ASHRAE WORK STATEMENT
TECHNICAL COMMITTEE 8.5
May 2, 2000

A. TITLE

Water-Side Fouling Inside Smooth and Augmented Copper Alloy Condenser Tubes in Cooling Tower Water Applications

B. BACKGROUND

Water-side fouling is an operational problem and must be controlled to maintain design performance for a condenser. In addition, fouling on augmented tubes imposes an additional uncertainty and may negate the superior thermal performance (Kim and Webb, 1989; Chamra and Webb, 1993). General guidelines for the effects of fouling on heat exchanger design do exist (Starner, 1976); however, it is essential to understand the dynamic nature of the fouling process for the mitigation of fouling. It is in the best interest of ASHRAE members to develop a database for water-side fouling inside smooth and augmented condenser tubes.

Two previous ASHRAE projects performed in the area of water-side fouling are worthy of note. RP-106 (Knudsen, 1980) focused on cooling-water fouling (condenser fouling associated with water circulated through a cooling tower), while RP-560 (Haider et al., 1991; Haider et al., 1992) focused on evaporator chilled water fouling. Notable in RP-106 was the observation that a 0.00025 hr-ft^2-°F/Btu fouling factor is not representative of clean tube performance. After completion of this work, ARI Standard 550 was modified, changing the clean tube fouling factor from a value of 0.00025 to 0.0 hr-ft^2-°F/Btu. RP-560 identified that fouling in evaporator chilled water systems, which are almost exclusively closed, is virtually nonexistent. As was the case with RP-106, RP-560 led to a change in ARI-550. The current release of ARI-550, ARI-550/590-98, uses a fouling factor of 0.0001 hr-ft^2-°F/Btu for the evaporator chilled water loop.

Contrary to chilled water results, cooling-water fouling is commonly observed for most applications (Rabas et al., 1991). The extent of the fouling problem depends upon the water quality, operating conditions, monitoring system, and maintenance practice. In addition, seasonal effects on the fouling rate should be considered in the design and operation of these condensers. For example, the condenser design should provide an adequate capacity at design conditions during the summer months when higher cooling capacity is required.

There are six possible mechanisms contributing to cooling-water fouling: 1) scaling (otherwise referred to as precipitation fouling), 2) particulate, 3) chemical reaction, 4) corrosion, 5) biofouling, and 6) freezing fouling (Epstein, 1979). Of these separate mechanisms, only particulate fouling has been relatively well studied (Kim and Webb, 1989; Somerscales et al., 1991; Kim and Webb, 1991; Haider et al.,1992; Chamra and Webb, 1993; Chamra and Webb, 1994; Webb and Li, 1999), and nonetheless, for this mode of fouling there are relatively little data available for those helical water-side geometries currently being applied in condensers in the HVAC field. The interactive effect of the above fouling mechanisms is a key technical issue that does not readily allow for extrapolation of laboratory data to field applications or from one site to another without meticulous characterization of the water quality; although, typical systems are treated with biocides and corrosion inhibitors greatly reducing the impact of these two fouling mechanisms upon the overall fouling rate. Scaling inhibitors are typically included in corrosion inhibitor formulations, but scaling is nonetheless one of the principal fouling mechanisms experienced in the field.

A recently completed research program (Webb and Li, 1999; Li and Webb, 1999) focused on precipitation and particulate fouling modes. Test facility water was treated with a corrosion inhibitor and a biocide, hence nullifying biofouling and corrosion mechanisms. Webb and Li determined significant precipitation and particulate fouling occurs for tubes having helical enhancements possessing a high lead angle and many internal elements along the internal diameter, i.e., structures commensurate with the mainstream of condenser tubing being applied today by US HVAC manufactures. However, Webb and Li's tests were carried out using water velocities lower than that typically found in application, and the water chemistry used in this program may or may not represent typical field applications. To establish what water chemistry to use for test in this program, water samples were collected from a variety of sites in the US and Canada; however, unlike RP-560 where 71 samples were analyzed, only 26 samples were evaluated in this cooling-water related project. It is possible that a larger water chemistry database may provide additional insight.

C. JUSTIFICATION OF NEED

Cooling tower water is commonly used for heat rejection. Depending upon seasonal variations and cooling tower location, water quality varies from site to site. Due to a lack of prediction capabilities, fouling characteristics cannot be easily generalized for all applications. A comprehensive approach is required to characterize the propensity for fouling in cooling-water applications. The purpose of this ASHRAE project is to develop a database for the characterization of fouling on smooth and augmented tubes. And more specifically, a key element of the proposed work is to confirm or disprove the tendency of enhanced water-side condenser tubing to suffer fouling rates greater than one would predict based upon case histories and modern design practices, most of which were developed considering water-side enhancements no longer applied today in new equipment production. Whether fouling rates prescribed by ARI-550/590-98 do, in fact, accurately portray fouling rates experienced by cooling machinery (systems equipped with shell-and-tube condensers tubed with enhanced technical tube) in the field is a subject under debate within the HVAC industry today. This ASHRAE project will either disprove or support the ARI prescribed condenser fouling factor of 0.00025 hr-ft^2-°F/Btu.

D. OBJECTIVES

a. Development of a water quality database for cooling-tower water applications.

b. Correlation of the fouling data with water quality.

c. Experimental determination of fouling on smooth and augmented tubes by directly using or simulating cooling-tower water.

E. SCOPE

Phase I – Literature Search

This study will focus on those two fouling modes deemed most prominent in cooling-water systems: scaling and particulate. The bidder will conduct a rigorous literature search focusing on scaling and particulate fouling. Special attention should be given to the correlation of fouling data with water quality and experimental methods for simulating scaling and particulate fouling. An executive summary covering the Phase I literature review shall be presented to the Project Monitoring Subcommittee prior to commencing later segments of the research program.

Phase II – Database Development

A database will be developed for cooling tower water using available open literature sources and a survey method similar to that used in project RP-560. In order to minimize analytical work, the number of parameters to be determined should be closely related to the fouling process as shown below:

Scaling: Total hardness, calcium hardness, magnesium hardness, phosphate, silica, alkalinity, pH, water and wall temperatures, velocity.

Particulate: Suspended solids, particle size distribution, velocity, characterization of particulate (i.e., silt, sand, clay, debris).

Biofouling: Total organic carbon (TOC), total organic nitrogen (TON), particulate organic carbon (POC), ammonia, pH, water and refrigerant saturation temperatures, water velocity, and dissolved oxygen.

Corrosion: Tube material, oxygen concentration, salinity, presence of certain metals for a given tube material (e.g. iron for aluminum tubes), presence of sulfate reducing and iron depositing organisms.

Scaling and particulate related data will be required to determine fouling constituent levels in Phase III of the research program. Biofouling and corrosion related data will be collected for the completeness of the database, which may be used in a follow-up research program focusing on one or both of these two fouling processes.

Phase III – Scaling and Particulate Fouling Experimental Program

Augmented tubes will be tested in this phase of the work in addition to determining baseline plain-tube performance. Whether the test apparatus will be operated in a laboratory setting or coupled in parallel with the condenser of an actual chiller system, which has been done in some previous studies, is open to the discretion of the bidder. Submitted proposals should build a case for one path versus the other.

All tests shall be carried out using a biocide and corrosion inhibitor so that observed fouling is a result of scaling and particulate fouling mechanisms. The Project Monitoring Subcommittee shall approve the specific biocide and corrosion inhibitor to be applied.

Experimental measurements taken must be statistically valid. Experimental uncertainty for fouling resistance measurements shall be no more than 25% of the ARI-550/590-98 0.00025 hr-ft^2-°F/Btu fouling factor. Wall temperature measurements may be used for the purpose of determining fouling resistance, but preference will be given to those bidders proposing *Log Mean Temperature Difference* (LMTD) based measurements, due to the difficulties associated with attaching wall mounted thermocouples to the surface of modern enhanced condenser tubing.

The same experimental series will be performed in a repeating manner to accomplish the following goals for all geometries in the evaluation: (1) the first test series will be performed using a water chemistry deemed representative of typical field conditions (the mean) defined in terms of fouling constituents; (2) the second series will be performed using an extreme case of fouling constituents; and (3) the third series will evaluate a perceived benign fouling constituent case. Through this approach not only nominal and extreme water chemistry fouling rates will be evaluated, but some effort will also be made to identify threshold water constituent levels. If the same tubes are used throughout this series of repetitive experiments, the bidder shall demonstrate that the cleaning method used to restore tubes to “clean” condition actually achieves this end.

Testing will be done to determine the influence of internal geometry upon scaling and particulate fouling rates. In the study recently completed by Webb and Li (1999), eight enhanced geometries were evaluated, as an example. Augmented tubes will be selected by a diverse Project Monitoring Subcommittee. The geometry matrix shall consist of no more than eight enhanced tubes plus one smooth tube. A parallel flow scheme for the test sections (tubes) within the test apparatus is preferred.

The fouling apparatus will incorporate a limited number of test coupons that can be withdrawn at a predetermined schedule of the bidder's design. Deposits accumulated on these test coupons will be analyzed for elements (calcium, magnesium, silica, phosphorus, etc.) present and organic material (loss on ignition), using light or scanning electron microscopy to describe the material present. Cycles of concentration, the ratio of chloride concentration in the recirculating water to chloride concentration in the make up water, shall be monitored during each test within this experimental program.

The influence of water velocity shall be evaluated by experiment. Typical and extreme water velocities experienced in the field will be known, resulting from Phase II activities. Mean water velocity plus extreme high and low water velocity cases shall be considered in the design of the experimental matrix.

Velocity of the water shall be held at a constant value for the duration of a given test; i.e., different water velocities described in paragraph above imply separate tests. If the test apparatus is coupled in parallel with the condenser of an actual chiller system, there is the concern that holding a constant water velocity may be difficult to achieve. It may be necessary to incorporate a booster pump into the system to ensure that a constant water flowrate is supplied to the test apparatus, when coupling the test apparatus to a chiller system. Constant water flowrate shall be verified through experimental measurement, using a measurement device which is not susceptible to erroneous readings in a fouling prone environment.

It is desirable that test data be taken using water temperatures representative of ARI-550/590-98 rating conditions. If the test apparatus is built and operated as a stand alone facility, an entering water temperature of 85°F to the test tubes shall be maintained. If the test apparatus is coupled to an actual chiller system, it will not likely be possible to control inlet water temperature to the test tubes, so some advantage exists for an uncoupled bench test facility in this regard. It should be clarified that quantifying the effect of bulk water temperature upon fouling rate is not within the scope of the proposed work. Rather, this project is intended to establish relevance of the ARI-550/590-98 0.00025 hr-ft^2-°F/Btu fouling factor, and this relevance may be investigated while using only a single inlet water temperature.

Heat flux is known to have some influence on the rate of build up of scale (Nasrazadani, 1996). The majority of water chillers manufactured today are designed to operate with a full-load condenser heat flux in the range of 6,000 to 10,000 Btu/hr-ft^2, depending upon unit efficiency. Given this, if the test apparatus is built and operated as a stand alone facility, it would be desirable to conduct fouling tests using a nominal heat flux of approximately 10,000 Btu/hr-ft^2, achieved via controlling the refrigerant saturation temperature. Some consideration could be given to establishing threshold heat flux levels for a given fouling constituent / water velocity / surface geometry case. If the test apparatus is to be coupled with an actual chiller system, heat flux across the test tube(s) will presumably be similar to that experienced by the primary heat transfer surface within the condensing heat exchanger. Hence, selecting a dated chiller system (more than 5 years old) is not desirable considering that heat flux has declined significantly over the past 20 to 30 years as unit efficiencies have been improved.

F. DELIVERABLES

The following are considered the minimum deliverables expected of the researcher:

a. Progress and Financial Reports shall be made to the Society through its Manager of Research at quarterly intervals.

b. The Principal Investigator shall report in person to the TC at the annual and winter meetings, and answer such questions regarding the research as may arise.

c. A Final Report shall be prepared and submitted to the Manager of Research by the end of the contract period covering complete details of all research carried out on the project. Unless otherwise specified, six draft copies of the final report shall be furnished for review by the Project Monitoring Subcommittee (PMS).

Following approval by the PMS and the TC, final copies of the final report will be furnished as follows:

- An Executive Summary suitable for wide distribution to the industry and to the public.
- Six bound copies.
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on 3 ½" diskette(s); one in ASCII format and one in the word processing format used to produce the report.

d. Two or more Technical Paper(s) shall be submitted in a form suitable for presentation at a Society meeting. The Paper(s) shall conform to Section 5 of the Society's "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publications Section.

e. All papers or articles submitted for inclusion in any ASHRAE publication shall be made through the Manager of Research and not the publication's editor.

A Technical Article suitable for publication in the *ASHRAE JOURNAL* may be requested by the Society. This is considered a voluntary submission and not a deliverable.

G. LEVEL OF EFFORT

It is anticipated that this project will be completed over a 36 month period at a level of effort of 6 person months for the principal investigator and 36 person months for the assistant. A total cost of $175,000 is anticipated.

H. ADDITIONAL INFORMATION FOR BIDDERS

Size of the experimental matrix described in this work statement is significant. Testing up to nine sample geometries (including the smooth tube) may be required using three fouling constituent cases (see Phase III, paragraph 4) and three water velocities. In addition, duration of test for a parametric combination could be as much as one year, for some cases. Most commercial equipment does undergo mechanical and / or chemical cleaning on an annual basis, hence the Project Monitoring Subcommittee will likely agree to a 12 month maximum duration of test, per parametric combination.

Thorough design of the experimental text matrix is extremely important to accomplish scope of the work within the proposed time period of 36 months. A facility capable of running multiple tube samples in parallel for a given constituent fouling case is a necessity for this project. An asymmetric test matrix is suggested by the authors.

TC 3.6 sponsored RP-765, "Laboratory evaluations of ozone as a scale inhibitor for use in open recirculating cooling systems." One technical paper was published from this work (Nasrazadani, 1996). In this project, a relatively large heat flux was required to generate appreciable scale deposits. This paper should be reviewed by bidders.

Biofouling is not addressed by the proposed research project. A follow-up project may be suggested by the authors at a later date to specifically investigate microbes and biofilm formation.

A copy of ARI-550/590-98 is available for free download through ARI's web site (www.ari.org).

I. REFERENCES

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J. AUTHORS

This work statement has been prepared by Shane Moeykens, Amanda Meitz, and Keith Starner.