ASHRAE
*Technology for a Better Environment*
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Michael Vaughn, PE
Manager of Research & Technical Services
email: mvaughn@ashrae.org

TO: Potential Bidders

FROM: Mike Vaughn

DATE: April 19, 2007

SUBJECT: Research Project 1394-RFP, "Study of Carbon Dioxide Condensation in Chevron Angle Plate Geometry Exchanger"

You recently indicated that you were preparing a proposal on the subject project. In order to ensure equal information is available to all bidders, I am listing the questions, and answers and/or comments received by the Technical Contact person on this project.

Q1: Question concerning the heat flux range specified in the proposal. The actual wetted heat transfer area associated with a given heat exchanger will be difficult to obtain unless it is provided by a manufacturer.

For the proposal, is it appropriate to use a nominal heat transfer area to determine if the heat flux requirement has been met? Specifically, can the length times the width of the plates times the number of plates be used to estimate the heat transfer area, or are you aware of a rule of thumb for relating the apparent area to the actual area.

A1: The manufacturer will provide you that info; however, to understand how area is calculated I suggest you get hold of the Ayub 2003 paper as cited in the WS.

**INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT- March 15, 2007**

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution may have an interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject

**1394-RFP**, "Study of Carbon Dioxide Condensation in Chevron Angle Plate Geometry Exchanger"

Sponsoring Technical Committee: TC 8.5 Liquid to Refrigerant Heat Exchangers

Budget Range: $150,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **September 3, 2007** or later.

All proposals (hardcopy or electronic format) must be received at ASHRAE Headquarters **May 15, 2007.**
**Electronic copies must be sent to rpbids@ashrae.org.**

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

**For Technical Matters**
Dr Zahid H Ayub
Isotherm Inc
3305 Thorntree Ct
Arlington, TX 76016
Phone: 817-472-9922
Fax: 817-472-5878
Email: zahid@iso-therm.com

**For Administrative or Procedural Matters:**
Manager of Research & Technical Services (MORTS)
Michael R. Vaughn
ASHRAE, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329
Phone: 404-636-8400
Fax: 404-321-5478
E-Mail: mvaughn@ashrae.org

**Contractors intending to submit a proposal should so notify, by mail, fax or e-mail, the Manager of Research and Technical Services, (MORTS) by April 15, 2007 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.**

Proposals may now be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below.

Hardcopy submissions require 1-signed original and 2-signed copies organized in the same order. **In all cases, the proposal must be in the hands of the ASHRAE MORTS by 5 p.m. EST May 15, 2007.**

ONLY electronic proposals are to be sent to rpbids@ashrae.org. All other correspondence must be sent to ddaniel@ashrae.org or **mvaughn@ashrae.org**.

The following forms must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (signed)
(2) Additional Information for Contractors (signed)

**ASHRAE reserves the right to reject any or all bids.**

**Background**

Carbon dioxide was used in industrial and marine applications quite extensively during the first half of the last century. With the introduction of halocarbons and the elevated pressure requirements (critical point: 87.53 °F/1066 psia) of carbon dioxide, its demise came around the end of WWII. However, this refrigerant has made a come back, especially in low temperature refrigeration applications due to its favorable thermodynamic, transport, and environmental properties. It is natural and non-toxic with an Ozone Depleting Potential (ODP) of zero and Global Warming Potential (GWP) of one that is compared to R134a with ODP of 0 and GWP of 1300.

Carbon dioxide has relatively lower specific volume, resulting in small size compressors for the same operating conditions. The ratio of vapor to liquid density (ρg/ρl) is larger than other refrigerants, which eliminates two-phase distribution problems. Carbon dioxide's vapor pressure curve is much steeper than other refrigerants as shown in Fig. 1. This feature makes it a favorable refrigerant, especially in low temperature applications where other refrigerants show a very shallow p-T curve, resulting in a large saturation temperature differential per unit differential pressure drop. Also, it has higher liquid and vapor thermal conductivities with lower liquid viscosity and surface tension, which makes it ideal for two-phase boiling and condensing applications. These qualities have resulted in a resurgence of this refrigerant in Europe where several new two stage system plants are successfully operating. Hence, the condensing heat transfer characteristics of carbon dioxide in a higher-performance industrial cascade system are of interest to the refrigeration professionals.

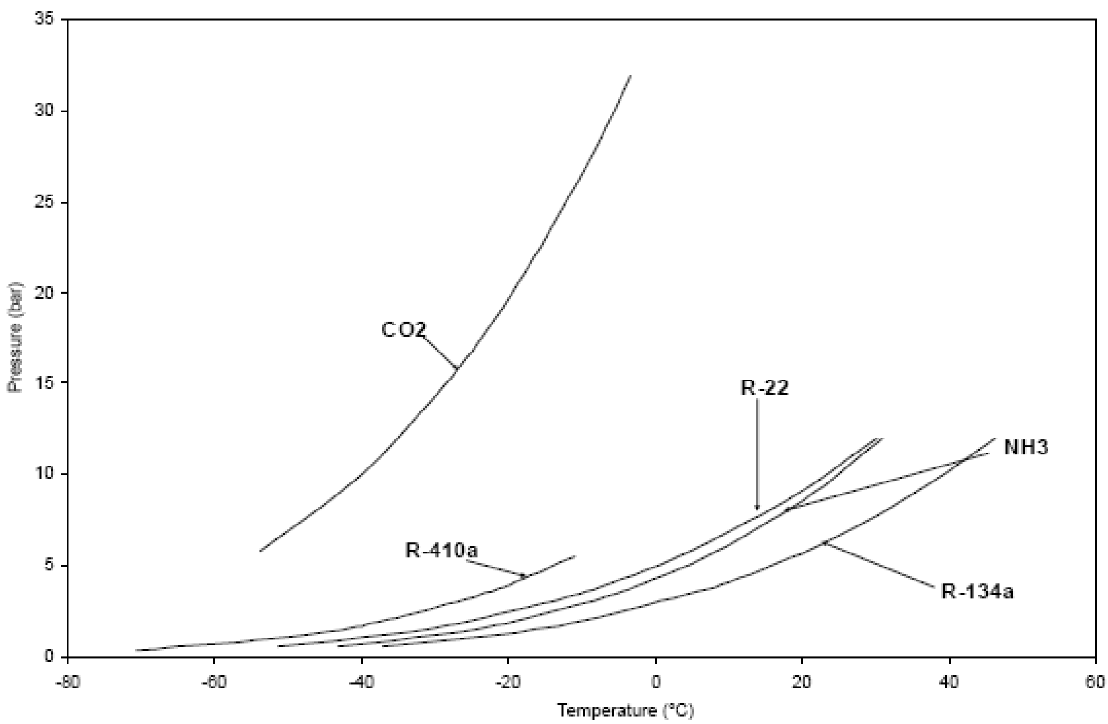



Fig. 1 Vapor pressure curves for different refrigerants

**Justification**

In order to achieve this it is important to understand the heat transfer and mechanical integrity aspects of equipment that would be able to withstand high condensing pressures. Therefore, it is important to undertake a comprehensive study on the subject that would identify exchanger(s) with high mechanical integrity and enhanced heat transfer characteristics. This requirement could be fulfilled by undertaking an experimental program on brazed plate or a shell and plate exchanger. These types of exchangers offer higher surface-area-to-volume ratios along with enhanced heat transfer and high pressure ratings. It is apparent that 1°F reduction in approach temperature on average results in 2-3% improvement in COP.

**Objective**

To date, ASHRAE has sponsored only one project that involved carbon dioxide focusing only on small-scale (residential /light commercial) systems and did not address the needs of industrial refrigeration industry. The proposed project would help understand the physics of condensing phenomenon of carbon dioxide in complex geometries such as plate heat exchangers and also help in optimizing such exchangers for industrial applications. The basic objective would be to perform condensing heat transfer and pressure drop tests on plate type heat exchangers at various temperature and pressure conditions within the sub-critical region. The tests should not be manufacturer specific, rather geometry specific so that universal correlations and/or charts could be developed for the general benefit of the stake holders. It would be expected of the investigator to present clear quantitative merits of the results stating the enhancement factors achieved over conventional condensers.

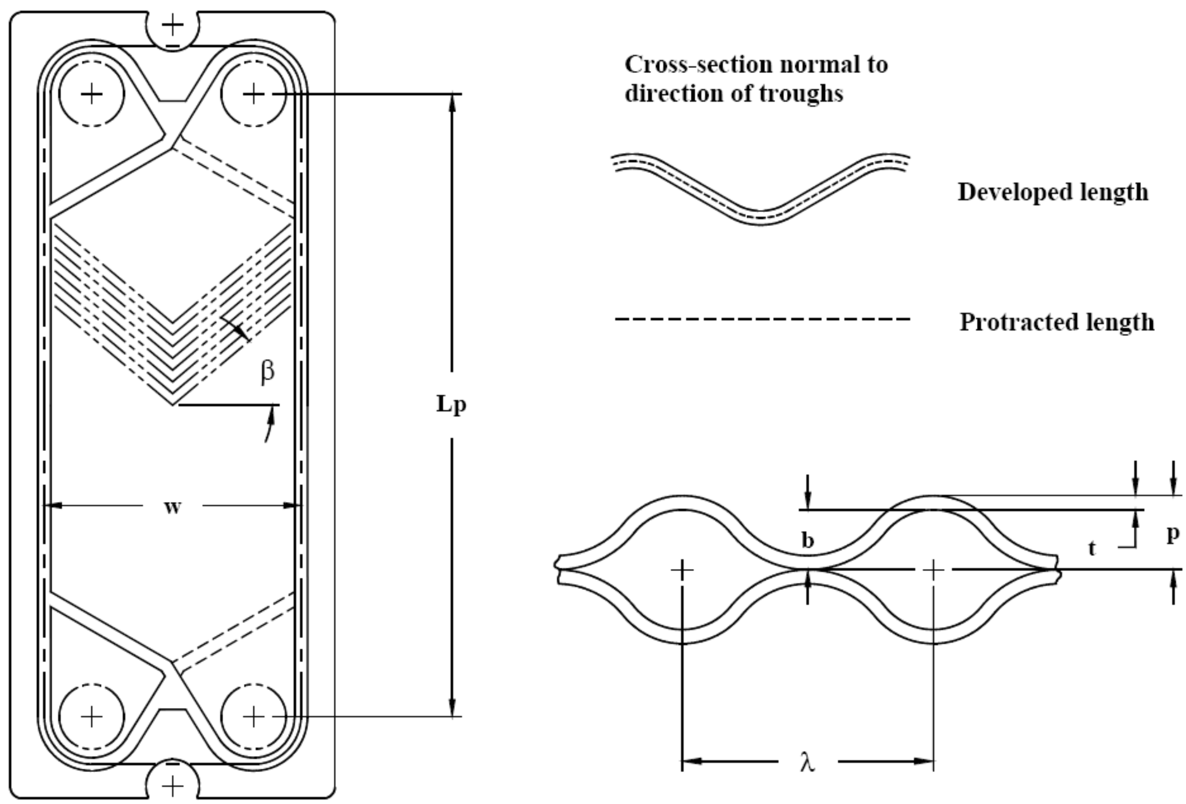
**Scope**

It is anticipated that this research work will comprise of detailed literature search on the subject, design, construction, and operation of a test setup capable of taking data over the following range of conditions:

1. Plate Geometry
   The investigator(s) will be expected to conduct tests on at least three (3) different stainless steel plate geometries (see Fig. 2 for definitions).
   a. Soft profile, $\beta$ = 60°-65°
   b. Hard profile, $\beta$ = 30°-35°
   c. Medium profile, $\beta$ = 45° or mix of soft and hard
   d. Corrugation pitch, $\lambda$ = 0.25” (6 mm) – 0.6” (15 mm) [min. one pitch]
   e. Corrugation depth, b = 0.08” (2 mm) – 0.16” ( 4 mm) [min. one depth]
   f. Plate width (or diameter), length, and thickness to be selected accordingly

2. Test Set-up
   Test set-up will be left to the investigator(s), however, they should have adequate equipment and compressor capacity to perform the minimum as elaborated in this work statement.

3. Test Conditions
   Test data will be taken on each of the plate configuration described above operating at the following conditions:
   a. Saturated CO2 temperature range: 0°F (-17.8°C) to -30°F (-34.4°C)
   b. Heat flux range: 800 Btu/hr-ft2 (2.5 kW/m2) to 5,000 Btu/hr-ft2 (17.7 kW/m2)
   c. Inlet condition: superheated gas to saturated vapor
   d. Exit condition: saturated liquid to sub-cooled liquid
   e. Approach temperature: not to exceed 10°F (5.6°C)




β = Chevron angle
ϕ = Enlargement factor = Developed length / Protracted length
λ = Corrugation pitch

Fig. 2 Plate Parameters

4. Data Reduction
It is anticipated that the researcher(s) will reduce the test data to heat transfer coefficients and pressure drops under specified steady state conditions. Medium side heat transfer coefficient should be established first. One way to perform this (if using single phase brine) would be to use equal-resistance technique where similar flow conditions are established on both sides, hence resulting in similar single phase thermal resistances on each side. For validation purposes, this could be compared to existing single phase correlations for plate exchangers in the open literature. Other data reduction methods can be discussed with the PMS members during the course of the work. The potential researcher(s) must provide a complete and thorough uncertainty analysis and test set-up arrangement to the PMS for their evaluation before commencement. This aspect of the work should be described in detail in the proposal. Maximum measurement inaccuracy for heat transfer coefficient and pressure drop should not exceed 10%.
The final heat transfer and pressure drop data for carbon dioxide should be reduced in the form of correlations/charts – preferably, a general correlation that incorporates the plate geometry effect, saturation temperature effect, inlet super-heat effect, and sub-cooling effect. The final correlation(s) could be compared with any correlation available at that time. The enhancement factors achieved (if any) over conventional condensers should be stated.

**Deliverables**
Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the only deliverables ("Deliverables") under this Agreement and shall be provided as follows:

a. Progress and Financial Reports

Progress and Financial Reports, in a form approved by the Society, 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.

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

b. Final Report

A written report, design guide, or manual, (collectively, "Final Report"), in a form approved by the Society, shall be prepared by the Institution 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, the final draft report shall be furnished electronically for review by the Society's Project Monitoring Subcommittee (PMS).

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

- One unbound copy, printed on one side only, suitable for reproduction.
-Two bound copies
-An executive summary in a form suitable for wide distribution to the industry and to the public.
-Two copies on CD-ROM disks; one in PDF format and one in Microsoft Word.

c. Technical Paper

One 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 (1394-RP) at the end of the title in parentheses, e.g., (1394-RP).

d. Data

Data is defined in General Condition VI, "DATA"

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.

e. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE *Insights*

The Society may request the Institution submit a technical article suitable for publication in the Society's *ASHRAE JOURNAL*. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

**Level of Effort**
Total period of this project is expected to be 24-30 months. In addition to a Principal Investigator (2-3 man months), it is expected that 1 or 2 assistants (balance) will be required to assist in construction of the test stand, taking measurements, reducing data, developing the correlations and conclusions, and publishing results. Estimated total cost to ASHRAE is expected to be $150,000.

**Other Information to Bidders**
Potential bidders could use shell and plate or brazed plate configuration as long as the plate geometry parameters are satisfied.

**Proposal Evaluation Criteria**
Principal Investigator will be expected to be well versed with past and current research done in the area of condensation and two phase flow and have experience with the type of test apparatus required to perform such work.

The following criteria and weighting factors will be used by the evaluation subcommittee for evaluating contractor proposals:

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

**References**
Ayub, Z. H., “Plate Heat Exchanger Literature Survey and New Heat Transfer and Pressure Drop Correlations for Refrigerant Evaporators,” Heat Transfer Engineering, Vol. 24, No. 5, 2003, pp. 3-16.
Jokar, A., Eckels, S. J., Hosni, M. H., and Gielda, T. P., “Condensation Heat Transfer and Pressure Drop of Brazed Plate Heat Exchangers using Refrigerant R-134a,” J. Enhanced Heat Transfer, Vol. 11, No. 2, 2004, pp. 161-182.
Kedzierski, M. A., “Effect of Inclination on the Performance of a Compact Brazed Plate Condenser and Evaporator,” Heat Transfer Engineering, Vol. 18, No. 3, 1997, pp. 25-38.