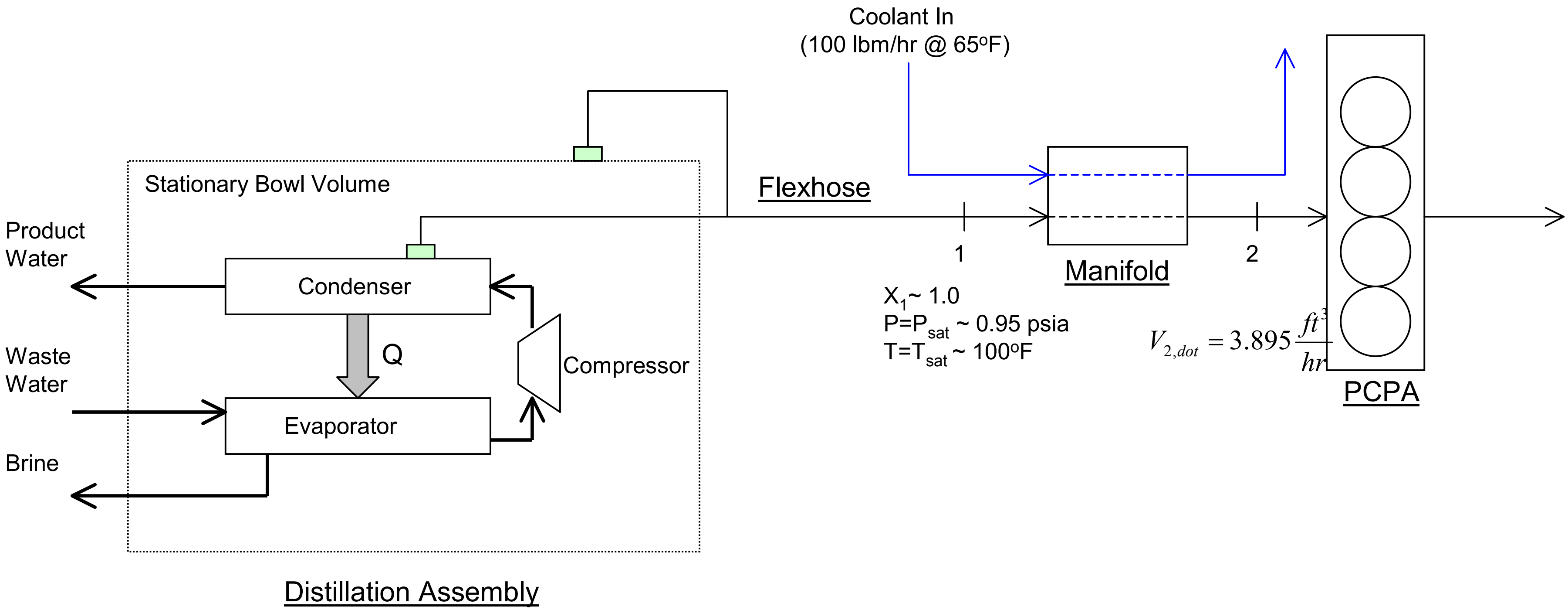
Space Station Environmental Control & Life Support System Pressure Control Pump Assembly Modeling and Analysis

September 10, 2001

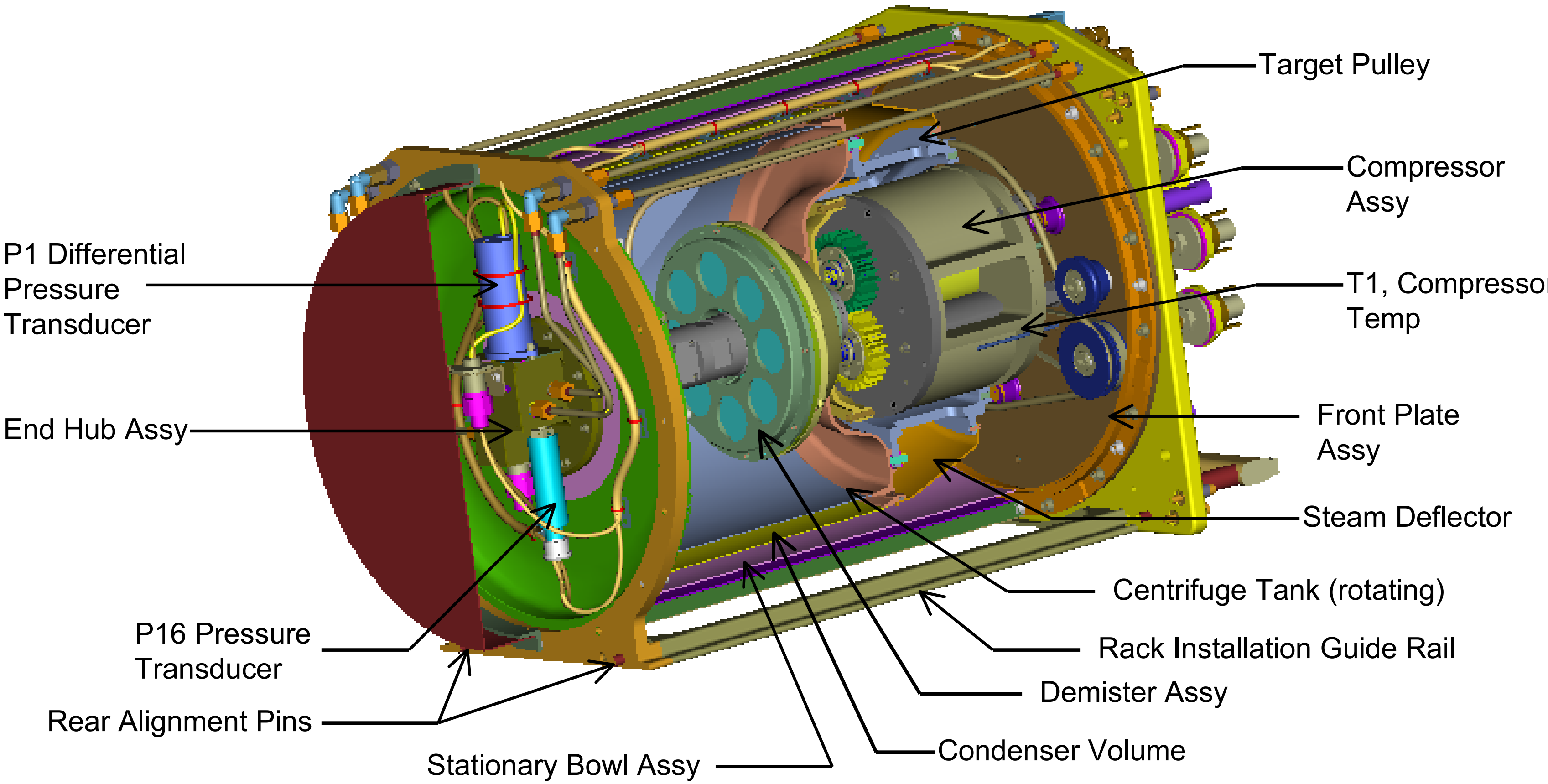
R. Gregory Schunk
NASA Marshall Space Flight Center
Thermal and Fluid Systems Group/ED26

- Overview
- Integrated PCPA/Manifold Analyses
- Manifold Performance Analysis
- PCPA Motor Heat Leak Study
- Conclusions/Future Plans

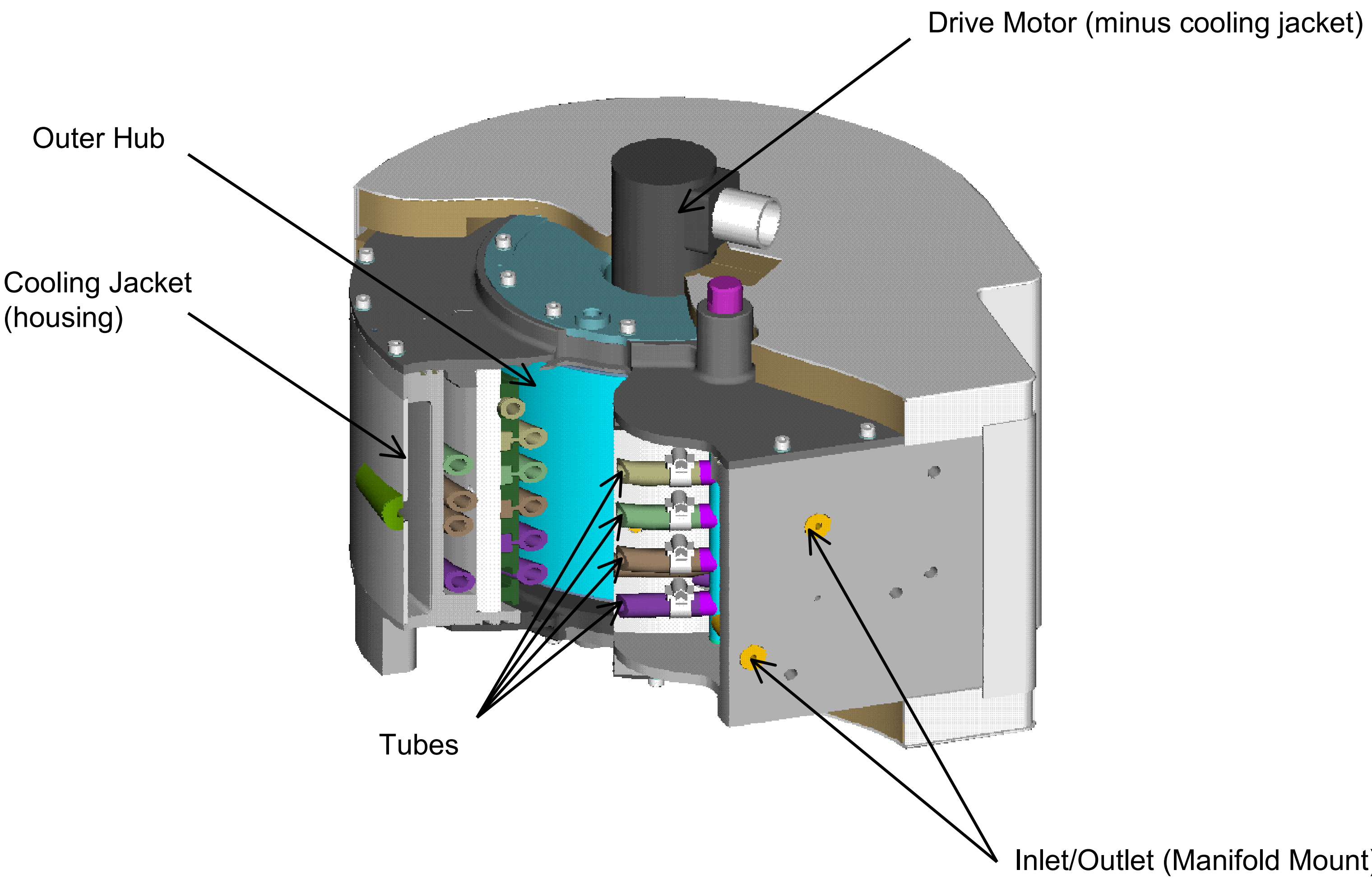
Simplified Distillation Assembly/PCPA Block Diagram



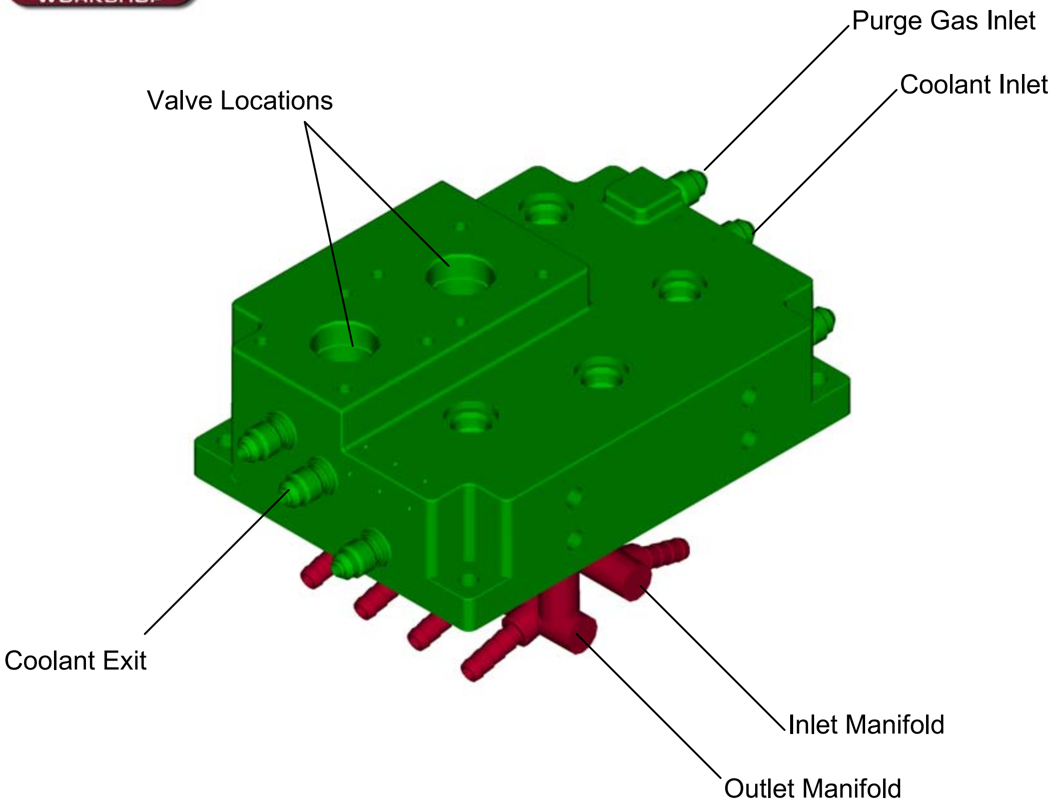
Distillation Assembly Cut-away View

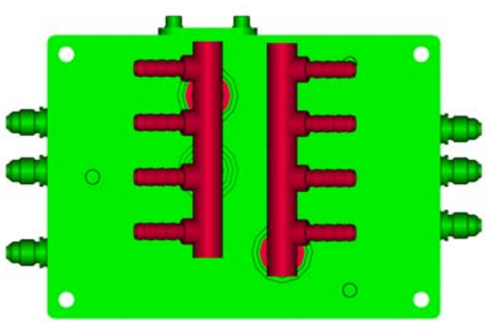


Pressure Control Pump Assembly

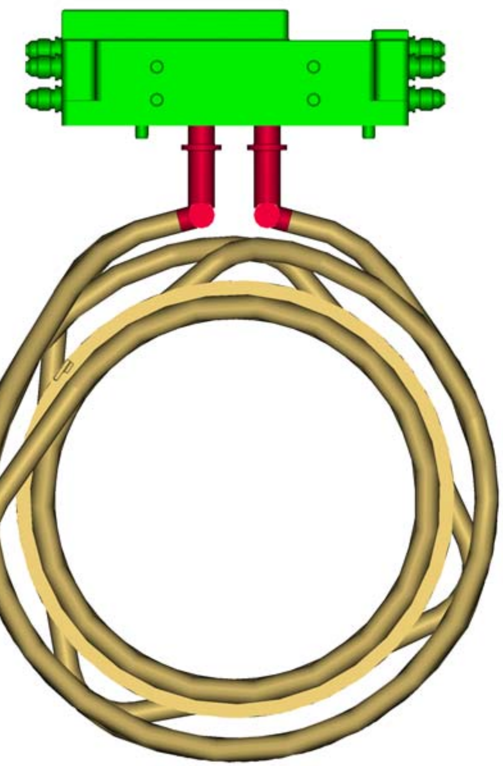


PCPA Chiller Block and Attachment





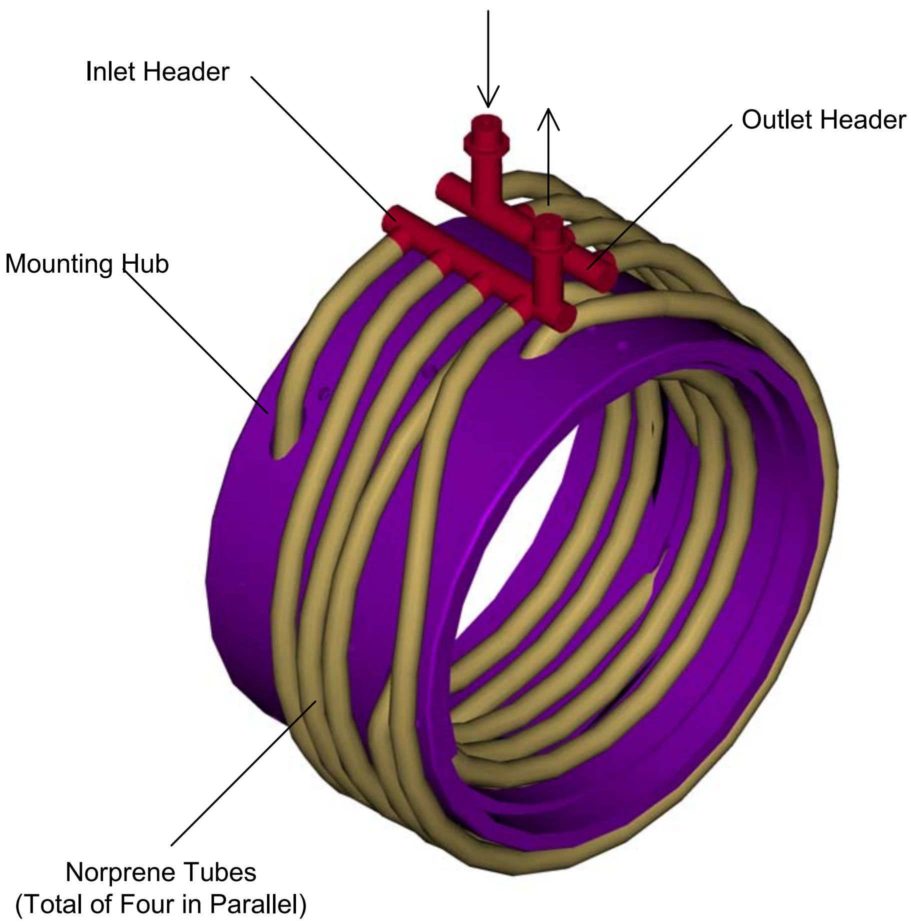
Bottom View



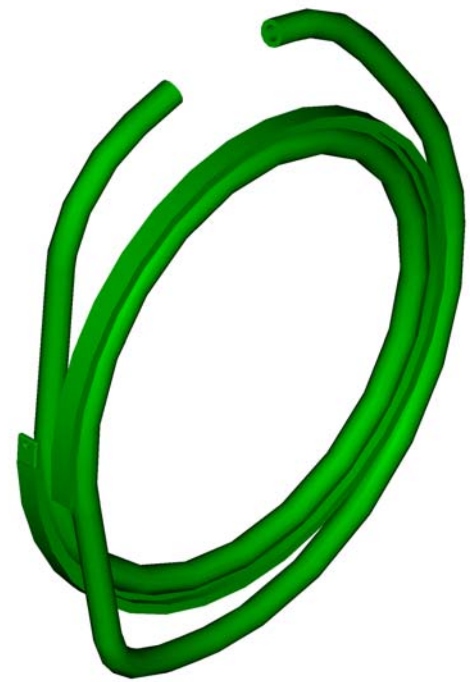
Chiller Block Attachment to the Pump

Inside the PCPA

Tubes and Mounting Hub



Individual Tube

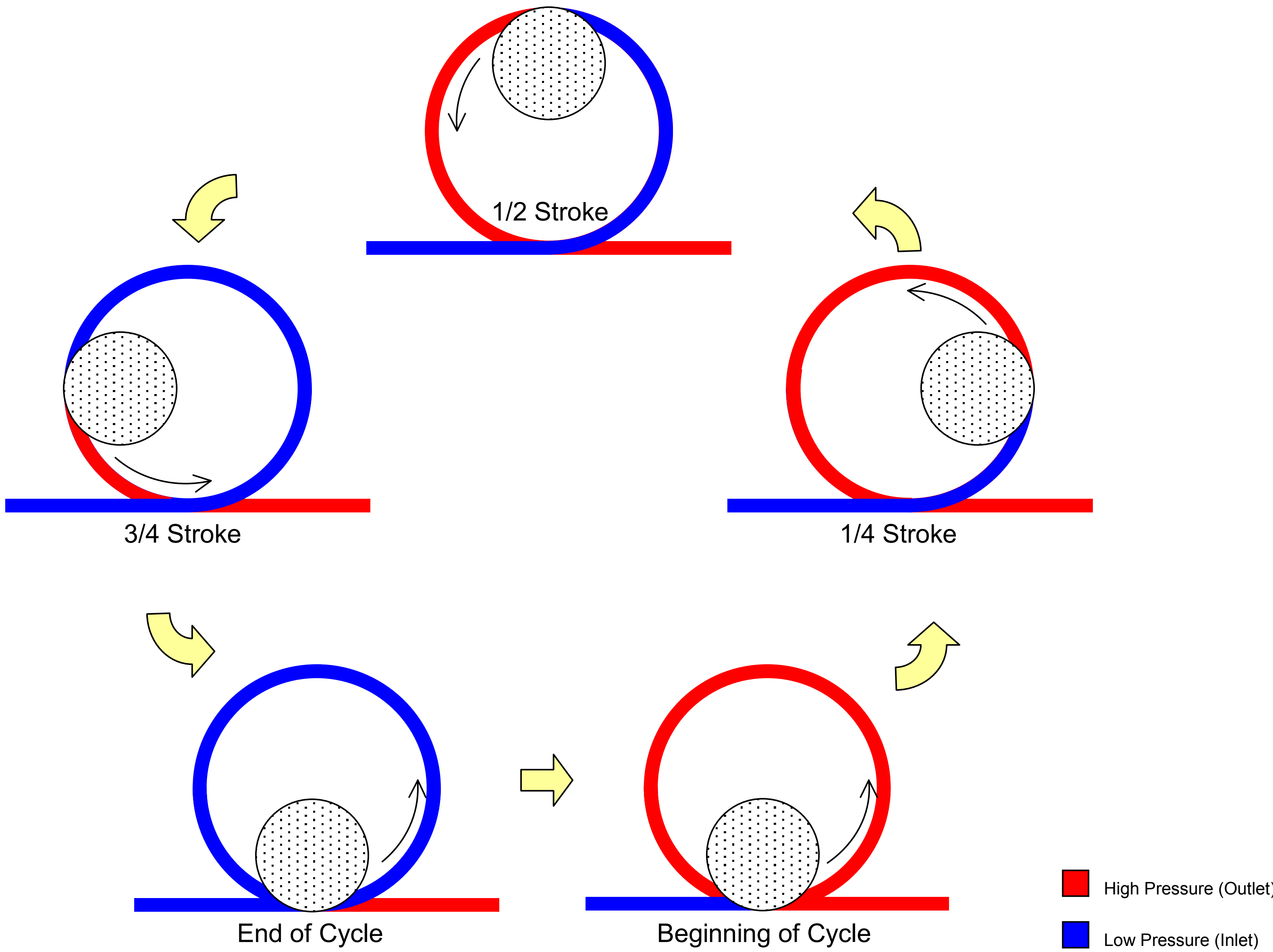


Fluid Volume per tube=<u>*1.167in*^{3}</u>

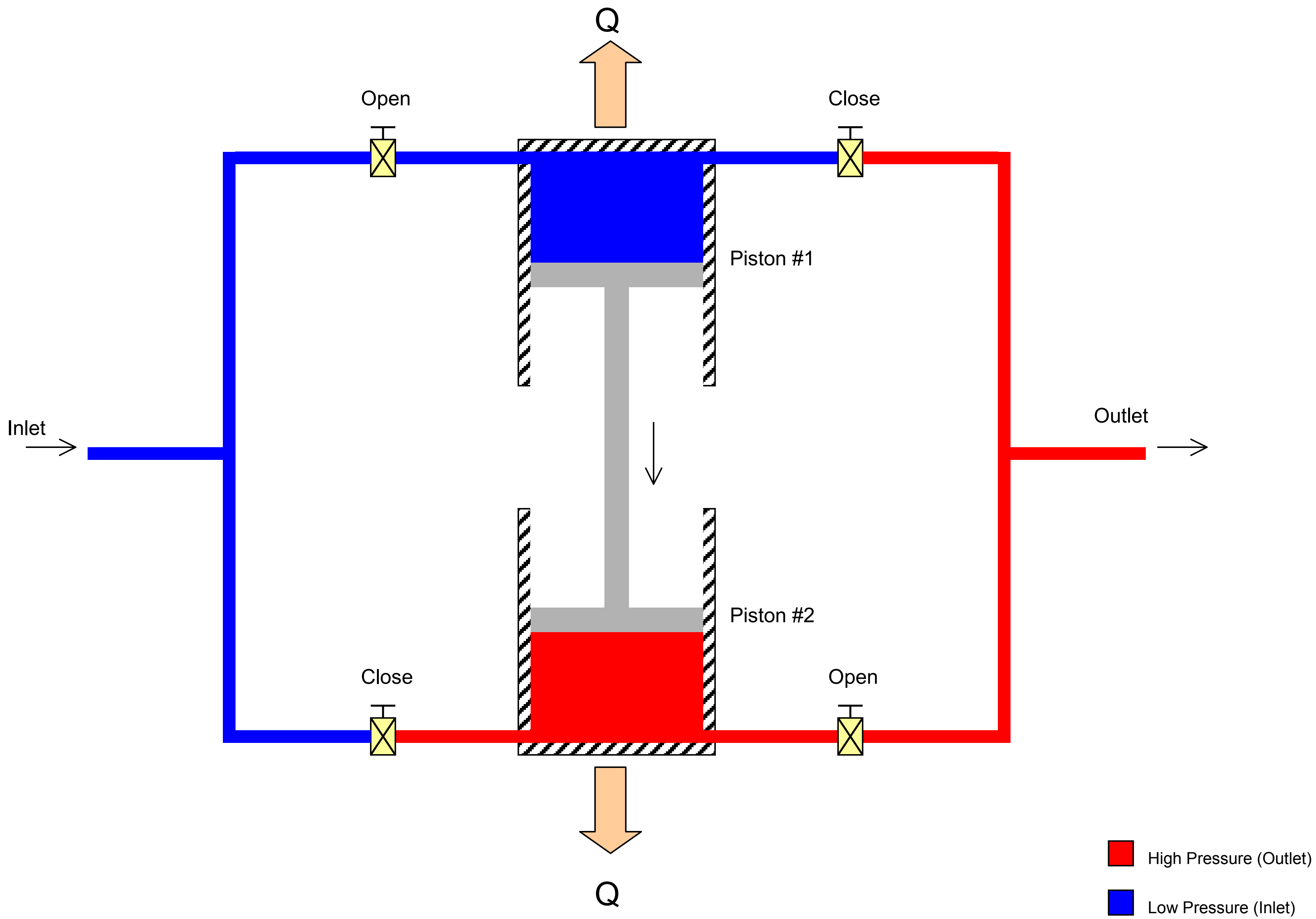
Volumetric displacement per tube (@24 rpm)=<u>*0.466in*^{3}*/sec*</u>

Total displacement (4 tubes)= <u>*1.87in*^{3}*/sec*</u>

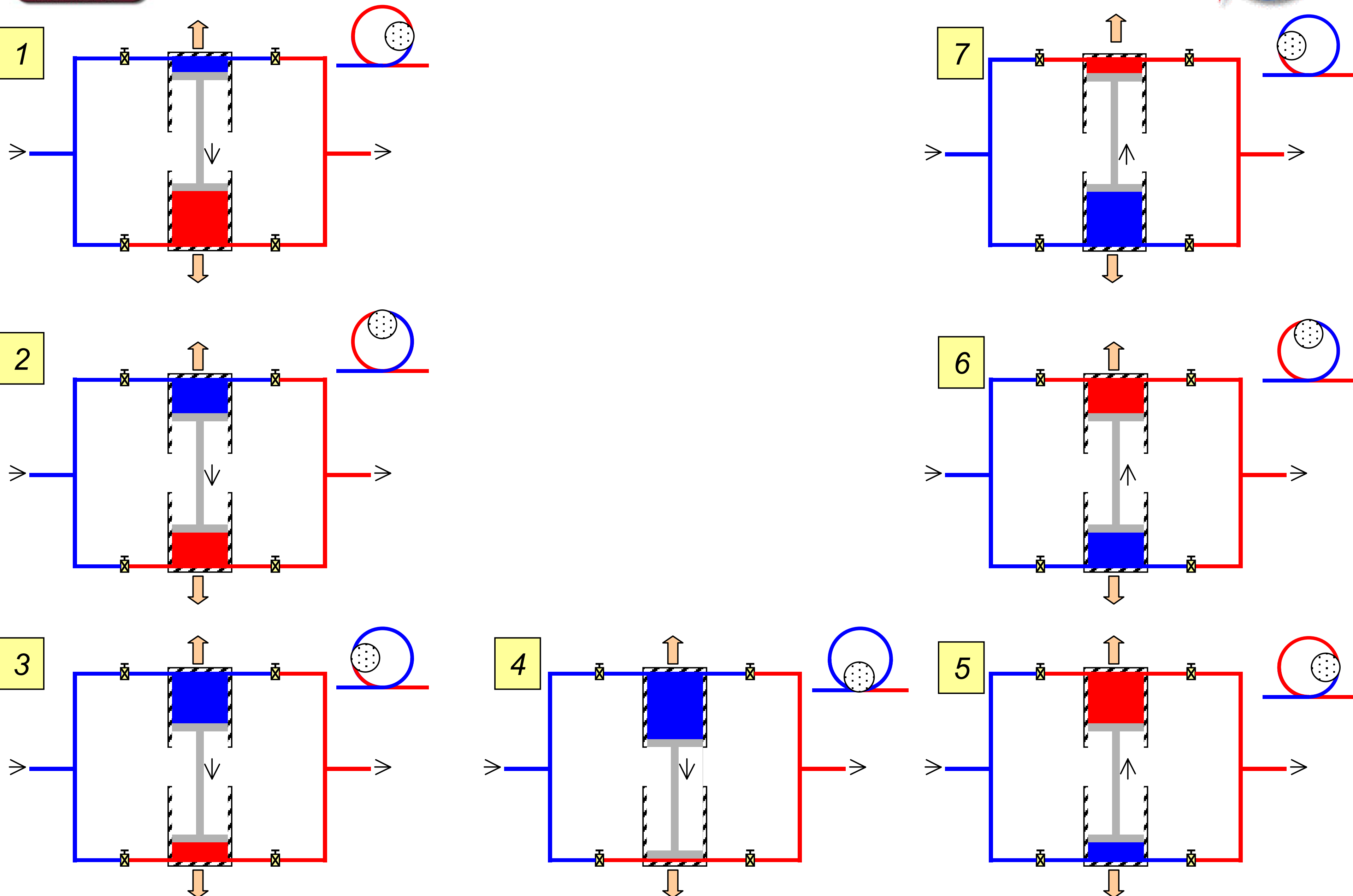
PCPA Pump Cycle



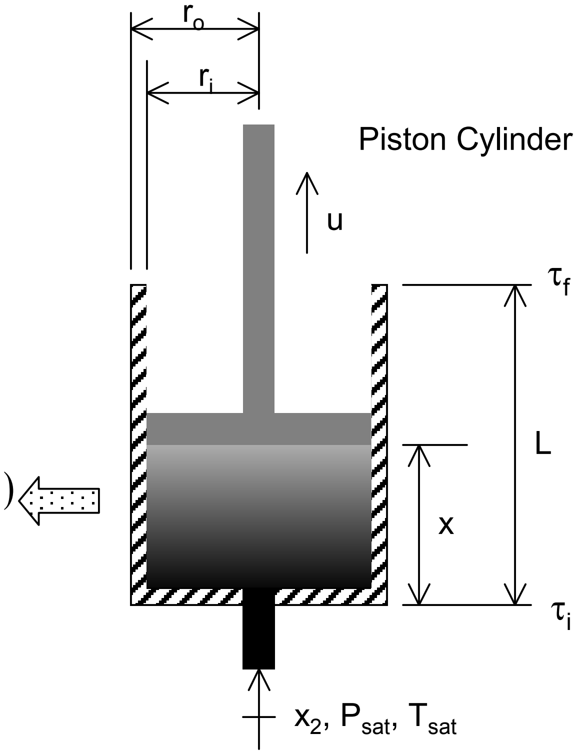
Opposing Piston-Cylinders used to Model Pump Cycle



Piston-Cylinder Analogy for a Complete Cycle



Derivation of the Pump Performance Equation



$$Qdot = \frac{2\pi k_{Norprene} x}{\ln(\frac{r_o}{r_i})}\left(T_{Piston} - T_{Coolant}\right)$$

$$V = AL = \pi r_o^2 L$$

$$Vdot = Axdot = Au$$

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

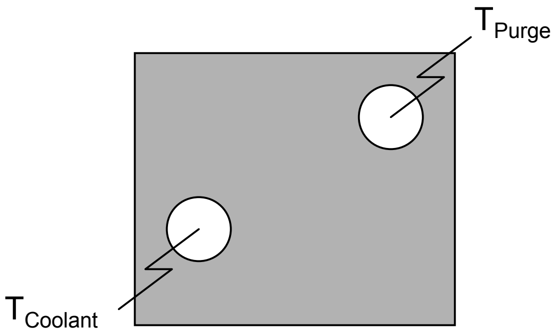
$$\Delta M = \int \frac{Vdot}{v_f + x_2 v_{fg}} d\tau + \int \frac{2\pi k x \Delta T}{\ln(\frac{r_o}{r_i}) h_{fg}} d\tau = \frac{Vdot}{v_f + x_2 v_{fg}} \int d\tau + \frac{2\pi k \Delta T}{\ln(\frac{r_o}{r_i}) h_{fg}} u \int \tau d\tau \therefore (x = u\tau, Vdot = const)$$

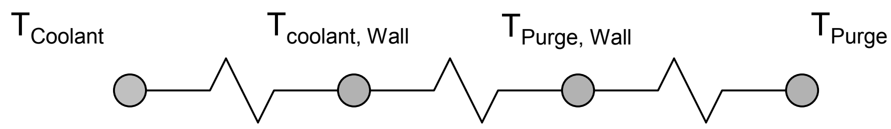
$$\Delta M = \frac{Vdot}{v_f + x_2 v_{fg}} \Delta\tau + \frac{2\pi k \Delta T}{\ln(\frac{r_o}{r_i}) h_{fg}} u \frac{(\tau_f^2 - \tau_i^2)}{2} = \frac{Vdot}{v_f + x_2 v_{fg}} \Delta\tau + \frac{2\pi k \Delta T}{\ln(\frac{r_o}{r_i}) h_{fg}} u \frac{(\tau_f + \tau_i)}{2} \Delta\tau$$

$$\frac{\Delta M}{\Delta\tau} \rightarrow \boxed{Mdot = \frac{Vdot}{v_f + x_2 v_{fg}} + \frac{\pi k L \Delta T}{\ln(\frac{r_o}{r_i}) h_{fg}}} \therefore \frac{L}{2} = u \frac{(\tau_f + \tau_i)}{2}$$

Derivation of Manifold (Chiller Block) Performance Equation

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



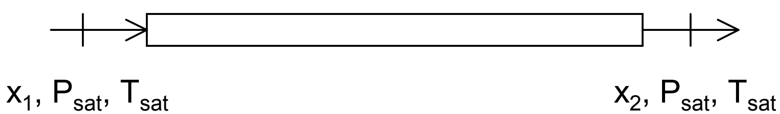


$$\frac{1}{hA_{Coolant}} \qquad \frac{1}{f(k,L,d)} \qquad \frac{1}{hA_{Purge}}$$

$$Qdot = \left\{ \frac{1}{hA_{Coolant}} + \frac{1}{f(k,L,d)} + \frac{1}{hA_{Purge}} \right\}^{-1} (T_{Purge} - T_{Coolant})$$

$$Qdot = \overline{G} \Delta T$$

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



$$Qdot = \overline{G} \Delta T = (x_1 - x_2) h_{fg} Mdot$$

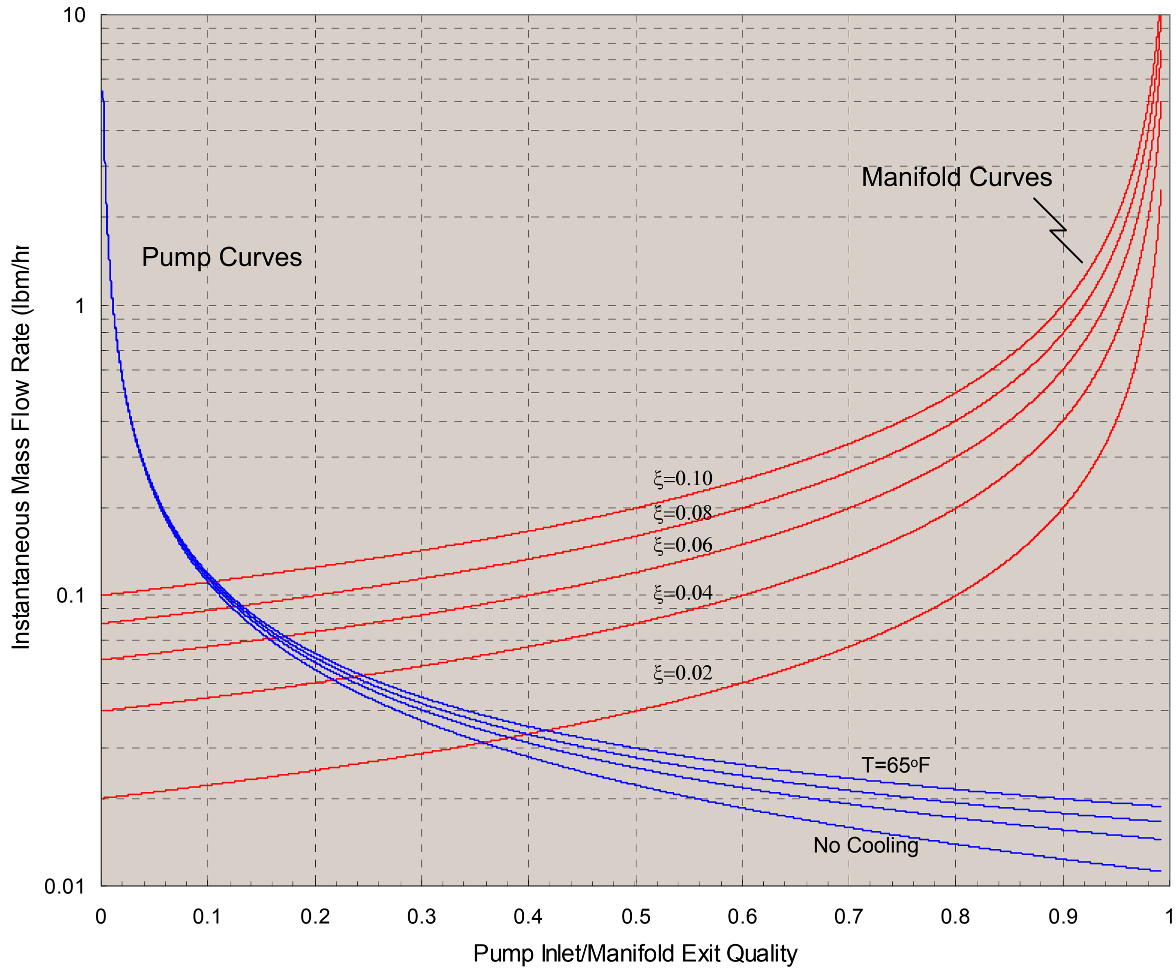
$$Mdot = \frac{\overline{G} \Delta T}{h_{fg}(x_1 - x_2)}$$

$$\zeta = \frac{\overline{G} \Delta T}{h_{fg}}$$

Let ξ=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.

$$\boxed{Mdot = \frac{\zeta}{(x_1 - x_2)}}$$

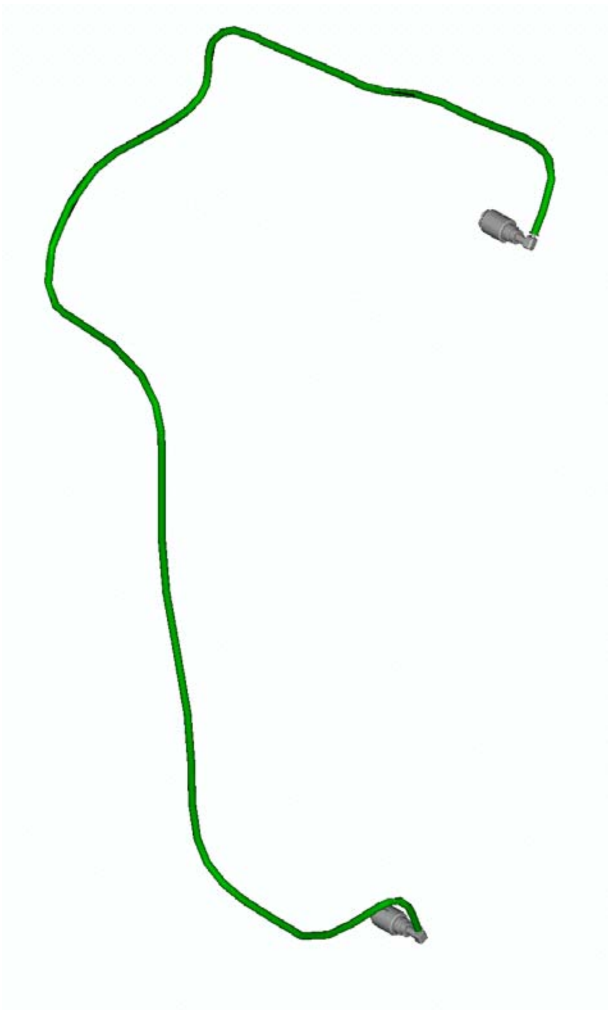
Pump versus Manifold Parametric
X_1=100%, T_1=100°F

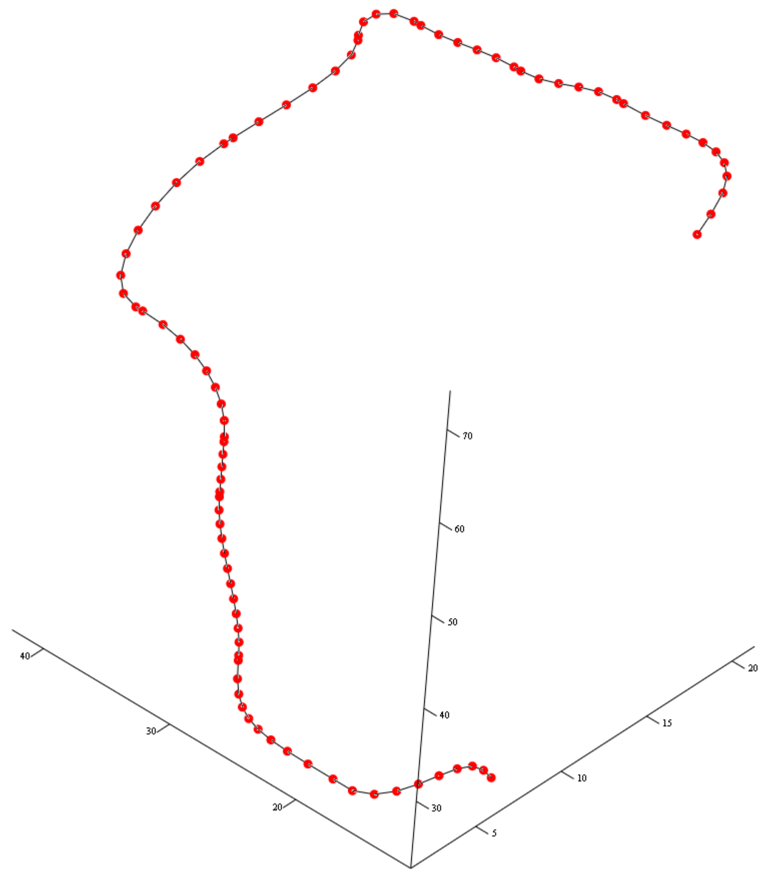


$$\xi = \frac{\overline{G}\Delta T}{h_{fg}}$$

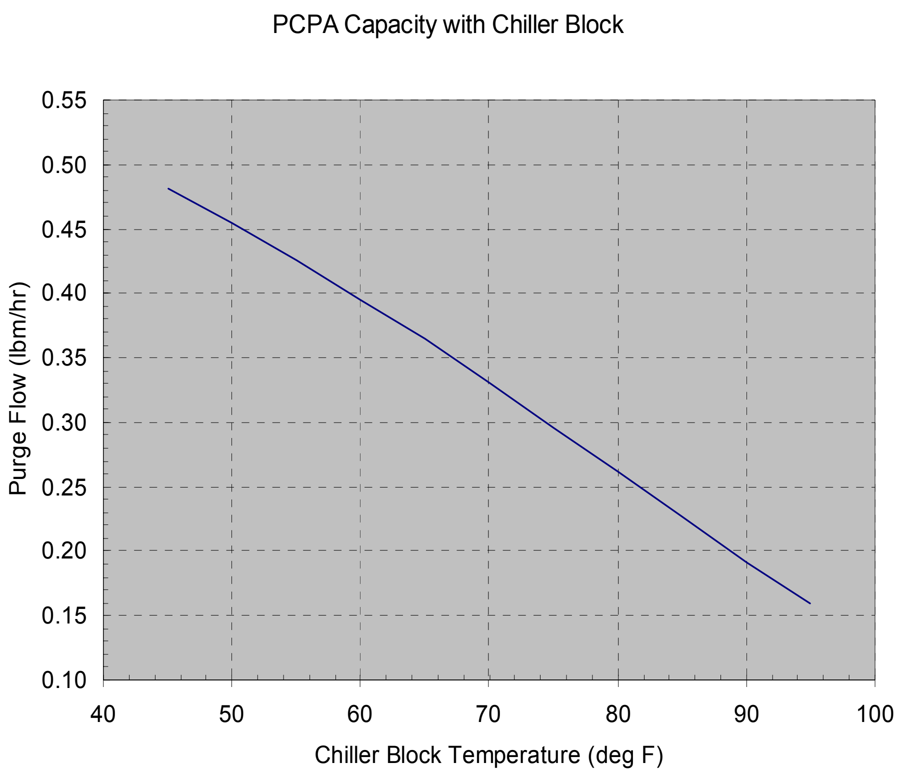
- ξ is a dimensional parameter (units of mass flow rate) that describes the thermal performance of the manifold.
- A larger value of ξ indicates a higher heat transfer rate between the coolant and purge lines.
- Per hand calculations, ξ is expected to range between 0.02 and 0.1 for the manifold.

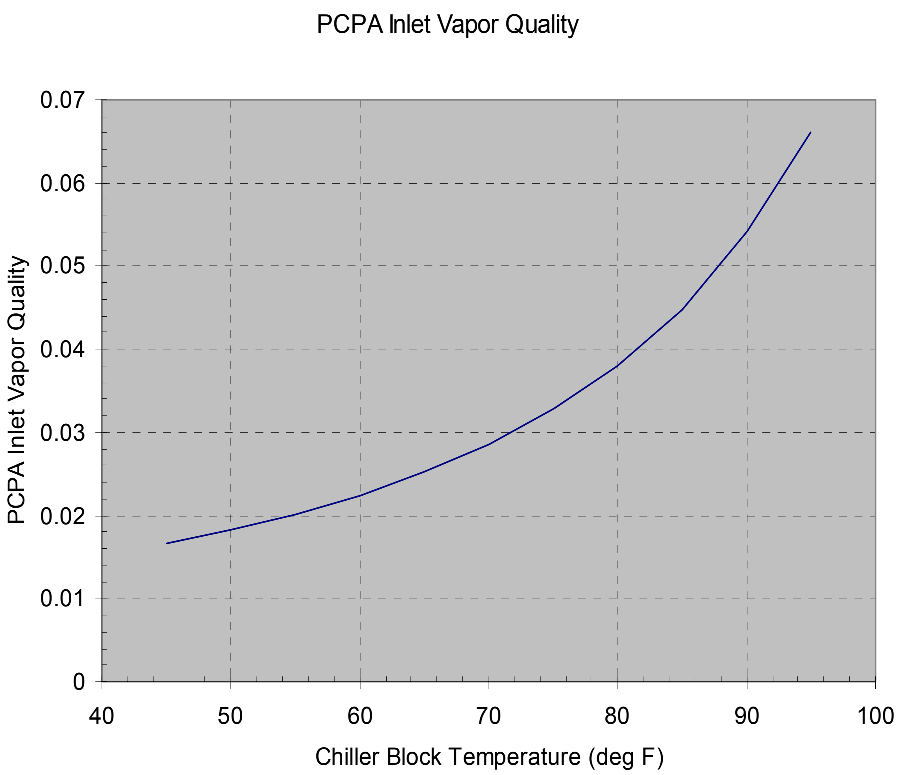
DA/PCPA Rack Interface Tubing Model



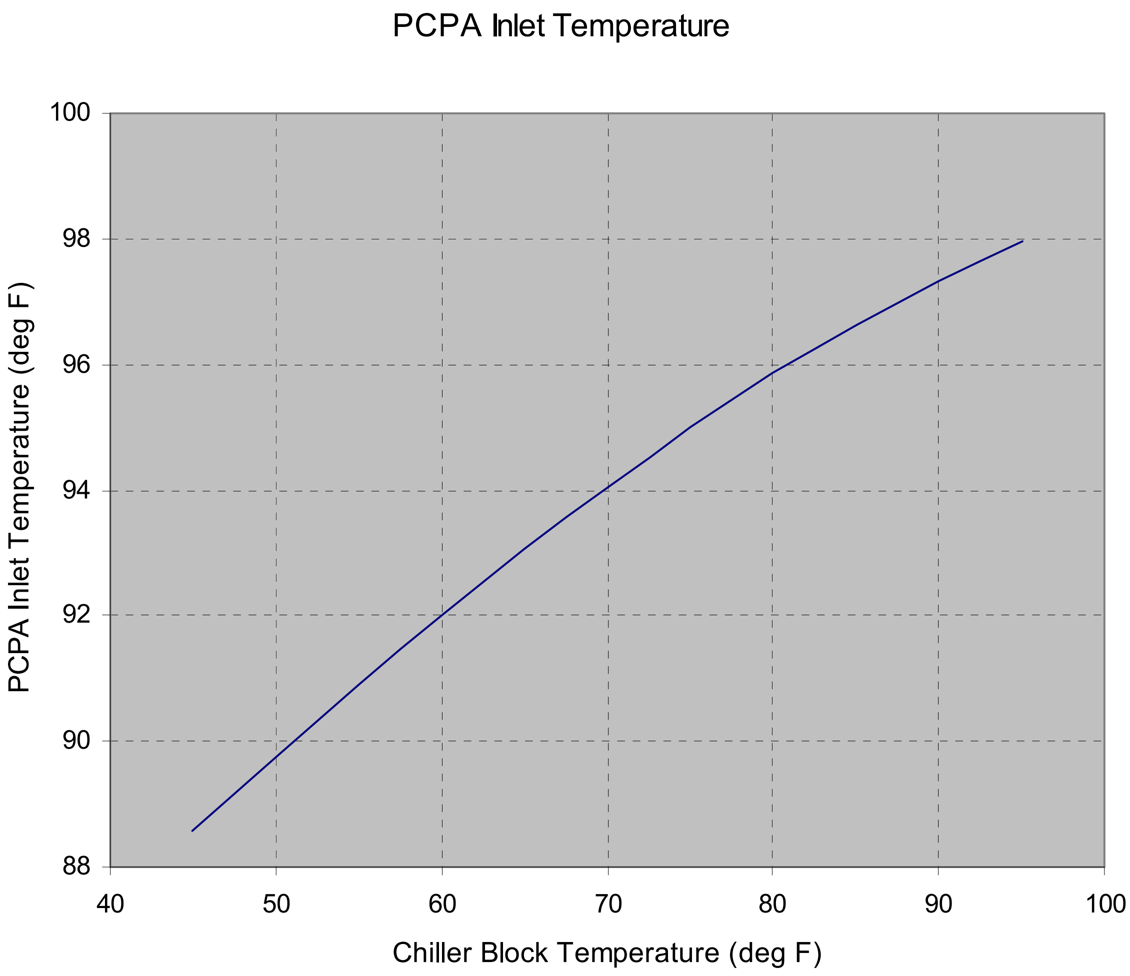


Steady State Results

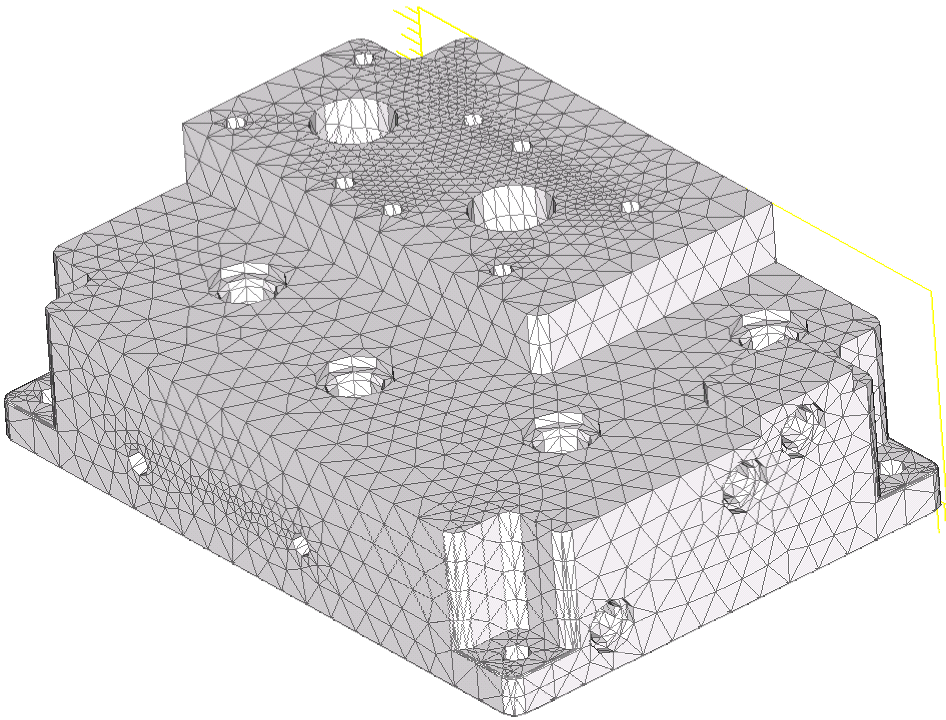


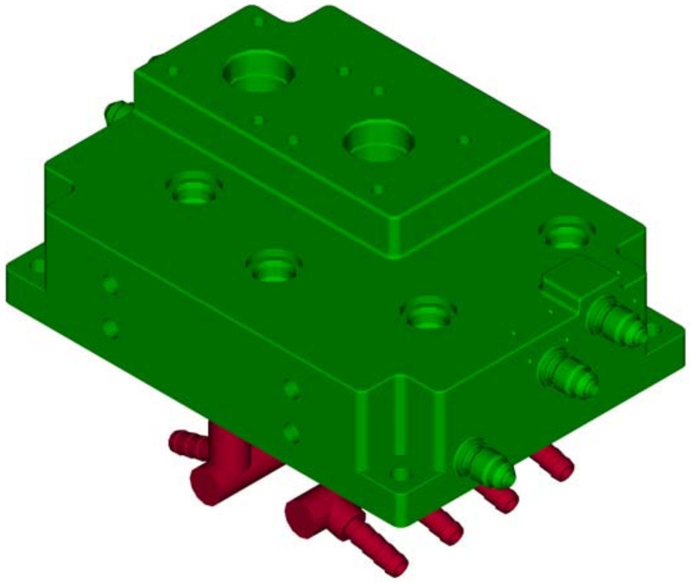


Steady State Results (Cont'd)



PCPA Chiller Block Thermal Model

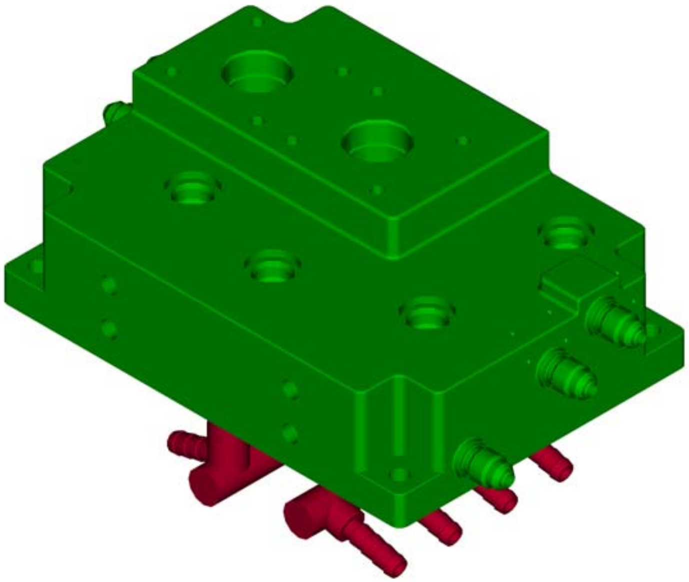




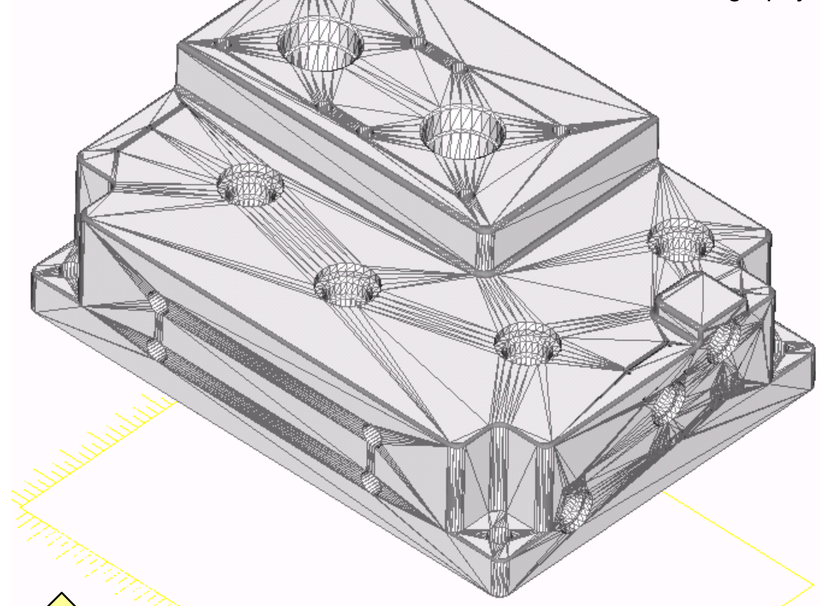
- Imported chiller block model directly from CAD file (stereo-lithography translation).
- Meshed as a solid with 10970 nodes and 43619 tetrahedrals.

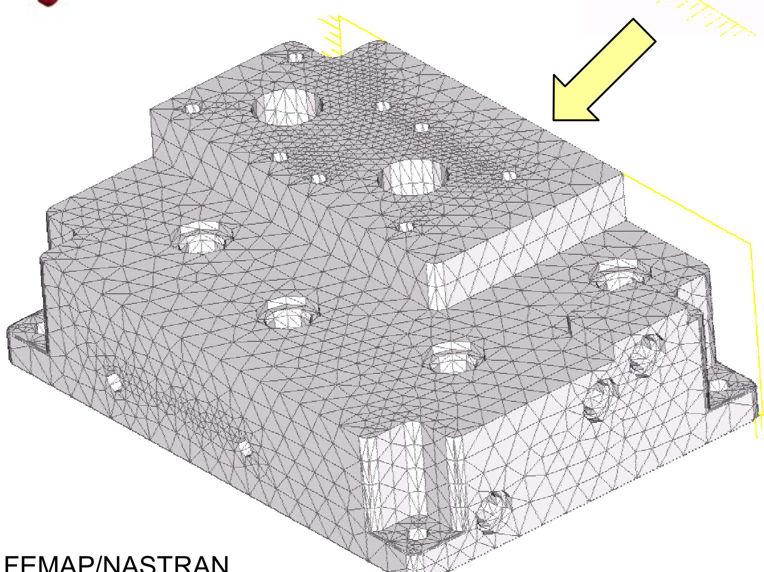
PCPA Chiller Block Thermal Model Development

CAD Representation



Stereo Lithography

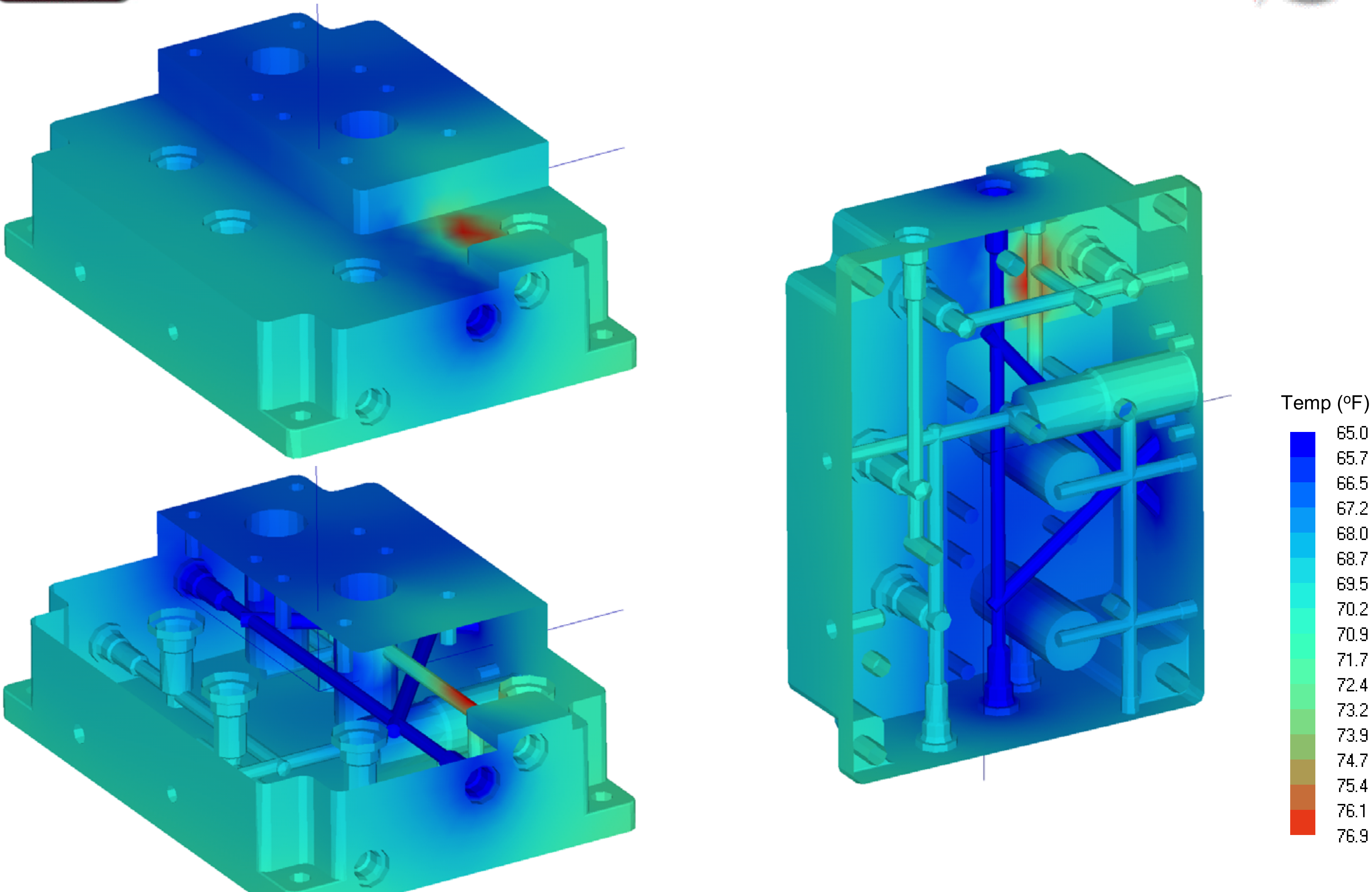




Final Mesh FEMAP/NASTRAN

- 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

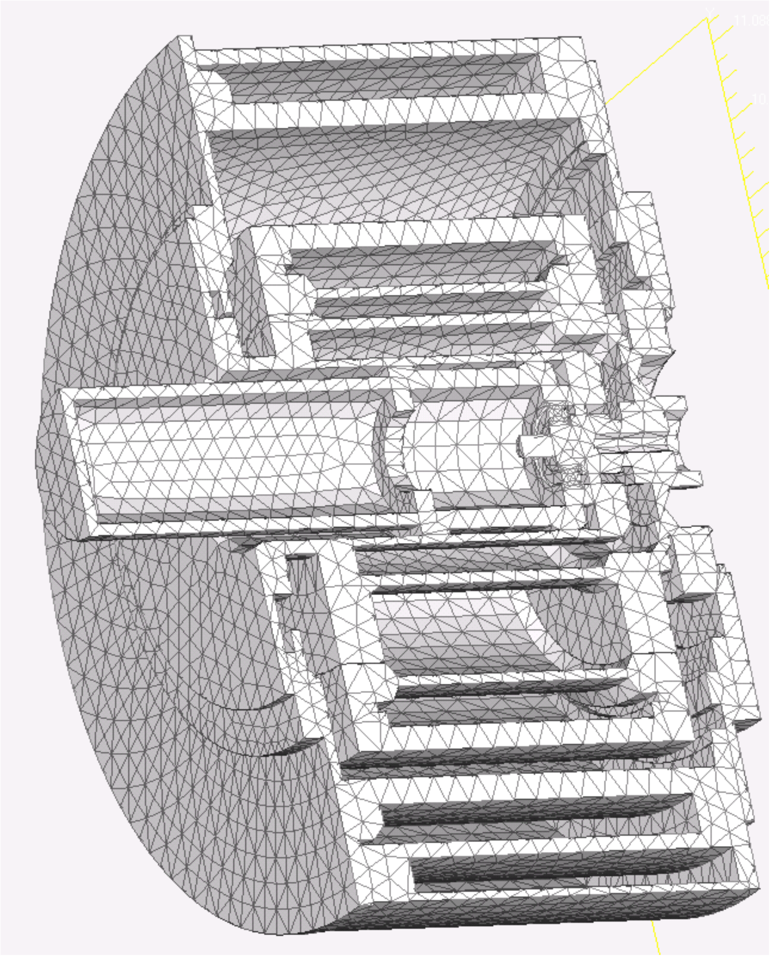
Cold Case (Motor Dissipation=18 watts)

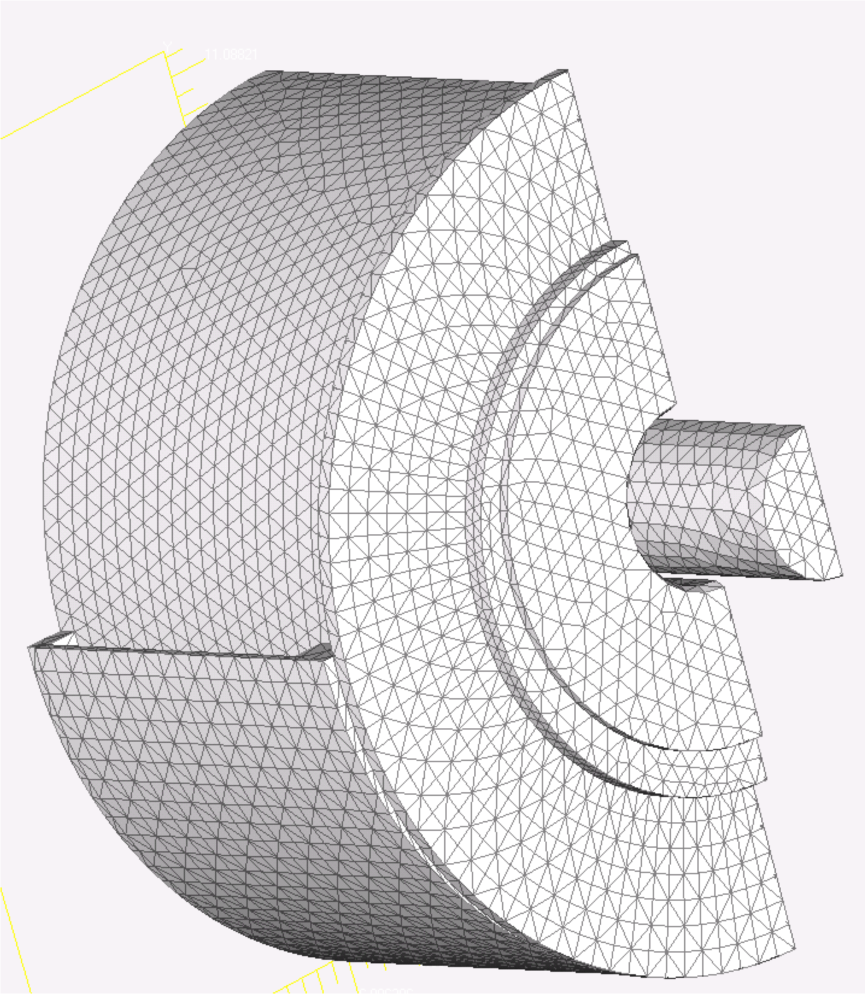
	Motor Dissipation (watts)	Fluid Dissipation (watts)	Motor Cooling Jacket Temp (F)	Outer Cooling Jacket Temp (F)
Nominal Operational	4.5	0.85	67	66
Worst Case Operational	18.0	3.38	72	71
Loss of Cooling	18.0	3.38	95	95

Hot Case (Motor Dissipation=55 watts)

	Motor Dissipation (watts)	Fluid Dissipation (watts)	Motor Cooling Jacket Temp (F)	Outer Cooling Jacket Temp (F)
Nominal Operational	13.8	0.85	65+ 6=71	65+ 4=69
Worst Case Operational	55.0	0	65+22=87	65+18=83
Loss of Cooling	NA	NA	NA	NA

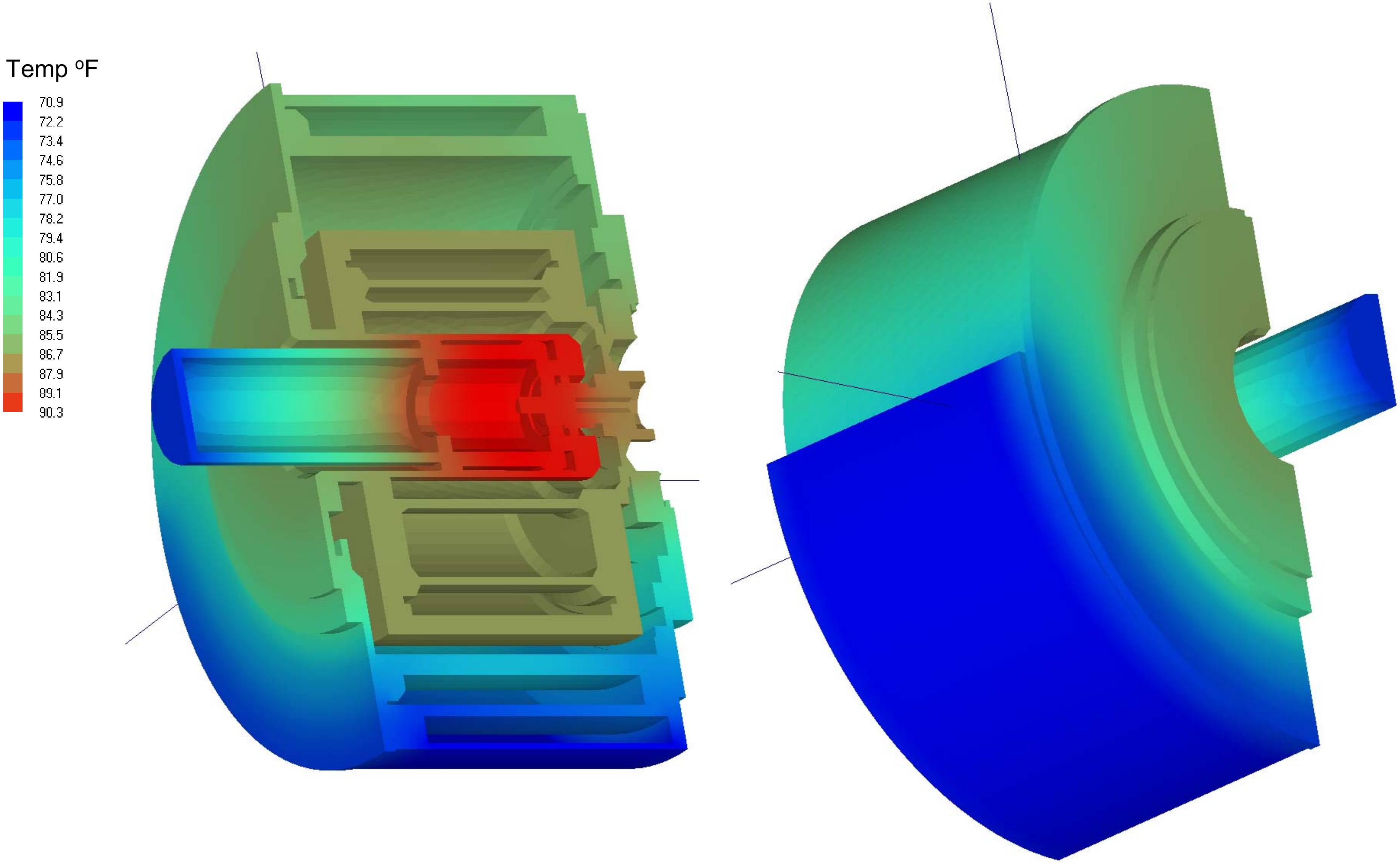
PCPA Thermal Model





Nodes: 14612
Elements: 45508

PCPA Temperature Distribution for the Worst Case Operational Scenario



Steady State PCPA Motor Heat Leak Study Results

Cold Case (Motor Dissipation=18 watts)

	Harmonic Drive Outer Temp (F)	Minimum Peristaltic Tubing Temp (F)	Maximum Peristaltic Tubing Temp (F)	Motor Temp (F)
Nominal Operational *(25% Duty Cycle)*	70.2	67.6	69.9	71.2
Worst Case Operational *(100% Duty Cycle)*	86.2	76.4	85.5	91.6
Loss of Cooling	109.8	100.3	109.3	113.8

Hot Case (Motor Dissipation=55 watts)

	Harmonic Drive Outer Temp (F)	Minimum Peristaltic Tubing Temp (F)	Maximum Peristaltic Tubing Temp (F)	Motor Temp (F)
Nominal Operational *(25% Duty Cycle)*	78.5	72.3	77.8	80.4
Worst Case Operational *(100% Duty Cycle)*	126.8	92.3	110.3	137.5
Loss of Cooling	NA	NA	NA	NA

Conclusions/Future Plans

- Preliminary results from a thermal/flow analysis of the PCPA indicate that the 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^{o}F max versus ~105^{o}F in the condenser) permitting condensation in the pump head.
- Future plans include the development of numerical models to characterize the integrated behavior of the PCPA/Manifold with the Distillation Assembly.