Space Station Environmental Control & Life Support System
Purge Control Pump Assembly Modeling and Analysis

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Overview

- DA/PCPA/Manifold Integrated Analyses
- Chiller Block Performance Analysis
- PCPA Motor Heat Leak Study
- Conclusions
Simplified DA/PCPA Block Diagram

Distillation Assembly

- Condenser
- Compressor
- Evaporator
- Stationary Bowl Volume
- Flexhose
- Manifold
- PCPA
- Coolant In (100 lbf/hr @ 65°F)

Product Water
Waste Water
Brine

\[ X_1 \approx 1.0 \]
\[ P = P_{sat} \approx 0.95 \text{ psia} \]
\[ T = T_{sat} \approx 100°F \]

\[ \dot{V}_2 = 3.895 \text{ ft}^3/\text{hr} \]
Purge Control Pump Assembly

- Drive Motor (minus cooling jacket)
- Outer Hub
- Cooling Jacket (housing)
- Tubes
- Inlet/Outlet (Manifold Mount)
PCPA Chiller Block and Attachment

Valve Locations

Coolant Inlet

Purge Gas Inlet

Coolant Exit

Inlet Manifold

Outlet Manifold

Bottom View

Chiller Block Attachment to the Pump
PCPA Pump Cycle

1/4 Stroke

1/2 Stroke

3/4 Stroke

Beginning of Cycle

End of Cycle

High Pressure (Outlet)
Low Pressure (Inlet)
Opposing Piston-Cylinders used to Model Pump Cycle

- Piston #1
- Piston #2

Inlet → Open → Piston #1 → Close → Outlet

- High Pressure (Outlet)
- Low Pressure (Inlet)
Piston-Cylinder Analogy for a Complete Cycle
Derivation of the Pump Performance Equation

\[ \dot{Q} = \frac{2\pi k_{\text{Noprene}} x}{\ln \left( \frac{r_o}{r_i} \right)} (T_{\text{Piston}} - T_{\text{Coolant}}) \]

\[ V = AL = \pi r_o^2 L \]

\[ \dot{V} = A\dot{x} = Au \]

Assume P, T inside the piston remain at P_{\text{sat}}, T_{\text{sat}}. The mass drawn into the volume over a timestep, \( \Delta \tau \), is equal to:

\[ \Delta M = \int \frac{\dot{V}}{v_r + x_2 v_{fg}} d\tau + \int \frac{2\pi k x \Delta T}{\ln \left( \frac{r_o}{r_i} \right) h_{fg}} d\tau = \frac{\dot{V}}{v_r + x_2 v_{fg}} \int d\tau + \frac{2\pi k \Delta T}{\ln \left( \frac{r_o}{r_i} \right) h_{fg}} \int d\tau \cdot (x = u\tau, \dot{V} = \text{const}) \]

\[ \Delta M = \frac{\dot{V}}{v_r + x_2 v_{fg}} \Delta \tau + \frac{2\pi k \Delta T}{\ln \left( \frac{r_o}{r_i} \right) h_{fg}} \frac{u (\tau_f^2 - \tau_i^2)}{2} = \frac{\dot{V}}{v_r + x_2 v_{fg}} \Delta \tau + \frac{2\pi k \Delta T}{\ln \left( \frac{r_o}{r_i} \right) h_{fg}} \frac{u (\tau_f + \tau_i)}{2} \Delta \tau \]

\[ \frac{\Delta M}{\Delta \tau} \rightarrow \dot{M} = \frac{\dot{V}}{v_r + x_2 v_{fg}} + \frac{\pi k L \Delta T}{\ln \left( \frac{r_o}{r_i} \right) h_{fg}} \cdot \frac{L}{2} = u \frac{(\tau_f + \tau_i)}{2} \]
Derivation of Manifold (Chiller Block) Performance Equation

Heat transfer between the coolant and purge gas passages in the manifold:

\[ \dot{Q} = \left( \frac{1}{hA_{\text{Coolant}}} + \frac{1}{f(k, L, d)} + \frac{1}{hA_{\text{Purge}}} \right)^{-1} (T_{\text{Purge}} - T_{\text{Coolant}}) \]

\[ \dot{Q} = \bar{G} \Delta T \]

Mass flow in the purge gas passage is inversely proportional to the condensation rate:

\[ \dot{M} = \frac{\bar{G} \Delta T}{h_f (x_1 - x_2)} \]

Let \( \xi = \) heat transfer rate/heat of condensation; expected values range between 0.02 and 0.1 for the chiller block per hand calculation; larger value indicates higher heat transfer rate.

\[ \dot{M} = \frac{\xi}{(x_1 - x_2)} \]
Pump versus Manifold Parametric
\[ X_1 = 100\%, \ T_1 = 100^\circ\text{F} \]

\[ \xi = \frac{G \Delta T}{h_{fg}} \]

- \( \xi \) is a dimensional parameter (units of mass flow rate) that describes the thermal performance of the manifold.
- A larger value of \( \xi \) indicates a higher heat transfer rate between the coolant and purge lines.
- Per hand calculations, \( \xi \) is expected to range between 0.02 and 0.1 for the manifold.
Steady State Results

PCPA Capacity with Chiller Block

PCPA Inlet Vapor Quality

Chiller Block Temperature (deg F)

Purge Flow (lbm/hr)

Chiller Block Temperature (deg F)
Steady State Results (Cont’d)

PCPA Inlet Temperature

Chiller Block Temperature (deg F)
- Imported chiller block model directly from CAD file (stereo-lithography translation).
- Meshed as a solid with 10970 nodes and 43619 tetrahedrals.
PCPA Chiller Block Thermal Model Development

- Imported chiller block model directly from CAD file (stereo-lithography translation).
- Meshed as a solid with 10970 nodes and 43619 tetrahedrals.
PCPA Chiller Block Thermal Analysis Results

Note: Inner solid volume removed for clarity to expose flow passages.
## Boundary Conditions for PCPA Motor Heat Leak Study

### Cold Case (Motor Dissipation=18 watts)

<table>
<thead>
<tr>
<th></th>
<th>Motor Dissipation (watts)</th>
<th>Fluid Dissipation (watts)</th>
<th>Motor Cooling Jacket Temp (°F)</th>
<th>Outer Cooling Jacket Temp (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Operational</td>
<td>4.5</td>
<td>0.85</td>
<td>67</td>
<td>66</td>
</tr>
<tr>
<td>Worst Case Operational</td>
<td>18.0</td>
<td>3.38</td>
<td>72</td>
<td>71</td>
</tr>
<tr>
<td>Loss of Cooling</td>
<td>18.0</td>
<td>3.38</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

### Hot Case (Motor Dissipation=55 watts)

<table>
<thead>
<tr>
<th></th>
<th>Motor Dissipation (watts)</th>
<th>Fluid Dissipation (watts)</th>
<th>Motor Cooling Jacket Temp (°F)</th>
<th>Outer Cooling Jacket Temp (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Operational</td>
<td>13.8</td>
<td>0.85</td>
<td>65+ 6=71</td>
<td>65+ 4=69</td>
</tr>
<tr>
<td>Worst Case Operational</td>
<td>55.0</td>
<td>0</td>
<td>65+22=87</td>
<td>65+18=83</td>
</tr>
<tr>
<td>Loss of Cooling</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
# Steady State PCPA Motor Heat Leak Study Results

## Cold Case (Motor Dissipation=18 watts)

<table>
<thead>
<tr>
<th>Harmonic Drive Outer Temp (°F)</th>
<th>Minimum Peristaltic Tubing Temp (°F)</th>
<th>Maximum Peristaltic Tubing Temp (°F)</th>
<th>Motor Temp (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Operational (25% Duty Cycle)</td>
<td>70.2</td>
<td>67.6</td>
<td>69.9</td>
</tr>
<tr>
<td>Worst Case Operational (100% Duty Cycle)</td>
<td>86.2</td>
<td>76.4</td>
<td>85.5</td>
</tr>
<tr>
<td>Loss of Cooling</td>
<td>109.8</td>
<td>100.3</td>
<td>109.3</td>
</tr>
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<th>Motor Temp (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Operational (25% Duty Cycle)</td>
<td>78.5</td>
<td>72.3</td>
<td>77.8</td>
</tr>
<tr>
<td>Worst Case Operational (100% Duty Cycle)</td>
<td>126.8</td>
<td>92.3</td>
<td>110.3</td>
</tr>
<tr>
<td>Loss of Cooling</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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Conclusions

- Preliminary results from a thermal/flow analysis of the PCPA indicate that pump performance (mass flow rate) is enhanced via cooling of the housing and lowering of the inlet vapor quality.

- Under a nominal operational profile (25% duty cycle or less), at the maximum motor dissipation, it appears that the peristaltic tubing temperature will still remain significantly below the expected UPA condenser temperature (78°F max versus ~105°F in the condenser) permitting condensation in the pump head.