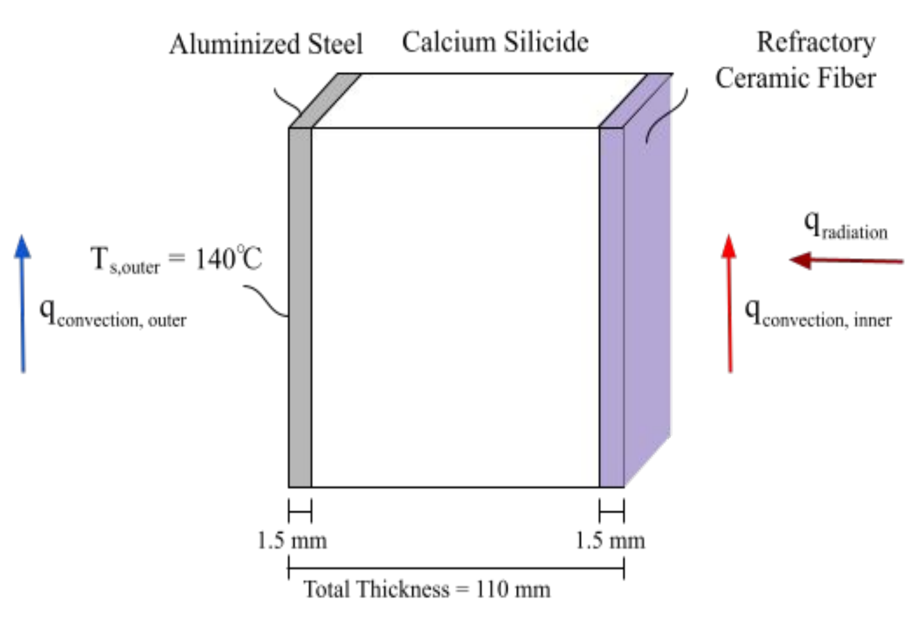
System Design



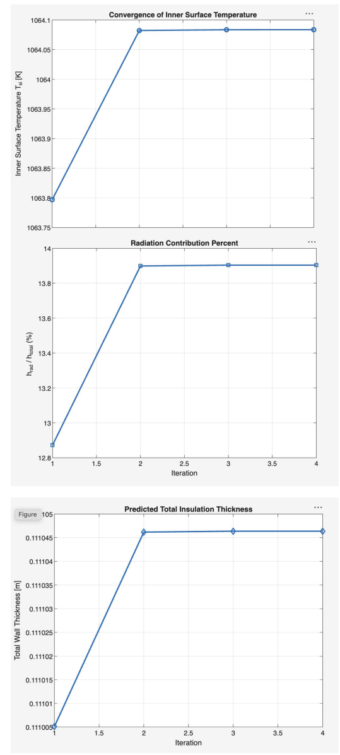
Air Processing Diagram

- Three Identical Systems:
  - Allows current system to be retrofit on top of the oven
  - Spreads weight out to allow for the roof of the oven to support the system
  - Each system processes 4,100 cubic meter of exhaust air per hour

Insulation



Burner Insulation Visual



Converging Plots - Burner Insulation

- Aluminized Steel
  - k = 52.0 W/mK
  - Protective outer shell with heat and corrosion resistance.
- Calcium Silicide
  - k = 0.140 W/mK
  - Insulator, makes up the majority of the thickness
- Refractory Ceramic Fiber
  - k = 0.167 W/mK
  - Hot face insulation exposed directly to the flame.

Heat Exchanger Specifics and Analysis

Material selection

Selected material was SiC. A close secondary wasl AL203, as it also had similar properties and was 3x less the prices. However after analysis on our heat-exchanger and due to its large size we determined thermal conductivity was more of a concern

Specifications

Saddle based Exchanger Design

Thermal Performance

- Q˙=2895 kW
- τ=180
- ΔP =1.85 PSI
- Saddles will heat up to 1200

Surface Area

- Required surface area: 322 m23\
- Achieved within 1m^3 however selected volume is 4 m^3

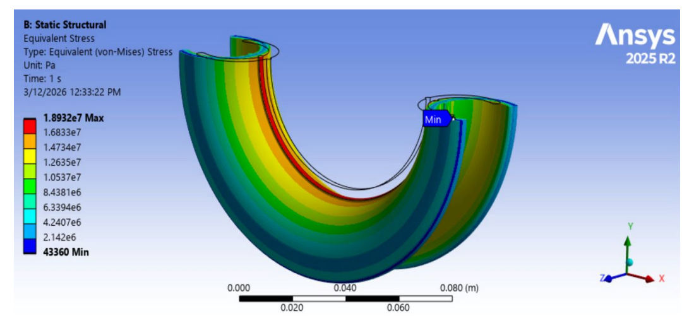
Media Selection — 1" SiC Intalox Saddle

- Specific surface area: 77 ft2/ft3
- Void fraction: 70%
- Max operating temperature change handled: 518°F

Airflow

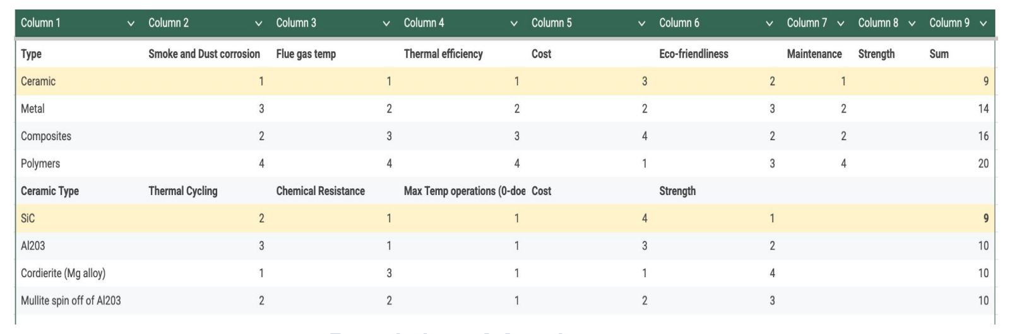
- Handles mass flow rate of 1.33 kg/s
- 6 total heat exchangers in 3 systems

Saddle Design



Saddle Design - Solidworks

Ranking of materials



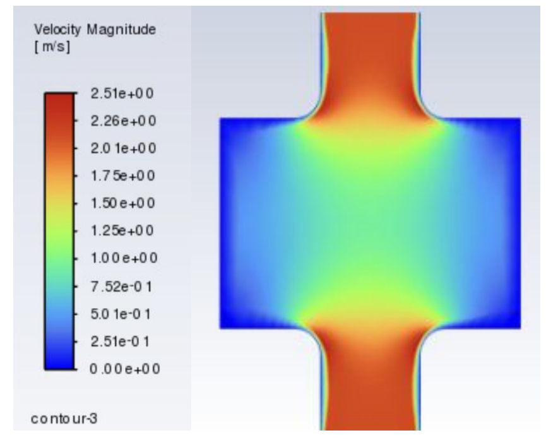
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Type	Smoke and Dust corrosion	Flue gas temp	Thermal efficiency	Cost	Eco-friendliness	Maintenance	Strength	Sum
Ceramic	1	1	1	3	2	1		9
Metal	3	2	2	2	3	2		14
Composites	2	3	3	4	2	2		16
Polymers	4	4	4	1	3	4		20
Ceramic Type	Thermal Cycling	Chemical Resistance	Max Temp operations (0-doe	Cost	Strength			
SiC	2	1	1	4	1			9
Al203	3	1	1	3	2			10
Cordierite (Mg alloy)	1	3	1	1	4			10
Mullite spin off of Al203	2	2	1	2	3			10

Decision Matrix

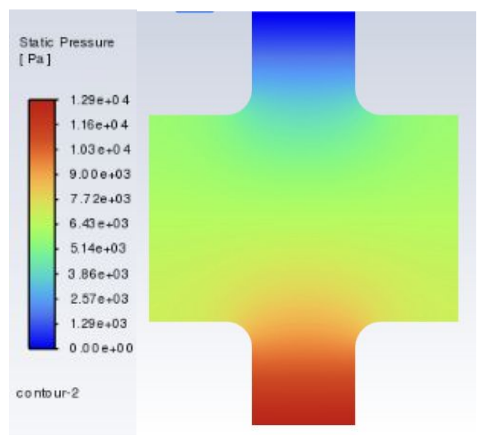
Contours of velocity and pressure drop

Iterations of CFD analysis resulted in

- 2x increase in HX cross sectional area
- Fillet at inlet outlets to decrease pressure drop and improve temperature uniformity
- Heat transfer is designed for saddle meds to heat up layer by layer. "Moving front"

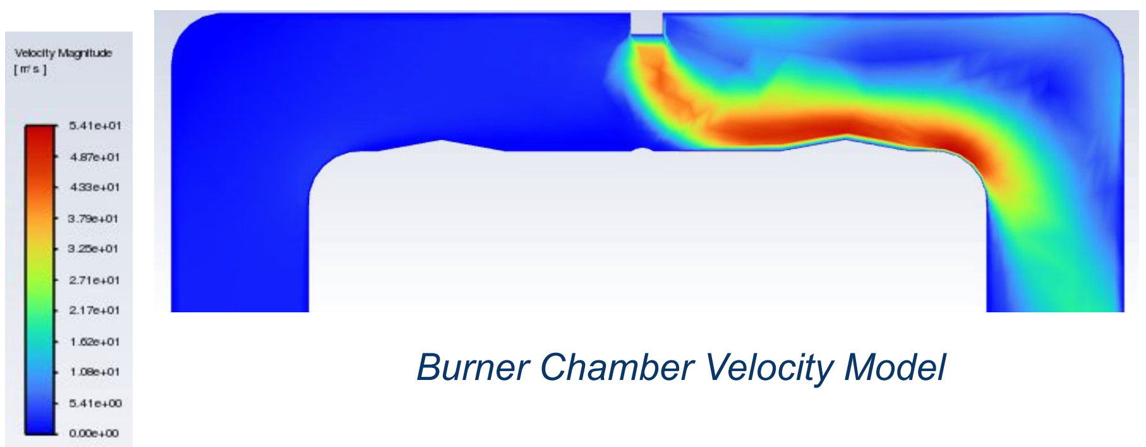


Heat Exchanger Velocity Contour

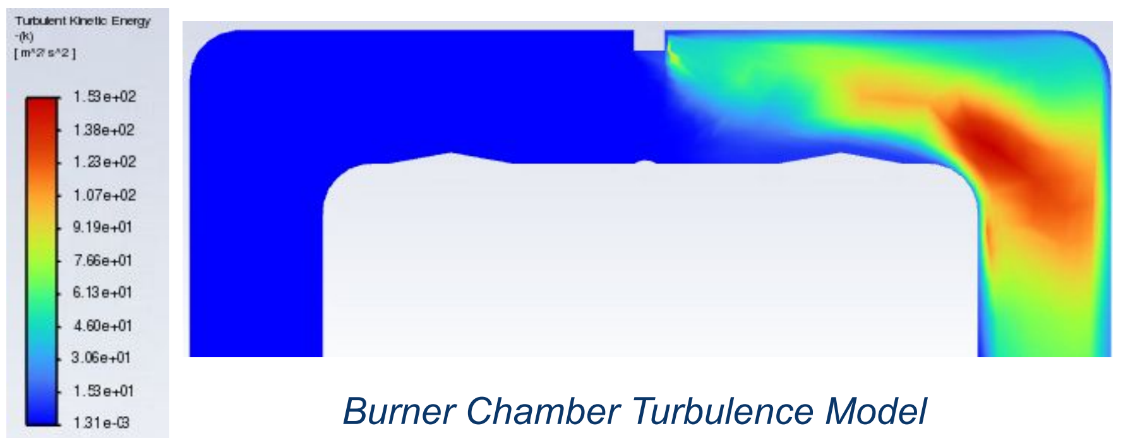


Heat Exchanger Pressure Drop

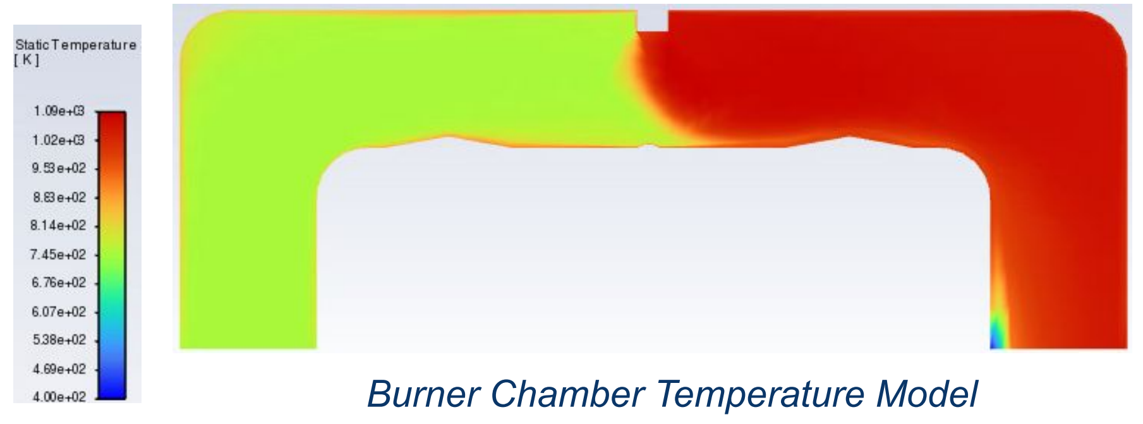
Ansys Modeling,
Burner Chamber:



Burner Chamber Velocity Model



Burner Chamber Turbulence Model



Burner Chamber Temperature Model

Crossflow of the Burner is modeled in ANSYS 2024 in order to ensure:

- Proper Mixing
- Uniformity of temperature following the burner
- Proper destruction of VOC's

Burner Specifics

HoneyWell Eclipse Burner

- **Natural Gas, Premixed**
- 3 Systems, 3 Burners
- 2 M Btu/hr, 6 M Btu/hr total
- Medium velocity outlet 250 ft/s
- Inlet pressure: 7.0 w.c. / 18 mcbar

Fan Specifics

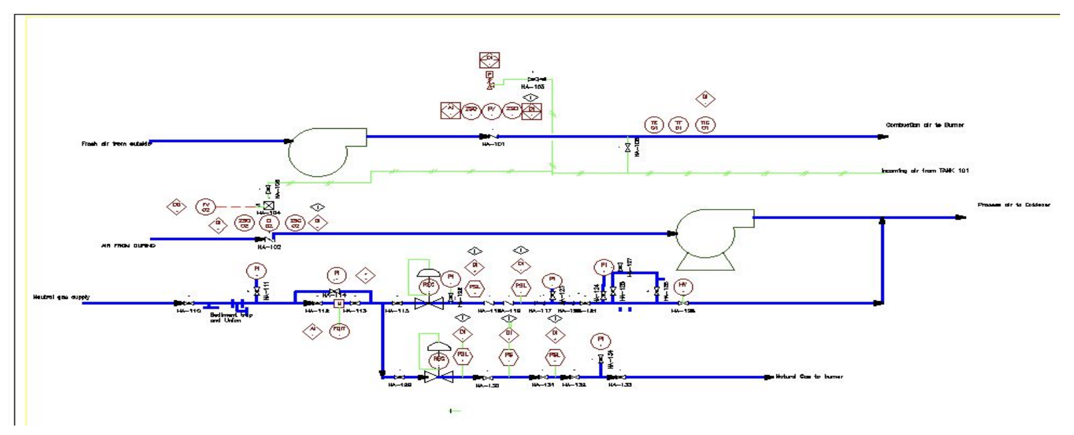
Centrifugal Fan

Centrifugal fan

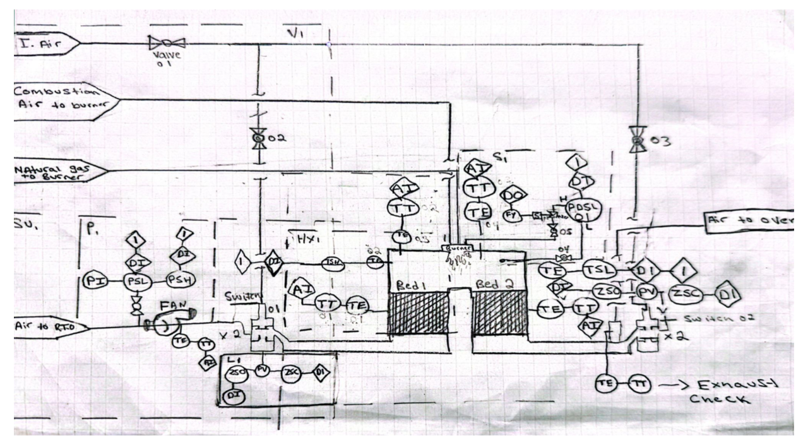
- Air systems with a 0.3HP per fan
- 3 fans, 3 RTO systems
- Fan Power: 0.23kW/fan

Documentation

P&ID



Upstream Piping and Instrumentation



RTO Piping and Instrumentation

P&ID documentation was via AutoCAD, with emphasis on controls and safety systems implemented using ISA standards. Here are some important systems

Natural gas to burner: Contains safety checks and shit of points, as well as a heavy filter system to ensure that the fuel injected is safe

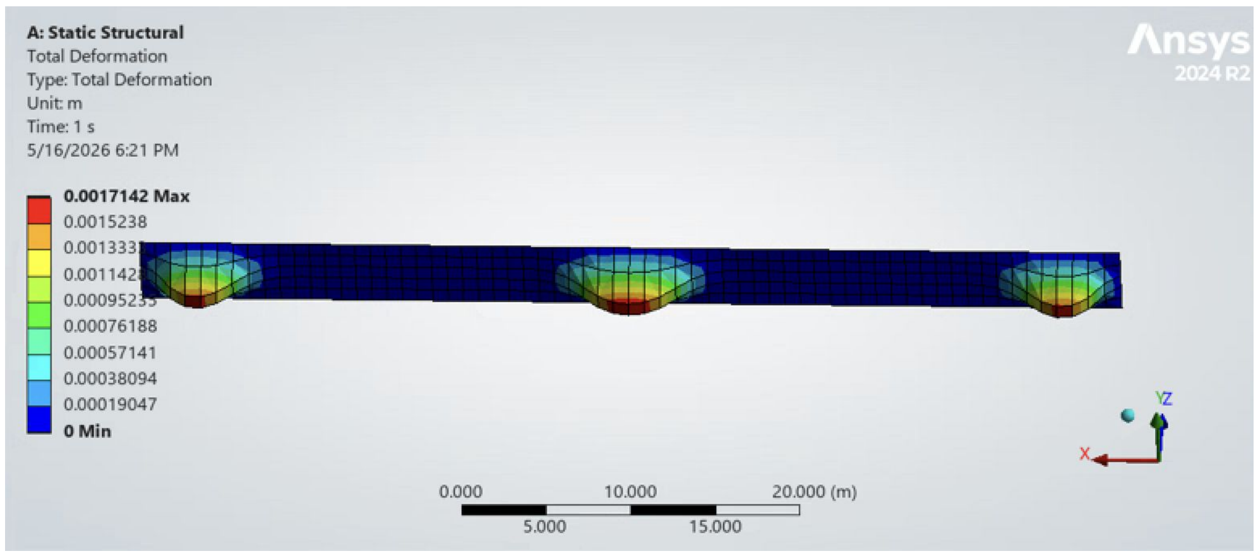
Combustion airline*: The blower, airflow piping, pressure sensors, and control valves supply pressurized combustion air to the burner, ensuring enough oxygen is available for stable combustion while preventing unsafe low-air conditions that could lead to incomplete combustion or flame instability.*

Process air line :The process air piping, fan, and control devices move process gases through the system while maintaining stable airflow, proper pressure, and safe operation

Pressure switch assembly :The pressure switch monitors line pressure and sends a shutdown or alarm signal if pressure becomes too high or too low, protecting the burner and fuel system from unsafe operating conditions.

Combustion air assembly : The blower, valves, and air instrumentation supply controlled airflow to the burner, ensuring proper combustion and preventing flame instability caused by insufficient air
Temperature monitoring assembly :The temperature sensors and transmitters monitor process temperatures to verify efficient operation and automatically shut down the system if overheating occurs.

Structural Analysis

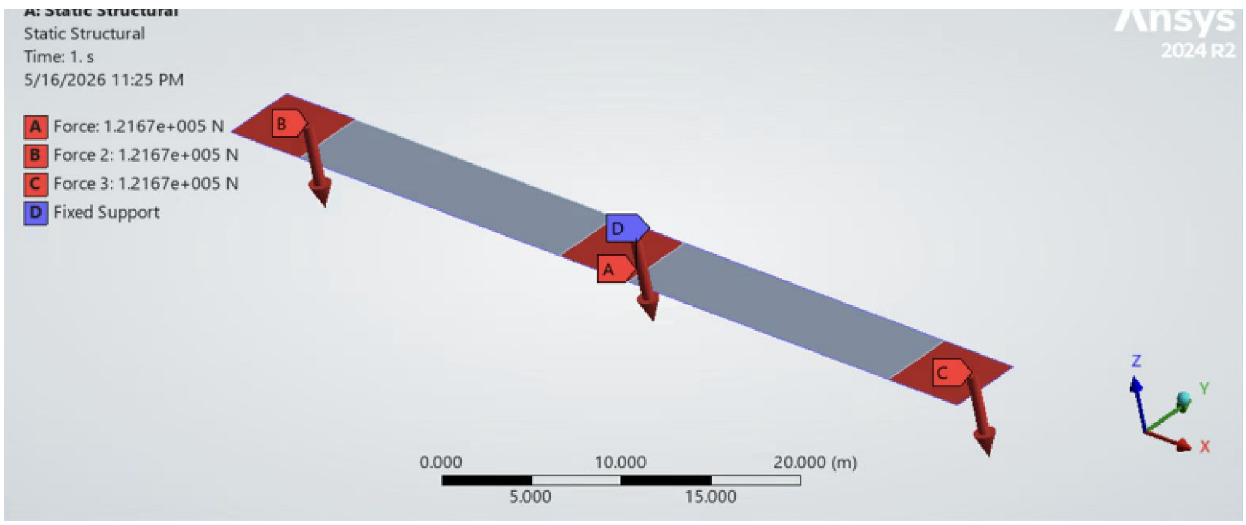


Total Deformation (m), Ansys 2024

<u>**Key Metrics**</u>
RTO Dimensions (m): 5.5*4.5*2.3 (W*L*H)
Roof Dimensions (m): 58*4.5 (W*L)
Each RTO includes: 1 burner and 2 heat exchangers (1 m^2 each)
Each RTO mass (kg) = 1*Burner mass + 2*Heat Exchanger mass + Wall mass = 1*210 + 2*1240 + 9713 = **12403 kg**

- Honeywell Eclipse Burner: **210 kg**
- Heat Exchanger density: **1240 kg/m^3**
- Wall Mass: Aluminized Steel Mass + Calcium Silicide Mass + Refractory Ceramic Fiber Mass= **9713 kg**

Downward Force from a RTO (N) = 12403*9.81=**12167.43 N**



Setup, Ansys 2024

<u>**Analysis Methods**</u>
Applied fixed support boundary conditions shown by blue edges on the figure to the left (annotated D).

- Represents the four walls of the mounted roof

Applied a downward force of 12167.43 N to each RTO locations.

- Shown by red arrows ABC, red area shows the RTO area.

<u>**Results**</u>
The structure is **safe** -> Less than 2 mm roof deformation
The shown RTO set up showed the most structural integrity, with no additional support needed.

Conclusion- Financial Analysis

CECO 1 system RTO- $2,500,275
Proposed 3 RTO system on the oven: $2,424,902
Steel fabrication: $635,000 vs $438,545 assuming our system has 43% more surface area
Ceramic media: $33,000 vs $53,375 as SiC is used instead of Alumina which is cheaper
Burner/Gas Train: $113,000 vs $37,645 as 3 burners and more gas pipings, safety valves and regulators
Fans + VFD's: $10,000 vs $166,463 as 3 fans with 0.3HP instead of 1.
Ductwork: $470,870vs $784,783 as the RTO will be on the oven which reduces the horizontal duct lengths
Controls+ Electricals: $549,000 vs $423,841 as each RTO chamber requires separate LVCP/instrumentation
Miscellaneous: $614,032 vs $595,623 as insulation increases by the surface area ratio
Overall savings is 3% compared to the CECO quotation

Acknowledgements

Thank you to our Faculty Advisor, Professor John Kramlich for his invaluable guidance and knowledge on RTO systems.
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Capstone Expo Fair- 5/29/26