INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1790-TRP, "Water Solubility and the Distribution of Water between Vapor and Liquid Phases of Low GWP Refrigerants" (re-bid)

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

Sponsoring Committee TC: 3.03, Refrigerant Contaminant Control

Budget Range: $75,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2023,** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, Thursday , December 15, 2022. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: "1790-TRP, Water Solubility and the Distribution of Water between Vapor and Liquid Phases of Low GWP Refrigerants" *and "Bidding Institutions Name"* (electronic pdf format, ASHRAE's server will accept up to 10MB)

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

For Technical Matters
Technical Contact
Brad Boggess
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For Administrative or Procedural Matters:
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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by December 1st, 2022, in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must 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. **ALL electronic proposals are to be sent to rpbids@ashrae.org.**

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, December 15th, 2022. NO EXCEPTIONS, NO EXTENSIONS.

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required)

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

Table 1, in the *Refrigeration Handbook* Chapter 7 provide moisture solubility of various refrigerants currently in use, such as R-404A, R-410A, etc. This table is used to design and predict performance of filter-driers under a wide range of operating temperatures to maintain system reliability and performance by removing this harmful contaminate before it causes harm.

Table 2, *Refrigeration Handbook* Chapter 7 provides values for the ratio of moisture between the vapor and liquid phases for many refrigerants similarly to Table 1. The data in this table is also used to evaluate the appropriate moisture level in the system to ensure no icing at the expansion device. Additionally, it may help optimize contaminate control performance by choosing the best system location for the filter-drier(s).

Current data on R-32 moisture solubility had suspect data points that made it unlikely to be used.

Objective

Objective 1: Literature Survey: Working with refrigerant manufacturers and reviewing literature identify existing sources of liquid vapor water solubility data for the following refrigerants; R32, R1234ze(E), R1234yf, R-1336mzz(Z), R1336mzz(E), R-1233zd(E).

Objective 2: Water Solubility In Liquid Refrigerant: If literature sources are not available or there is significant discrepancy or gaps in the source data, determine the solubility in water in the liquid phase of the objective 1 refrigerants, from -40 °F (-40 °C) to 160 °F (71 °C). Run R-134a as a control.

Objective 3: Determination of liquid-vapor water equilibrium (K-values): Determine vapor-liquid equilibrium water distribution ratios (K-values) with the objective 1 refrigerants to provide sufficient data to produce equation-of-state vapor-liquid equilibrium models for water in the temperature range of 40 °F (4.4 °C) to 120 °F (49 °C). Run R-134a as a control.

Scope:

Task 1:

Review data currently available from refrigerant manufacturers and/or literature sources to identify Water Solubility and the Distribution of Water Between Vapor and Liquid Phases for the following refrigerants; R32, R1234ze(E), R1234yf, R-1336mzz(Z), R1336mzz(E), R-1233zd(E).

Task 2:

If literature sources are not available or there is significant discrepancy or gaps in the source data, determine the solubility in water in the liquid phase of the task 1 Refrigerants. Run R134a as a control.

1. Temperature range: -40 °F (-40 °C) to 160 °F (71 °C)
2. Test Levels: Refrigerant to be saturated, 1% w/v.
3. Investigator must also report the measured temperature and pressure of the equilibrated system to the nearest 1°F (0.5°C) and ±1% of the total absolute pressure, with each water content measurement.
4. Confirm by appropriate measurements that equilibrium has been reached.
5. Analyze system for statistical variation.
6. The project monitoring subcommittee will have the authority to change the temperatures and concentrations, as long as the total number of test levels is not changed.
7. Test method is to be proposed by bidder.

Task 3:

Measure equilibrium water content of vapor and liquid phases for Task 1 refrigerants. Run R134a as a control.

1. Temperature range: 40 °F (4.4 °C) to 120 °F (49 °C)
2. Test Levels: Exhibit 1 shows the Nominal Test Levels for each temperature and refrigerant. Both vapor and liquid water concentrations must be measured at each test level. Determination of water content should be replicated sufficiently to ensure data quality.

3. Investigator must also report the measured temperature and pressure of the equilibrated system to the nearest 1°F (0.5°C) and ±1% of the total absolute pressure, with each water content measurement.
4. Confirm by appropriate measurements that equilibrium has been reached.
5. Analyze system for statistical variation.
6. The project monitoring subcommittee will have the authority to change the temperatures and concentrations, as long as the total number of test levels is not changed.
7. Test method is to be proposed by bidder.

Temp °F	40	75	120
Temp °C	4.4	24	49
	ppm H_2O in initial Refrigerant		
R134a	20	20	20
R134a	60	60	60
R134a	120	120	120
R1233zd(E)	20	20	20
R1233zd(E)	60	60	60
R1233zd(E)	120	120	120
R1336mzz(E)	20	20	20
R1336mzz(E)	60	60	60
R1336mzz(E)	120	120	120
R1336mzz(Z)	20	20	20
R1336mzz(Z)	60	60	60
R1336mzz(Z)	120	120	120
R1234ze(E)	20	20	20
R1234ze(E)	60	60	60
R1234ze(E)	120	120	120
R1234yf	20	20	20
R1234yf	60	60	60
R1234yf	120	120	120
R32	20	20	20
R32	60	60	60
R32	120	120	120

Appendix A

Background
According to the ASHRAE Handbook (1998):
Elsey and Flowers (1949) recognized that the concentration of water by mass at equilibrium is greater in the gas phase than in the liquid phase of R-12. The opposite is true for R-22 and R-502. The ratio of mass concentrations differs for each refrigerant; it also varies with temperature. Table 2 shows the distribution ratios of water in the vapor phase to water in the liquid phase for common refrigerants. It can be used to calculate the equilibrium water concentration of the liquid phase refrigerant if the gas phase concentration is known, and vice versa. The water content in the vapor phase is determined by

W = [PW/(PW)0] [(dW)0/(dR)0] (1)

where:
W = mass water/mass refrigerant
PW = partial pressure of water vapor
(PW)0 = partial pressure water vapor at saturation
(dW)0 = density of water vapor at saturation
(dR)0 = density of refrigerant vapor at saturation
The values in Table 2 are calculated by dividing W from equation (1) at a given temperature by the solubility of water in the liquid at that temperature as given in Table 1 (ASHRAE Handbook 1998).

Strictly speaking, the values in Table 2 apply only at the water saturation point. Elsey and Flowers (1949) state:

It is safe to assume that the ratios of moisture distribution shown … will apply to less-than-saturated solutions of water in Freon, if it can be assumed that Henry's Law is obeyed. Exact obedience to this law is to be had only when the dissolving gas (or vapor) follows the gas law and, as has been shown previously, water vapor does act as an ideal gas at the temperatures under consideration.

Elsey and Flowers go on to point out other justifications for accepting the assumption that Henry's law is valid in R-12. The examples given are solutions of water in hydrocarbons, which are non-polar fluids. R-12 is also non-polar compared with R-22 and the HFC alternative refrigerants.

Appendix B
Summary of ASHRAE Seminar
Vapor/Liquid Distribution Ratio for Lower Concentrations of Water in Refrigerant
February, 2000
Alan P. Cohen

In preparation for this work statement, measurements and calculations were done by several volunteer experimenters. Three laboratories measured the water content of vapor and liquid R134a at room temperature using three different methods for comparison with the values in the ASHRAE Handbook. Another volunteer calculated the water content using an equation of state. The measurements and calculations are plotted in Figure 1 along with the ASHRAE Handbook value. While the ASHRAE Handbook predicts a ratio of 0.58, the three participating experimenters measured 0.93 to 1.19, and Kao calculated 0.89 using an equation of state.

Douglas Gehring used a 1000-pound tank, approximately 75% liquid full of R-134a, equilibrated to room temperature. The tank was equipped to dispense both vapor and liquid. A 17-ounce cylinder was used to take samples of vapor and liquid, which were then analyzed by Coulometric Karl Fischer titration. Sample size was determined gravimetrically. Measurements were made on two tanks, one at 11 ppm/wt and the other at 36 ppm/wt water in liquid.

Raymond Thomas used a 1-Liter cylinder of R134a at room temperature. Samples were taken using a gas syringe, needle, and septum. Samples were injected into a Coulometric Karl Fischer for water analysis. Sample mass was determined gravimetrically. Measurements were made at 203 ppm/wt water in liquid.

Alan Cohen used the apparatus shown in Figure 2. The vapor-liquid interface was located in vessel 2. Silica gel was used in vessel 2 to stabilize the water level. The vapor in vessel 1, in equilibrium with vapor and liquid in vessel 2, was isolated by closing valve B. The vapor sample in vessel 1 was then analyzed for water content by titration using a Coulometric Karl Fischer instrument. The pressure gauge and thermocouple were used to calculate the amount of residual gas in vessel 1 after titrating.

The liquid was sampled by chilling vessel 3 slightly and opening valve D to fill vessel 3 with liquid. The sample is isolated by closing valve D and immediately titrated. Sample size was determined volumetrically after calibrating the volume of vessels 1 and 3. This apparatus has the advantage of not needing to make and break vessel connections to sample the system. However, gravimetric measurement of sample size will be more accurate than volumetric. Measurements were made at several points from 18 to 130 ppm/wt water in liquid.

Chien-Ping Kao used the Peng-Robinson equation of state to calculate a ratio of 0.89 at low ppm levels of water in R134a at 70°F.

Deliverables:

Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the 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, including a summary of the control strategy and savings guidelines. Unless otherwise specified, the final draft report shall be furnished, electronically for review by the Society's Project Monitoring Subcommittee (PMS).

Tabulated values for all measurements shall be provided as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for correction).

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:

-An executive summary in a form suitable for wide distribution to the industry and to the public.
-Two copies; one in PDF format and one in Microsoft Word.

c. *Science & Technology for the Built Environment* or *ASHRAE Transactions* Technical Papers

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 publication. Papers specified as deliverables should be submitted as either *Science & Technology for the Built Environment* or *ASHRAE Transactions*. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in "Manuscript Central" for an *ASHRAE Transactions* Technical or HVAC&R Research papers. The paper title shall contain the research project number (1790-RP) at the end of the title in parentheses, e.g., (1790-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.

d. Data

Data is defined in General Condition VI, "DATA" of the research agreement.

e. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience documenting: (i) the main findings of the research project, (ii) why the findings are significant, and (iii) how the findings benefit ASHRAE membership and/or society in general.

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

Funding Amount Range: $75,000. Duration in Months: 12 months
Man-months: principal investigator (1.5 man-month) Man-months: technician (3.5 man-months)

Other Information for Bidders

Run R134a control to verify historical data in ASHRAE Chapter 7 (Refrigeration Handbook), Table 1 and 2 prior to running other refrigerants.

Proposal Evaluation Criteria

1. Contractor's understanding of Work Statement as revealed in proposal. 20%
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. Student involvement 0%
6. Probability of meeting the objectives and schedule of the Work Statement. 20%

Project Milestone

No.	Major Project Completion Milestone	Deadline Month
1.	Objective 1	2
2.	Objective 2	6
3.	Objective 3	10

References

1. ASHRAE Handbook Refrigeration, Chapter 7
2. ASHRAE Standard 35, Methods of Testing Desiccants for Refrigerant Drying
3. ASHRAE Standard 63.1, Method of Testing Liquid Line Refrigerant Driers
4. AHRI Standard 710/711, Performance Rating of Liquid-Line Driers
5. ASHRAE RP1239 – Distribution of Water Between Vapor and Liquid Phases of Refrigerants
6. ASHRAE RP1495 -Effect of Lubricant on the Distribution of Water between Vapor and Liquid Phases of
7. Refrigerants
8. ASHRAE 34 – Designation and Safety Classification of Refrigerants
9. AHRI 700-2006 – Specification for Fluorocarbon Refrigerants (2006), including Addendum 1 (2009)
10. Appendix C to AHRI Standard 700, Analytical Procedures for AHRI Standard 700
11. ASHRAE RP923 - Water Solubility and Clathrate Hydrates in HFC Refrigerants and Refrigerant Blends