Collector Cooling

Design example

Failures in the field

Water quality

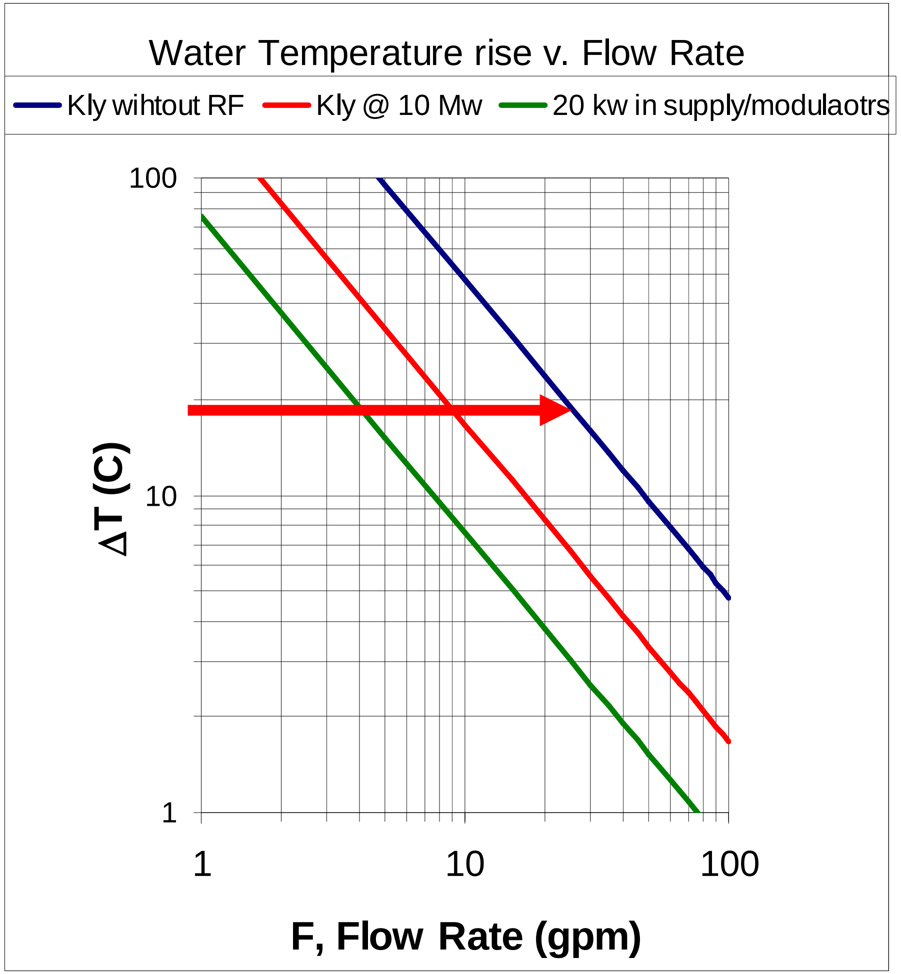
Temperature Rise of water and minimum flow rates

$$\Delta T = \frac{.0038}{F(gpm)} Q(watts)$$

Minimum flow rate is determined By:

1. Inlet water temperature
2. DC operation at full duty
3. Desired ΔT of water
4. Collector Surface Temperatures below 90C (10C margin?)
5. Turbulent Flow in cooling channels

(Without RF 125 kW
With RF 47 kW)



Simplified Klystron Collector Geometry Example

$$\Delta P = 2.4\times10^{-5}\,\frac{F^{1.8}L}{n^{1.8}A^{2.4}\phi^{.6}}$$

F, (gpm)
L, length of duct (in)
n, number of ducts
A, cross sectional area of duct
ϕ, duct geometry factor ($4\pi A/p^2$)
    p, perimeter of duct

Square Duct		
F	22	gpm
L	50	in
n	24	
duct sides	0.23	in
A	0.0529	in^2
perim	0.92	in
ϕ	0.8	
Δ P	1.4	psi

L-band Spec 1.4 typ

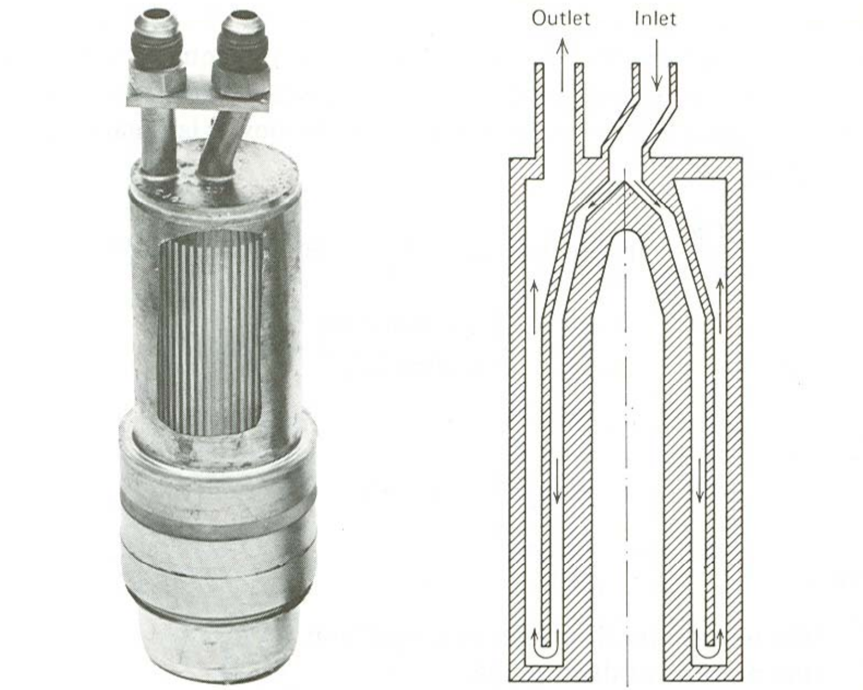


FIGURE 5.20
Cutaway photograph of the liquid cooled collector of the high power klystron and a schematic drawing showing liquid flow (Photo courtesy of Varian Associates)

“Cooling of Electronic Equipment”, Al Scott, 1974, John Wiley & Sons,

Laminar to Turbulent Flow (water)

$$\frac{F\phi^{.5}}{nA^{.5}} < .7 \quad \text{Laminar}$$

F, (gpm)
n, number of ducts
A, cross sectional area of duct
ϕ, duct geometry factor ($4\pi A/p2$)
p, perimeter of duct

In the example F>5 gpm for turbulent flow

5.3 Coolant Liquids

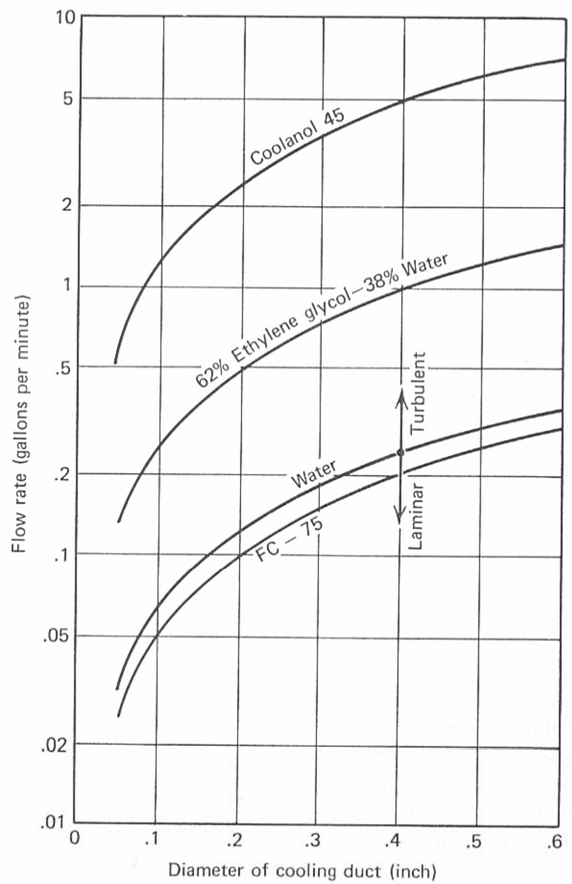


FIGURE 5.12
Flow rate at which the flow changes from laminar to turbulent as a function of cooling duct diameter for four different coolants

"Cooling of Electronic Equipment", Al Scott, 1974, John Wiley & Sons,

Temperature Rise of Duct above Water for Turbulent Flow

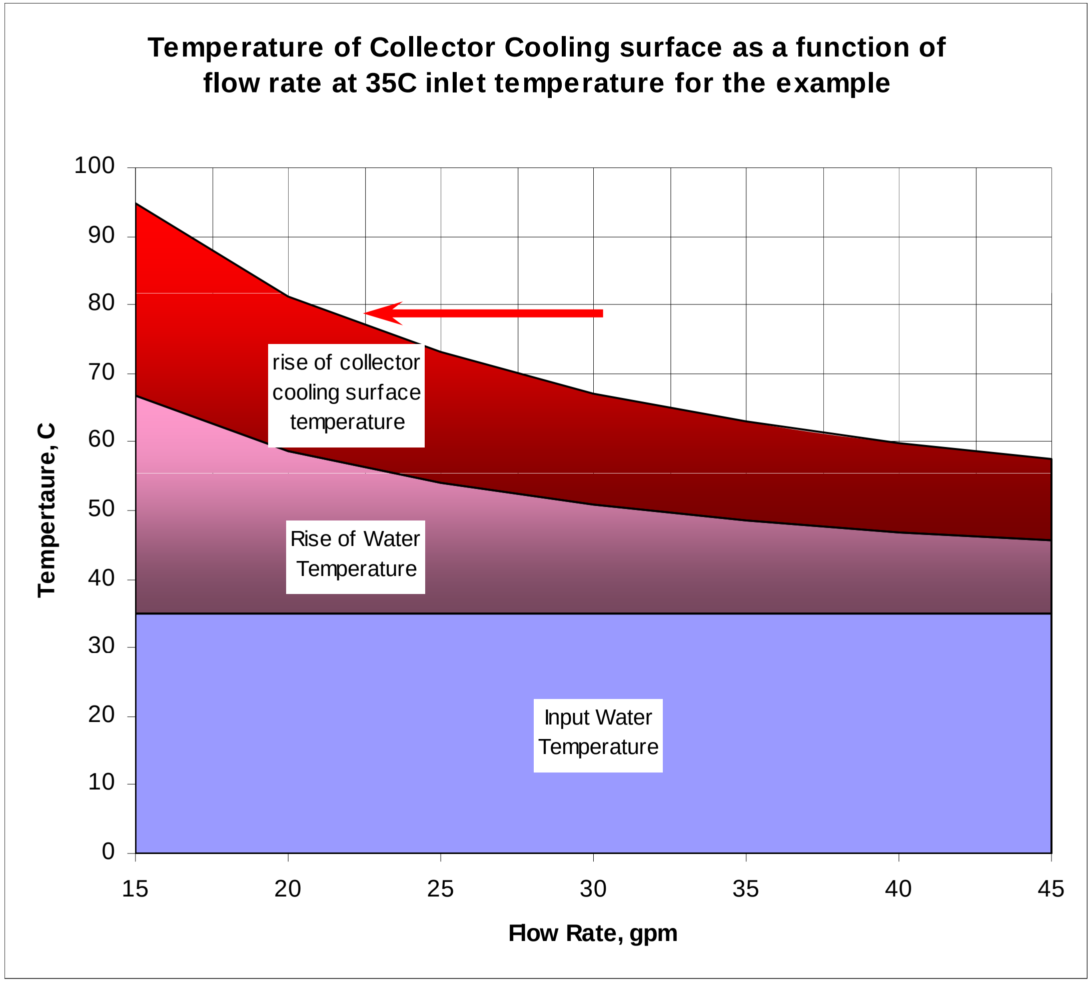
$$\Delta T(duct) = .7 \frac{A^{.4}\phi^{.6}}{Ln^{.2}F^{.8}} Q$$

Square Duct		
F	22	gpm
L	50	in
n	24	
duct sides	0.23	in
A	0.0529	in^2
perim	0.92	in
ϕ	0.8	
Δ P	1.4	psi

	temp rise of duct	
	0.000167	Δ T duct
Q (dc)	125000	20.9
Q (rf)	47000	7.8

Summary of Example

- DC power into the collector, 125 kW
- 22 gpm input at 35C
- Pressure drop .1bar
- Water ΔT, 18C
- Copper surface ΔT, 15C above water
- Collector Cooling surface temperature, 35+18+21=74C



Stresses in Collector from Hydrostatic pressure

- Margin needed to prevent copper plastic deformation
- Assume full force on the inner collector bucket (i.e. no mechanical support from outer bucket)

$$\boxed{P_P = 2\sigma_y (t/D)}$$

Factor of 2 safety at 6.5 bar max

P_p	*hydrostatic pressure for plastic instability*		
σ_y	*yield stress (lb/in^2)*		
t	*pipe thickness (in)*		
D	*Outside Diameter, in*		

σ_y	4000	psi, copper yield stress	
D (in)	t (in)	t/D	P_p (psi)
5	0.5	0.100	400
6	0.5	0.083	333
7	0.5	0.071	286
8	0.5	0.063	250
9	0.5	0.056	222
10	**0.5**	**0.050**	**200**
11	0.5	0.045	182
12	0.5	0.042	167
13	0.5	0.038	154

***Max Pressure in ILC Spec is 10 bar (160 psi) *** This could be a problem.

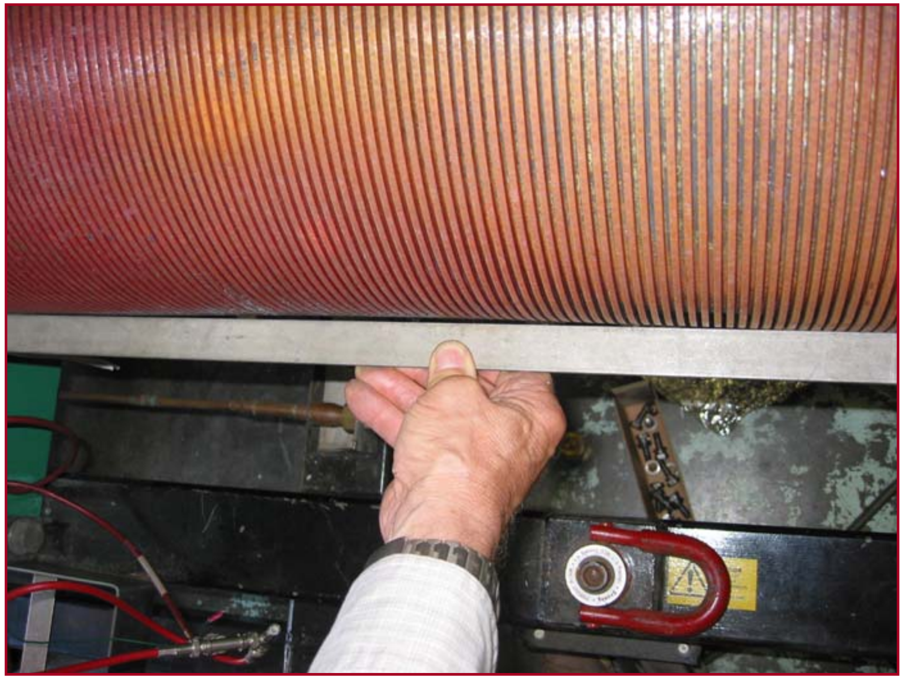
A Collection of Collector cooling/design failures

- PEP-II
- LHC
- APT
- KEKB

Marconi Klystron (Oct 2002)

PM-RF-System-Status-MAC-10-09-03.ppt Peter McIntosh

- Vacuum leak identified at the collector braze joint on each of the 3 failed Marconi klystrons.
- When trying to find the, found each of the collector bodies had deformed.
- Deformation occurred in approximately the same location for all 3 klystrons.
- Excessive heating of the collector the primary cause.
- Marconi S/N 02 and 03 rebuilt at CPI with an improved collector design:
  - has longitudinal cooling channels as opposed to radial channels.
  - Baffled water circulation to specifically direct water around the collector braze joint.



lhc.web.cern.ch/lhc/**icc**/**icc**20**07**-03/brunner.pdf

RF Power

- ✓ Equipment installed (klystrons, circulators, RF loads, drivers, heaters, waveguide systems)
- ✓ Local control tests (i/o, communication, interlocks)
- ✓ Klystrons tested at nominal voltage (60kV low power)

- Status: ready for the power tests
  - waiting for cooling water

- Concerns:
  - One LHC (spare) klystron died due to vacuum leak after only 16khr ➔ burned collector
  - Two other klystrons also showed traces of burn, at the same place
    - ➔ bad design of the water cooling system?! – confirmation tests in progress

  - Action & plan:
    - RF power limited to 200kW
    - validation test of a new design at Thales/CERN (April)
    - replacement of collector water cooling systems on all klystrons...
      - ➔ dismantle UX45 RF system

Collector Failures on 350 MHz, 1.2 MW CW Klystrons at the Low Energy Demonstration Accelerator (LEDA)

Rees, D. Los Alamos Nat. Lab., NM; **Vacuum Electronics Conference, 2000.**

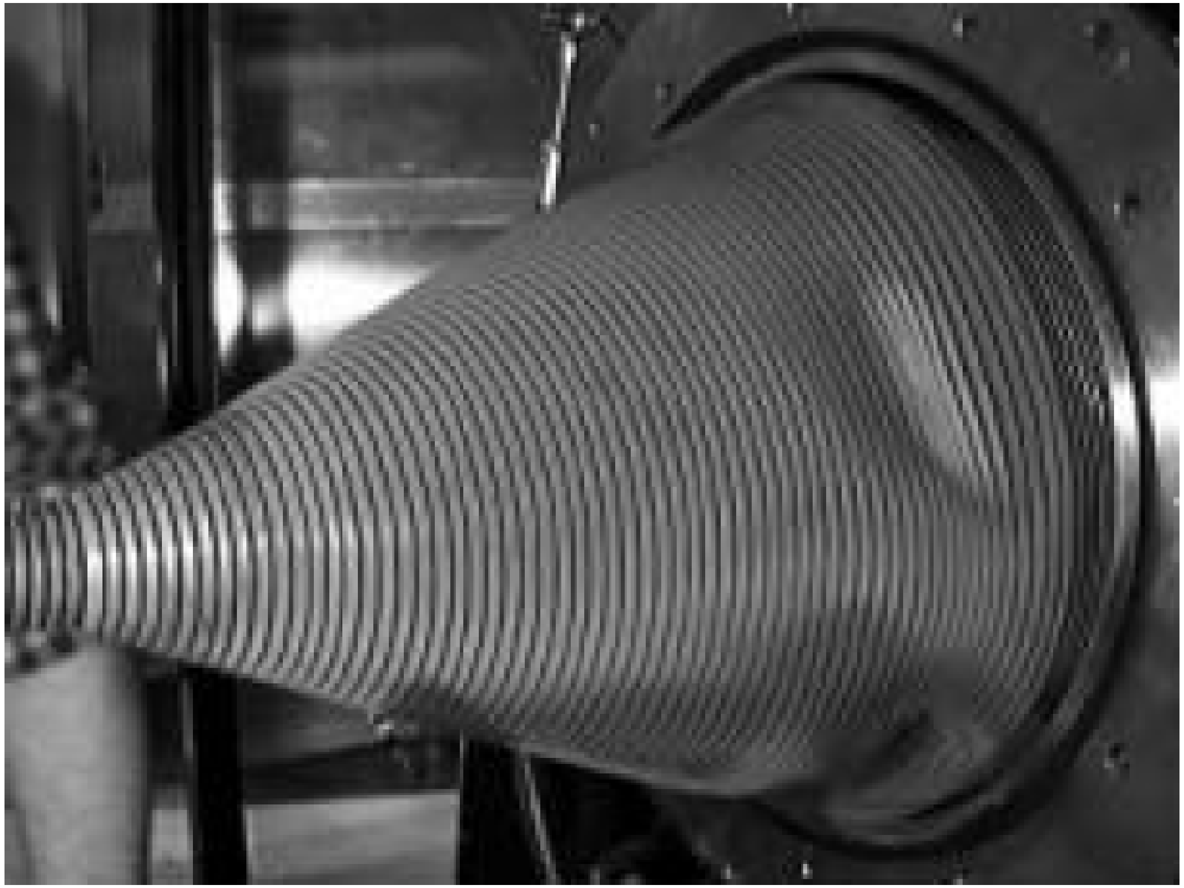


Figure 3: External view of collector damage.

Mixed phase collector cooling system allowing for boiling and recondensation

Fringing magnetic field into the collector was inconsistent from tube to tube.

Collector overheating and the mechanical support system allowed the collectors to droop

Improved inner bucket support system and changed operating conditions to minimize full dc beam power into the collector

KEKB

HIGH POWER CW KLYSTRONS AND MAINTENANCE OF WATER QUALITY

S. Isagawa, H. Baba, K. Bessho, K. Ebihara, Y. Kanda, H. Nakanishi, M. Taira and M. Yoshida,
KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

important factor is the water quality. Especially silicon is the most dangerous material as it causes the steam skin along the collector (danger of Lydenfrost phenomenon). Grease, gaskets and O-rings containing silicon must be strictly avoided. A foaming test measuring the

Spectroscopy). When a Philips tube, for example, v01, died due to collector leak in December 1987, Si was 1.66 mg/l, about 3 times as large as the allowable level.

APAC98

Vapor Cooled Collectors

Cooling Water specifications

- Scale formation tests
- CPI specifications
- Thales specs

Cooling System Design for Scale Prevention in High Powered Klystrons*

G. REYLING†, MEMBER, IRE, F. JENSEN†, MEMBER, IRE, and C. F. CLARK‡

* Received May 17, 1962.
† Varian Associates, Palo Alto, Calif.
‡ Stanford Research Institute

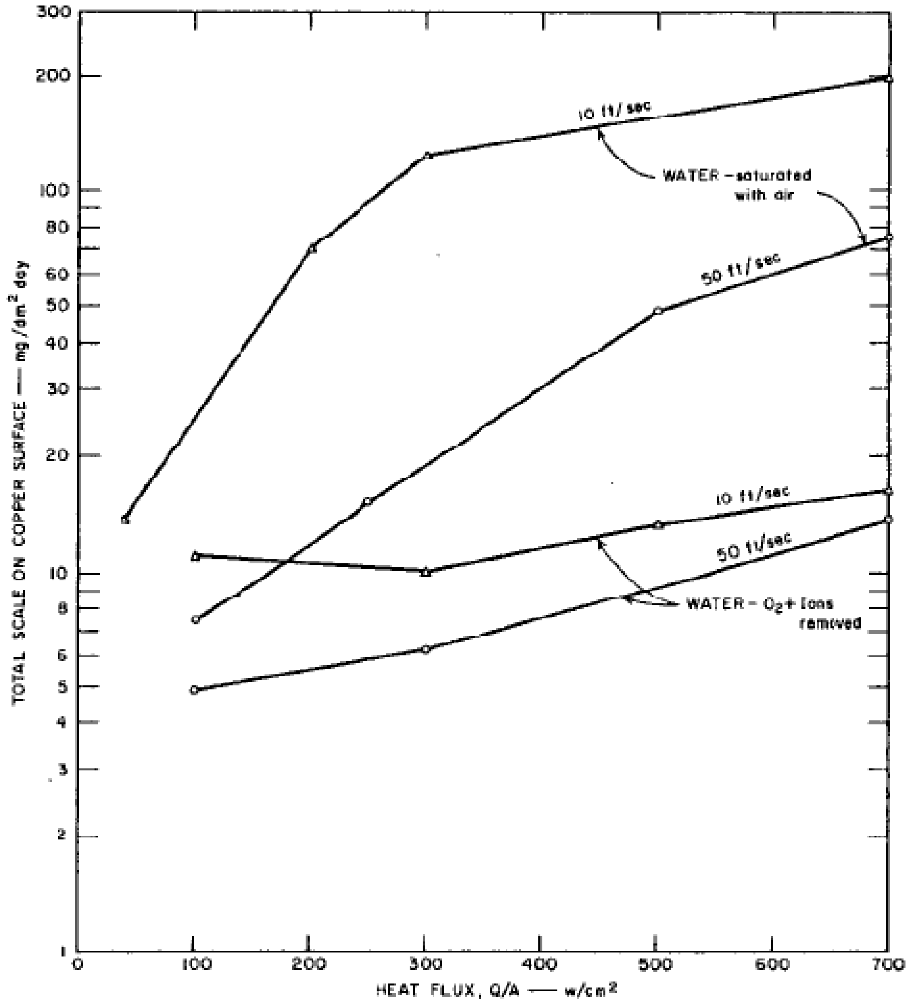


FIGURE 7
TOTAL SCALE FORMED PER DAY ON SURFACE OF COPPER AT VARIOUS HEAT FLUXES
(Coolant: distilled water with and without ion and oxygen removal.)

Scale formation occurs over time.

High flow rates and low power densities slow the rate of formation

Ion and Oxygen removal is optimum

Communications & Power Industries microwave power products division	**APPLICATION NOTES** AEB-31, Pub. 2696 Rev. A 4/28/03	**WATER PURITY REQUIREMENTS IN WATER- AND VAPOR-COOLING SYSTEMS**

The recommendations given herein are based on a study of liquid-cooling systems conducted for Varian Associates (CPI) by Stanford Research Institute and the subsequent analysis and correction of the problems in various field-operating situations.

WATER PURITY SPECIFICATION

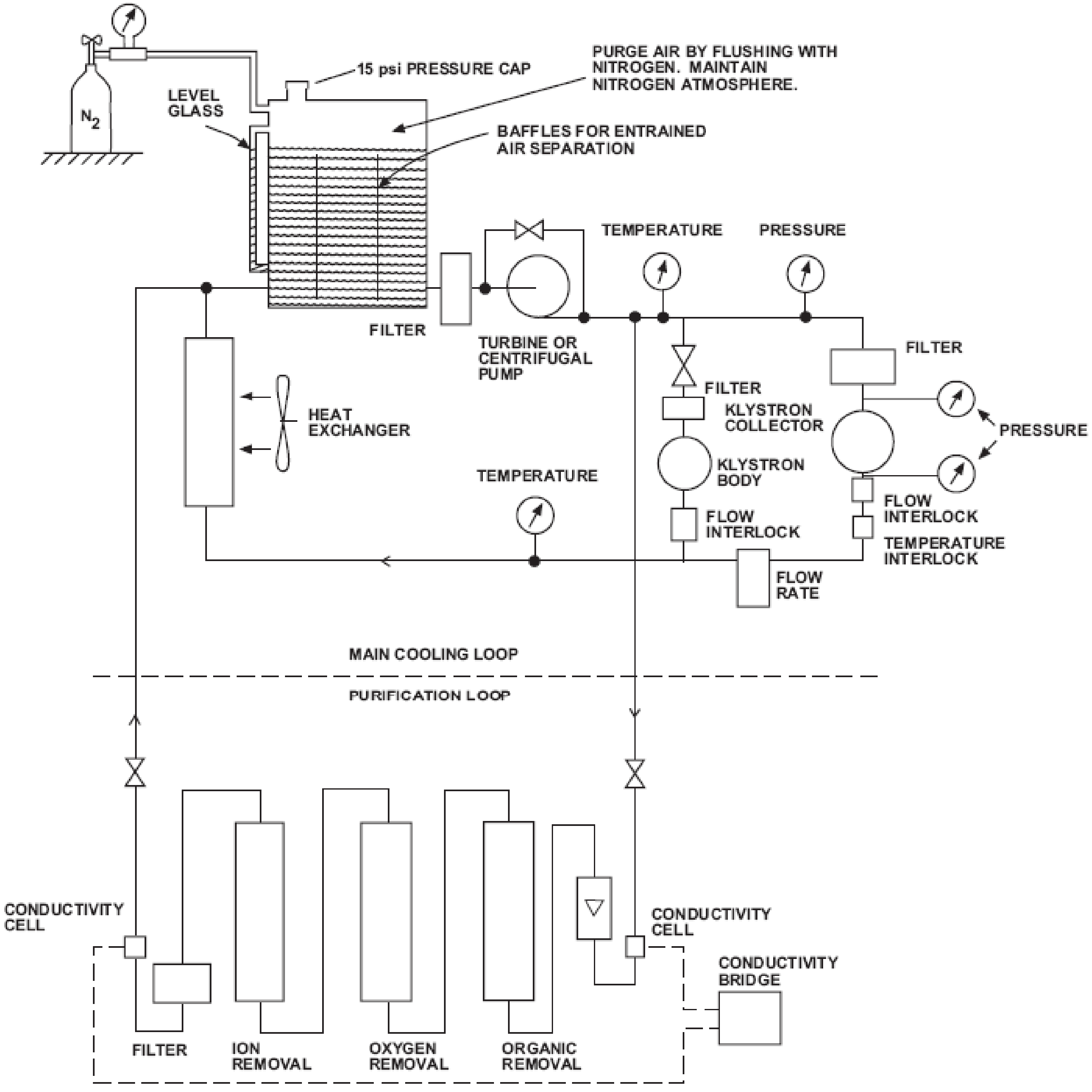
1. The resistivity of the water shall be maintained at a level of 100 kΩ-cm or higher at 30°C.
2. Dissolved oxygen should not exceed 0.5 parts per million.
3. The pH factor shall be within the range of 6 to 8.
4. The particulate-matter size shall not be greater than 50 microns (325 mesh).
5. The inlet water temperature should not exceed 60°C, and it is recommended that this temperature be regulated to ±5°C.

Communications & Power Industries
microwave power products division

APPLICATION NOTES

AEB-17, Pub. 2071
Rev. A 4/28/03

RECOMMENDATIONS FOR COOLING HIGH-POWER MICROWAVE DEVICES



Thales

<u>NOTE 10</u> -	Water quality :	- dry residue	: < 5 cg/dm3
		- Ph	: 6.5 to 7.5
		- (Ca + Mg) dissolved	: < 2 cg/dm3

Tube Specs

- TH2104C (5 MW tube)
- ILC 10 MW tube

5 MW tube

Reference : CA 2104C-102 Date : June 25, 1998	THOMSON TUBES ELECTRONIQUES	Type : TH 2104C Page : 3/13

Parameter	Isol	Water flow		Water temperature	Window pressurization	Water pressure
		Collector	Body			
Unit	A	dm^3/mn	dm^3/mn	°C	bar (with dry air)	bar relative
Maximum	70	-	-	35	3	$\boxed{6.5}$
Minimum	vn - 7.5%	240		-	2.5	-
Note	7	18	18	9 - 10	11	-

240/3.8=63 gpm

NOTE 10 - Water quality : - dry residue : < 5 cg/dm3
- Ph : 6.5 to 7.5
- (Ca + Mg) dissolved : < 2 cg/dm3

10 MW ILC Spec

2.3	Collector cooling water	Inlet temperature	25°-51°C
		Outlet temperature	≤ 75°C
		Inlet pressure	3.5 bar, typical 10bar, max.
		Differential pressure	0.1 bar, typical 0.5 bar, max
		Test pressure	16 bar

Water flow:

22 gpm ≤ 85 l/min at 5Hz repetition rate

≤170 l/min at 10Hz repetition rate

This may be a problem due to hydrostatic stresses in the collector

Appendix

- Pressure Drop for Turbulent Flow
- Evaporative Cooling requirements

Pressure Drop for Turbulent Flow

in 3/8 in diameter duct

$$\Delta P = 2.4\times10^{-5}\,\frac{F^{1.8}L}{n^{1.8}A^{2.4}\phi^{.6}}$$

F, (gpm)
L, length of duct (in)
n, number of ducts
A, cross sectional area of duct
ϕ, duct geometry factor ($4\pi A/p^2$)
p, perimeter of duct

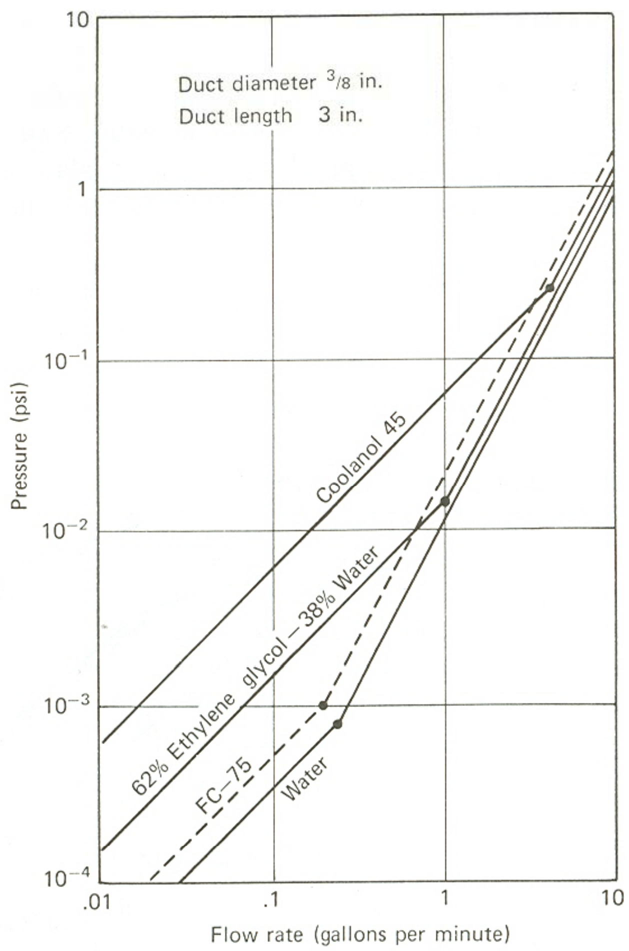


FIGURE 5.11
Pressure required to force the coolant through the duct as a function of flow rate for four different coolants

Limits of Evaporative Cooling

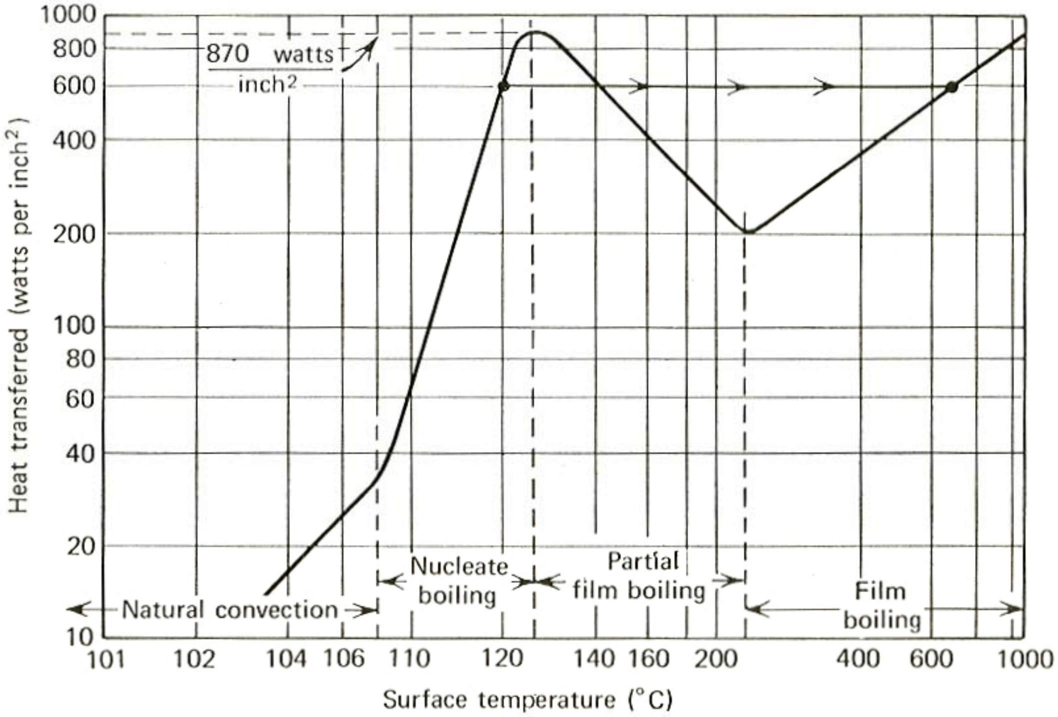


FIGURE 6.3
Heat transferred per unit area of component surface as a function of surface temperature for evaporation cooling with water