Mitigation of Orion Ammonia Boiler Outlet Coolant Thermal Stratification

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• 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
• 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
• 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, \( \tau \), and the PGW thermal diffusivity, \( \alpha \)

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L = \sqrt{\tau \alpha}
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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

with scaled elbows

heat exchanger exit

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
• 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