Design Challenges of Digital Radiator Technology for Future NASA Space Missions

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Digital Radiator Basic Design
Challenges

• Stopping flow in a leg
  – Fluid freezing
• Fluid evacuation
  – Restarting flow
Stopping Flow in a "Leg"
Fluid “Freezing”

- PPG/ H2O -30°C (baseline)
- Therminol D-12 -100°C
- MultiTherm ULT-170 -129°C
- MultiTherm WB-58 -62°C
- Novec 7200 -138°C
- Galden HT-170 -97°C
- QTherm SZ2 -50°C
Freeze Experiment Setup

Lexan containment box for GN2 purge

GN2 purge line

Heat x-changer cup

Bulk fluid T

Inside wall T (replaced by datalogger)

Mag. Stir plate
Freeze Experiment Setup (top view)

- Manual stir rod
- Heat x-changer cup
- GN2 purge line
- Mag. Stir bar
- Bulk fluid T (mid depth)
- Inside wall T (touching wall in corner)
Unstirred freeze test (50 min bet 1st and last frame)

 Bulk T: -34C  
 Wall T: -39C

 Bulk T: -36C  
 Wall T: -44C

 Bulk T: -37C  
 Wall T: -46C

 Bulk T: -38C  
 Wall T: -48C

 Bulk T: -38C  
 Wall T: -50C

 Bulk T: -38C  
 Wall T: -50C  (min attainable T - extra 20 min)

Liquid sample taken here
Concentration analysis

- PPG percentage measured in sample of unfrozen liquid
- Results show little concentration change
In this video, the liquid begins at bulk $T=-29^\circ C$. At the start of the video, the chiller is set to $-38^\circ C$, which drops the wall $T$ to $-35^\circ C$. Final bulk $T=-35^\circ C$.

The post-freeze clip at the end is after 40 minutes of unstirred freezing. Bulk $T=-57^\circ C$.
Thermocouple data from unstirred test

PPG Full Freeze Lid On

Lid removed and fluid stirred (1st video)

Fluid T

Wall T
Qtherm freeze test
(Temp at center. 70 min. time)

Initial State > 0 C
Cooling -5 C
Freezing -26 C

Frozen -30 C
(Hand stir) Broken up -30 C
Thawing -10 C
Qtherm TC data unstirred

Temperature vs. Time

- Temperature (°C)
- Time (min)

- Freezing
- Frozen
- Machine Set-point
- Rapid Thaw

DI Water
Q Therm
Lessons Learned from Freeze Tests

• Freezing behavior not well characterized

• Difficult to predict flow-stopping T

• Must fully evacuate fluid from stopped legs
Fluid Evacuation Experiments

• Test of different evacuation techniques
  – Vacuum pump
  – Vent to space
  – Dissolved CO$_2$
  – Bubble Injection
  – Heater/ pump

15
Dissolved CO$_2$ Experiment

- RV
- Pump
- MV-5
- MV-4
- Polycarbonate tube
- MV-3
- MV-2
- MV-1
- Tank valves
- Carbonation stone
- H$_2$O
- CO$_2$
Dissolved CO$_2$ Experiment

- Fails to evacuate due to uniform bubble forming all over tube

Video: carbonation_video_cut.wmv
Dissolved CO$_2$ Experiment
Bubble Injection Experiment

- **RV**
- Pump
- Polycarbonate tube
- MV-5, MV-4
- MV-2, MV-1, MV-6, MV-3
- CO₂
- H₂O
Bubble Injection Experiment

- Evacuates well
- Added complexity to S/C to remove gas

Video: bubble_injection_video_cut.wmv
Startup Heater Experiment

PPG/ H₂O mix

Immersion heater in “stub” leg

Polycarbonate tube

pump

MV-5

MV-4

MV-2

MV-1

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Startup Heater Experiment

- Successful evacuation in 45s with 35W heater power.
- Works w/ favorable and adverse gravity

Video: single tube 12ft heater evac-cut.wmv
Multiple Tube Evacuation

• Evacuation of three tubes with individual heaters demonstrated successfully.

• ~15% of fluid remains in each tube due to adhesion to walls.
Incomplete Evacuation

• 15% of fluid remains in tube as film on walls due to surface tension for all techniques.
  – Occurs for polycarbonate, teflon, Al tubes

• This fluid coalesces into “clots” to block flow upon freezing

• Use **internally finned** tubes to combat
Internally Finned Tubing

- Tube with internal fins to trap excess fluid by capillary action.
Internally Finned Tubing Experiment

- Smooth and finned tubes attached to chiller line to freeze remaining fluid

- Post freeze flow test to indicate blockage
  - Finned tube flows
  - Smooth tube – no flow
Summary

- Coolant freezing behavior not well defined
- Evacuation of stagnant fluid necessary
- Stub heater evacuation method is promising
- Internally finned tubes prevent blockage
Supplementary

• The following slides are for back-up QA purposes
Test results

- 50/50 PPG/H₂O mix behaves according to literature

- Liquid becomes opaque and highly viscous at ~ -30°C (bulk T) and mag. stirrer fails.

- This is not a hard freeze, but essentially useless beyond this point (except for stag. Rad.)

Fig 11 from “A Guide to Glycols” – Dow corporation, 2003
PPG surface tension/ drop angle test

- Teflon: 42°
- Polycarbonate: 37°
- Aluminum: 36°
- Glass: 28°