



APPLICATION NOTES

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RECOMMENDATIONS FOR COOLING HIGH- POWER MICROWAVE DEVICES

In addition to this document, the following three related technical publications are available from CPI to provide guidance in the design and maintenance of liquid-cooling systems for high-power microwave vacuum electron devices (VEDs):

- AEB-26 Foaming Test for Water Purity
- AEB-31 Water Purity Requirements in Water- and Vapor-Cooling Systems
- AEB-32 Cleaning and Flushing Water- and Vapor-Cooling Systems

Each document addresses a different aspect of the concern about proper design and care of cooling systems; together, they should answer the most common questions concerning liquid cooling. If additional information is needed, please contact the CPI Engineering Department.

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INTRODUCTION

The high power levels of present-day microwave electron devices require careful attention to the design and operation of cooling systems. In some cases, inadequate or improper cooling due to scale or corrosion may be the limiting factor in VED life. Scale is formed as a deposit upon the wetted surface of the coolant system as the result of the conversion of a coolant-soluble salt to an insoluble compound due to the chemical reaction of the various elements in the coolant; corrosion is the result of chemical reaction products of some portion of the wetted surface itself. This document discusses causes of scale and corrosion in liquid-cooled systems and recommends ways to minimize their occurrence. When cooling is not the limiting factor in product life, the precautions and practices described below may not be required.

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.

THE MICROWAVE VACUUM ELECTRON DEVICE

The high-power, liquid-cooled VED is generally fitted with two cooling paths, one for the collector, the other for the body of the device. Other elements of the system, which are usually liquid cooled by the same heat-exchange system, typically include the electromagnet, focus coil, rf dummy load, and various pieces of microwave plumbing between the VED and the antenna.

The coolant flow from the collector inlet fitting is redirected at the inlet manifold into numerous small paths arranged around its cylindrical periphery, rejoined in an outlet manifold, and passed out of the device through the outlet coolant fitting. If the direction of flow is of consequence, the connections are clearly marked on the device.

The body-cooling circuit is intended to cool and thereby stabilize the operating temperature of the various microwave cavities and their tuners. Again, coolant is generally introduced into and removed from the VED body through fittings that are typically of the quick-disconnect, self-sealing type.

In some VEDs, as much as 4 kilowatts per square inch must be transmitted through the collector wall and dissipated into the coolant. The heat flux in the collector is not uniformly distributed and, at high values of heat dissipation, a small amount of scale can cause a large rise in temperature in some portion of the collector, thereby greatly increasing the possibility of premature product failure.

The fundamental factors involved in the exchange of heat between a body and its liquid-cooling medium are:

1. Maximum allowable vacuum-wall temperature. In VEDs using copper, this temperature should not exceed 300°C.
2. Coolant specific heat.
3. Coolant boiling temperature.
4. Coolant viscosity.
5. Coolant velocity.

Cooling-channel cross sections as small as 0.025 inch by 0.050 inch are used, and the relative ease with which these channels can be plugged with foreign matter must be given careful consideration. Regardless of the type of liquid coolant used, a method for continual purification of the coolant is necessary.

COOLANTS

As a coolant for VEDs, deionized water (which is chemically stable with a high heat-transfer capability) is much preferred over antifreeze mixtures. If protection against low temperatures is required, draining a system or using electric water heaters during nonoperating periods will prevent the problems introduced by antifreeze.

If a freezing-point depressant is necessary, a closed cooling system complete with purification loop can be used with an *uninhibited* solution of ethylene glycol and water as the coolant. Although inhibited glycols are more stable than uninhibited glycols when the coolant is saturated with air, field experience has shown that present operating methods using inhibited glycols are inadequate and lead to shorter VED life. Inhibited ethylene glycol cannot be used with coolant-purification systems, because the inhibitor will saturate the ion-exchange resin and render it useless. Inhibited glycol may be used if the cooling system is sealed against air.

Since antifreeze mixtures typically do not cool as well as water, a greater flow rate is required. Before using these antifreeze mixtures in CPI VEDs, the CPI Marketing Department should be consulted for specific recommendations.

COOLANT-SYSTEM DESIGN

Tubing, fittings, pumps, and other material that will be in direct contact with the coolant should be made from copper, nickel, bronze, Monel, Inconel, 304L stainless steel, and 347 stainless steel for welded parts to minimize galvanic action. *Metals that should not be used in direct contact with the coolant include steel, cast iron, galvanized iron, aluminum, and magnesium. Brass should be used as sparingly as possible.*

All-bronze or stainless-steel turbine pumps are suitable for devices requiring flows from 5 to 40 gallons per minute at pressures from 85 to 200 pounds per square inch. All-bronze or stainless centrifugal pumps are suitable for lower pressures.

Teflon-lined hoses are preferred for cooling-system use, because natural or synthetic rubbers, which are typically vulcanized and contain sulfur, tend to deteriorate when used with hot liquids. If electrical insulation is required (a frequent case), the hoses should be covered with fabric; otherwise, metal armor may be used. Silicone rubber is not allowed in the cooling system. Field experience has shown that it will tend to leach out and deposit on the hottest surfaces in the system, degrading the heat transfer at that point.

As previously mentioned, the cooling system ideally should include means to continuously purify the coolant. This can be a purification loop, which processes a small amount of coolant from the main recirculating loop by removal of soluble salts through ion exchange, dissolved oxygen and carbon dioxide, small particulate matter, and other contaminants. If a mixture of ethylene glycol and water is to be used, provision must also be made for the removal of organic-breakdown products of the ethylene glycol. Packaged purification systems suitable for this purpose are available; one manufacturer of suitable equipment is Barnstead International (www.barnsteadthermolyne.com).

Figure 1 shows a typical arrangement of a klystron recirculating cooling system with a purification loop. A single replaceable cartridge generally supplies the filtering, ion-exchange oxygen removal, and organic removal functions. The system also includes flow- and pressure-adjusting valves, a flow meter, and the necessary conductivity cells and electronics to evaluate the conditions of the filter cartridge with respect to metal-ion capture. As stated previously, the filter cartridges and filter membranes are replaceable, and the size and operating characteristics of the purification system should be in accordance with the manufacturer's recommendation. A nitrogen gas pressurized system as shown is recommended to minimize oxidation.

Referring again to Figure 1, the main cooling loop shows particulate filtering (10- to 50-micron size) between the accumulator tank and pump and filtering beyond the parallel branching paths to the various circuits (represented in Figure 1 by the collector and body paths in the klystron). Entering and returning bulk coolant temperature is also monitored. Pressure measurement is indicated at the pump head and *directly* across the collector; this will be explained further in a later section. The collector flow rate should be continuously monitored. Many systems also include the control equipment for maintaining the incoming coolant's temperature at a preset point, independent of seasonal changes of ambient temperature.

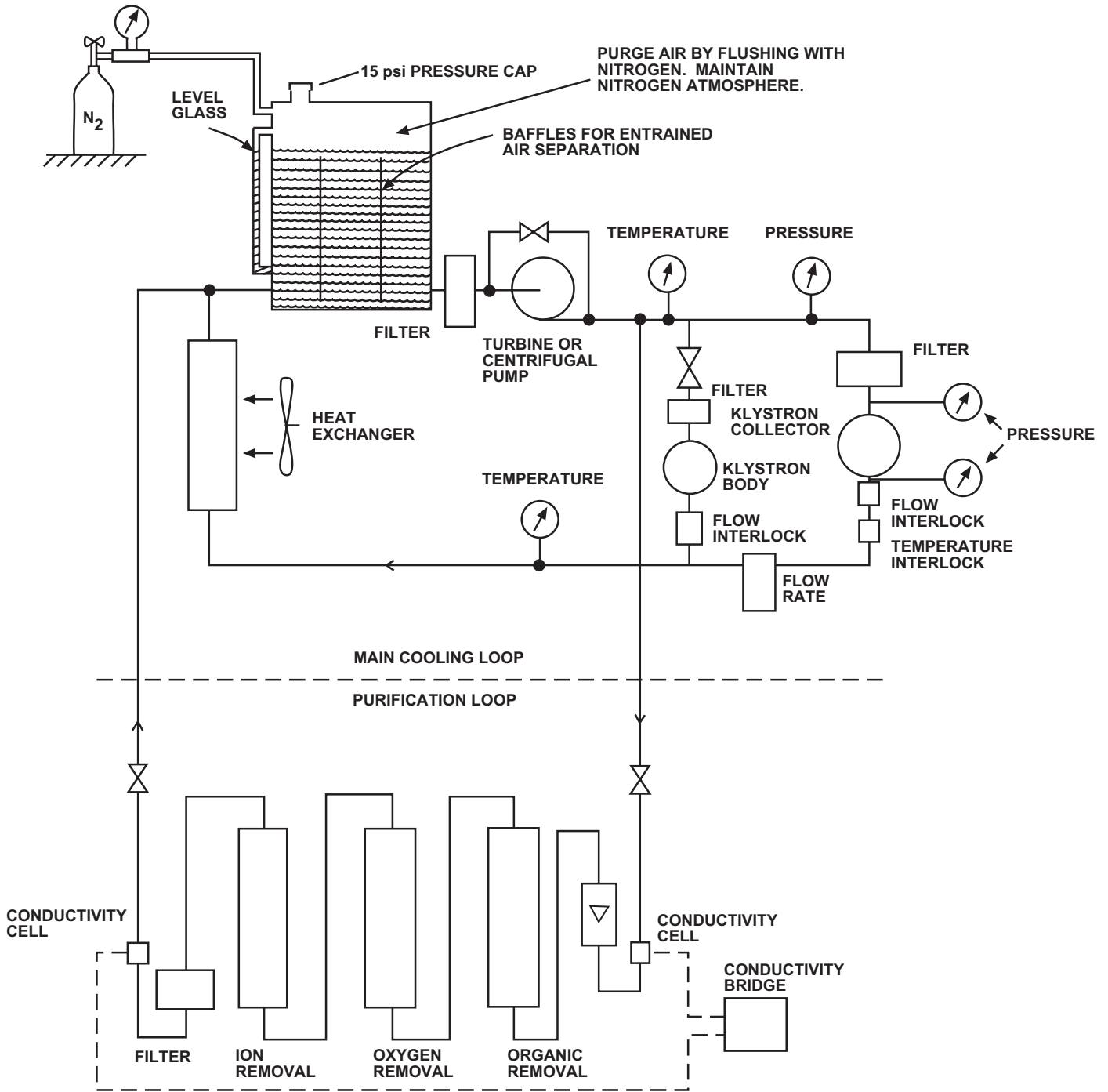


Figure 1. KLYSTRON COOLING SYSTEM WITH PURIFICATION LOOP

COOLING SYSTEM OPERATION

All contaminants such as oils, greases, and particulate matter should be removed from the system, since they may deposit on the heat-exchange surfaces inside the device and reduce the heat-transfer capability. The cooling loop should, therefore, be degreased with a solvent or detergent, followed by a number of clean-water flushes. Also, no soluble oil inhibitors or stop-leak compounds should be added to the coolant, since detergents, soluble oils, etc., may cause foaming.

When initially operating a new installation, special precautions must be taken to remove potential contaminants such as pipe compound, solder salts, Teflon pipe-tape thread seal, and bits of solder. With all the main cooling-loop filters in place but with device, magnet, and other components replaced with jumpering connections, the system should be thoroughly flushed as described in the preceding paragraph. Once this system maintenance is complete, normal operation can begin after cleaning and replacing the filters.

Maintaining operating-system purity is critical to ensuring maximum product lifetimes. Manufacturers of purifying equipment normally include a method of monitoring coolant resistivity with their product package to measure the ion content and other conductive foreign matter. Ion-removal-cartridge replacement is indicated when the coolant leaving the purification system falls below 1 megohm resistivity. A fresh cartridge at recommended throughput will return 10 to 19 megohm-cm at 25°C of coolant resistivity to the main loop for an intake resistance of 2 megohms. Rapid exhaustion of the ion-exchange cartridge may indicate a source of contamination, electrolysis, the use of inhibited glycol, or a lack of sufficient capacity in the purification loop for the bulk coolant being processed. Membranes in the submicron filter of the purification loop should be replaced when the pressure drop across the loop becomes excessive.

Two sources of *corrosion* effects in the coolant system are recognized: deterioration of the piping, manifolds, and radiator due to electrolysis between dissimilar metals as previously mentioned; and the oxidation of copper material from the device itself in the areas of high heat transfer to the coolant, primarily in the collector. The corrosion rate is directly related to the amount of dissolved oxygen in the coolant and the temperature of the copper collector core, i.e., the collector power dissipation. In a system operating at atmospheric pressure at the accumulator tank and with no special effort made to close the system from the atmosphere, it is common to measure 3.5 to 5 parts per million of dissolved oxygen in the coolant. It is also important to note that it is possible to aspirate air into a closed coolant circuit at the pump rotary seal and at quick-disconnect fittings, even without evidence of liquid leakage at these points. Aspiration of air into the system will result in rapid depletion of oxygen-removal chemicals without indication of a change in coolant resistance. Corrosion-free operation can only be attained by holding the dissolved oxygen level to 0.5 parts per million or less. This means that the oxygen level must be measured and removed frequently, and the reservoir and radiator empty space should remain filled with nitrogen.

One alternative to the relatively expensive design and maintenance problems associated with tight control of oxygen in the system is to institute routine flushing procedures for the VED. Figure 1 includes pressure gauges at the inlet and outlet ports of the collector, as well as a flow-rate meter in the collector branch. Collector corrosion effects are indicated by a slowly increasing pressure differential across the collector as the flow rate is held constant by branch-valve adjustment. Thus, when the pressure drop across the collector has increased by 20 to 25 percent from the value at initial installation, corrosion products must be removed from the system. After removing the device, these contaminants (mainly copper oxide, CuO) can be flushed out or dissolved out of the cooling channels by means of dilute hydrochloric acid, followed by a neutralizing flush

and then tap-water flushing. It is especially important that flushing procedures be instituted before any of the cooling channels inside the device become so full of the corrosion products that the flow of the flushing liquid is completely blocked. To prevent this, it necessary that collector flow and pressure instrumentation be a permanent part of the coolant-system installation. Contact CPI for specific flushing-solution recommendations and procedures.

Generally speaking, the manufacturer's recommendations should be followed for overall cooling-system maintenance; however, to obtain the longest possible life of the VED, the following points must be considered:

1. Keep the coolant temperature constant and as low as ambient weather conditions and other total system requirements will allow.
2. Use clean deionized water for original flushing, final filling, and make-up.
3. Use ethylene glycol *only* (do *not* use automobile radiator antifreeze).
4. Monitor the condition of the ion-exchange cartridge, recognizing that this will not provide any knowledge of the condition of the cartridge's oxygen-removal section.
 - An instrument that measures the dissolved oxygen in any liquid by direct readout in parts per million is available from several manufacturers, including Beckman Coulter (www.beckman.com).
5. Maintain the cleanliness of the main loop and branch loop filters through routine inspection.
6. Ensure the system remains free of dissolved oxygen, or flush the device when the collector differential pressure increases by 25 percent above the original value at the equivalent flow rate.
7. Follow the purification-loop manufacturer's instructions for the replacement of filter membranes and cartridges.

OTHER CLEANLINESS ISSUES

The sight glass and float of the water-flow indicators must also be kept clean to achieve efficient system operation. The water-flow indicators usually become contaminated during use, and this contamination collects on the sight glass and float, making the readouts difficult to see. If too much contamination is present on the glass and float, they may stick and produce an erroneous reading. The detergent and cleaning solutions may not remove all of this contamination. If this is the case, the flow meter must be removed and cleaned and the glass surface brushed.

CAUTION

This cleaning and flushing procedure is meant to provide an additional method for cleaning coolant passages of VEDs and transmitters, whether new or already in use, and *NOT* to supersede any transmitter manufacturer's procedure. Merely adhering to this procedure does not guarantee that the liquid coolant in the refilled system is sufficiently pure. More information can be obtained from CPI publication AEB-31.