Role of Water Treatment in Corrosion Control of ITER Cooling Water System

Frances Cutler, Consultant

Andrei Petrov, Engineer, US-ITER

ABSTRACT

ITER is an experimental Tokamak fusion reactor that has been developed in collaboration with seven international partners, including the United States. The ITER cooling water system (CWS) is an integral part of the Tokamak reactor complex and is designed to perform the following key functions:

* Remove heat from in-vessel components during the fusion process
* Control the fluid thermodynamic parameters
* Maintain water chemistry within acceptable limits

To perform these functions safely and reliably, the CWS requires an adequate supply of high-quality demineralized and deaerated water since corrosion mechanisms are frequently related to water purity. It should also be noted that the chemistry environment is an important factor in certain fatigue failure mechanisms. Unsatisfactory water chemistry can also lead to deposition of solids that could permit underdeposit corrosion and increase the level of activated corrosion products formed. This paper discusses the influence of makeup water purity on cooling water chemistry and the criteria for makeup water specifications. Design features of the initial water treatment facility, alternative methods for supplying makeup water, and problems and issues of concern relative to the makeup water treatment system are summarized.

BACKGROUND

Tokamak operation and maintenance requires draining and refilling of the cooling water system as well as additional makeup water to compensate for losses due to leakage. Water quality requirements for the Tokamak cooling water system have been studied by experts in a number of fields such as metallurgy, radiation, corrosion, and water treatment. The resulting consensus is that strict control of water quality with respect to oxygen and dissolved solids such as chloride and sulfate is required to minimize corrosion and deposition. Consequently, the initial cooling water specifications were re-examined and were subsequently made more stringent resulting in re-evaluation of the design for the makeup water storage and treatment systems.

RELATIONSHIP BETWEEN MAKEUP WATER QUALITY AND THE GENERATION AND DEPOSITION OF CORROSION PRODUCTS

A number of failure mechanisms and other availability problems have been identified as being directly influenced by the generation, transport, and deposition of corrosion products. In a radioactive environment, it is even more critical to minimize the generation of activated corrosion products. Tight control over the purity of the cooling water and selection of the appropriate metallurgy are essential to maintaining the appropriate environment to minimize corrosion.

Following proper pre-operational cleaning and start up of the system, causes of chemistry excursions in the cooling water of the Tokamak would primarily result from contamination of the makeup water or the storage tanks within the system. The actual types of contamination associated with makeup treatment systems will vary depending on the source water composition and makeup system design, but typically include sodium, chloride, sulfate, silica, oxygen, carbon dioxide and organic carbon. Chloride and oxygen are the constituents most frequently associated with inducing corrosion while sulfate and silica are associated with deposition.

The magnitude of the influence of makeup water quality on cooling water chemistry depends on a number of factors:

* Makeup rate
* System water quality requirements
* Anticipated number of start-ups
* Presence or absence of in-line polishers in the cooling water system

Criteria for Makeup Water Specifications

Makeup Rate In systems where the rate of makeup is less than 1% and concentration within the system is not a problem, the quality of the makeup water may be less stringent than the water chemistry requirements for the operating system. For example, if the chloride limit for a system with a makeup rate of <1% is 0.1 ng/kg (ppb), the chloride limit for the makeup treatment plant may be between 1-10 ppb although an upper limit close to 10 ppb would provide no safety margin.

Cooling water systems are rarely free of areas where concentration of contaminants can occur. For this reason, even a system with less than 1% makeup should consider limits no more than 50% of the maximum allowable to meet in service requirements. The higher the rate of makeup to the system, the closer the limit on makeup water quality should be to in-service water quality requirements.

System Water Quality Requirements In-service system water quality requirements determine the quality of the makeup water that should be sent to the system. In general, in-line polishers within the cooling water system should not be relied upon to treat the makeup water, but should be used as “insurance” in the event of an excursion in quality from the makeup water treatment system.

Anticipated Number of Startups For system startup, the makeup water quality should meet in-service water quality requirements unless there are in-line polishers that can be used to treat the makeup water. However, even in this case, the quality of the makeup water should be sufficiently close to the required quality so that the polishers are not exhausted prematurely. The greater the number of anticipated startups, the more important it is to have the quality of treated makeup water meet in-service requirements.

Experimental systems such as the Tokamak are likely to have frequent startups, some of which may follow extended outages. In this type of circumstance, sufficient demineralized water storage for preliminary fill up and drains would reduce the demand for high purity water required for the final fill.

Presence of In-Line Polishers The presence of full in-line condensate polishers should not be used as justification for relaxing makeup water quality requirements. Since the current design of polishers for the Tokamak cooling water system is for ~1% polishing, it is even more important <u>not</u> to relax makeup water quality requirements or rely upon in-service polishing.

MAKEUP WATER TREATMENT SYSTEM

Design Features of the Initial Water Treatment Facility

The design features of the initial water treatment system were for an ion exchange demineralizer with decarbonator. Interim modifications included reductions in makeup demineralizer flow and greater reliance on tanker delivered water. It is believed that there are a number of preferable demineralizer designs that would better meet the needs of the Tokamak cooling water system.

Alternative Methods for Supplying Makeup Water

A number of alternative makeup demineralizer designs are available that would provide both the quality and quantity of high purity makeup water required for the Tokamak. These include, but are not limited to the designs summarized below:

* Pretreatment, 3 or 4 bed ion-exchange demineralizer, vacuum degasifier, and demineralized water storage

* Pretreatment, reverse osmosis (RO), polishing mixed-bed ion exchange, vacuum degasifier, and demineralized water storage

* Pretreatment, RO, electrodeionization, vacuum degasifier, and demineralized water storage

* Pretreatment, double pass RO, electrodeionization or ion exchange for polishing RO effluent, primary demineralized water storage prior to vacuum degasification (also able to accept water from tanker and to recirculate through polishing demineralizer), polished demineralized water storage in “protected” storage tank (nitrogen blanket, nitrogen sparging, floating roof, or combination of protection)

A major advantage to membrane systems is continuous operation without the need for regeneration and storage of hazardous regenerant chemicals (sodium hydroxide and either sulfuric or hydrochloric acid). Membrane systems are also effective for organics removal. The disadvantages of membrane systems include greater complexity in operation compared to ion exchange systems, requirement for good pretreatment and greater sensitivity to fouling. Membrane systems also prefer continuous rather than intermittent operation. Ion exchange systems better tolerate intermittent operation.

Consequently, membrane systems are often designed with lower flow rates and greater storage capacity compared to all ion exchange systems.

Additional alternatives to an on-site, Project owned and operated makeup demineralizer system include a vendor operated system, a vendor owned and operated system that may be located on-site or just off-site with on-site demineralized water storage and a vendor owned and operated system that also includes demineralized water storage. With vendor supplied demineralized makeup water, the details of demineralizer design may be left to the vendor as long as demineralized water quality and flow requirements are guaranteed. Whichever option is chosen, sufficient on-site demineralized water storage should not be overlooked.