ICRN 26

IAPWS Certified Research Need - ICRN

Behavior of Aluminum in the Steam Water Cycle of Power Plants

Aluminum is of interest for use in heat exchangers and for some structural components in a steam water cycle. Generally, corrosion process is so limited that it does not challenge component integrity, but the corrosion products may transport and deposit, causing problems like deterioration of flow, blockages, efficiency changes and loss of heat transfer. Presently there is insufficient knowledge to define the cycle chemistry conditions under which aluminum can be used in a steam / water cycle.

IAPWS recognizes that further research work is needed to improve knowledge in this field and has prepared this document to assist potential investigators to obtain sponsorship. Priority areas for research are:

- Definition of the aluminum species in the steam/water cycle of a power plant with aluminum components
- Interaction with water treatment chemicals, corrosion products and impurities
- Solubility in condensate, feedwater, boiler water and steam
- Volatility in boiler water and steam

Although encouraging this work, IAPWS is not generally able to provide financial support. The IAPWS contact can provide any further development information and will liaise between research groups

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Behavior of Aluminum in the Steam Water Cycle of Power Plants

Background

Due to its high thermal conductivity and relatively good corrosion resistance in high purity water, aluminum is of interest for use in heat exchangers and for some structural components in a steam water cycle [1].

Aluminum, however, will corrode in alkaline (as well as in acidic) water [2] and consequently there are limits to its usefulness. In certain low-temperature applications in systems associated with the steam water cycle as well as in cooling loops it is successfully employed up to a pH of 8.5, exceptionally up to 9.0 [3]. Generally, the corrosion process under these conditions is so small that it does not challenge component integrity, but the corrosion products that are released to the water may deposit at other points of the system and cause problems such as deterioration of flow, blockages, efficiency changes and loss of heat transfer.

It is known that aluminum oxide / hydroxide has a significant volatility in steam [4] and thus may transport into the steam turbine and deposit on the blade surfaces as the steam expands. Aluminum based oxides / hydroxides have low solubility in common chemical cleaning solutions and are therefore hard to remove by chemical means which would be the only option for removing water-side deposits from boiler tubes. These concerns are supported by experience of steam turbine fouling in plants with aluminum heat exchanger for steam condensation (dry cooling tower), in plants with aluminum used for water storage tanks, and in plants using cooling water with high levels of aluminum, as exemplified in reference [5].

Presently there is insufficient knowledge to define thoroughly the cycle chemistry limits under which aluminum can be used in a steam / water cycle. What is known, are cases with good and with bad experience, but not necessarily the related criteria that separate them. IAPWS recently published a Cycle Chemistry Guidance Document [6] that includes preliminary guidance for plants with aluminum cooling towers.

Research Needs

Research questions to be answered

Laboratory investigations

1. Quantitative description of the corrosion of aluminum under oxygenated low pH conditions which exist in the condensate of power plants, with particular emphasis on those conditions that preferentially form aluminum oxide.

2. Definition of aluminum species that are present:
   - form: dissolved, colloidal, particulate
   - structure: identification of the molecular species in each form
   Information on these items are available from geothermal research [7] but need to be verified for power plant conditions, which may be different for condensate, feedwater, boiler water and steam.

3. Interaction of the species with ion exchange resin: retention efficiency in mixed beds, resin capacity, regenerability of the resin, effectiveness when operated in NH_4^+/OH^- form, effectiveness of powdered resin precoat filters, and other filtering media if the transported products are particulate.

4. Volatility of species from boiler water into steam (partitioning). What fraction of species will carry over into the steam?

5. Solubility of species in steam to allow calculation of what fraction of species will deposit in the steam turbine? Here it is important to determine the solubility as a function of steam density.

6. Influence on above items of the interaction of these species with:
   - water treatment chemicals (ammonia, sodium hydroxide, sodium phosphates)
   - corrosion products (iron-hydroxides and -oxides, traces of copper from certain steels, etc.)
   - other impurities (e.g., silica, regeneration media, salts, hardness, dirt, etc.)

7. Analytical methods for aluminum in water samples with at least 1 ppb accuracy and considering the various possible species

Plant experience investigations and engineering studies:

8. Total release rate of aluminum from dry cooling systems with an aluminum heat exchanger, in dependence of condensate pH and possibly other parameters. Reasonable information is already available [3], but data from more power plants would be useful for verification.

9. Solubility limits of species in boiler water. What fraction of species will deposit on the boiler tubes, what fraction is removed by blowdown?

10. Case studies with deposits of aluminum species in the steam water cycle, correlated with the respective cycle chemistry.

11. Evaluation of the cycle with respect to materials/chemistry requirements when operating with a feedwater pH range well below the normal 9.0-9.6 range. The pH in two-phase regions could be even lower by as much as 0.2-0.3 units of the feedwater pH.

Anticipated output

The investigations shall provide background information to ultimately the following questions:

1. Definition of water and steam purity limits for aluminum species (dissolved, particulate) in feedwater, boiler water and steam, limits in condensate pH, restrictions regarding water treatment chemicals, corrosion products and other impurities.
2. Definition of necessity of condensate polishers and/or filtering systems. Definition of optimum parameters for condensate polisher performance. Clarification if resin operation in the NH_4^+/OH^- form is functional, and if powdered resin filters are a valid and useful option.
3. Clarification of the usefulness of boiler blowdown to influence deposition of Al species on the boiler tubes and in the turbine.
4. Relation of aluminum concentration between feedwater, boiler water and steam.
5. Analysis of cost to benefit of the use of aluminum in relation the necessary adaptations of materials, cycle chemistry and design in the rest of the steam / water cycle.
6. Methods for removal: chemical cleaning (off-line, on-line), mechanical cleaning etc. Choice of water chemistry to transform aluminum species so that removal methods are more effective.
7. Development of suitable methods for the determination of all aluminum species in the required concentration range. There may be the possibility of coordination and collaboration with the separate ICRN 19 on "Improved Coolant Sampling and Analysis of Low Concentration Metals".

Beneficiaries

- Plant and component manufacturers
- Utilities and supporting organizations

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[6] IAPWS Technical Guidance Document: Volatile treatments for the steam-water circuits of fossil and combined cycle/HRSG power plants (2010). Available from www.iapws.org.

[7] Information by D. Palmer on various research projects at ORNL.