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LAWRENCE LIVERMORE NATIONAL LABORATORY

HEPA Filter Technology R&D Tools: The Miniature High Temperature Testing Unit

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June 6, 2016 through June 7, 2016

HEPA Filter Technology R&D Tools: The Miniature High Temperature Testing Unit

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Erik Brown (LLNL)

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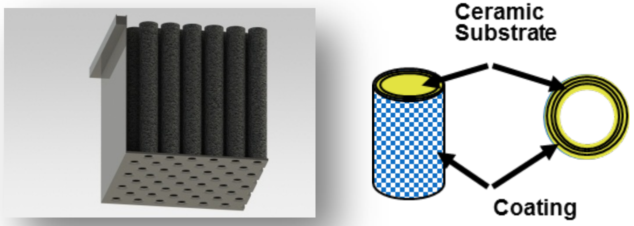
Lawrence Livermore National Laboratory

Big Picture
Technical Objective

- Develop and deploy advances in HEPA filter technology (e.g., related to ceramic HEPA filters) to benefit DOE nuclear facilities by providing lower life-cycle costs and reducing or eliminating certain safety basis costs associated with safety class and safety significant systems in nuclear facilities



Conceptual diagram of ceramic filter and filter element

Project Background

- Filter bank fires demonstrate need for improved filter technology

Project Background

Original, full-size High Temperature Testing Unit (HTTU)

- Full scale HTTU built at Cal Poly
  - 1000°F at 250ACFM
  - Very large
  - High power demand (480V ~37.5kW)
  - Full scale filter testing capability

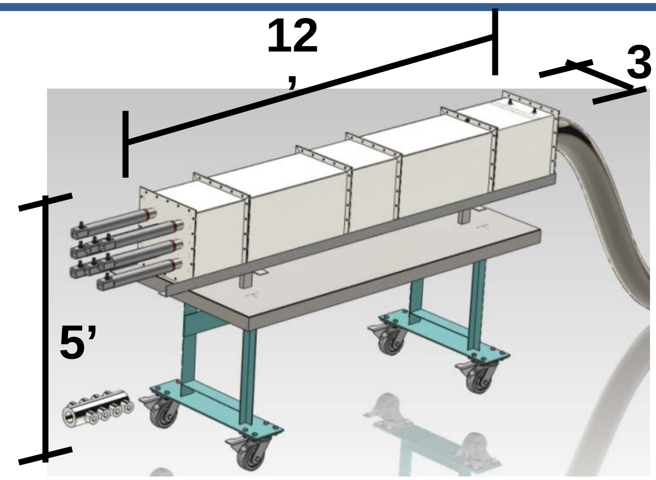
Miniature High Temperature Testing Unit
Objective

Purpose of this project was to best utilize the unique capabilities of the full-scale HTTU by designing and building a Mini High Temperature Testing Unit (MiniHTTU)

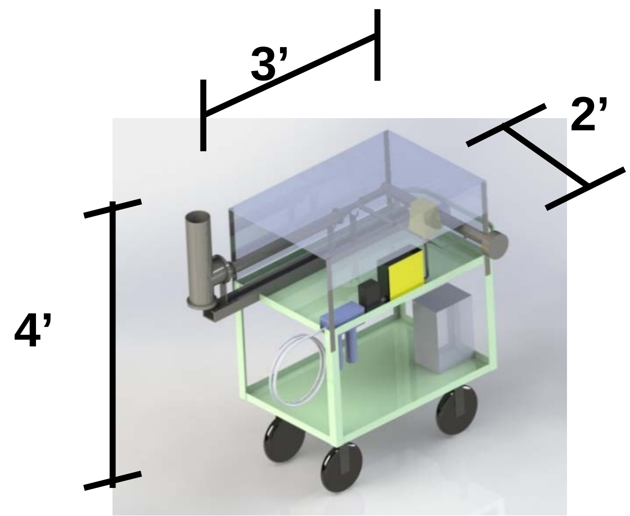
- MiniHTTU can rapidly, efficiently, and inexpensively test a large number of new and innovative materials for HEPA filter components
- MiniHTTU test results will be used to down select the most promising materials for HEPA filter components (e.g., media, sealants, gaskets) for full scale testing in the HTTU
- Also supports ASME AG-1 Section FO testing

Problem Statement - MiniHTTU Part 1
Team Phoenix (Fall 2013- Spring 2014)

- Needed: Faster testing
  - Rapid testing of multiple materials and HEPA filter component designs needed to down select final test materials (sealants, gaskets, filter media)
- Solution: A smaller HTTU
  - Rapid sample change out
  - Easier access for testing
    - Design around lower flow rates
    - Increase operating temperature
    - Reduce power requirements
    - Increased portability
  - Faster warm up
  - Intuitive control scheme



Original HTTU



MHTTU

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Design Specifications and Considerations

Primary Specifications

Primary Specifications	Target	Tolerance
Operating Temperature (°F)	1300	min
Time to Operating Temperature (min)	15	max
Test Section Flow Rate (ACFM)	1.25-12	min/max
Maintain Flow With Test Section Pressure Drop (in H_2O)	0.5-12	min/max

Mini-HTTU developed around considerably lower flow rates, enabling it to utilize standard compressed air as its air source and 240 volt power supply for its heaters

- Good insulation, overpowered heaters and minimizing amount of metal made for fast warm-up times, allowing for rapid and efficient tests
- Low-flow inline heater created by using a heating element designed for stagnant fluids in a tube
- Flow can be diverted to either low-flow heater or the off-the-shelf heat torch depending on desired flow rate
- Bi-layer insulation strategy keeps heat losses to a minimum and maintains a surface temperature less than 200°F, even when heaters are glowing at 1600°F inside

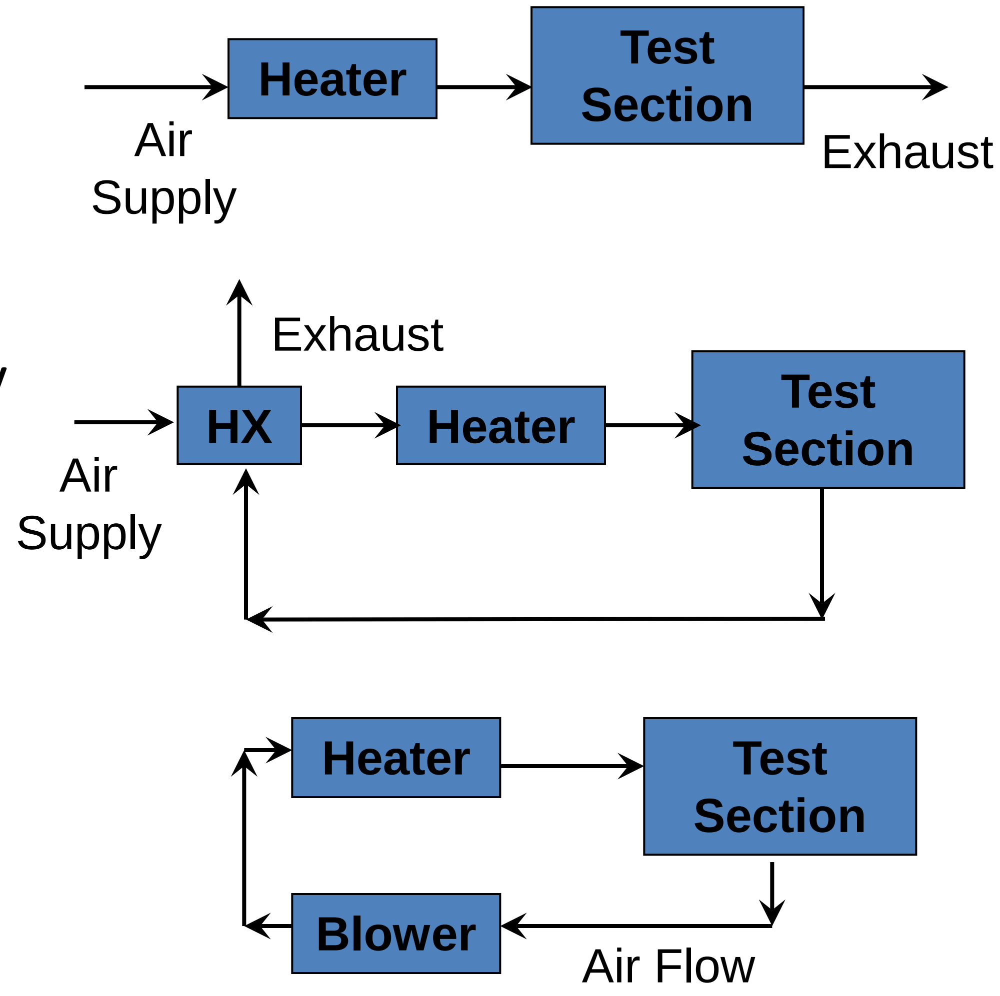
Design Specifications and Considerations

Additional Considerations

Mount to movable cart	√
Flow, temperature, and pressure readouts for operator feedback	√
Adherence to safety codes (ASME, OSHA, IEEE)	√
Digital capability for integration to control system	√
Debris catch in case of filter failure	√
Integration with a universal test section	√
Safe surface temperature	√

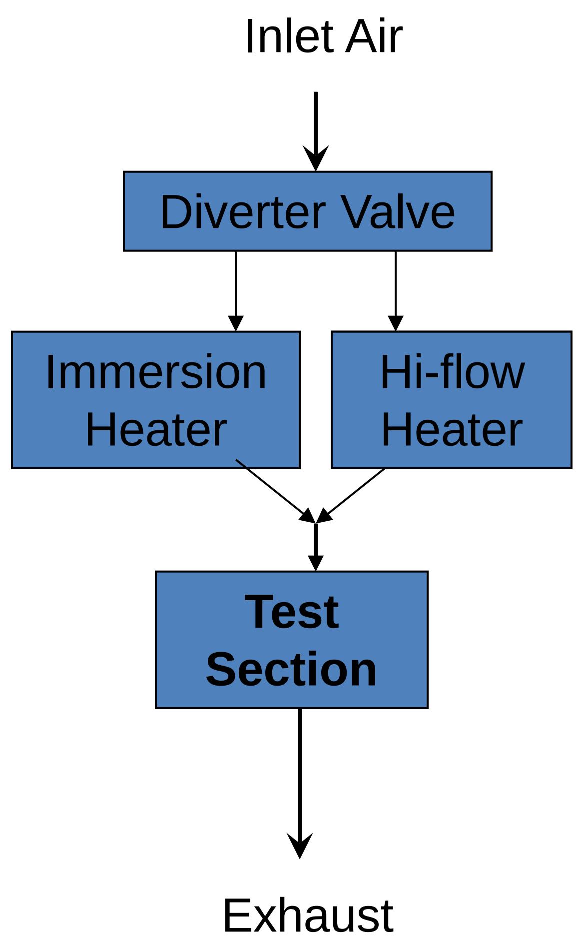
Considered Design Ideas

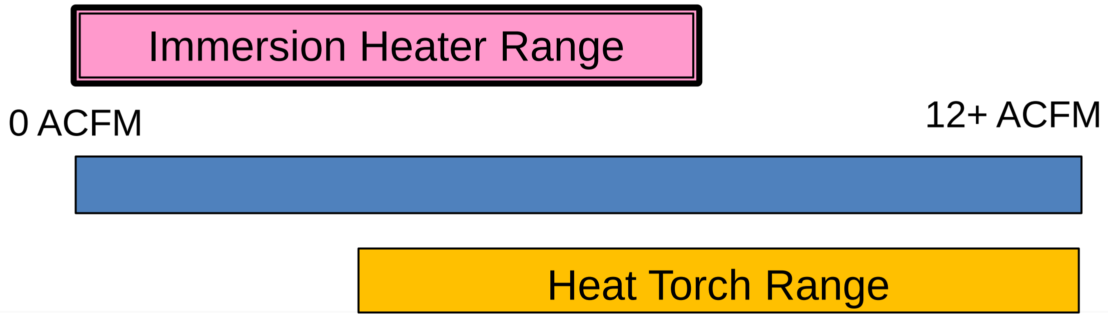
- Single Pass w/o Heat Recovery
  - Simple
  - Cheap
- Single Pass w/ Heat Recovery
  - More Efficient
  - Energy savings deemed not worth expense
  - Savings limited by heater
- Fully Re-circulating
  - Most efficient
  - Difficult/ cost-prohibitive



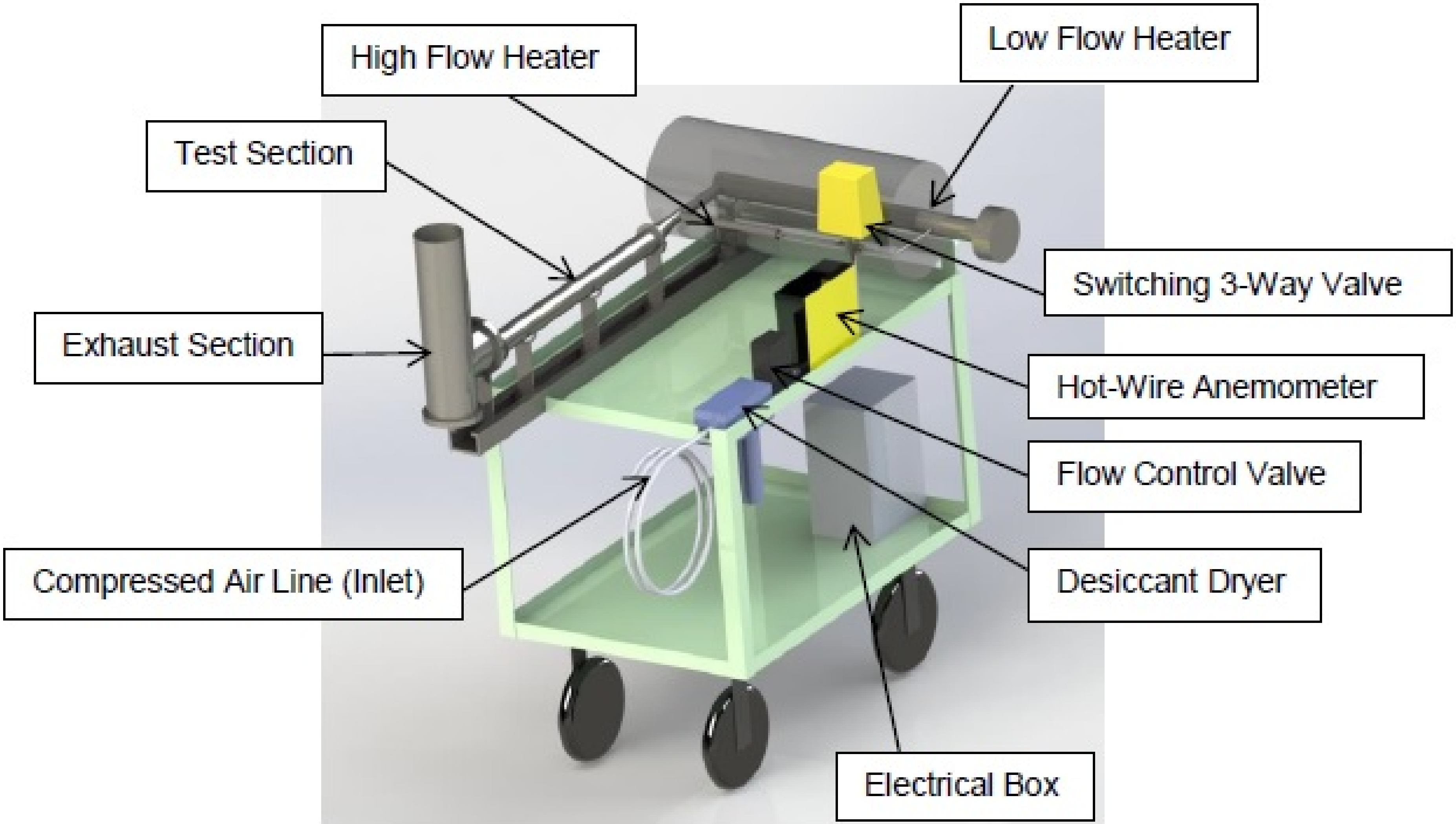
Chosen Design
Dual Heater System

- Only 1 heater operating at a time
- Off-shelf “hi-flow” heater not capable of lower flow rates
- Team designed heater built around commercial immersion heater capable of lower half of flow range





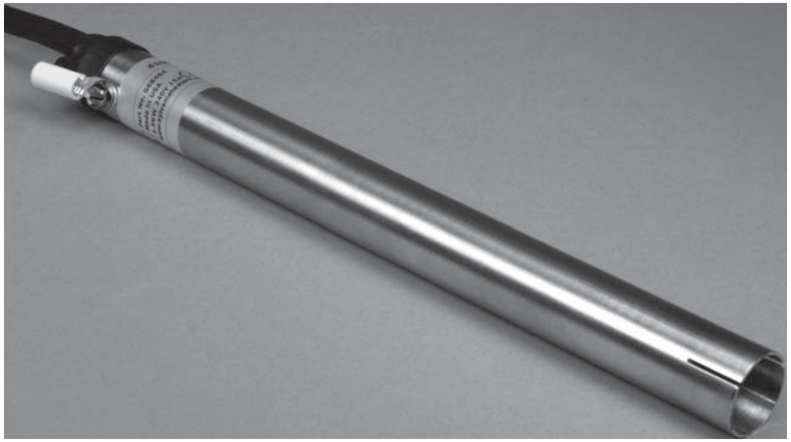
Chosen Design
Full Assembly



Primary Specification: Operating Temperature at Flow

Heaters

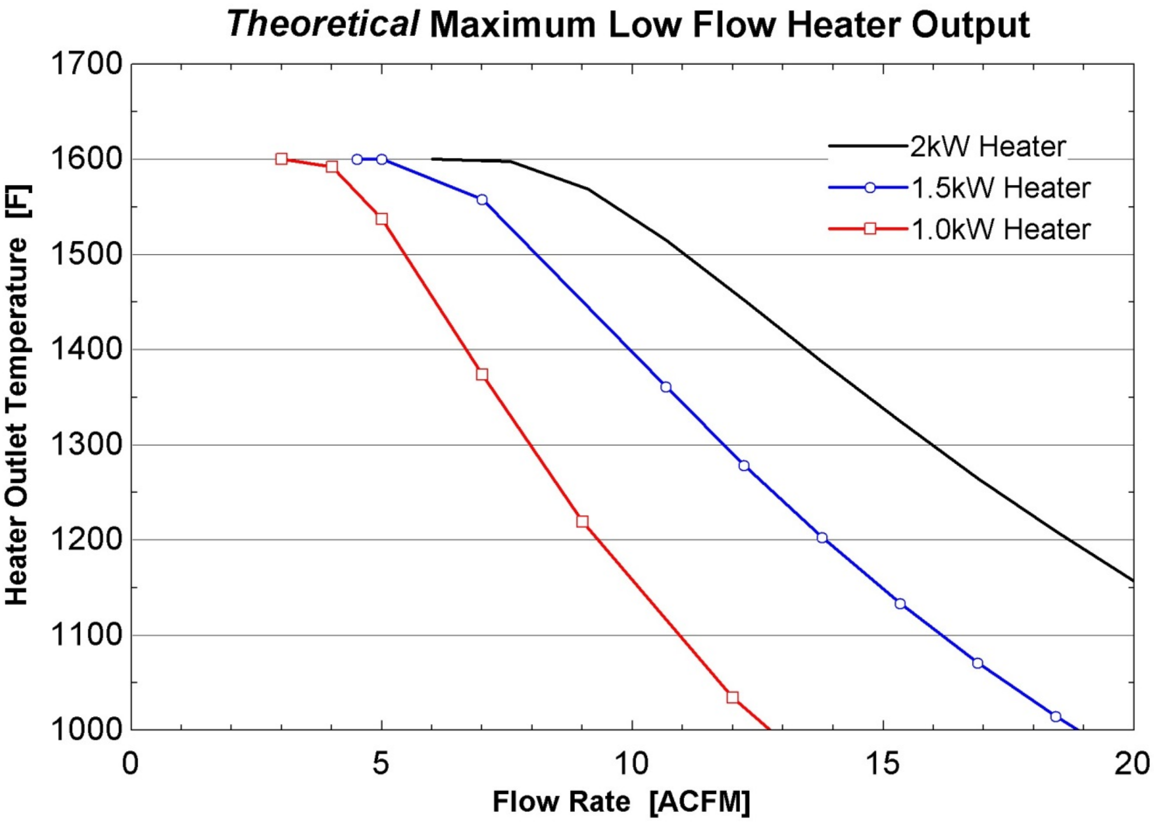
- Off-the-shelf inline flow heaters incapable of safety heating extremely low flow rates
- Immersion heaters (left) capable of heating stagnant flows, but untested at higher flow rates
- Inline heaters (below) capable of effectively heating higher flow rates



Primary Specification: Warm-up Time

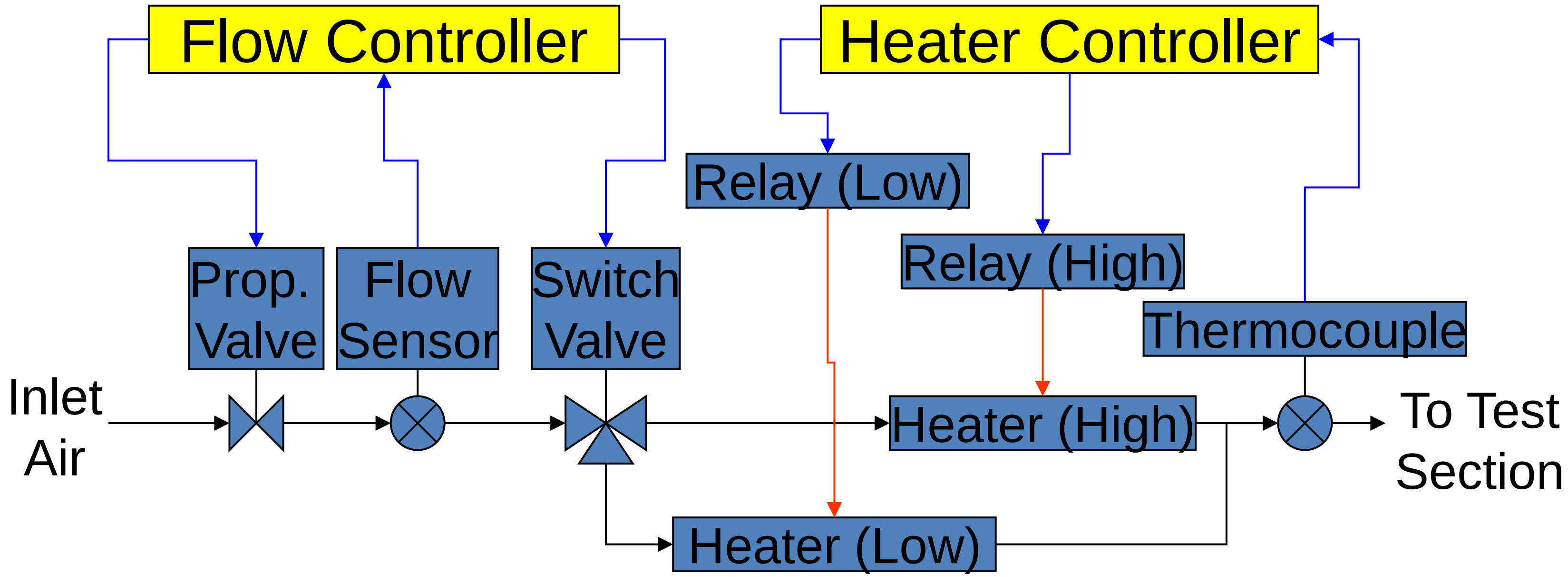
Low Flows

- Reducing heat capacity key concern- minimize thickness of steel walls
- Heaters capable of temperatures greater than spec to account for losses



Control Scheme

- Heater selection determined by flow set point
- Controller adjusts heater output and flow control valve on the fly
- Operator determines set points and is provided constant flow, temperature, and pressure drop feedback
- Controls team develops flow and heater controllers



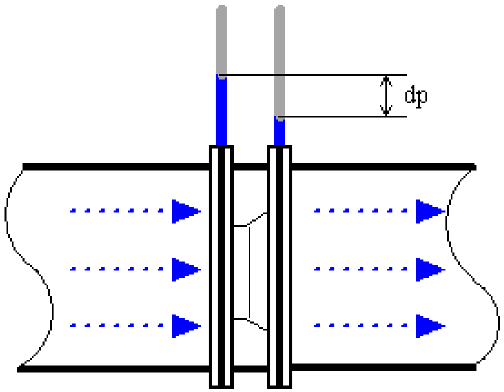
Flow Measurement and Control

- Measurement- Hot Wire Anemometer
  - Measure mass flow rate precisely
  - Pressure and temperature at test section used to calculate volumetric flow (CFM)
  - Measure flow from the “cold” side
- Control- Stepping Motor Actuated Proportioning Valve
  - Flow rates adjustable between 0 and 100% of rating
  - Electronically controlled
  - Many flow ratings (coefficients) available- 0.855 selected to achieve flow range and maintain resolution

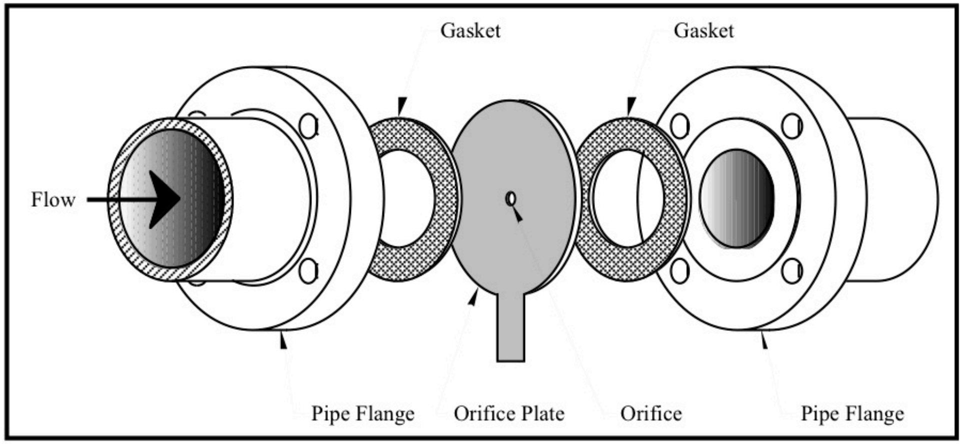
Primary Specification: Pressure Drop

Orifice Plates

- Orifice plates generate pressure drop at test section interface
- Differential pressure transducer measures pressure drop across plate
- Allows for verification of pressure drop capability without need for universal test section completion

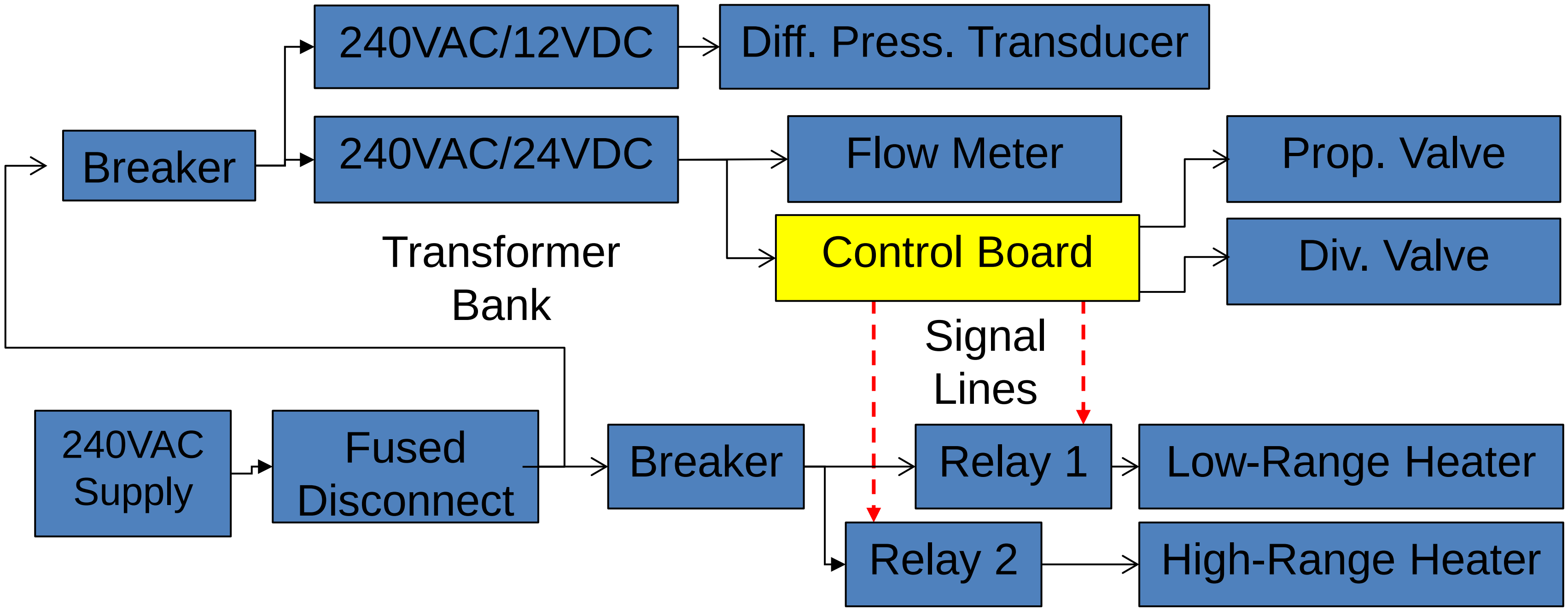


www.EngineeringToolBox.com

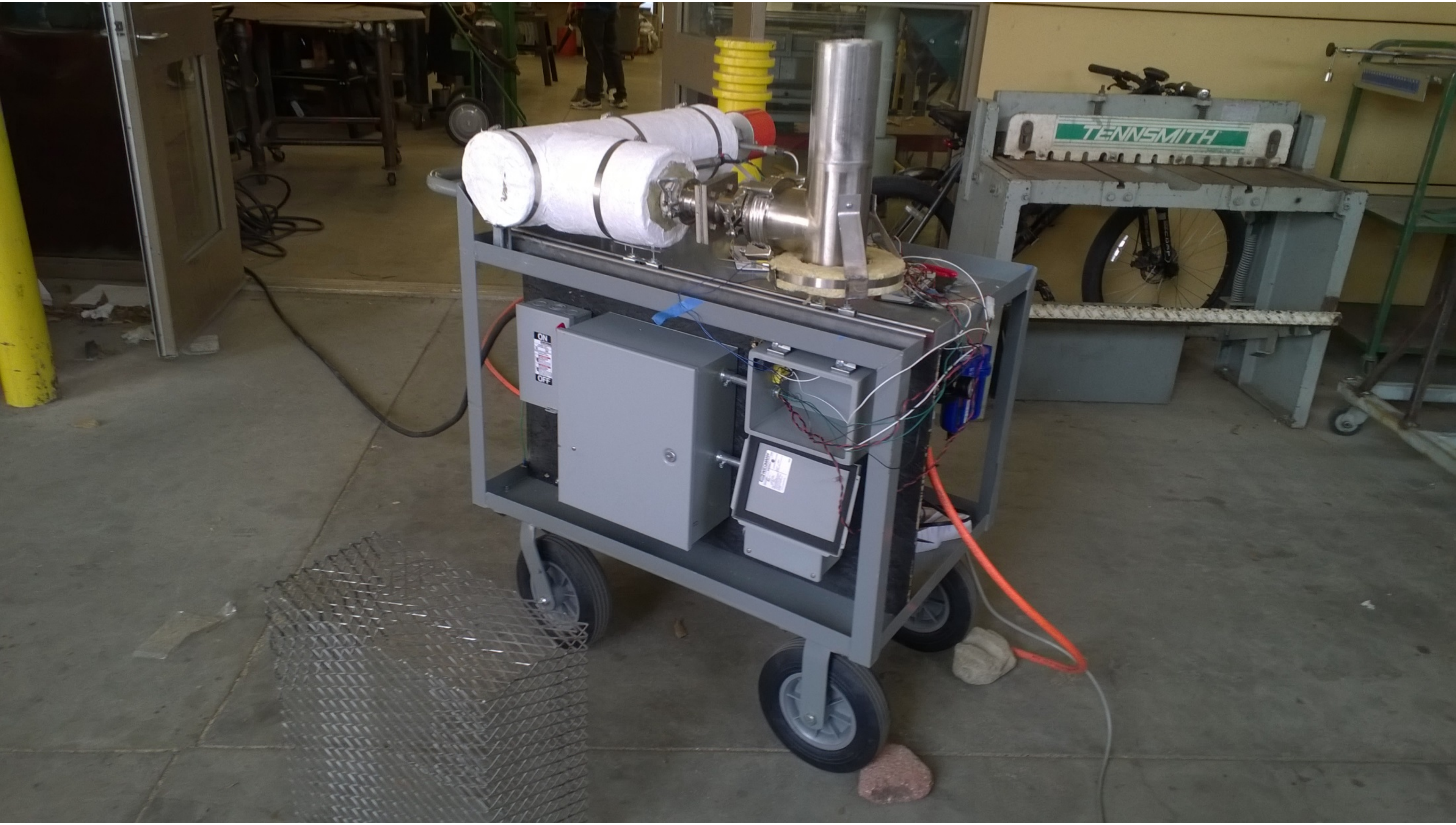


Power Scheme

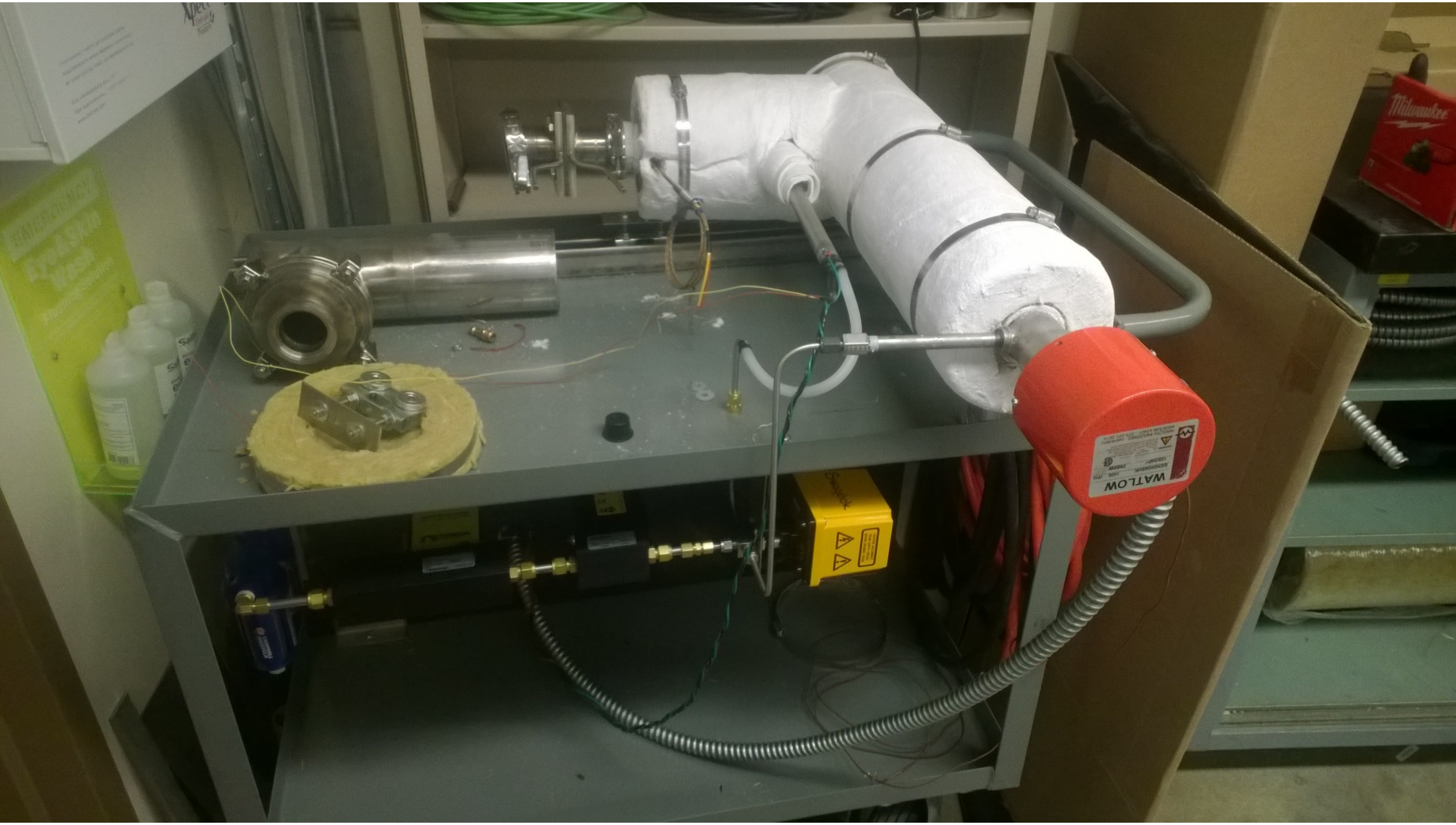
- 240V 1ph supply, with controls and heaters on separate breakers
- 24VDC and 12VDC power supplied by transformers
- Max Draw: ~9A with 2kW heater
- Control board provides valve excitation



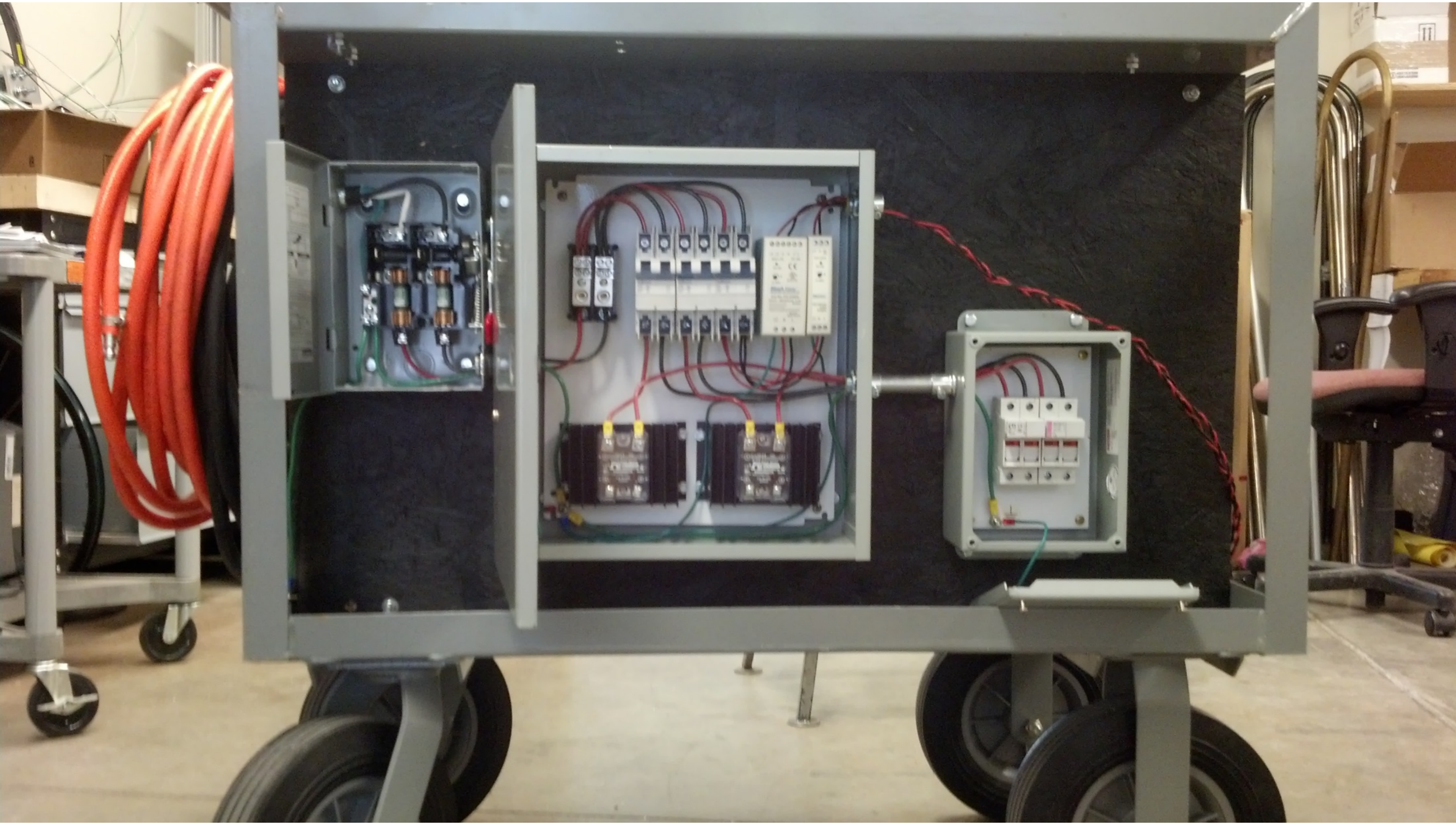
Completed Device



Completed Device

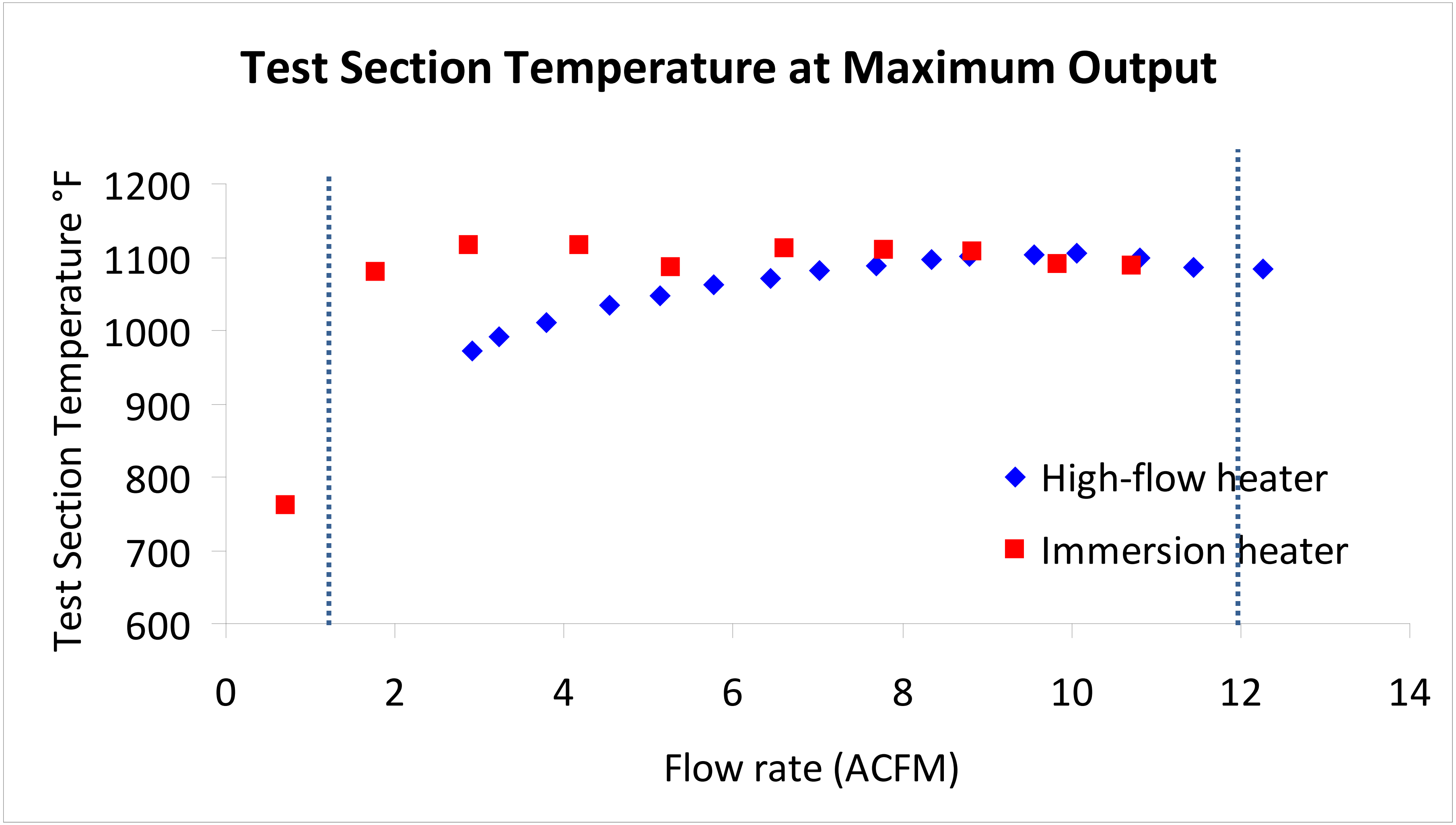


Completed Device



Results

Final Design Testing



Results

Conclusions, Recommendations

- MiniHTTU max temperature exceeds R&D testing requirements
  - Max achieved 1116°F, exceeding max temperatures of two independent fire modeling studies by almost 200°F
  - Heat loss between heaters and test section greater than estimated
    - Application of insulation questionable in places
    - High-flow heater acting as pin-fin heat sink when off
- The immersion heater's performance exceeded expectations
  - High-flow heater not needed, could be removed
    - Further shorten flow path to reduce heat losses

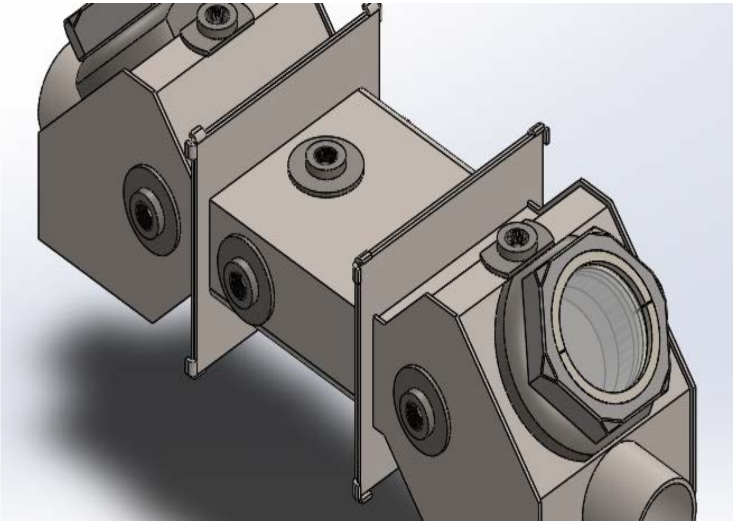
MHTTU Part 1

Team Phoenix (Fall 2013- Spring 2014)

Next generation success story - two students hired by LLNL NucOps, building upon the expertise they gained in their senior project

MHTTU Part 2

Team Microfire

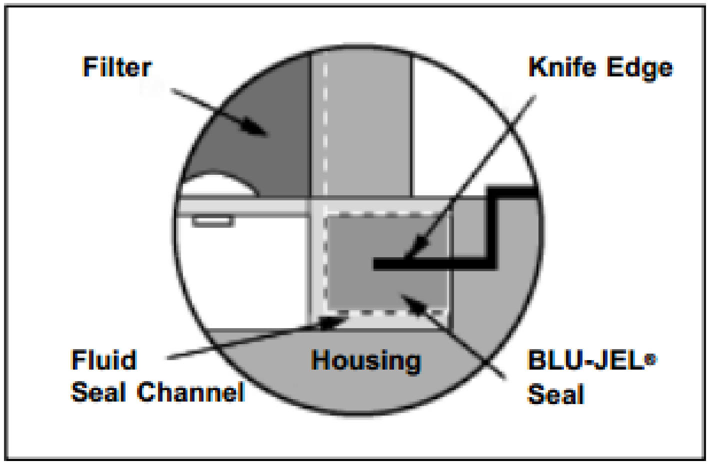


Team Microfire Accomplishments

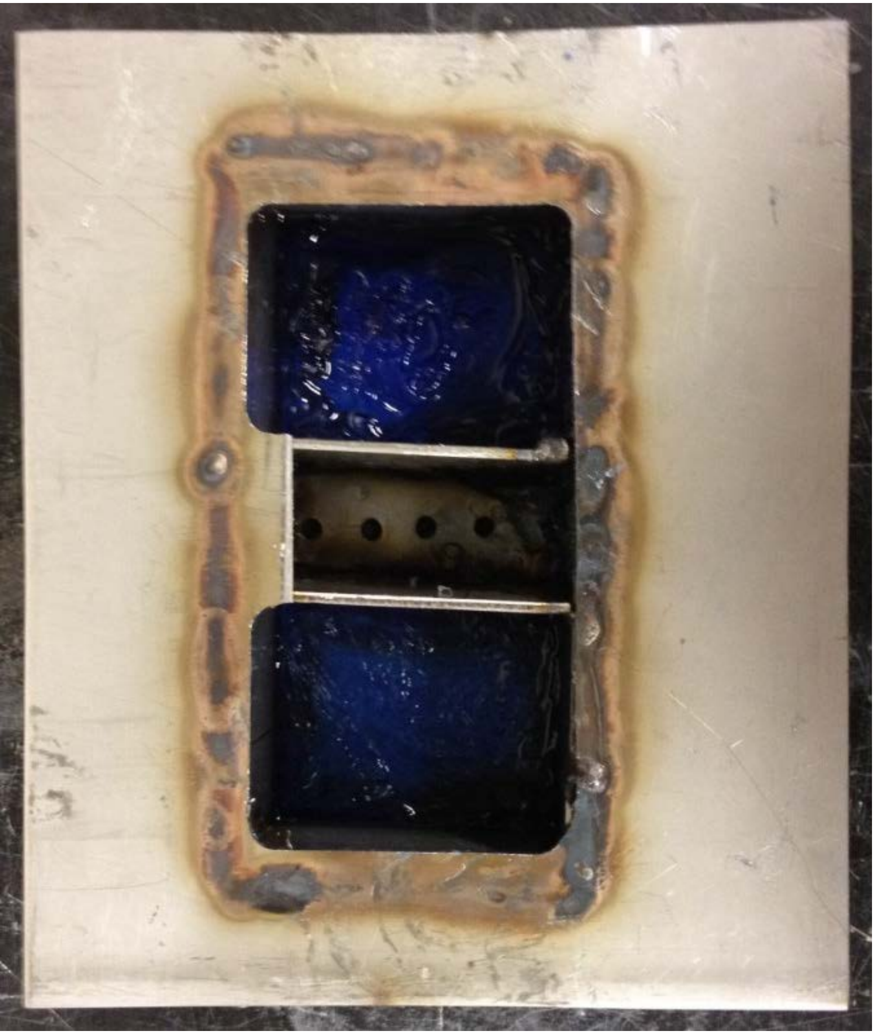
- Team 2 (Team Microfire)
  - Began work in January 2014 to design, build and test, the test chamber and sample fixtures, integrate the test section into the MiniHTTU and perform tests on various sealants and gaskets.
  - Built and integrated the test section
  - Built test fixtures
  - Thermal mass of test section reduces operating temperature from 1116°F to 750°F (minor modifications will improve this to meet requirements)
  - Conducted tests on sample materials (need to test more for downselect)
  - Used additive manufacturing to 3D print a filter material sample
    - A LLNL/NSSC summer student designed several more advanced material samples

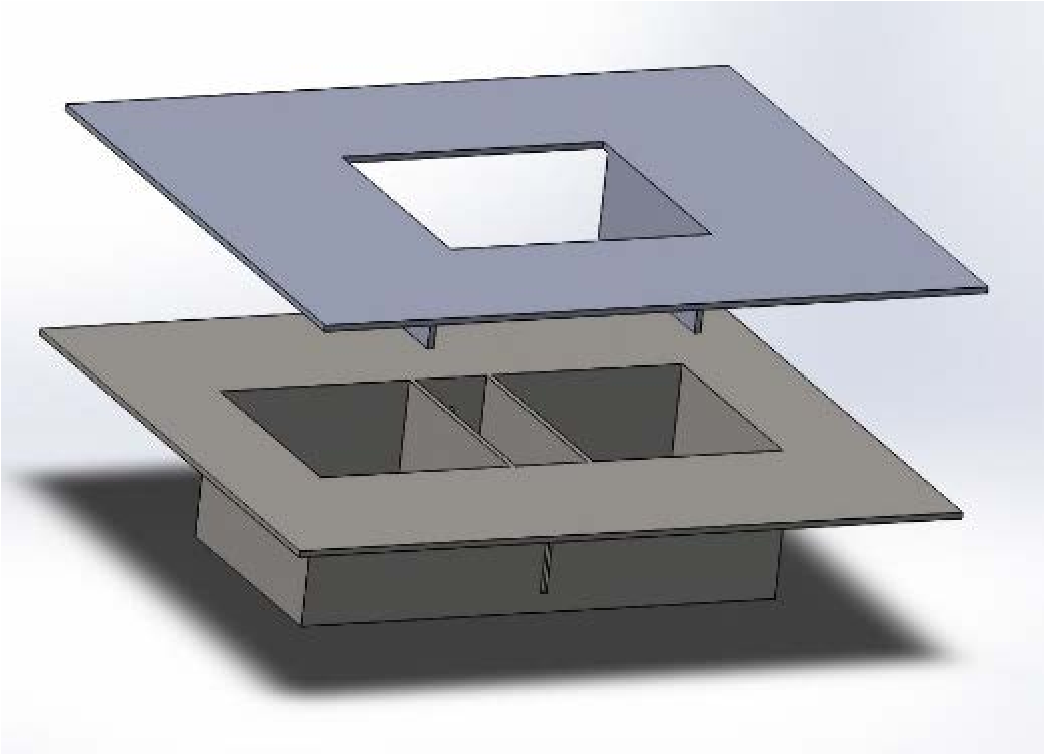
Test Chamber

Background on Rapid Test Chamber for Sealants

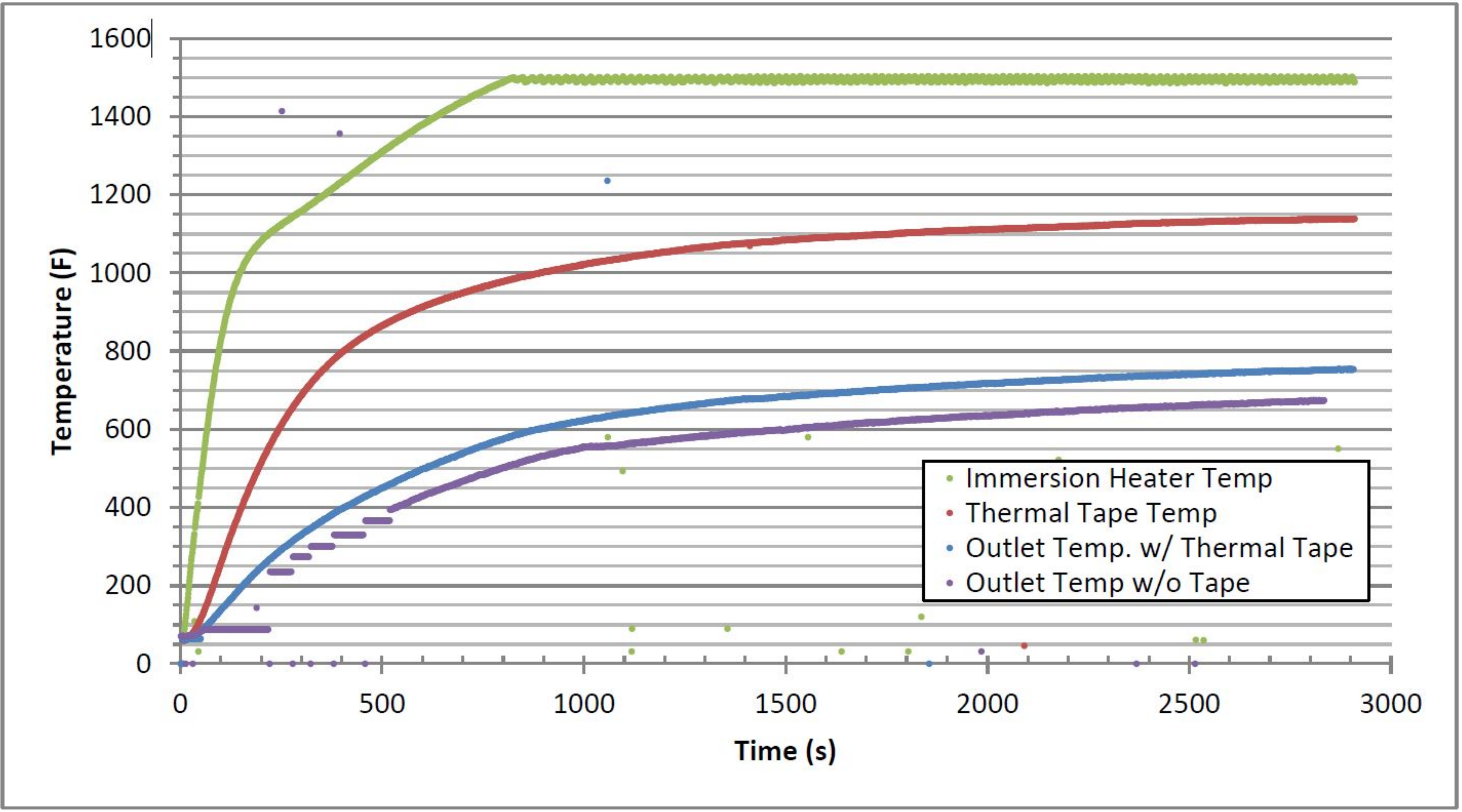


Test Chamber for Rapid Change Out of Sealants





Results

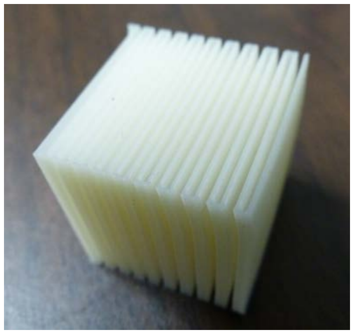


1600
1400
1200
1000
800
600
400
200
0
Temperature (F)
0
500
1000
1500
2000
2500
3000
Time (s)
Immersion Heater Temp
Thermal Tape Temp
Outlet Temp. w/ Thermal Tape
Outlet Temp w/o Tape

Moving Forward

- Some of the test fixtures of the MiniHTTU need refining
- Team 3 (In recruitment, *switched to Masters Thesis Research*)
  - Effort to recruit a third senior project team with the Cal Poly Materials Department was unsuccessful (one set of students per year), pursuing other approaches
  - List of materials to test drafted, includes input provided from another DOE site, graduate student proposed additional materials for potential testing
  - Conduct testing to down select optimal samples for full-scale testing
  - Test full-scale down selected samples (sealant, gasket, filter media) in full scale HTTU
- Masters Degree Student (UT – El Paso)
  - List of test materials, components, objects (Drafted, conducting in depth study)
  - Utilizing study results, will select optimal materials to perform down select

New and Innovative Materials to Test



3D printing produces complex shapes depending on flow and performance specifications

Conclusion

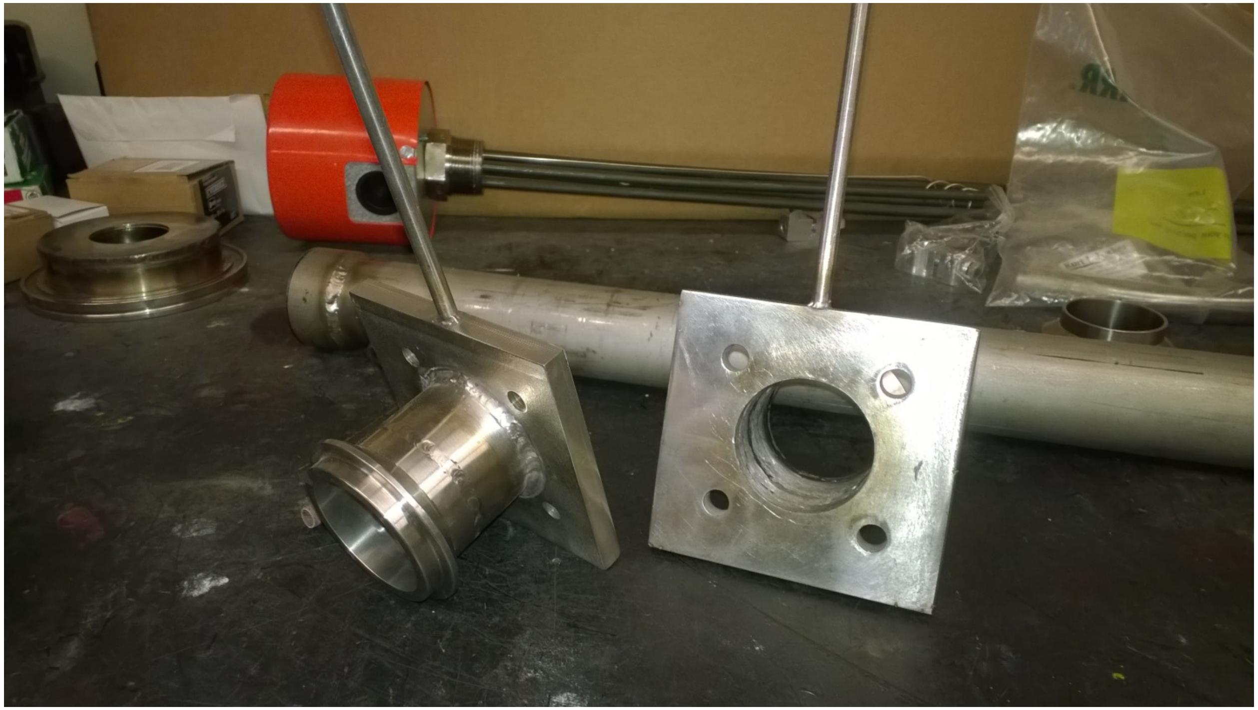
- MiniHTTU can rapidly, efficiently, and inexpensively test a large number of new and innovative materials for HEPA filter components
- MiniHTTU test results will be used to down select the most promising materials for HEPA filter components (e.g., media, sealants, gaskets) for full scale testing in the HTTU
- This will help researchers best utilize the unique capabilities of the full-scale HTTU

Background

Manufacturing

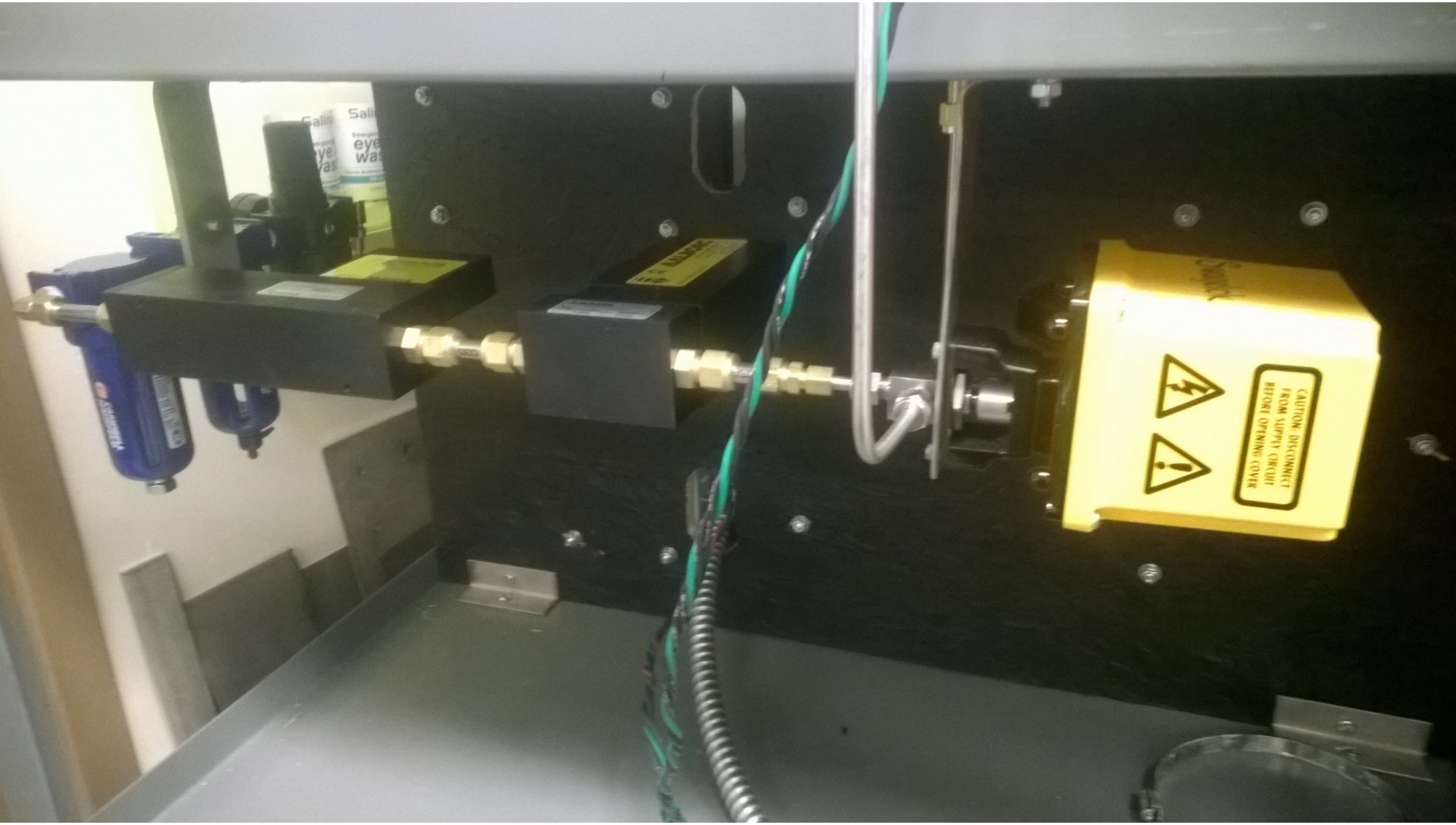
- All parts requiring fabrication made in house at Cal Poly facilities
- Machining and TIG welding of stainless steel
  - Low flow heater housing
  - Hot side flow path

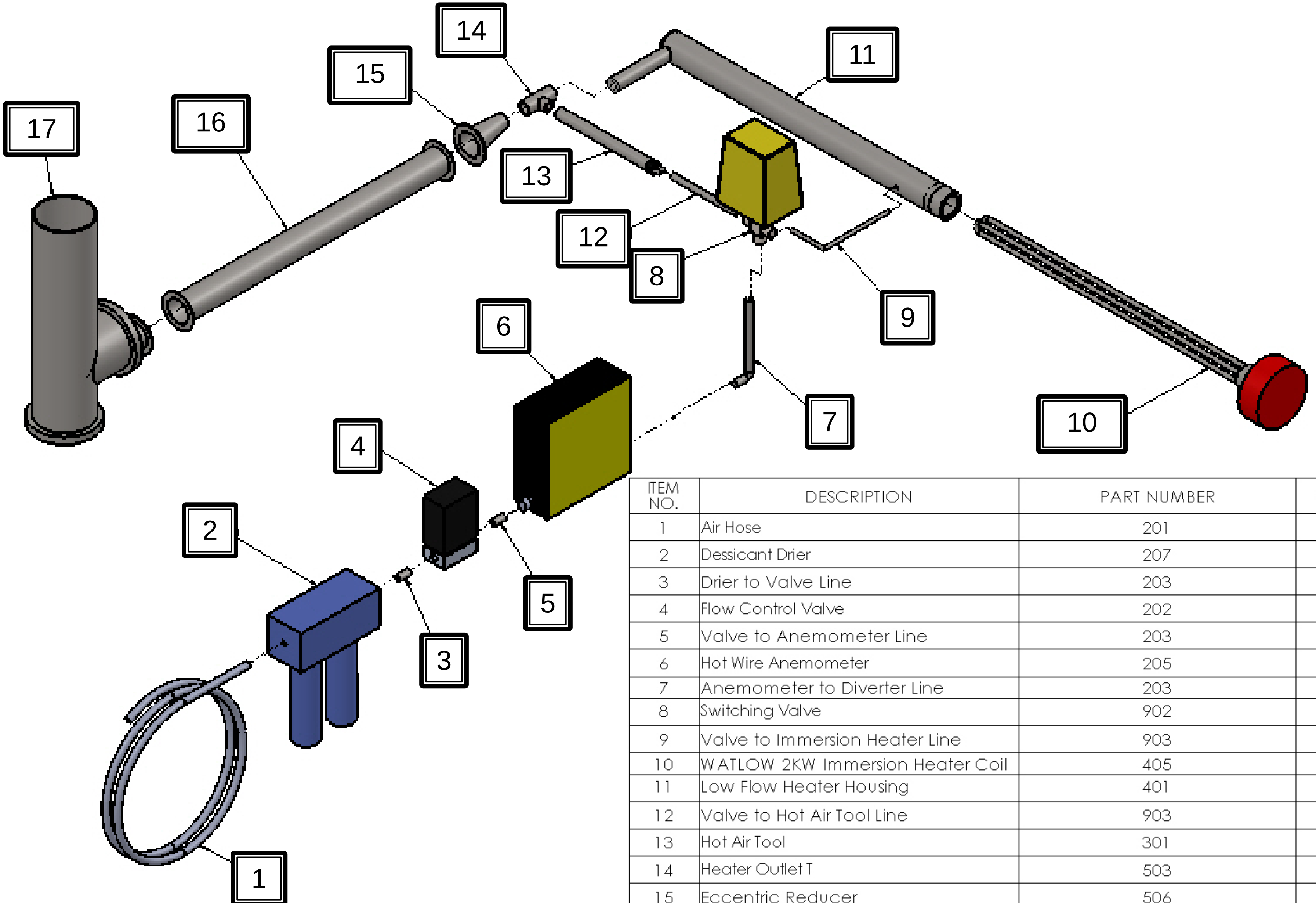
Manufacturing



Completed Device

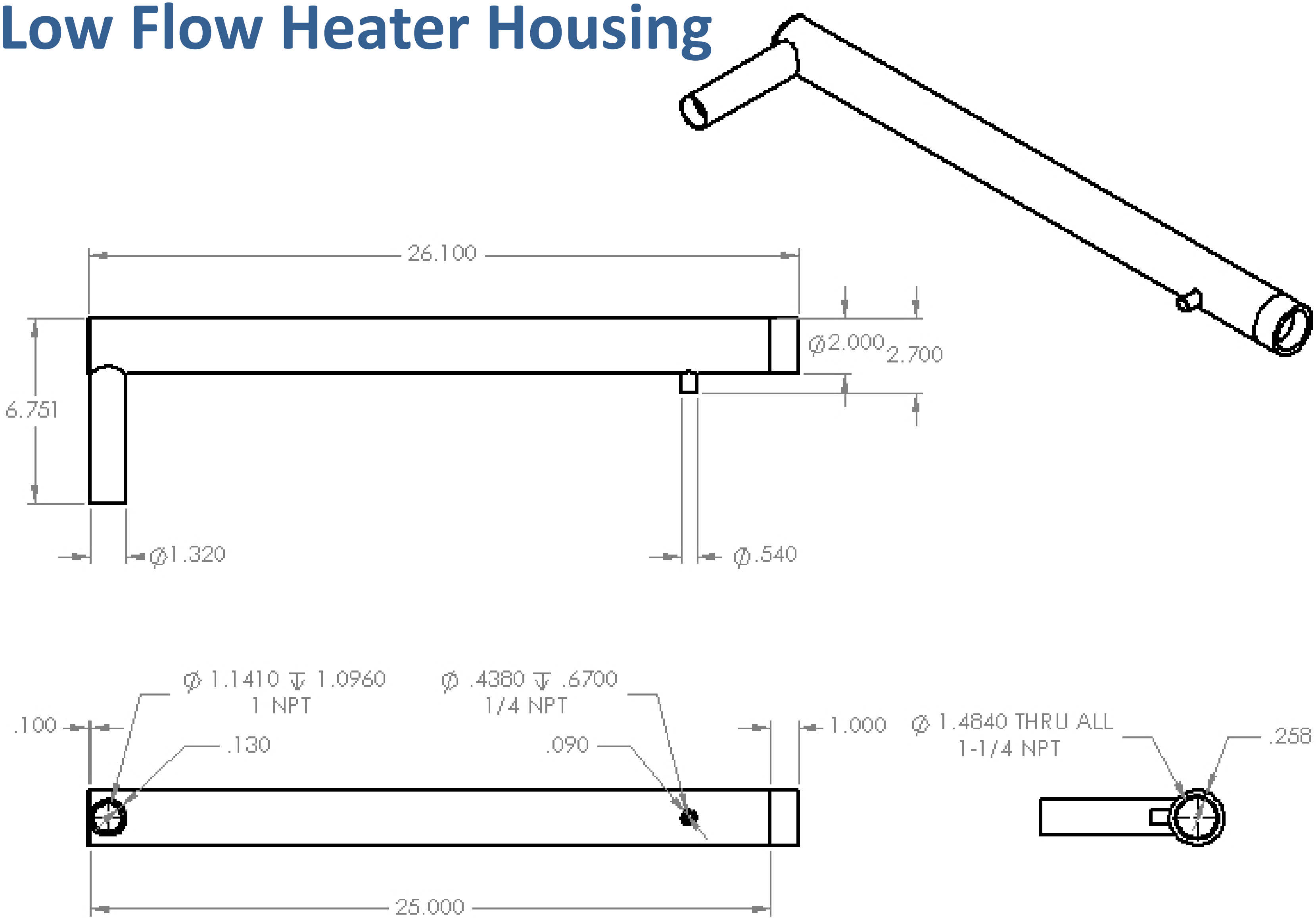
Completed Device





ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
1	Air Hose	201	1
2	Dessicant Drier	207	1
3	Drier to Valve Line	203	1
4	Flow Control Valve	202	1
5	Valve to Anemometer Line	203	1
6	Hot Wire Anemometer	205	1
7	Anemometer to Diverter Line	203	1
8	Switching Valve	902	1
9	Valve to Immersion Heater Line	903	1
10	WATLOW 2KW Immersion Heater Coil	405	1
11	Low Flow Heater Housing	401	1
12	Valve to Hot Air Tool Line	903	1
13	Hot Air Tool	301	1
14	Heater Outlet T	503	1
15	Eccentric Reducer	506	1
16	Test Section Tube	501	1
17	Dead Leg Exhaust	600	1

Low Flow Heater Housing



Cal Poly Mechanical Engineering	WINTER 2014	Assignment #4	Title: LOW FLOW HEATER HOUSING		Drwn. By: Nagengast, Juan
TEAM PHOENIX	Dwg. #: 400	Nxt Asb:	Date: 2/11/14	Scale: 1:5	Chkd. By: TEAM

Primary Specification: Warm-up Time

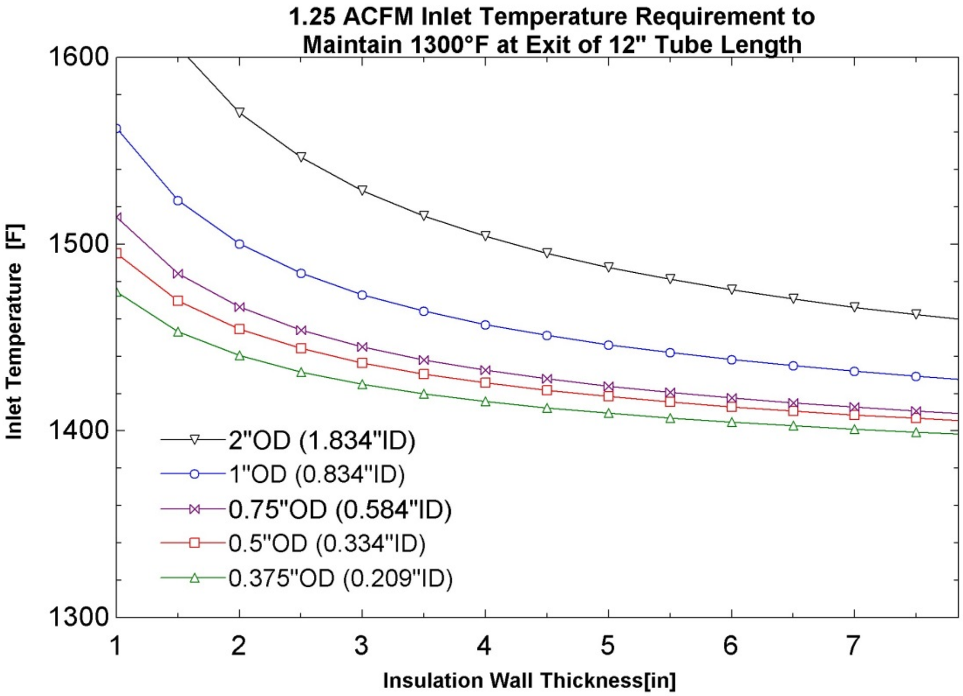
High Flows

- Available inline heaters efficient at heating higher flow rates
- Less additional temperature needed to offset energy losses from higher flow rates
- Higher power heaters are not more expensive
- Conclusion: Off-the-shelf high power heater sufficient for high flow rates

Primary Specs: Warm-up Time & Operating Temp.
Insulation

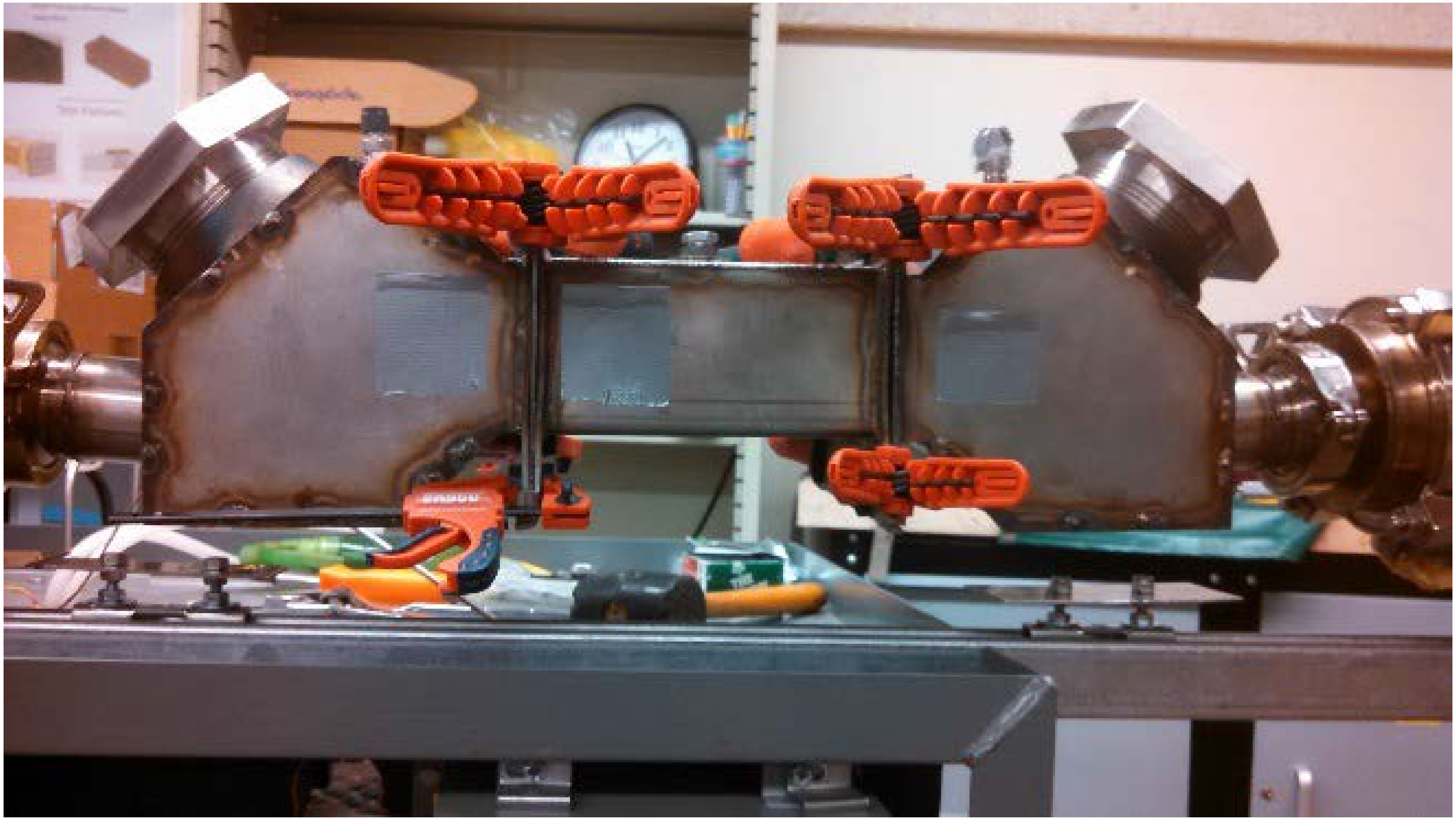
- Alumina oxide wrap inner layer w/ mineral wool outer layer
- Thermal diffusion much slower in insulation, resulting in faster tubing warm-up
- Heat transfer analysis of varying insulation thickness shown at right
- Reduction in heat loss especially important at lower flow rates, where temperature differential is large and small heat losses result in large temperature changes



Test Chamber

Test Chamber



Test Chamber