Cooling Water Conditioning & Quality Control For Tokamaks*

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ABSTRACT

Designers and operators of Tokamaks and all associated water cooled, peripheral equipment, are faced with the task of providing and maintaining closed-loop, low conductivity, low impurity, cooling water systems. Most of these systems must provide large volumes of high quality cooling water at reasonable cost and comply with local and state government orders and EPA mandated national pretreatment standards and regulations.

The primary reason for supplying low conductivity water to the DIII–D vacuum vessel coils, power supplies and auxiliary heating components is to assure, along with the use of a non-conducting break in the supply piping, sufficient electrical resistance and thus an acceptable current-leakage path to ground at operating voltage potentials. As important, good quality cooling water significantly reduces the likelihood of scaling and fouling of flow passages and heat transfer surfaces. Dissolved oxygen gas removal is also required in one major DIII–D cooling water system to minimize corrosion in the ion sources of the neutral beam injectors. Currently, the combined pumping capacity of the high quality cooling water systems at DIII–D is ≈5,000 gpm.

Another area that receives close attention at DIII–D is the chemical treatment of the water used in the cooling towers. The water from the towers is used to cool equipment and components critical to the project, e.g., motor generators, helium compressors, vacuum pumps and all heat exchangers that extract energy from the vacuum vessel and its coils, power supplies, and all auxiliary plasma heating components and equipment.

This paper discusses the DIII–D water quality requirements, the means used to obtain the necessary quality and the instrumentation used for control and monitoring. Costs to mechanically and chemically condition and maintain water quality are discussed as well as the various aspects of complying with government standards and regulations.

INTRODUCTION

Over the past 20 years, a user-specific, cooling water program has effectively been implemented at General Atomics' DIII–D Fusion Research Facility. Much care was taken to assure that the design of the four main cooling systems would provide the required and optimum flow parameters at reasonable cost. The operating history has validated this design goal. First, a description of the systems is given. Second, certain quality aspects that are common to all the deionized water and cooling tower water systems are discussed.

A. *Main systems*

There are four main cooling systems used at DIII–D.

1) DIII–D (Tokamak Interspace, Tokamak Coils and Tokamak Power Supplies) — This system, Fig. 1, consists of three primary pumps connected in parallel delivering 3800 gpm combined flowrate at 70 psig and two boost pumps in parallel (only one is operated at a time) delivering 1000 gpm each at 95 psig. The boost pumps' motors are controlled by variable frequency drives and have capability to boost the discharge pressure to 175 psig at a lessor flowrate. Storage/surge capacity is accomplished with twin 15,000 gallon, fiberglass tanks. Heat is extracted from the coolant with cooling tower water in two, full-flow all stainless steel, plate and frame heat exchangers rated at approximately 4 MW each.

Conductivity of the water is controlled by automatically draining a portion of the cooling water from the system and refilling with highly deionized water. This system is operated at a nominal conductivity of 14 micro-Siemens. Filtration of the cooling water is performed at the pumps with 150 micron, all stainless steel, wire mesh strainers.

2) High Pressure (Neutral beam Ion Sources and Electron Cyclotron Heating (ECH) — This system, Fig. 2, consists of five centrifugal pumps connected in parallel delivering 4000 gpm combined flowrate at 200 psig pump discharge pressure. The pump motors are controlled by viable frequency drives to allow optimum adjustment of user inlet

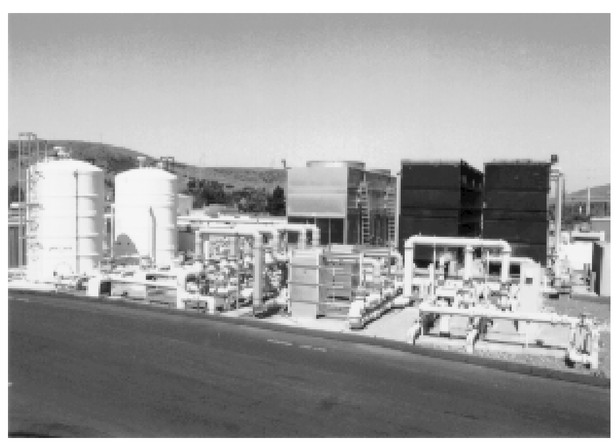

Fig. 1. DIII–D Primary Cooling Water System.

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Fig. 2. Auxiliaries High Pressure Cooling Water System.

pressure and to assure a "soft" start of the high pressure equipment. Storage/Surge capacity is obtained with a 15,000 gallon fiberglass tank.

In this system, conductivity is maintained at a nominal 0.5 micro-Siemens. Dissolved oxygen gas in the coolant is maintained at 10 ppb or less. Water quality and dissolved oxygen gas content requirements and heat removal are accomplished with a side-loop off the storage tank. This side-loop has two pumps connected in parallel. Each pump capable of delivering 275 gpm at 35 psig. The heat removal in this side-loop is accomplished with cooling tower water in a single all stainless steel, plate and frame heat exchanger rated at a nominal 0.6 MW.

3) Low Pressure [Neutral beam power supplies and ion cyclotron heating (ICH)] — This system, Fig. 3, consists of five centrifugal pumps connected in parallel delivering 6250 gpm combined flowrate at 110 psig pump discharge pressure. There are no motor speed controls on these pumps but there are reduced voltage starters on the motors for a "soft" start to operating pressure. Storage/surge capacity is provided by a 15,000 gallon fiberglass tank.

In this system, conductivity is maintained at a nominal 0.5 micro-Siemens. Water quality and heat removal are accomplished with a side-loop off the storage tank with two

Fig. 3. Auxiliaries Low Pressure Cooling Water System.

pumps connected in parallel. Each pump capable of delivering 500 gpm at 35 psig. The heat removal in this side-loop is accomplished with cooling tower water in a single stainless steel, plate and frame heat exchanger rated at a nominal 1.5 MW.

In this system, conductivity is maintained at a nominal 0.5 micro-Siemens. Water quality and heat removal are accomplished with a side-loop off the storage tank with two pumps connected in parallel. Each pump capable of delivering 500 gpm at 35 psig. The heat removal in this side-loop is accomplished with cooling tower water in a single stainless steel, plate and frame heat exchanger rated at a nominal 1.5 MW.

4) The DIII–D Facility has four cooling towers, two of forced draft and two of induced draft design. The design basis for all towers is a conservative wet bulb temperature of 72°F. During operating periods, the warmest tower water outlet temperature experienced has been about 70°F. Acceptable water return temperature to the towers is limited by the PVC spray nozzles at 120°F. The chemistry in all towers is maintained essentially the same and discussed later.

Tower 1, forced draft, nominal rating is 8 MW, provides cooling for Motor Generator 1 with two pumps connected in parallel delivering a combined flowrate of 3000 gpm. This tower also supplies cooling to the Main Systems 2 and 3 above and miscellaneous equipment throughout the facility with two pumps connected in parallel delivering a combined flowrate of 1500 gpm.

Tower 2, forced draft, nominal rating is 8 MW, supplies cooling only to the DIII–D heat exchangers in Item 1 above with two pumps connected in parallel delivering a combined flowrate of 4000 gpm.

Tower 3, induced draft, nominal rating is 8.5 MW, supplies cooling to Motor Generator 2 with two pumps connected in parallel delivering a combined flowrate of 4500 gpm.

Tower 4, induced draft, nominal rating is 0.75 MW, supplies cooling to the cryogenic system's helium compressors. Pumps combined flowrate is 250 gpm.

DIII–D REQUIREMENTS

The original intent was to operate the tokamak coil cooling water at a conductivity of 1 micro-Siemen. Since plant commissioning, the cooling water system has been operated at approximately 14 micro-Siemens so that the water would be less corrosive as it passes through the extensive copper coils. In addition, the design philosophy incorporates an accepted, process industry standard of limiting water velocities in copper cooling tubes and channels to 5 to 6 ft/s to minimize effects of erosion.

Electrical isolation is achieved by interrupting the electrical paths between the piping and the metallic coils with insulating hoses. The 14 micro-Siemens conductivity water together with a specified, minimum length of high quality, reinforced rubber hose, provides acceptable electrical isolation between the tokamak, operating at a nominal 5 kV potential, and ground.

In the neutral beam program, the long pulse, ion sources and power supplies and in the rf program, the gyrotrons, cyclotron transmitters and power supplies all have higher voltage requirements and a specified cooling water requirement for a minimum conductivity of 1 micro-Siemen. The corrosiveness of the deionized water in these systems has not been a problem so the conductivity is maintained at 0.5 micro-Siemens to allow a safe flexible operating range.

Over the years, samples of deionized water from these systems have been tested by analytical consultants for bacteria contamination. Analysis has been performed to determine colony-forming organism concentrations or colony-forming units (cfu/ml) and total oxidizable carbon (TOC). Results of several analyses indicate that cfu/ml range from 30 to 130 and TOC ranges from about 2.5 to 5 ppm. Although these bacteria concentrations are significant, biocidal control, e.g., the use of UV radiation, has not been recommended as necessary. No deleterious effects from the bacteria in the coolant systems have been observed.

The neutral beam, long pulse, ion source accelerator grids are constructed of the refractory, molybdenum. To protect the molybdenum from attack by the dissolved oxygen gas in the cooling water, the dissolved oxygen is significantly lowered. The ion source specification requires a dissolved oxygen gas content of 10 ppb or less in the cooling water. The rigorous adherence to this specification has resulted in no degradation due to corrosion in the molybdenum grids.

Chemical treatment of the water in the four cooling towers is specified to be consistent with good industrial practice.

CONDITIONING AND QUALITY CONTROL

A. *Deionized water*

Deionization of the DIII–D cooling water is accomplished with mixed-bed ion exchangers. Mixed-bed arrangements consist of an intimate mixture of anion and cation exchange resins.

The cation exchange resin used at DIII–D is classified as a strong acid cation exchanger with great affinity for divalent ions, e.g., calcium and magnesium which are extremely troublesome as scale formers. The anion exchange resin is classified as a strong base exchanger; very effective for removing highly ionized anions such as sulfates, chlorides and carbonates. This resin is also desirable for it's efficiency in removing weakly ionized silica; another bad actor in scale formation. The porous structure of this resin makes it a good absorber and remover of organic material. Demineralizer beds though less costly, do not have the efficiency of the mixed-bed ion exchangers.

Until late 1991, the DIII–D cooling water conductivity was maintained by routing the re-circulated cooling water through the ion exchangers as required. In early 1992, it was determined by the supplier that these ion exchangers could process only potable water in order to comply with local water quality regulations. That is, during re-generation of the deionizers, the suppliers found that they were expelling too high a concentration of copper ions in the water to the sewer system when the deionizers were used for processing other than potable water.

After investigating several alternatives, a cost effective solution was implemented which utilizes a reverse osmosis filtration system with the ion exchangers for make-up water. This highly deionized make-up water is then added in concert with the draining of a small amount of water from the circulating cooling system. The end result is that the copper ion concentration released to the sewer system from both the reverse osmosis unit and the water drained from the cooling system is very dilute and meets government mandates. This entire program including process and controls has been previously discussed [1].

In system 2 above, cooling water for the Neutral beam ion sources, dissolved oxygen gas is removed from the water by chemical scavenging. Sodium sulfite is the reducing agent used. The process is accomplished with Purolite's base product, A-300, a strongly basic gel anion exchange resin. These ion exchanger beds are received from the supplier as A-310, a special regeneration to optimize sulfite capacity.

All three deionized cooling water systems have 150 micron strainers at the inlets of the pumps. Essentially, that means there is a very high probability that the 15,000 gpm of deionized cooling water entering the machine building has no particulate matter larger than about 6 mils, which is approximately twice the nominal diameter of human hair.

Additionally, five micron, 200 gpm cartridge filters are located at the inlet of the long pulse ion sources of each Neutral beam. The cooling water for the remainder of the beamline components is processed with 75 micron cartridge filters.

COOLING TOWERS AND CHILLERS

Chemical analysis is performed daily on the water in the DIII–D cooling towers.

Scale prevention and corrosion protection of both ferrous and nonferrous surfaces cooled by tower water are accomplished with a single product containing polyacrylamide for sludge dispersion; organo-phosphonate to inhibit corrosion; sodium molybdate a ferrous specific metal corrosion inhibitor; and tolytriazole, a copper specific corrosion inhibitor. This product has been accepted as "environmentally safe".

Two non-oxidizing biocides are routinely used in the towers and are rotated monthly for optimum efficiency. These biocides: polymeric quaternary ammonium and organo-sulfur compounds have proved effective in controlling the growth of algae, bacteria and fungi as well as slime-forming bacteria and fungi in heat exchangers.

Conductivity in each of the deionized cooling water systems is automatically controlled by a Rosemount Analytical Inc., microprocessor based, "Solucomp" conductivity analyzer. Each conductivity analyzer receives a signal from two cells. The first cell is located in the storage/surge tank for overall system control and brings the ion exchangers on line as required. The second cell is located in the outlet piping of the ion exchangers and gives an alarm when the exchangers are depleted and need to be replaced. Comparative conductivity measurements are made with a Myron Company, hand held conductivity meter.

Dissolved oxygen gas in the deionized, cooling water of System 2 is automatically controlled and read with a Beckman Industrial, Model 7001 Oxygen Monitor. This monitor has been in service for over ten years but is still an extremely reliable and accurate, on-line instrument for measurements in the parts-per-billion range. Comparative dissolved oxygen gas measurements are obtained with Chemetrics, "Chemets" colorimetric analysis.

PROCESS INSTRUMENTATION

Conductivity in each of the deionized cooling water systems is automatically controlled by a Rosemount Analytical Inc., microprocessor based, “Solucomp” conductivity analyzer. Each conductivity analyzer receives a signal from two cells. The first cell is located in the storage/surge tank for overall system control and the second cell is in the outlet piping from the two banks of ion exchangers. This second cell signals when one bank of exchangers is depleted and the need to switch banks and replace exhausted beds. Comparative conductivity measurements are made with a Myron Company, hand held conductivity meter.

Dissolved oxygen gas in the deionized, cooling water of system (2) is automatically controlled and read with a Beckman Industrial, Model 7001 Oxygen Monitor. This monitor has been in service for over ten years but is still an extremely reliable and accurate, on-line instrument for measurements in the parts-per-billion range. Comparative dissolved oxygen gas measurements are obtained with Chemetrics, “Chemets” colorimetric analysis.

COOLING WATER CONDITIONING COSTS

At DIII–D, the leasing of the mixed-bed ion exchangers, regeneration of the mixed-beds and cooling tower water treatment chemicals are procured by competitive bid. No ion exchanger beds are regenerated on site.

For the past few years, the average annual cost to provide deionized cooling water for the plant is approximately $18,000. This cost includes lease of the beds and resin regeneration.

Average annual cost for the lease of the oxygen scavenging beds and resin exchanges is $4,000.

Currently, the annual cost for chemicals, including scale/ corrosion inhibitors and biocides, for the cooling towers water treatment is approximately $40,000.

GOVERNMENT REGULATIONS

DIII–D has demonstrated an effective means to meet their cooling water requirements and be in compliance with government regulations: (1) in the handling and disposal of copper ion; (2) in the handling and disposal of treated water and (3) in the handling and use of environmentally safe, water treatment chemicals.

The current DIII–D cooling water conditioning program discussed above is consistent with the San Diego Water Utilities' Industrial Waste Program and in addition is readily manageable and economical to operate.

REFERENCES

[1] Gootgeld, A.M., "Impact of environmental regulations on control of copper ion concentration in the DIII–D cooling water," in Proc. 15th Symp. on Fusion Engineering, p. 958, 1993.
[2] “Guidance For Industrial Users.” San Diego, CA: Metropolitan Industrial Waste Program, US-1627 (Rev. 4/90), 1990.