WORK STATEMENT

FROM TC 8.5, LIQUID TO REFRIGERANT HEAT TRANSFER

TITLE

The Effects of Inundation and Miscible Oil upon the Condensation Heat Transfer Performance of R-134a

BACKGROUND

The heat exchangers being produced today by HVAC original equipment manufacturers are optimized for ozone friendly refrigerants, and in general, lower heat flux operation than units built in the previous decade. To take advantage of unit foot print and metal cost savings, notched-fin condenser tubing is replacing both plain-surface and integral-fin tubing. Notched-fin condenser tube is termed 3-D enhanced surface tube, in comparison to integral-fin tube, which has a 2-D fin profile.

Condensate retention is detrimental to shell-side heat transfer performance (Webb et al., 1982). This is due to the fact that for laminar film-wise condensation, the shell-side coefficient is inversely proportional to the thickness of the film (Incropera and De Witt, 1990). It follows that in order to maximize shell-side condensation performance, the film thickness should be minimized. Hence, 3-D enhanced surface condenser tubing was developed to minimize and/or prevent flooding of the fins with condensate via improved surface tension driven drainage, relative to integral-fin tubing.

To date, several studies have been conducted documenting the effects of miscible lubricants upon the shell-side condensation process. It was reported by Williams and Sauer (1980) that lubricant concentrations of 6% to 7% and greater reduce the shell-side condensation performance for plain-surface tubes. Webb (1984) commented in a later review paper that the concentrations reported by Williams and Sauer (1980) were over estimated, and suggested that a concentration of 1.4% was more representative for the initiation of performance penalty as a result of the lubricant. Wang et al. (1985) presented lubricant effect results for plain-surface tubes and refrigerants R-12 and R-22. It was noted that R-12 suffered a 3% decrease in shell-side coefficient for each 2% increase in lubricant concentration, while R-22 only experienced a 2% performance decrease per 2% lubricant concentration increase.

The effects of miscible oil upon heat transfer coefficient for integral-fin tubing are different than the trends established for plain-surface tubing. Sauer and Williams (1982) reported that integral-fin tube condensation coefficients showed little to no degradation in the presence of lubricant through the range of concentrations evaluated. Wang et al. (1989) presented oil effects condensation data for integral-fin tubing, and the results indicated that the presence of oil in both R-12 and R-22 vapors, in any proportion, reduced the shell-side coefficient. However, Wang et al. stated that it could not be concluded from the data that increasing oil concentration directly lead to further decreases in condensation coefficient.

Although developed with the intention of better condensate management, it has been demonstrated by Honda et al. (1992) and later by Huber et al. (1994) that 3-D enhanced surface tubing suffers greater inundation penalty than standard integral-fin tubing. This is an important observation considering what is known about the influence of lubricant upon the shell-side condensation process. It is likely that condensation heat transfer performance for 3-D enhanced surface tubing will be affected adversely by a miscible lubricant.

JUSTIFICATION OF NEED

Because small concentrations of oil circulate with the refrigerant throughout the system in most HVAC and refrigeration machines, there is practical interest in quantifying the effects of miscible oil upon shell-side heat transfer coefficient. These oil effects have not been addressed in previous shell-side condensation studies for 3-D enhanced surface tubing. It is likely that the 3-D enhanced surfaces will suffer shell-side coefficient degradation equal to or greater than that found with integral-fin tubing for small oil concentrations.

The proposed investigation will quantify the relationship between oil concentration and heat transfer coefficient degradation using an ozone friendly refrigerant and a miscible oil. Specifically, the study will generate oil effects performance data for columns, or bundles, of both 2-D and 3-D commercially available condenser tubing. Correlations of the data provided by this research project would be used for condenser modeling and design by engineers in the HVAC and refrigeration industries.

OBJECTIVES

a. Undertake a literature survey on horizontal shell-side condensation, especially in the area of air-conditioning and refrigeration applications.
b. Perform both single tube and tube bundle experiments for at least one saturation temperature and enough flow conditions to establish performance trends.
c. Quantify the effects of surface enhancement on shell-side heat transfer coefficient.
d. Quantify the combined effects of miscible oil and inundation rate upon shell-side heat transfer coefficient.
e. Develop correlations/charts suitable for publication in the ASHRAE Fundamentals Handbook that could be used by design engineers.

SCOPE

Task I - Literature Search

A literature search shall be performed in an effort to review techniques for modeling shell-side condensation performance. The proposed method for presenting and correlating heat transfer data shall be included in the proposal. Particular focus should be given to how the effects of inundation and oil will be accounted for in the resulting correlations.

Task II - Experimental Effort

Heat transfer experimental facilities shall be capable of meeting the following test conditions:

Refrigerant - R-134a

Range of flux - 1,000 to 20,000 Btu/h-ft^2 (3.2 to 63.0 kW/m^2)

Range of condensate Reynolds numbers - 100 to 4,000 (based upon pure refrigerant)

Acceptable nominal tube diameter - 0.75 and/or 1.0 inch (19.1 and/or 25.4 mm)

Saturation Temperature - 105 F (40.6 C)

Exact dimensions of the test section should be described in the proposal. The tube bundle should have a minimum of five rows of depth, have a triangular-pitch tube alignment (staggered alignment), and the uncertainty of the shell-side coefficient measurement must be no greater than 8.0% at a heat flux of 10,000 Btu/[hr-ft^2]. A tube length of 42 inches (1.07 meters) or more should be used to achieve this measurement accuracy. One or two passes, but no more than two, through the tube bundle for the tube-side fluid are desired. The test section should be equipped with sight glasses to allow for visual observations.

A comprehensive description of the test facility including instrumentation should be provided in the proposal. The measurement of parameters which influence the shell-side coefficient shall be described in detail, including the following items: temperature, pressure, liquid flowrates, energy transfer rate, and oil concentration. Particular focus should be given to the proposed method for determining the oil concentration in the condensate film, as well as describing the technique(s) for introducing the oil into the refrigerant vapor stream and/or inundation flow stream(s).

The actual oil concentration in the condensate film may vary from row to row, and some methods of oil introduction may exaggerate this effect. Preference will be given to those investigators intending to evaluate the effects of row depth upon both local oil concentration and heat transfer coefficient in addition to measuring the overall bundle performance.

How the tube-side heat transfer coefficient will be determined for the tubes evaluated in this work should be described in detail. Use of vendor supplied heat transfer correlations is deemed unfavorable with preference given to those researchers proposing to determine the tube-side heat transfer performance experimentally. Entrance effects associated with testing tube lengths considerably shorter than those typically found in industry will be accounted for using this approach.

Data must be taken for a smooth tube so that performance trends established in previous studies may be compared to results taken on the facility used in the current work. In addition to the plain-surface tube, one 3-D enhanced surface condenser tube and one integral-fin tube will be recommended by the Project Monitoring Subcommittee (PMS) for evaluation.

Several oil concentrations shall be evaluated to establish performance trends. Oil concentrations tested will include 0.1 percent, and the range evaluated should go at least as high as 3 percent, specified by mass fraction in the condensate film. The oil used in the proposed investigation will be recommended by the PMS. Those investigators willing to evaluate an additional oil of different viscosity than the oil suggested by the PMS should state this objective in the proposal. In addition, pure refrigerant testing shall be conducted so that baseline performance may be established.

Although only one saturation temperature is required, evaluation of additional temperatures to establish the effects of refrigerant properties upon heat transfer performance is deemed desirable for the purpose of correlating data generated in this study. Those investigators intending to provide additional temperature effects work should state the fact in the proposal submitted for review. To establish these property effects, an additional refrigerant may be evaluated in lieu of performing additional saturation temperature work. Refrigerant R-123 is suggested for those investigators preferring this approach.

Task III - Reporting of Data

The results of this research project must be reported as described below in “DELIVERABLES”. A schedule for estimating the time to completion shall be developed by the contractor and kept up to date throughout the work for the benefit of the committee.

DELIVERABLES

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

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 Society 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 PMS.

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

   - Four bound copies.
   - One unbound copy, printed on one side only, suitable for reproduction.
   - Two copies on 3-1/2 inch diskette(s); one in ASCII format and one in the word processing format used to produce the report.

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

e. A Technical Article suitable for publication in the ASHRAE Journal may be requested by the Society or the PMS.

LEVEL OF EFFORT

It is expected that Tasks I through III, shown above, will take twenty-four (24) months to complete. Eight (8) person-months of the Principal Investigator and twenty-four (24) person-months of the research assistant are estimated. A total cost of $120,000 is anticipated.

OTHER INFORMATION TO BIDDERS

Those bidding on this project should have extensive experience with condensation, two-phase flow, and fluid mechanics.

Suggested Approach

a. Review 378-RP with respect to the test facility and experimental methods. The technique used for introducing oil into the refrigerant vapor stream was well thought; however, 378-RP did not consider inundation effects.

b. Review 676-RP with respect to survey and evaluation. This study was recently completed, and a literature search was performed on the area on inundation effects. It should be noted that the method used to introduce liquid into the tube bundle in 676-RP is deemed not desirable for the current study. A separate flow loop to provide the inundation liquid to the tube bundle is recommended. This allows for independent control of the inundation supply rate from the primary refrigerant loop (i.e. the loop equipped with the boiler). This approach will simplify operation of the test facility, expand range of operation, and ensure high quality data.

c. It was demonstrated during 676-RP that the row-to-row heat transfer coefficient profile for a five row bundle persisted throughout the inundation work regardless of the inundation supply rate. The inundation flowrate was varied by altering the exiting boiler quality on the facility used for 676-RP. To overcome this drawback, inlet qualities were varied and heat transfer coefficients were reported for the lower rows of the bundle, making relative comparisons between different inlet qualities. In contrast, the test section used by Honda et al. (1994, 1995) is equipped with thirteen to fifteen active rows of tubes depending upon setup. This may be described as a preferable experimental design relative to a tube bundle or column of tubes incorporating a fewer number of rows. However, proposals will be accepted from facilities having a test section equipped with at least five active rows.

PROPOSALS

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

a. Background and literature review.

b. Statements describing test facilities, equipment, capabilities, procedures, methods of data presentation, etc., to be used.

c. Statements indicating experience in conducting research related to condensation, two-phase flow, and fluid mechanics.

d. Resume of the Principal Investigator and other key personnel involved in the study.

e. Planned schedule and length of time for the project to be completed.

f. Budget information.

REFERENCES

Honda, H., Uchima, B., Nozou, S., Torigoe, E., and Imai, S., 1992, “Film Condensation of R-113 on Staggered Bundles of Horizontal Finned Tubes,” ASME Journal of Heat Transfer, Vol. 114, pp. 442-449.

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Incropera, F.P., and De Witt, D.P., 1990, "Fundamentals of Heat and Mass Transfer - Third Edition," John Wiley and Sons, Incorporated.

Sauer, H.J., and Williams, P.E., 1982, "Condensation of Refrigerant-Oil Mixtures on Finned Tubing," Proceedings of the 7th Int. Heat Transfer Conference, pp. 147-152.

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