WORK STATEMENT 1345-WS

Sponsored by: TC8.5 Liquid-to-Refrigerant Heat Transfer
Co-sponsor: Air-Conditioning and Refrigeration Technology Institute (ARTI)

TITLE: Waterside Fouling Performance of Brazed-Plate Type Condensers in Cooling Tower Applications.

EXECUTIVE SUMMARY

Brazed plate heat exchangers are compact alternatives to shell-and-tube (S/T) type heat exchangers in many water-to-refrigerant applications. Brazed-plate condensers are particularly useful for providing: reduced chiller package sizes, notably smaller refrigerant charges, and economical high pressure designs – units are available for service in excess of 650 psi for R-410A applications. Unfortunately, since brazed plate heat exchangers cannot be disassembled for mechanical cleaning and their fouling characteristics have not been studied extensively, the industry's use of this compact technology has been limited primarily to clean service (closed loop) only, in air-conditioning and refrigeration (AC&R) systems and closed-loop ammonia refrigeration systems. Fouling information is available for other heat exchanger configurations, such as the Shell-and-Tube (S/T) type and the gasketed plate type. Several fouling studies have been presented in the open literature for the gasketed plate type heat exchangers because this type can be disassembled for cleaning, however the studies were performed with fluids and conditions normal for process industries, therefore the results are not generally applicable to AC&R applications nor to brazed plate heat exchangers.

APPLICABILITY TO ASHRAE STRATEGIC PLAN

Information generated by this project will assist HVAC equipment manufacturers and their customers to design and select cost-effective equipment with improved energy efficiencies (Goal D1 of Section D - Equipment, Components and Materials).

APPLICATION OF RESULTS

The results of this study will enhance the information provided in the *ASHRAE Handbook, HVAC Systems & Equipment Volume, Chapter 35 – Condensers*. The results may also be incorporated into *ARI Guideline E – Fouling Factors: A Survey of Their Application in Today's Air-Conditioning and Refrigeration Industry.* System and chiller package engineers will also benefit by being able to apply the results of this project in their designs.

STATE-OF-THE-ART (BACKGROUND)

The primary source of information on fouling in heat exchangers used in the air-conditioning and refrigeration industries has been generated through ASHRAE research:

GRP-106 – Water Side Fouling Resistance Inside Condenser Tubes
J.E. Knudsen, Oregon State University

RP-560 – Evaluation of Water-side Fouling Resistance in Flooded Evaporators of Water Chilling Machines
R. L. Webb, Pennsylvania State University

RP-1205 – Waterside Fouling Inside Smooth and Augmented Copper-Alloy Condenser Tubes in Cooling Tower Water Applications (summary of work done, project not completed)
L. M. Chamra, Mississippi State University

The information developed through GRP-106 and RP-560 has been incorporated into *ARI Guideline E – Fouling Factors: A Survey of Their Application in Today's Air-Conditioning and Refrigeration Industry*. Unfortunately, RP-1205 did not produce any useful data on fouling in internally enhanced tubes. ARI Guideline E is the primary source of fouling information used by OEM manufacturers, system designers, and stationary and building service engineers for the selection of equipment and development of proper system maintenance programs. To date, there is no information included in Guideline E for plate-type heat exchangers because a comprehensive study has not been documented in the open literature. Thus the users of this type of equipment have typically applied the same fouling factors that are recommended for tube-type heat exchangers in ARI Guideline E or those recommended by the Tubular Exchanger Manufacturers' Association (TEMA) which can be excessively high for air-conditioning applications, while others have used manufacturers' recommendations that may or may not agree with the values given in Guideline E. An inappropriate heat exchanger selection can increase first-costs, refrigerant volumes, and fouling rates (by decreasing the fluid velocity) while inappropriate maintenance programs can reduce system efficiencies and equipment operational life. Therefore a significant need exists for unified industry recommendations for fouling factors to be applied to air-conditioning and refrigeration equipment for plate-type condensers.

ADVANCEMENT TO THE STATE-OF-THE-ART

The fouling characteristics and cleanability of brazed-plate heat exchangers are not generally known - only basic guidelines for chemical cleaning are available from the brazed plate heat exchanger manufacturers. However the effectiveness of this cleaning method is undocumented for AC&R applications and in some cases the cleaning is not possible because of installation constraints. Thus, for critical service applications, brazed-plate heat exchangers are less-likely to be specified than other heat exchangers for which the fouling characteristics are better known. For high-pressure refrigerant applications, such as with R-410A which is gaining widespread industry acceptance, brazed-plate heat exchangers generally offer lower first-costs than other heat exchanger types, require smaller refrigerant charges, and reduce overall system footprints than tubular types. This is because the internal structural design of the brazed-plate type heat exchangers allows for the use of thinner metal sections than in tubular heat exchangers for high pressure designs. The resulting smaller system package sizes then require less mechanical room floor space and offer reduced floor and roof loadings in comparison to system packages that utilize tubular type heat exchangers for these applications. Successful determination of the fouling characteristics of brazed plate heat exchangers and the subsequent incorporation of the results into the ASHRAE Handbook and ARI Guideline E will allow AC&R system designers to properly select these heat exchangers for use in less-than-ideal fluid situations and to provide proper maintenance recommendations. This will lead to more flexibility in system design with high-pressure refrigerants, lower overall unit first cost and reduced condenser refrigerant operating charges on the order of 50%.

JUSTIFICATION AND VALUE TO ASHRAE

The worldwide market for brazed-plate heat exchangers is in excess of $350M and the North American market for these products is estimated to be in excess of $30M, with the majority being used in HVAC&R applications. Thus the results from this project will impact a large, growing part of the industry and have immediate usefulness to original equipment manufacturers, consulting engineers, end-users, and anyone else involved in the design and selection of system components. The compact packages that use these condensers will allow for greater utilization of floor space while requiring notably smaller refrigerant charges. Also, service engineers and technicians will be able to confidently develop maintenance schedules to keep the cooling packages operating at peak efficiencies with maximized system life.

OBJECTIVE

a. Quantify the difference (if any) in fouling rates between brazed plate heat exchangers and tube types.

b. Experimental determination of fouling on brazed plate heat exchangers using simulated cooling tower water.

c. Correlation of fouling data with water quality for brazed plate heat exchangers.

d. Correlation of fouling data with plate aspect ratio, chevron design & flux within the scope of this project.

e. Update information contained in *ASHRAE Handbook, HVAC Systems & Equipment Volume, Chapter 35 – Condensers* and possibly *ARI Guideline E– Fouling Factors: A Survey of Their Application in Today's Air-Conditioning and Refrigeration Industry*.

SCOPE

Specifically, the study should include the following tasks:

1) Literature Review
    a. A comprehensive review of the literature of fouling in plate heat exchangers should be performed.
    b. The key geometric parameters that affect fouling should be identified.

2) Experimental study

a. Condensing tests shall be performed on a minimum of four (4) plate types. These plate types shall consist of 3 with similar chevron patterns and differing plate overall aspect ratio and one plate type that is the same aspect ratio as one of the first 3, but with a different chevron pattern that yields a low pressure drop.

b. Each test condenser will consist of no fewer than 6 plates to simulate typical slight variations in cooling water flow/channel that are typical in actual use.

c. The first step of the experimental study shall include submission of the test set-up design along with an appropriate uncertainty analysis and expected operating conditions to the PMS for approval prior to the start of testing of the first article. The results of the first article test shall then be examined and compared to the proposed uncertainties and discussed with the PMS for approval to proceed with further testing.

d. The condensing tests shall be performed with either a pure fluorocarbon refrigerant, such as R-22 or R-134a, or a near-azeotropic refrigerant mixture, such as R-410A. Non-azeotropic refrigerants shall not be used because the associated temperature glide may skew the results. The selection of the refrigerant must be approved by the PMS.

e. The heat flux for the condensing tests shall be in the range of 3,000 to 9,000 Btu/hr-ft^2 to represent typical air-conditioning and refrigeration conditions. Tests are to be run at two levels of flux for each fouling potential. These values are to be decided by the PI & PMS. The PMS will decide whether the flux, or water velocity, shall be held constant among plate types during each test series.

f. The three (3) fouling water qualities (low, medium, and high fouling potential) to be used are listed in Appendix A. This water chemistry is essentially the same as that specified by the PMS for ASHRAE project 1205-RP.

g. The saturated condensing temperature of the refrigerant shall be held constant for all tests 105ºF ± 1 ºF (41°C ± 0.5 ºC). Refrigerant gas discharge superheat shall be 65ºF ± 3 ºF (36°C ± 1.5 ºC) yielding a nominal gas inlet temperature of 170°F (77°C).

h. The entering water temperature for each test shall be 85°F ± 1 ºF (29°C ± 0.5 ºC) for the clean condition and the heat flux closest to nominal air conditioning conditions. For the other heat flux tests, the entering water temperature shall be selected to maintain the saturated condensing temperature of the refrigerant. The inlet water temperature can be reduced to maintain the required heat flux and saturated condensing temperature as the heat transfer surfaces foul.

i. Presentation of the data shall indicate the thermal performance, fouling rate, and water-side pressure drop of each brazed plate heat exchanger condenser plotted as a function of time such that the effects of fouling are clearly shown.

j. A test series shall be ended when it is determined that the fouling has reached an asymptotic level. This shall be by agreement with the PMS.

k. As in 1205-RP, a corrosion inhibitor and biocide should be used during testing to represent actual cooling tower water treatment.

l. The test matrix will consist of four (4) brazed plate heat exchanger designs, two (2) levels of heat flux, and three (3) water chemistries representing the three levels of fouling potential. Assuming the heat exchangers are tested simultaneously, this represents six (6) test series.

DELIVERABLES

1. Progress and Financial Reports:
   Progress and Financial Reports, in a form approved by ASHRAE, shall be made to the Society through its Manager of Research and Technical Services at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

   Additionally, the Institution's Principal Investigator shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee (TC) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

2. Final Report:
   A Final Report, in a form approved by ASHRAE, shall be prepared and submitted to the Society's Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement. Unless otherwise specified, six copies of the final report shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS).

   The Final Report shall include:
   - Detailed literature survey.
   - Appropriate results as described in the scope of this work statement.
   - Experimental uncertainty analysis.
   - Experimental data in tabular form.

   Following approval by the PMS and the TC, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:
   - An executive summary in a form suitable for wide distribution to the industry and to the public.

- Two (2) bound copies.
- One (1) unbound copy, printed on one side only, suitable for reproduction.
- Two (2) copies on disks; one (1) in PDF format and one in Microsoft Word®.

3. Technical Paper:
   One (1) or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the "ASHRAE Manuscript Central" website-based manuscript review system in a form and containing such information as designated by the Society suitable for presentation at a Society meeting. The Technical Paper(s) shall conform to the instructions posted in "Manuscript Central" for a technical paper. The technical paper title shall contain the research project number (xxx-RP) at the end of the title in parentheses, e.g., (9999-RP).

   All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

4. Data:
   Data as defined per General Condition VI, "DATA," will be maintained on file for a period of two years after receipt of final payment. Upon request, the Institution will make a copy of this data available to the Society during this period.

All documents shall be prepared using dual units; e.g., SI with rational inch-pound units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

LEVEL OF EFFORT

It is expected that this project would take 30 months to complete at an estimated cost of 175,000 USD. This would include: 6 months to complete the literature review, complete test facility modifications, and install the first test exchangers; 22 months for the testing phase; and 2 months for completion of the Final Report.

OTHER INFORMATION FOR BIDDERS

It is expected that those bidding for this project will have the capability to develop the requisite test facility and perform two-phase testing on heat exchangers operating under fouling conditions. The cost of the refrigeration equipment is not included in the estimated cost. Certain manufacturers have agreed to donate the necessary brazed plate heat exchangers.

PROPOSAL EVALUATION CRITERIA

Proposals submitted to ASHRAE for this project should include the following minimum information:

1. Statements describing test facilities, equipment, capabilities, procedures, methods, etc., to be used.

2. Statements indicating experience in conducting research related to fouling of heat transfer surfaces.
3. Resumes of the principal investigator and others involved in the study.
4. Planned schedule and length of time for the project to be completed.
5. Budget information.

Proposals will be evaluated on:

1. Contractor's understanding of Work Statement as revealed in proposal. 15%
2. Quality of methodology proposed for conducting research. 25%
3. Contractor's capability in terms of facilities. 20%
4. Qualifications of personnel for this project. 15%
5. Probability of contractor's research plan meeting the objectives of the Work Statement. 20%
6. Performance of contractor on prior ASHRAE projects or other energy projects. (No penalty for new contractors) 5%

REFERENCES

ARI Guideline E (1998) – Fouling Factors: A Survey of Their Application in Today's Air-Conditioning and Refrigeration Industry

ARI Standard 450 (1999) – Water-Cooled Refrigerant Condensers, Remote Type

LA Curcio, Jr. and AS Wanni, (1999) "Operating Experience With Plate Type Heat Exchangers In Petroleum and Petrochemical Applications", International Conference on Compact Heat Exchangers and Enhancement Technology for the Process Industries, July 18-23, 1999, Banff, Alberta, Canada.

GRP-106 – "Water Side Fouling Resistance Inside Condenser Tubes", JE Knudsen, Oregon State University.

RP-560 – Evaluation of Water-side Fouling Resistance in Flooded Evaporators of Water Chilling Machines, RL Webb, Pennsylvania State University

RP-1205 – Waterside Fouling Inside Smooth and Augmented Copper-Alloy Condenser Tubes in Cooling Tower Water Applications, LM Chamra, Mississippi State University
(Note: RP-1205 was not successfully completed. The final report contains minimal data from tests run with low fouling potential water. However, the report does contain a summary of relevant literature, a small survey of cooling water qualities, and a description of the test procedures and data analysis methods used.)

AUTHORS

This work statement was originally prepared by Jim Bogart and Art Fovargue. Editorial changes were made by Ken Schultz in Aug 2007 prior to the second release of 1345-RFP.

APPENDIX A for 1345-WS

The water chemistry for the various potential tests is listed in the table below. This chemistry is based on the water sample from the cooling tower at the Boston Museum of Science in Cambridge, MA, for 1205-RP and taken to be representative of those samples with low LSI's. Cycling up the makeup water chemistry from the Cambridge, MA, water supply three (3) times matched well with the constituents as measured in the Museum of Science cooling tower sample. The medium and high fouling potential cooling tower waters were also derived from the same makeup water chemistry by cycling it six (6) and eight (8) times, respectively.

Water Chemistry
based on Cambridge makeup water (Sept 2002) cycled 3, 6, & 8 times and modified per the following:

(a) pH values are set at 7.8, 8.6 & 9.3 for the cycled water in order to yield LSI values of approximately 0.2, 1.8 & 2.8, respectively.

(b) Chlorides of cycled water are to be limited to <200 ppm to not overly influence corrosion potential.

(c) Total dissolved solids are to be limited to <100 ppm to minimize the impact of particulate fouling.

Fouling Potential	Total Hardness	Calcium (as CaCO3)	Magnesium (as $CaCO_3$)	"M" Alkalinity (as $CaCO_3$)	Chloride	Silica	Sulfate	Specific Conductance
low	240	180	59	96	< 200	5.7	72	TBD
medium	480	360	119	192	< 200	11.4	144	TBD
high	640	480	158	256	< 200	15.2	192	TBD

Fouling Potential	pH	Total Iron	Copper	TDS	Total Suspended Solids	P-Type Alkalinity	LSI
low	7.80	0.15	0.03	1140	< 100	0	0.198
medium	8.60	0.30	0.06	1500	< 100	0	1.864
high	9.30	0.40	0.08	1800	< 100	0	2.803