WORK STATEMENT
from
TC 8.5 *Liquid-to-Refrigerant Heat Exchangers*

TITLE

The Applicability, Design Aspects, and Long Term Effects of EHD-Enhanced Heat Transfer of Alterant Refrigerants/Refrigerant Mixtures for HVAC Applications

BACKGROUND

It is now well established that the Electrohydrodynamic (EHD) method can increase heat transfer coefficients of air and refrigerants by several hundred percent depending on geometry of the electrode, the heat transfer surface, the flow conditions and materials [1, 2]. The technique utilizes the effect of secondary motions that are generated by coupling a high-voltage, low-current electric field with the flow field in a dielectric fluid medium. The EHD technique has demonstrated proven potential for significantly reducing the heat exchanger size while providing enhancements that are electrically-controllable and can respond to seasonal or periodic heating/cooling load variations. Commercialization of the technique for selected applications in the near future is now a certainty [3, 4].

JUSTIFICATION

A careful search of the literature and assessment of the EHD technology suggests that the technique has now passed its infancy stage. Its applicability to environmentally safe refrigerants has been successfully demonstrated in a number of experiments, including ***in a 15-Ton*** prototype EHD condenser (5). The preliminary work in the U.S. [6] also has demonstrated the potential applicability of the technique for heat transfer enhancement of non-CFC refrigerants. Since 1990 the Japanese have actively began advertising this technology and all evidence suggests that the technique will find its way in the commercial market within the next few years. Although the Japanese have published extensively on the EHD subject matter in the past few years, little or no information is available on the technical know-how and development of components for reliable operation of the system. In most cases the emphasis has been on the magnitude of enhancements with little explanation on the mechanism or method of test and apparatus development.

OBJECTIVES

A. Demonstrate by experiment the feasibility of the EHD technique for heat transfer enhancement of selected, environmentally safe, refrigerant/refrigerant mixtures, for geometries and operating conditions most relevant to HVAC applications.

B. Provide data to allow direct comparison of heat transfer performance and electrical power requirements for heat transfer surfaces, electrode geometries, and operating conditions of practical significance to the HVAC&R industries.

C. Collect quantitative data on the long term effects of EHD on refrigerants, oils, heat exchanger and electrode materials. Address the influence of prolonged use of high-voltage in commercial heat exchangers.

D. Develop design guidelines and identify the most optimum EHD conditions for implementation in practical HVAC equipment.

SCOPE

The desired result and applicability of this work is that from the many possible refrigerant/surface combinations, the EHD conditions providing the greatest enhancement potential be discovered and highlighted. Since the scope of this research is broad, with a large number of experimental combinations, it is expected that the work be grouped into a series of several related tasks. In each portion of the project, the Principal Investigator and the monitoring committee should review the results of the tasks already completed, along with work reported in the literature to assure that all appropriate combinations of heat transfer surface and refrigerant conditions are investigated in accordance with the objectives stated above.

Refrigerants considered in the initial screening analysis should include R-134a, R-123, and refrigerant blends R-404A, R-407C, and R-410A. For the refrigerants selected for additional evaluation, boiling tests should be performed at approximately 40°F temperature. (If water is used as the chilled test fluid, the test sections must be long enough to provide a delta-T large enough for accurate measurement.) Data should be taken over a range of heat fluxes from 3000 to 20,000 BTU/Hr-Sq Ft-°F.

In-tube boiling tests should be performed on both smooth bore and micro-fin tubing. External boiling tests should be conducted on state-of-the-art high performance commercially available enhanced surfaces in addition to a plain tube. As a minimum, the data should be presented for heat transfer coefficients and electrode power requirement, displayed graphically as functions of electrode voltage and mass velocity (for in-tube test) or heat flux (for external boiling).

The first task of the project should be to plan and design the experiments to be conducted, based on a careful review of the literature on external and in-tube passive and active enhancement techniques previously applied to the boiling heat transfer of alternate refrigerants and refrigerant mixtures. A major criteria for determining the applicability of the EHD technique is to ensure that the dielectric fluid medium has a low enough electrical conductivity that the resulting EHD electrical power consumption will be negligible. Therefore, project should include analysis of the electrical conductivity of the test fluids and their current vs voltage (I-V) performance.

A second task includes the evaluation of the tube/refrigerant combinations shown in Table 1. The choice of the external boiling enhanced tube and the choice between refrigerant blends R-407C and R-410A should be based on the results of tasks one.

TABLE 1

	External Boiling		Internal Boiling	
Refrigerant	Enhanced Tube #1 or Tube #2	Plain Tube	Micro-Fin Tube	Plain Tube
R123	**Test**	**Test**	(no test)	(no test)
R134a	**Test**	**Test**	(no test)	(no test)
R-404A	(no test)	(no test)	**Test**	**Test**
R-407C or R-410A	**Test**	**Test**	(no test)	(no test)

The third task should include investigation of the electrode geometry and design, the effects of refrigerant temperature/pressure, the effect of oil/refrigerant combinations, and the long term effects such as fouling, corrosion, refrigerant decomposition, and electrode component reliability using the most promising refrigerant/tube combinations elected from task two. The refrigerant should be mixed with 2% of an appropriate refrigeration oil for this evaluation. Although this would not furnish complete data for the enhancement effect of EHD with all oil/refrigerant combinations, it would indicate if the EHD techniques change the effect that the presence of oil has on heat transfer coefficients.

DELIVERABLES

a. Progress and Financial Reports shall be made to the Project Monitoring Subcommittee (PMS) 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. Draft copies of the Final Report shall be prepared and submitted to the Manager of Research and the PMS by the end of the contract period covering complete details of all research carried out on the project. The final report shall include, as a minimum, the following:

1. An Executive Summary suitable for wide distribution to the industry and to the public.

2. Recommended changes to the ASHRAE Handbook series as appropriate.
Following approval by the sponsoring TC/TG, Final draft of the report shall be furnished in the following manner:

- Six bound copies
- One unbound copy, printed on one side only, suitable for reproduction.

•Two copies on 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 "checklist for Preparing Manuscript for ASHRAE *Transactions*."

e. A Technical Article suitable for publication in the *ASHRAE JOURNAL* may be requested by the Society.

LEVEL OF EFFORT

Completed over a two year period, the project would require 3-1/2 man-months for the Principal Investigator, 4-1/2 main-months for a research engineer, plus 24 man-months for a full time Graduate Assistant. Estimated cost is $140,000.

OTHER INFORMATION TO BIDDERS

It is expected that those bidding for this project will have a capability for performing experimental studies of EHD enhanced boiling heat transfer. The project budget should not include funds to develop this capability.

Successful bidders will be required to make semiannual reports to the Research Oversight Committee at both the Winter and Summer ASHRAE meetings.

PROPOSALS

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

A. Statements describing test facilities and capabilities, equipment, instruments, etc., to be used.

B. Statements indicating experience in conducting research associated with performing EHD-enhanced boiling heat transfer experiments.

C. Resumes of Principal Investigator and others involved in the project.

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

E. Reports to be published.

F. Budget information.

REFERENCES

A. M.M. Ohadi, 1991, "EHD Heat Transfer Enhancement in Heat Exchangers," ASHRAe Journal, December 1991, pp. 42-48.

B. M.M. Ohadi, D.A. Nelson, and S. Zia, "Augmentation of Laminar and Turbulent Forced Convection Heat Transfer in Tubes via Corona Discharge," International Journal of Heat and Mass Transfer, Vol. 34, No. 4-5, pp. 1175-1187, 1991.

C. A. Yabe, Senior Researcher and program manger, MITI of Japan, Personal Communications with M.M. Ohadi, ASHRAE Summer Annual Meeting, Baltimore, June 1992.

D. A. Yabe, 1991, "Active Heat Transfer Enhancement by Applying electric Fields," *Proceedings of the ASME/JSME Thermal Engineering Joint Conference, Reno, Nevada,* Vo. 3, pp. xv-xxiii.

E. M.M. Ohadi, S. Dessiatoun, A. Singh, and M.A. Fanni, 1993, "A Feasibility Study on EHD Enhancement of External and In-tube Boiling of Alternate Refrigerants," ARTI Final Report, Project No. 655-51700.