Passive Two-Phase Liquid Cooling as an Alternative to Aqueous Forced Convection

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OUTLINE

- Terminology
- Boiler Performance
  - Working Fluid
  - Boiling Technology
  - Typical R_{sf}
- Condenser Performance, R_{fa}
  - 340W, 120x120x17mm
  - 340W, 240x120x17mm
  - 200W, 40x80x34mm
- Typical Geometric Configurations
- Conclusions

Terminology

Total Resistance:

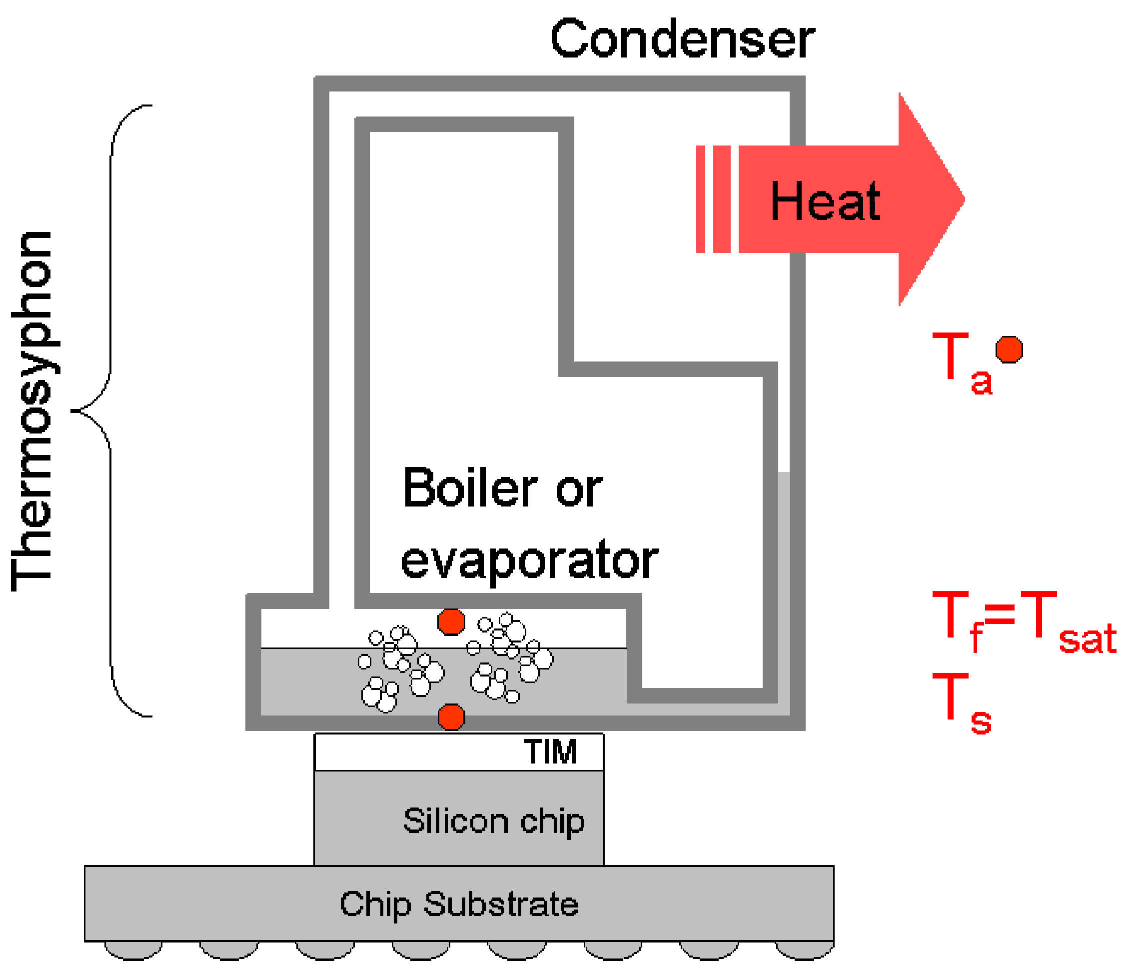
$$R_{sa} = R_{sf} + R_{fa}$$

Boiler Resistance:

$$R_{sf} = \frac{T_s - T_f}{Q}$$

Condenser Resistance:

$$R_{fa} = \frac{T_f - T_a}{Q}$$



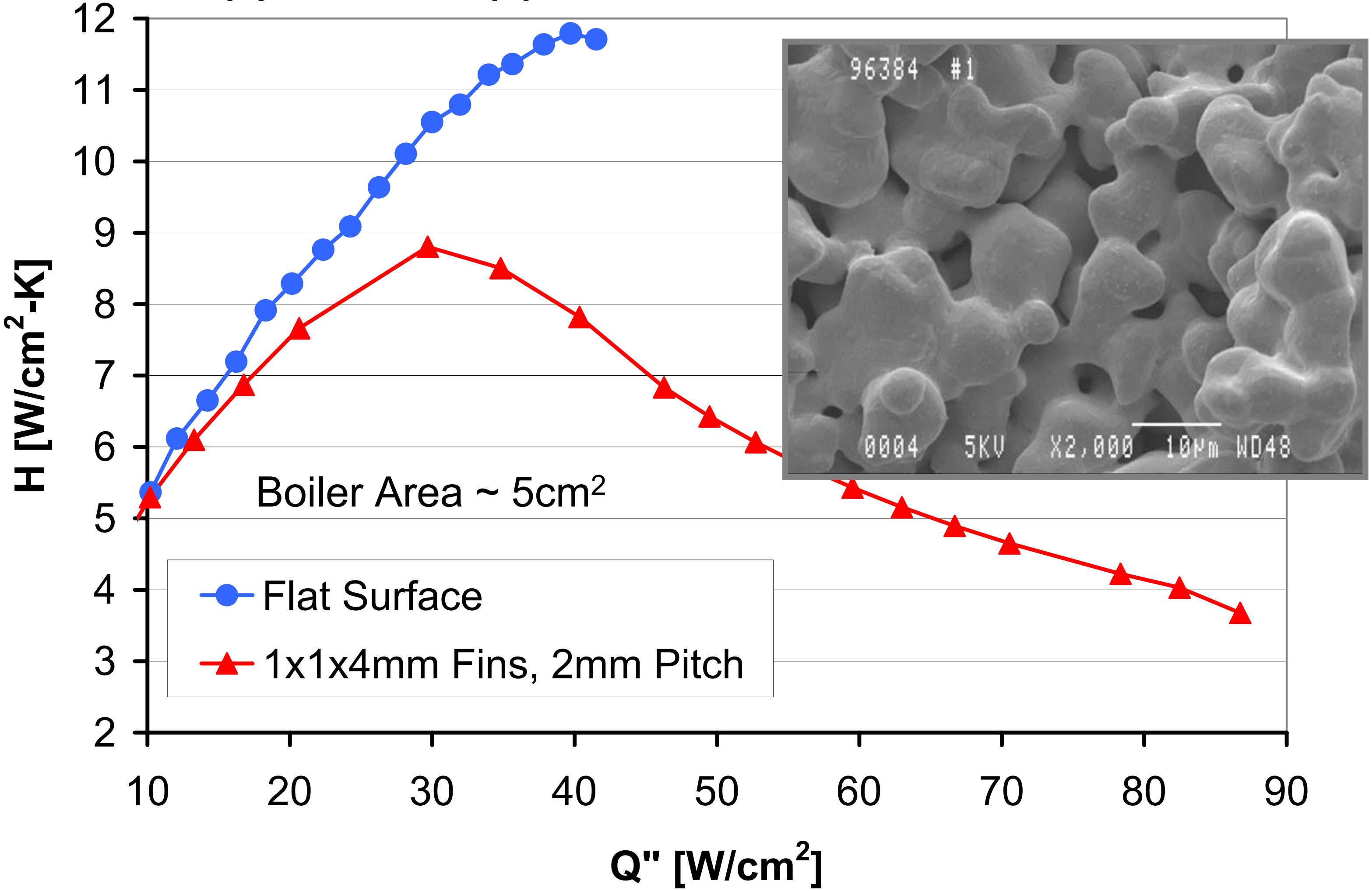
Boiler Performance - Working Fluid

Properties of $C_3F_7OCH_3$ (at 25°C unless noted).

Molecular Weight	200
Normal Boiling Point (°C)	34
Vapor Pressure (kPa)	64.6
Vapor Pressure at 70°C (kPa)	308
Liquid Density (kg/m^3)	1400
Viscosity (cSt)	0.32
Specific Heat (J/kg-K)	1300
Heat of Vaporization (kJ/kg)	142
Thermal Conductivity (W/m-K)	0.075
Coefficient of Expansion (1/K)	0.00219
Surface Tension (mN/m)	12.4
Electrical Resistivity [ohm-cm]	10^8
Atmospheric Lifetime (yrs)	4.9
Global Warming Potential	370
Ozone Depletion Potential	0
VOC	No
Flammable	No
8-Hour Exposure Guideline	75ppm
Acute Toxicity	Low

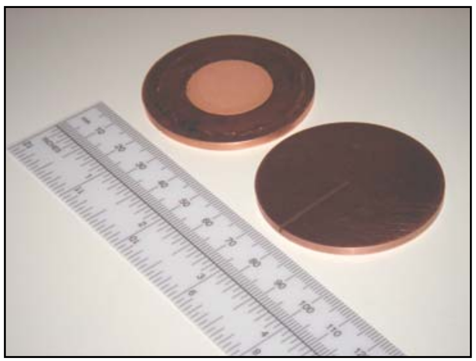
Boiler Performance - Boiling Technology

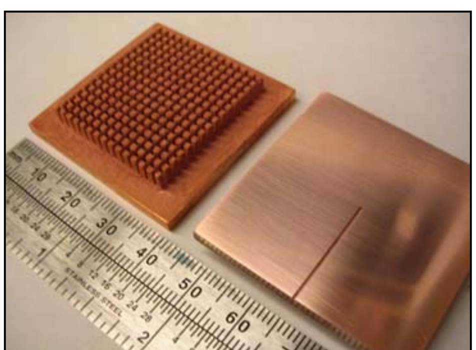
- Porous copper on copper substrate



Boiler Performance – Typical R_{sf}

- Boilers have different shapes and form factors
  - Best design depends upon peak power, Q, and heat source Size, L_c, where $A=L_c^2$





Typical Boiler Resistance, R_{sf}, as a function of Heat Source Size for Q<200W

Heat Source, L_c [mm]	Area, $A=L_c^2$ [cm^2]	R_{sf} [°C/W]	H_{eff} [W/cm^2-K]
7.5	0.5	0.122	14.5
10	1.0	0.077	13.0
20	4.0	0.029	8.6
37	13.7	0.017	4.2

Tuma, P.E., Evaporator/Boiler Design for Thermosyphons Utilizing Segregated Hydrofluoroether Working Fluids, Proc. 22nd IEEE SEMI-THERM Symposium, Dallas TX, March 2006, pp. 69-77.

Condenser Performance – 120x120x17mm

Thermosyphon Shown here has an off-the-shelf 120x120x17mm condenser.

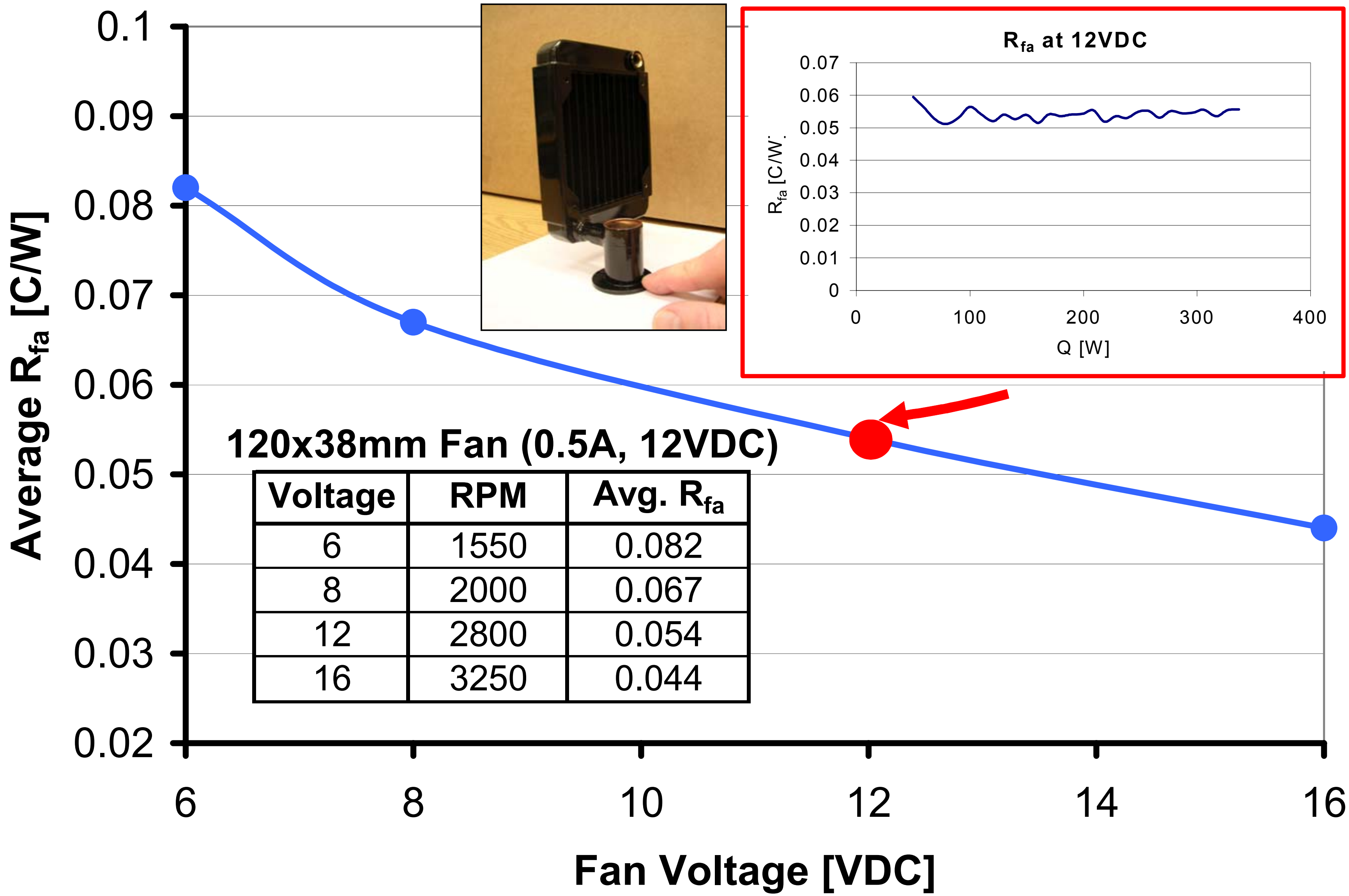
Construction is brazed copper and brass.

It was evacuated, filled with 20cc of fluid and sealed

It was run on a 25.4mm (6.5 cm^2) heat source up to 340W and the fluid-to-ambient resistance, R_{fa}, was measured

It was run with a 120x38mm fan rated for 0.5A@12VDC

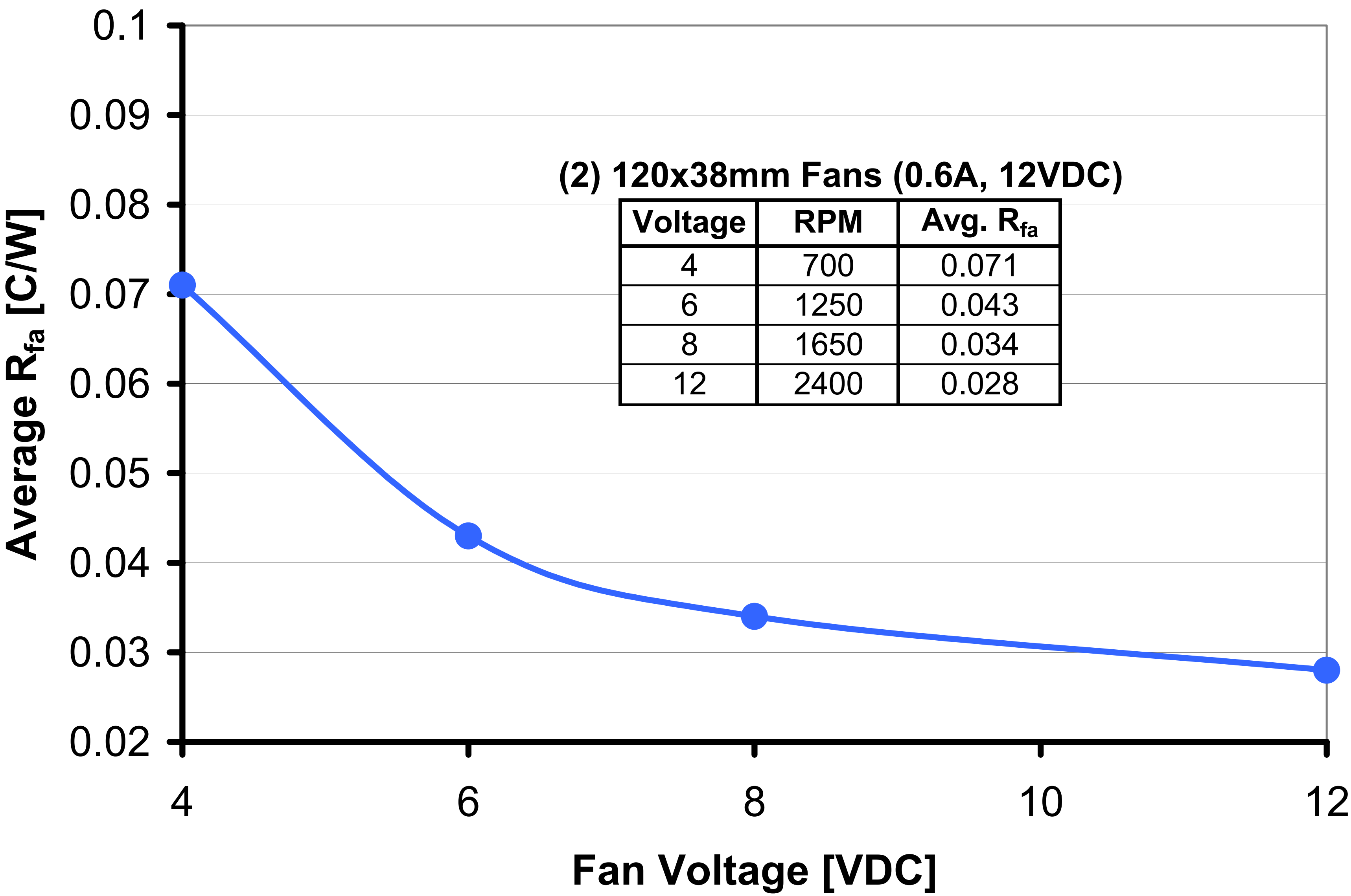
Condenser Performance – 120x120x17mm



120x38mm Fan (0.5A, 12VDC)

Voltage	RPM	Avg. R_{fa}
6	1550	0.082
8	2000	0.067
12	2800	0.054
16	3250	0.044

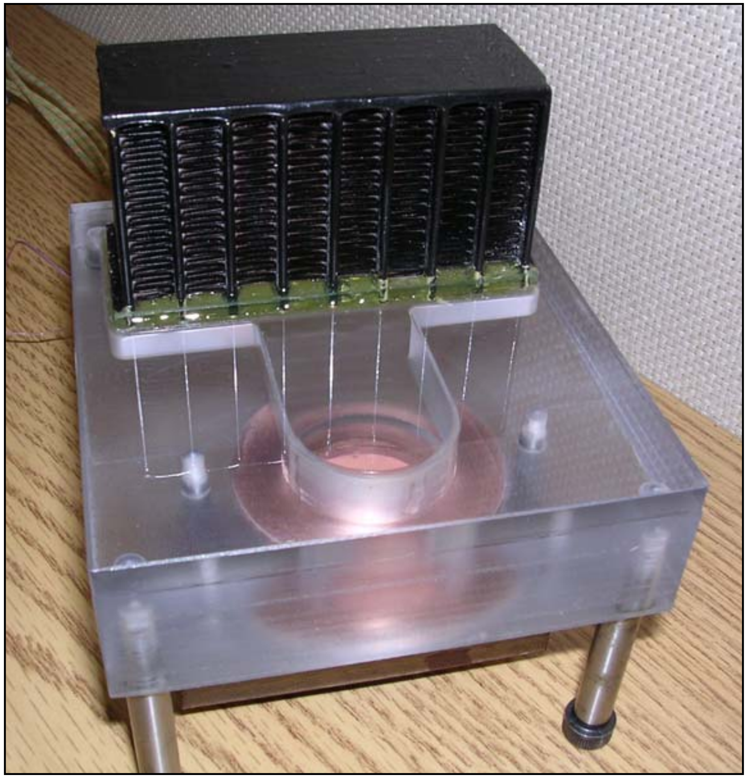
Condenser Performance – 240x120x17mm



(2) 120x38mm Fans (0.6A, 12VDC)

Voltage	RPM	Avg. R_{fa}
4	700	0.071
6	1250	0.043
8	1650	0.034
12	2400	0.028

Condenser Performance – 40x80x32mm



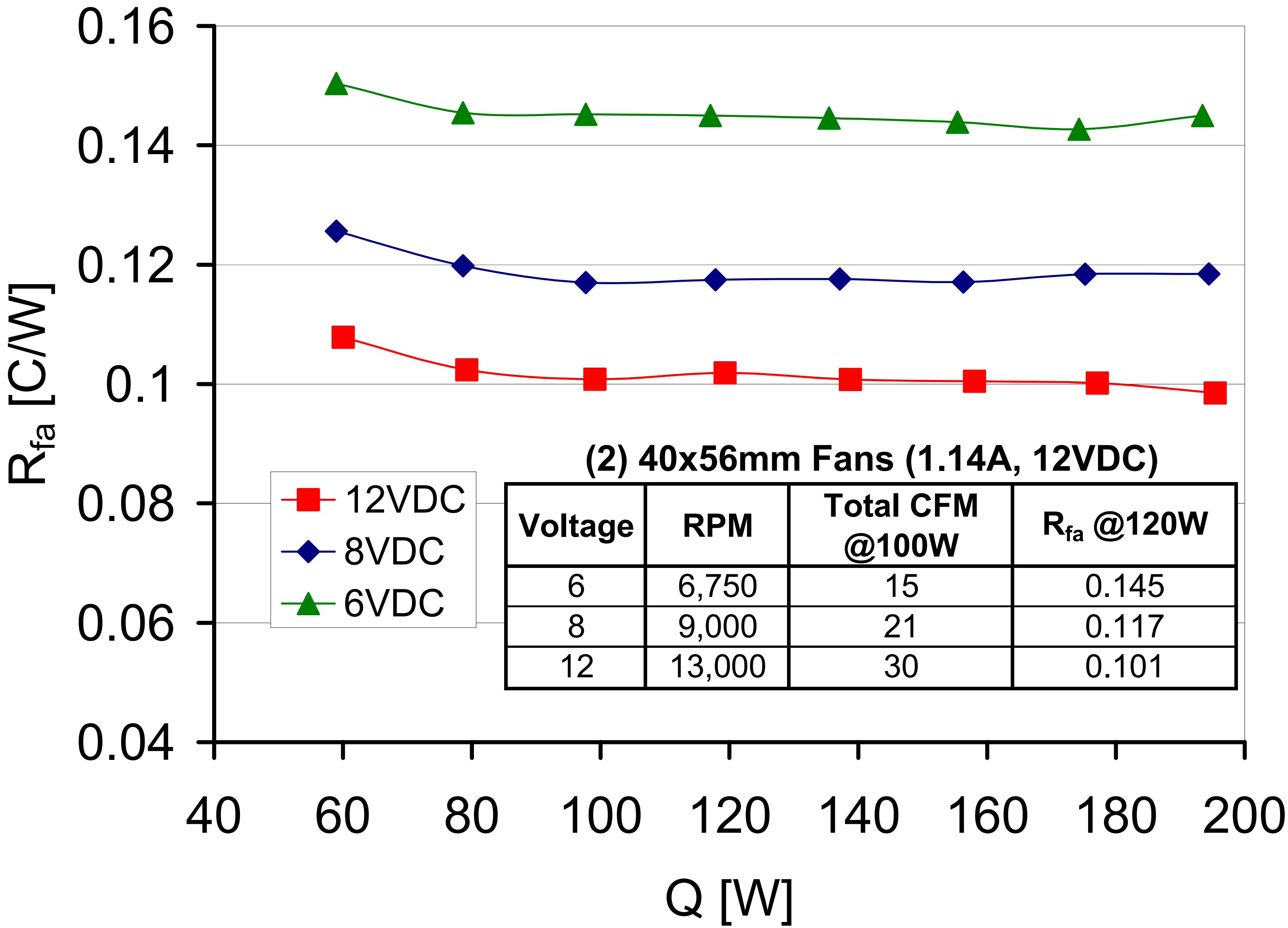
Thermosyphon Demo shown here has a 40x80x32mm condenser.

It was evacuated, filled with 15cc of fluid and sealed

It was run on a 20.0 mm ($4.0\ cm^2$) heat source up to 200W and the fluid-to-ambient resistance, R_{fa}, was measured

It was run with two, dual stage 40x40x56mm fans rated 1.14A@12VDC each

Condenser Performance – 40x80x32mm



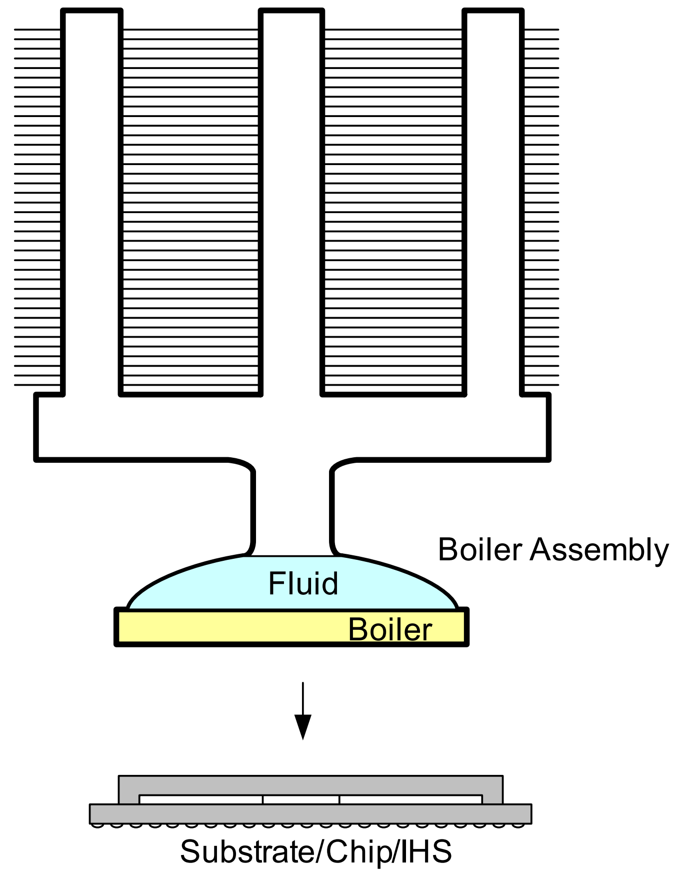
(2) 40x56mm Fans (1.14A, 12VDC)

Voltage	RPM	Total CFM @100W	R_{fa} @120W
6	6,750	15	0.145
8	9,000	21	0.117
12	13,000	30	0.101

Typical Geometric Configurations

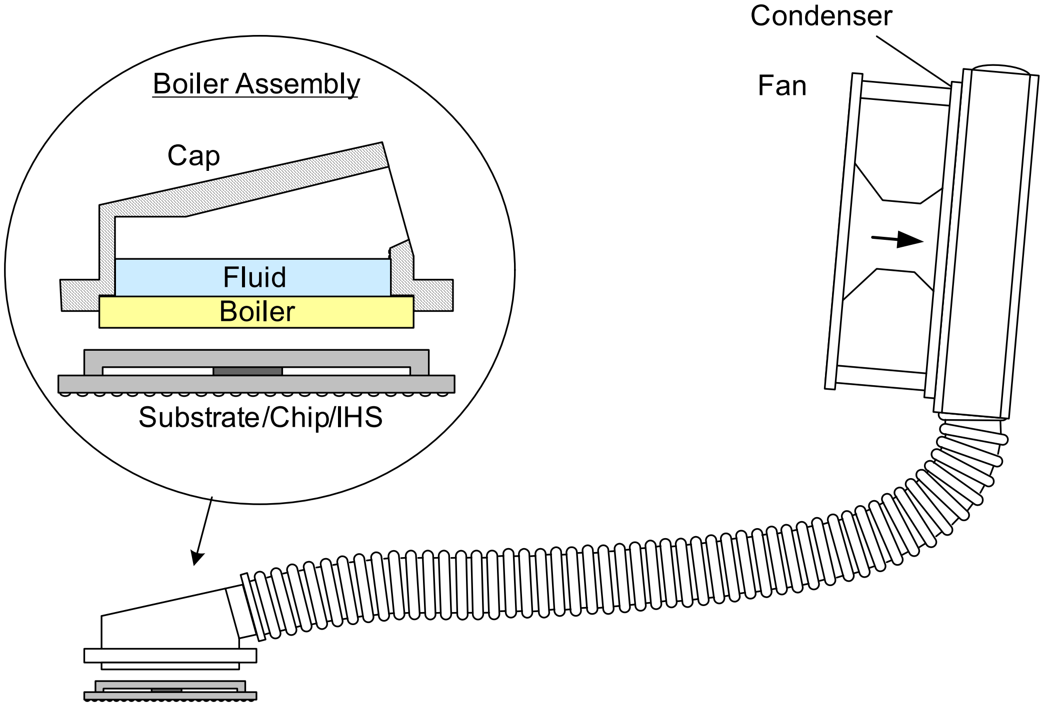
Single Tube, Integral Air-cooled Condenser

Asetek Vapochill®

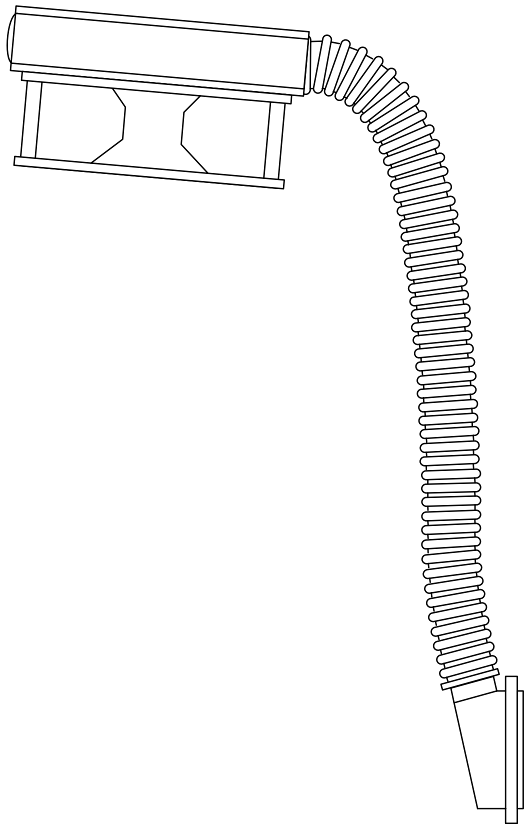


Typical Geometric Configurations

Single Tube, Remote Air-cooled Condenser



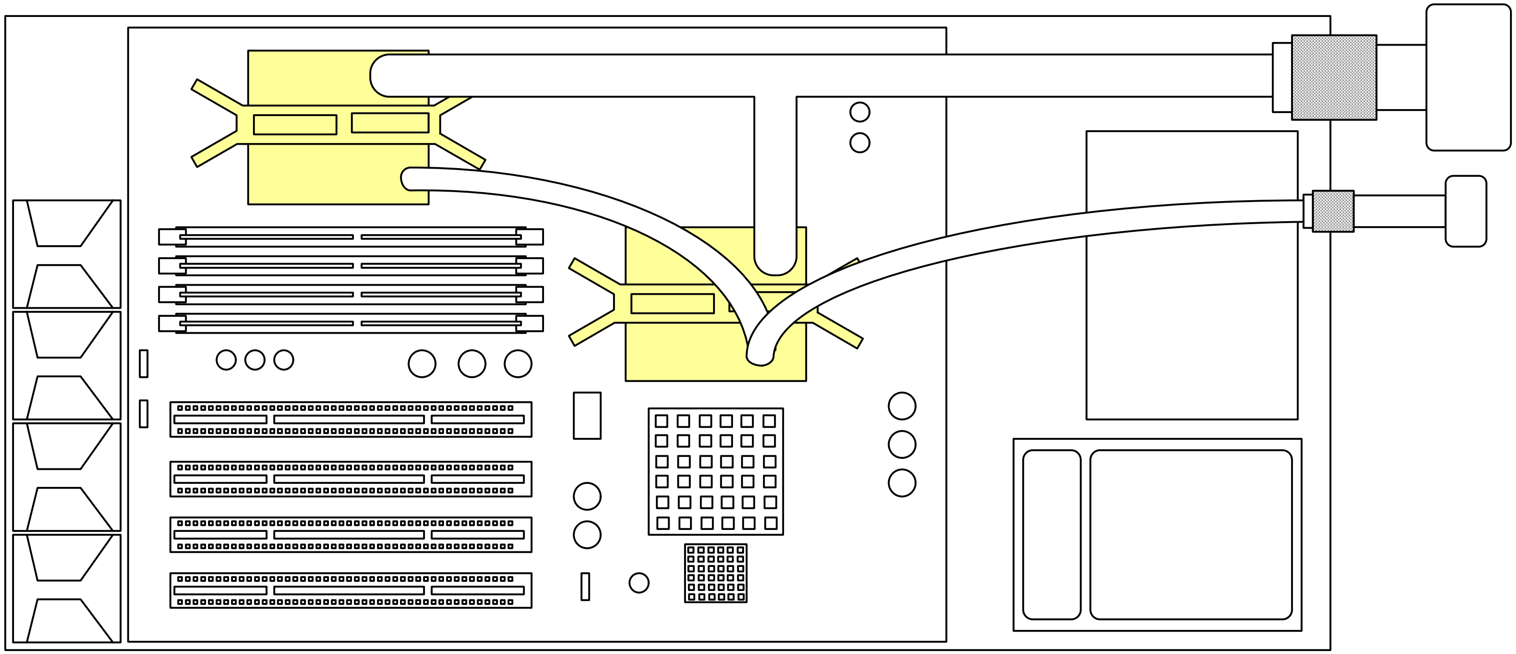
Horizontal Orientation



Vertical Orientation

Typical Geometric Configurations

Large, Distributed, Rack Mount Systems



Conclusions

- Passive thermosyphons offer distinct advantages over forced convection aqueous technologies for many applications
  - No Pump
    - Reduced cost, weight, complexity
  - Practical
    - Time-proven joining and filling technologies
  - Reduced Risk
    - Fluids will not damage electronics if they leak
  - Performance
    - As good or better than forced water for similar geometries
      - R_{sa}<0.06 C/W for a 20mm heat source with large condenser
      - R_{sa}<0.13 C/W for a 20mm heat source in a 100cc 2U form factor