Mitigation of Orion Ammonia Boiler Outlet Coolant Thermal Stratification

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Background

- Orion Multi-Purpose Crew Vehicle Ammonia Boiler Heat Exchanger (ABHX) has a temperature control issue
- Propylene glycol/water mixture (PGW) and evaporating ammonia flow through the ABHX in counter-flow
- After exiting the boiler, the PGW travels through a tube with three bends to a temperature control sensor block containing two thermistors
- Development testing showed that the flow at the sensor block was not well mixed - the two PGW temperature sensors registered temperature differences of up to 5°C

Background

- A water test stand was constructed to investigate the stratification of the flow downstream of the boiler and assess possible solutions
  - Scaled
  - Gravity-fed
  - 1 inch clear PVC pipe
  - Dye injection
- Little pressure drop is available in the system to enhance mixing
- A low pressure drop mixer was identified and tested

Physics

- **35/65% inhibited propylene glycol and water**
- **Flow rate is 0.0359 kg/s through the ABHX**
- **Nominal control temperature is 8.3°C**
- **The Reynolds number in the 10.9 mm ID tubing is 670 at these conditions - the flow is laminar**

Physics

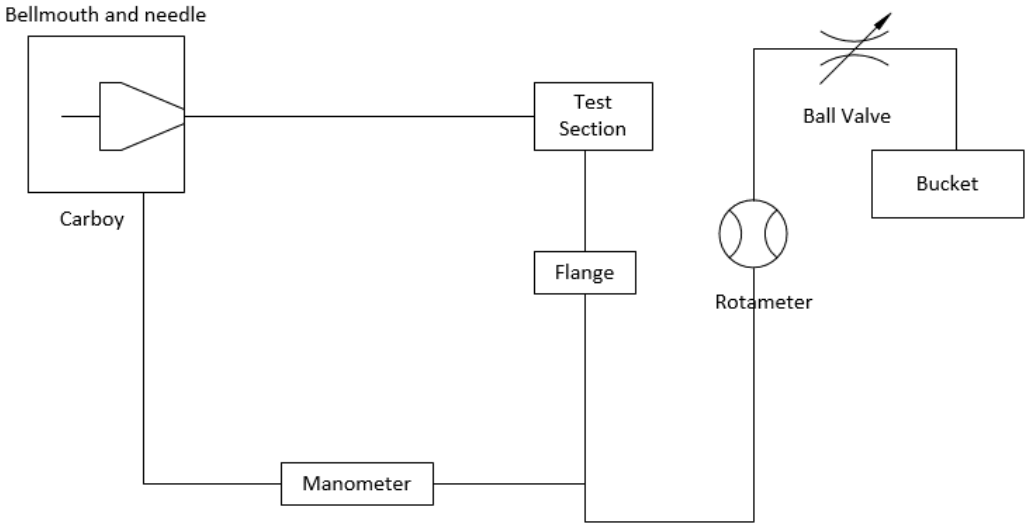
- **The characteristic heat conduction length can be used to characterize the mode of thermal mixing**
- **The residence time in the 286 mm long tubing section is 0.785 seconds**
- **The characteristic conduction length, L, is calculated using the transport time, τ, and the PGW thermal diffusivity, α**

$$L = \sqrt{\tau\alpha}$$

Physics

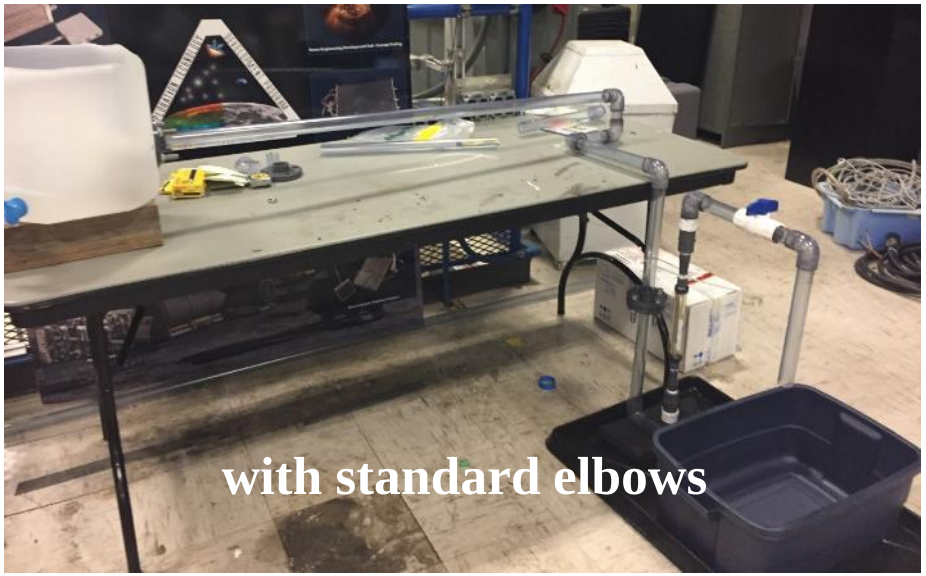
- **The characteristic conduction length over this time is 0.28 mm – a small fraction of the 5.5 mm tube radius**
- **Conduction in the flow is small - mixing is the dominant mode of eliminating thermal stratification**
- **Flow visualization is an accurate method of assessing the degree of thermal mixing**

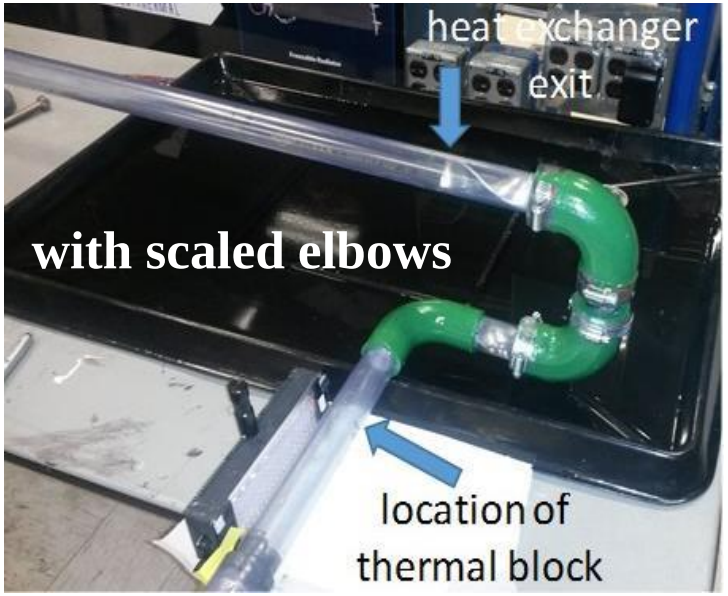
Test Stand



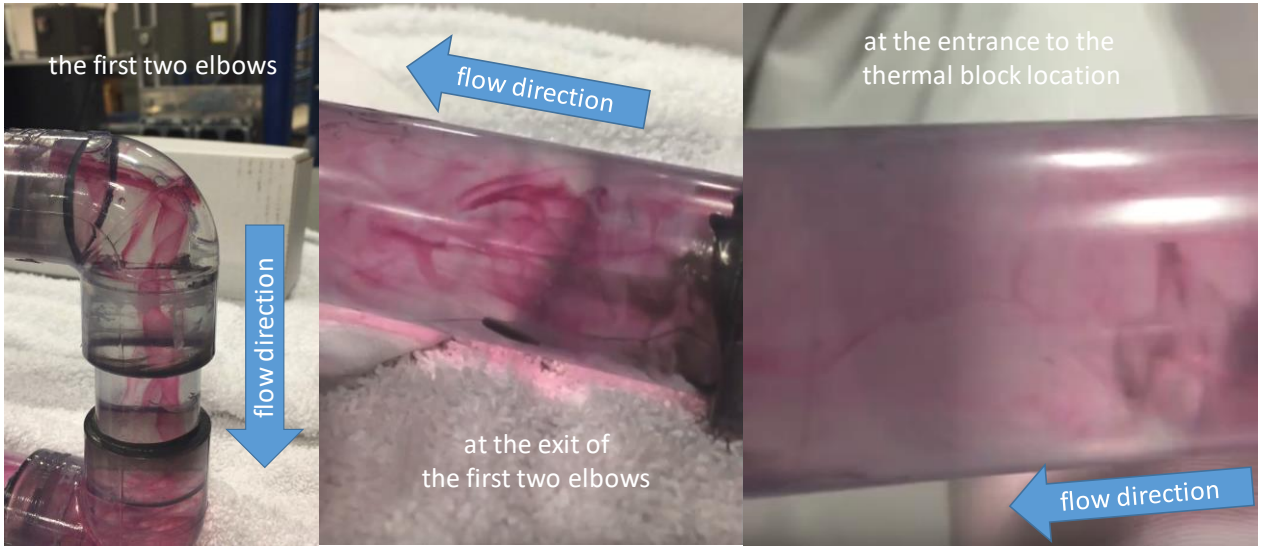
- **Bell mouth creates smooth entrance**
- **Needle allows injection of neutrally buoyant dye**
- **Ball valve adjusts flow to match Reynolds number**
- **Lengths and elbow dimensions are scaled geometrically with tube ID**

Test Stand


with standard elbows


heat exchanger exit
with scaled elbows
location of thermal block

Baseline Test

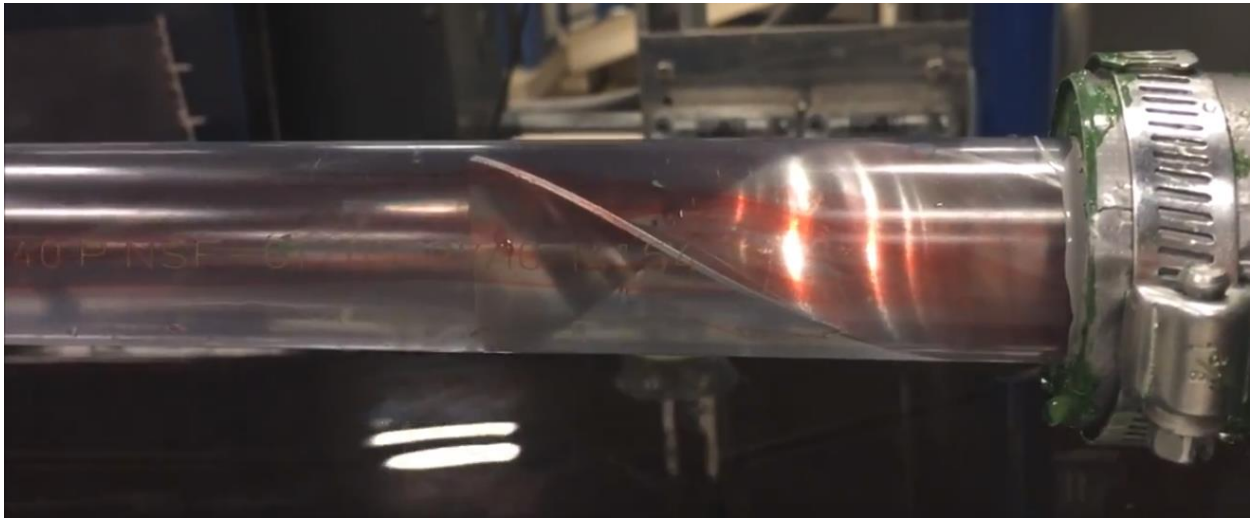


- **Baseline test was performed with standard elbows**
  - **smaller bend radius would provide better mixing than flight bent tubing**
- **Poor mixing at entrance to thermal block**

Mixers

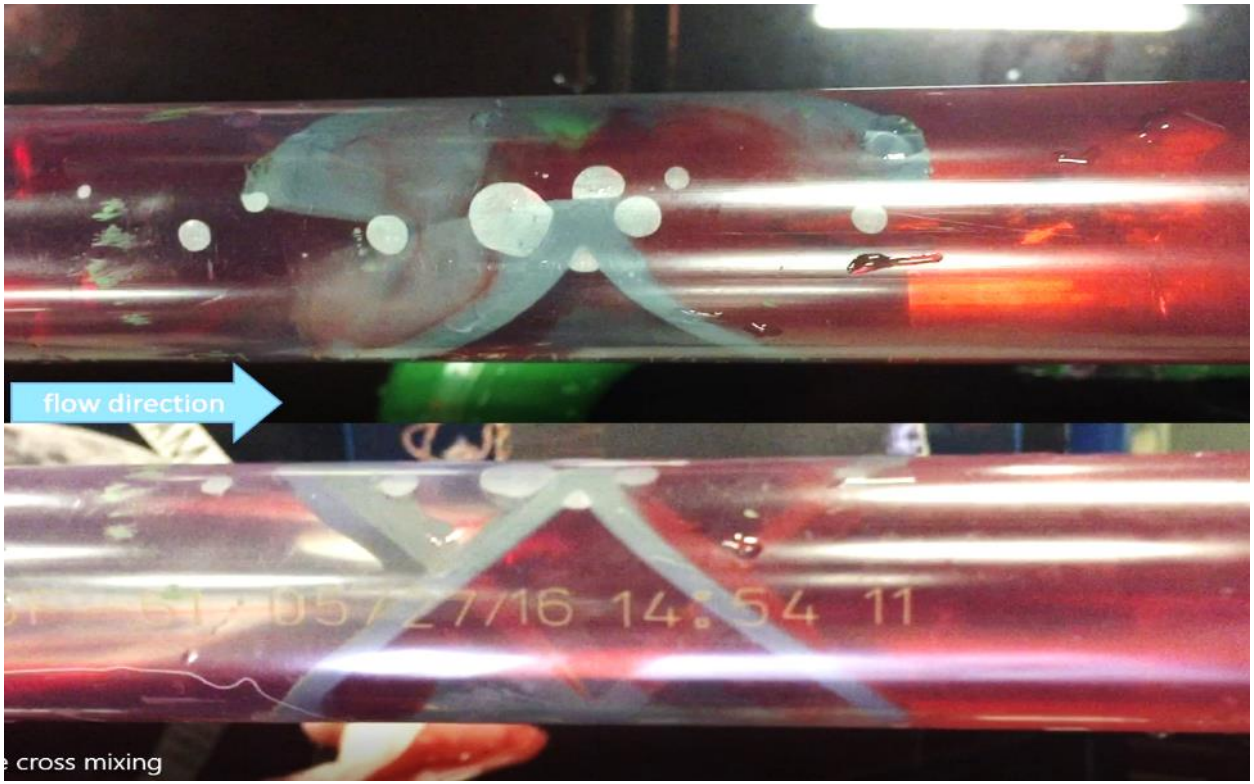
- Twisted aluminum tape
  - fabricated from 1.5 mm thick aluminum sheet
  - width 26 mm
  - half twist length of 85 mm
- Koflo® static mixer

Twisted Tape Results



- **Twisted tape at the heat exchanger exit was ineffective**
- **No mixing apparent**
- **Twisted tape only provides a longer flow path – which was insufficient**

Koflo® Mixer Results



- **Excellent mixing even with short length of mixer at the heat exchanger exit**

Pressure Drop

- The pressure drop measured in the test section without the mixers was negligible
- To obtain measurable pressure drop with the short static mixer, the flow rate was doubled
- The pressure drop with the short mixer at the entrance was 15 to 28 velocity heads
- In the flight system, 28 velocity heads yields an additional pressure drop of 2.0 kPa, which is minor

Summary

- Flow visualization testing of the Orion ABHX exit confirmed the lack of mixing at the temperature sensing block
- A twisted tape mixer in the tubing was shown to be ineffective
- A short piece of a Koflo® static mixer was shown to thoroughly mix the flow
    - acceptable pressure drop of 2.0 kPa
- A recommendation was made to the Orion program to include a Koflo® static mixer in the ABHX tubing