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Michael R. Vaughn, P.E.
Manager Research & Technical Services

TO: Evraam Gorgy, Chair TC 1.3, evraam.gorgy@trane.com

FROM: Michael R. Vaughn
Manager of Research and Technical Services

CC: Shinsuke Kato, Research Liaison 1.0, kato@iis.u-tokyo.ac.jp
Joseph Huber, Research Subcommittee Chair TC 1.3, jhuber@multistack.com
Sankar Padhmanabhan, Chad Bowers, Steven Eckels; Work Statement Author(s), sankar@danfoss.com; eckels@ksu.edu;

DATE: September 19, 2018

SUBJECT: Work Statement (1683-WS), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

During their fall meeting, the Research Activities Subcommittee (RAS) of RAC reviewed the subject Work Statement (WS) and voted 5-0-1 CNV to return with comments.

Below are the main issues and concerns that must be addressed in your next submission of the WS if you choose to resubmit.

1. Need the vote for co-sponsoring TC 8.4.
2. The reference numbers do not match with the reference listed in the reference section - this needs to be updated!
3. There are a number of small typos, or use of wording that should probably be clarified so bidders will all have the same understanding of what is meant.

A WS evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on a specific review criteria. This should give you an idea of how your WS is being interpreted and understood by others. Some of these comments indicate areas of the WS where readers require additional or corrected information or rewording for clarification.

Please coordinate changes to this Work Statement with your Research Liaison Shinsuke Kato, kato@iis.u-tokyo.ac.jp or RL1@ASHRAE.net prior to resubmitting it again to the Manager of Research and Technical Services for further consideration by RAC.

Also, it is necessary that you provide with your next submission a new TC vote on the revised Work Statement, and a letter describing how each of the above items were addressed in the revision.

If you wish for this work statement to be reconsidered at the next RAC meeting, the revised Work Statement must be sent (electronically) to Michael Vaughn, Manager of Research and Technical Services (morts@ashrae.net) by **December 15, 2018.** The next opportunity for consideration after this deadline is May 15, 2019.

Project ID	**1683**	
Project Title	**Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia**	
Sponsoring TC	TC 1.3 (Heat Transfer and Fluid Flow) Co-sponsored by:TC 8.4 (Air to Refrigerant Heat Transfer Equipment)	
Cost / Duration	$150,000 / 30 Months	
Submission History	**Accepted for bid F17, 5th WS Submission, 4th WS Submission Feb. 2017, 3rd Submission Nov. 2015, 2nd Submission Oct. 2013, 1st Submission Oct. 2012**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2018 Fall Meeting Review	**RTAR STAGE FOLLOWED**	
Check List Criteria	**Voted NO**	**Comments & Suggestions**
State-of-the-Art (Background): The WS should include some level of literature review that documents the importance/magnitude of a problem. If not, then the WS should be returned for revision. **RTAR Review Criterion**		
Advancement to the State-of-the-Art Is there enough justification for the need of the proposed research. Will this research significantly contribute to the advancement of the State-of-the-Art. **RTAR Review Criterion**		
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards.		
IF THE THREE CRITERIA ABOVE ARE NOT ALL SATISFIED - MARK "REJECT" BELOW BUT ADDRESS THE FOLLOWING CRITERIA AS APPROPRIATE		
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		**6** - Yes, last WS revision had more details, but not a concern. Page 1 of WS should read 8.4 for co-sponging TC. **11** - 5 identified.
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.		**11 -** 5 tasks as defined, although the authors say 4.
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.		**7** - interim report identified at the completion of task2 and completion of task 4 **11** - Task deliverables are embedded in the task description but they are no specifically highlighted. The authors of the WS list the usual progress, interim and final reports. The name of the ASHRAE research Journal is outdated.
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		**12** - they suggest roughly 1500 test point and require the bidder to build a test facility within a short timeframe and with a very low budget!
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		**12** - they suggest roughly 1500 test point and require the bidder to build a test facility within a short timeframe and with a very low budget! **11** - $150Kover 30 months may be too light for a project in which an ammonia-capable experimental facility is to be developed (Task 3). It may be that the suggested bidders all have ammonia-capable facilities that can be modified for the proposed project rather than develop such a facility specifically for this project. The cost could be reasonable if such a facility already exists.
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**11** - Until the questions I raised below are addressed.
Decision Options	**Initial Decision**	**Final Approval Conditions**
ACCEPT		**12** - the co-sponsor listed on the cover page is TC8.4 and on the first page is TC8.5; I can see that both TCs would be relevant in co-sponsoring this research; however we need the accurate co-sponsorship! the cost of only $150k to develop a test facility and perform roughly 1500 test point don't match up! I know that the performer of RP1444 will no longer be able to bid as he is retiring and his laboratory has been dismantled. that means that there will be a need for significant investment in facilities (beyond $25k; especially due to safety and material compatibility issues with handling NH3)! **6** - No changes necessary. The reference numbers do not match with the reference listed in the reference section - this needs to be updated! **7** - Need to verify issues with bid fall 17? **13** - There are a number of small typos or use of wording that should probably be clarified so bidders will all have the same understanding of what is meant. TC 8.4 is listed as coordinating on cover sheet, but TC 8.5 is listed on page 2. Ammonia use is listed as a preferred refrigerant in industrial refrigeration (pages 2, 5, 6), but is probably more widely used in commercial food and beverage applications (refer to industrial terminology used in ammonia chapter in Ref Hdbk). On p 3, not sure that info on ammonia pressure drop will be used in S&E Chps 23 and 39 which cover external (air, water) fluid flow and heat transfer. Likely to be used in only Ch 5 of Fundamentals. Since R22 has been phased out, probably should refer to R134a or 410A on p 4. On p. 4, says ALL pressure drop studies on ammonia was with straight pipes, then in next sentence says reference 3 already studied ammonia in U-bends. Page 6 refers to return bends and U-bends. What is the difference? Are return bends to be included? Page 7 says condensers are not in the scope of the project, but then later says tests should be adiabatic, so the ammonia in the tube will be neither condensing nor evaporating. U-bend orientation is listed as both horizontal and vertical. For vertical U-bends, should the flow go up or down or both ways? Flow direction will make a difference in the pressure. Should 45 degree angles be included (as in some multirow coil u-bends)? Mass velocity units shows m2, 2 should be superscript. Subtask 3 refers to pressure measurement (singular) when you ask for at least 4 different pressure measurement points. Page 7 last line, contaminates is a verb; you mean contaminants. Some places you use ammonia and some Ammonia; any reason for the caps? For deliverables, you first say SHALL prepare monthly progress reports, then in next paragraph say SHALL prepare quarterly reports. Probably quarterly is correct. For deadline months under project milestones, you list months 5, 8, 13, 25, 28. If they are reporting quarterly, these should probably be 6, 9, 12, 24, 27? **11 -** TC8.4 (or 8.5?) has been listed as a co-sponsor but no votes given. Text overflows the Exec Summary box and is truncated. There are a number of exaggerated claims in this WS: 1) ammonia is a polar molecule, so is R22. The dipole moment of ammonia is 1.5 debye and that of R22 is 1.4 debye, the dipole moment of R134a is even higher at ~2.0 debye; 2) The vapor pressure curves of ammonia and R22 are close and the slope of the vapor pressure curves in the saturated temperature range from -30C to 0C is about the same. At condensing temperatures (~40-50C) dP/dT for ammonia is a little higher than that for R22, meaning that a given pressure change in ammonia in the condenser will result in a smaller change in saturation temperature. If data for R22 U-bend pressure drop exist, it is clear why a new research project is needed for ammonia. The authors of this WS need to include a discussion of the differences between ammonia and R22 in particular as part of the SoA section, and explain why R22 data and correlations, if available, cannot be used as a basis for ammonia. It may be that there are differences between ammonia and R22 that affect 2-phase-flow pressure drop in U-bends beyond the vapor pressure curve slope and dipole moments, e.g., viscosity of vapor and liquid, vapor quality vapor to liquid density ratio, surface tension...etc. The authors need to explicitly address those, rather than just highlight the difference in vapor pressure slopes. It may make more sense to have a project focused on Task 1 first to assess the adequacy of the existing models and correlations and their potential applicability to ammonia before proposing a full study for ammonia. The arguments made to justify this project for ammonia could apply to a wide range of new refrigerants, including the new low GWP refrigerants. A study like Task 1 could highlight if the existing correlations could or could not be applied to these new refrigerants and recommend gaps in our knowledge that need to be addressed through new experimental projects.
COND. ACCEPT		
RETURN	**X**	
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

WORK STATEMENT COVER SHEET

Date: 8/12/2018

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	X
B Executive Summary	X
C. Applicability to ASHRAE Research Strategic Plan	X
D. Application of the Results	X
E. State-of-the-Art (background)	X
F. Advancement to State-of-the-Art	X
G. Justification and Value to ASHRAE	X
H. Objective	X
I. Scope	X
J. Deliverables/Where Results will be Published	X
K. Level of Effort	
Project Duration in Months	X
Professional-Months: Principal Investigator	X
Professional-Months: Total	X
Estimated $ Value	X
L Proposal Evaluation Criteria & Weighting Factors	X
M. References	X
N. Other Information to Bidders (Optional)	X

Title:
Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

WS# 1683
(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

- Fundamentals: Chapter 5 (Two-phase flow)
- Systems & Equipment: Chapter 23 (Air-Cooling)
- Systems and Equipment Chapter 39, Condensers

Responsible TC/TG: 1.3 Heat Transfer and Fluid Flow

Date of Vote: May 2017

For		10
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	2
Total Voting Members		12

This W/S has been coordinated with TC/TG/SSPC (give vote and date):
TC 8.4

Has RTAR been submitted? Yes
Strategic Plan
Theme/Goals

Work Statement Authors: **
Sankar Padhmanabhan
Chad Bowers
Steven Eckels

Proposal Evaluation Subcommittee:
Chair: Steven Eckels, Kansas State University
Members:
Sankar Padhmanabhan, Danfoss
Kashif Nawaz, ORNL
Bruce Nelson, Colmac Coil
Chad Bowers, Ingersoll Rand

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)

Recommended Bidders (name, address, e-mail, tel. number): **

Lorenzo Cremaschi, Auburn University, lorenzo.cremaschi@auburn.edu

Ricardo Lima	HEPIA	ricardo.lima@hesge.ch
Pega Hrnjak	Creative Thermal Solutions	pega@illinois.edu
Xiaofei Wang	University of Illinois	wangxf@illinois.edu
Josua Meyer	Univ of Pretoria	josua.meyer@up.ac.za
Gherhardt Ribatski	Univ of Sao Paulo	ribatski@sc.usp.br

(Three qualified bidders must be recommended, not including WS authors.)

Potential Co-funders (organization, contact person information):

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		X	
Has an electronic copy been furnished to the MORTS?	X		
Will this project result in a special publication?		X	
Has the Research Liaison reviewed work statement?	X		

* Reasons for negative vote(s) and abstentions

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1683

Title:

Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

Sponsoring TC/TG/MTG/SSPC:

TC 1.3

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

TC 8.5

Executive Summary:

The refrigeration community worldwide depends on ASHRAE to provide basic information and knowledge for all t of working fluids, including ammonia. Ammonia is already a preferred refrigerant in many industrial refrigeration applications. Because ammonia is a natural refrigerant with near-zero GWP, it is currently being considered for use many non-traditional commercial refrigeration and air-conditioning applications. In traditional air-to-refrigerant hea exchangers, the refrigerant passes through a series of tubes connected through a U-bend or a return bend. The pressu drop caused by this U-bend is not properly studied in the case of ammonia as the refrigerant. The workstatement de here proposes basic research to develop correlations for pressure drop in U-bends with ammonia. Engineers workin design ammonia evaporators and condensers will be able to make use of this new information to predict refrigerant pressure drop more accurately thereby improving equipment designs for increased efficiency and performance

Applicability to the ASHRAE Research Strategic Plan:

The proposed research will support the following goals of the 2010-2018 ASHRAE Strategic Research Plan:

Goal 8: Facilitate the use of natural and low global warming potential (GWP) synthetic refrigerants and seek methods to reduce their charge.

Ammonia is, of course, a natural refrigerant with extremely low GWP (near zero). The proposed research project will better quantify frictional pressure drop in 180 degree U-bends for this very important refrigerant. Providing heat exchanger designers with accurate two phase pressure drop correlations will allow more accurate predictions of performance for evaporators and condensers, and hence more compact and efficient designs having less internal volume and reduced charge.

Goal 9: Support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety.

Needed Research 12: Conduct studies and experiments to support the proper evaluation of low GWP refrigerants, including exploration of methods for developing compact heat exchangers around the properties of these refrigerants and the impact of low GWP refrigerant heat exchanges on equipment sizing

This project directly supports the development of more compact heat exchangers using low GWP refrigerants.

Application of Results:

The results of the project are to be disseminated to ASHRAE and general society. A technical paper is a specified deliverable from the work. The technical paper is expected to divulge the facts and knowledge acquired as a result of the study. It is expected that a designer will be able to directly apply the results contained in the technical paper. In addition, progress will be periodically reviewed by members of TC 1.3 and other interested parties at the ASHRAE annual and winter meetings for the duration of the project. It is likely that the results will be presented in an ASHRAE seminar or symposium to a wider audience. The correlations developed will be added to the ASHRAE Fundamentals Handbook. Information could also be incorporated in Systems & Equipment Chapters 23 and 39.

State-of-the-Art (Background):

Ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. In addition, the saturation vapor pressure curve for ammonia is steeper than other comparable refrigerants such as R22, especially at lower evaporating temperatures. Thus, the saturation temperature will drop significantly with pressure drop in the evaporator. It is important that an accurate prediction of pressure drop in the evaporator be obtained so as to not operate at evaporating temperatures lower than designed, which will result in inefficient compressor operation.

Performance of ammonia evaporators is very sensitive to pressure drop due to the steep saturation temperature curves. This is especially true at lower evaporating temperatures. Due to this, it is important that the pipe diameter in the ammonia heat exchanger be as large as possible. Another factor that influences the performance of ammonia evaporators is the fact that the liquid density to vapor density for ammonia is significantly higher than for other refrigerants. This means that as quality changes in the evaporator, the void fraction in the evaporator increases significantly. The designer must thus choose the diameter of the pipe carefully so as not to fall into the stratified flow regime. This consideration requires that the pipe diameter be small.

Pressure drop in heat exchangers employing ammonia as the refrigerant has been studied and reported previously [1,2]. All the reported pressure drop studies for ammonia have been done on straight sections of pipe and typically with a single inside diameter of the pipe.

Recent research [3] has focused on visualization and qualitative analysis of two-phase flow of ammonia in U-bends. The study was focused on the visualization of flow regime upstream and downstream of the U-bend and did not capture the changes in the bend itself. Also, experimental data and correlations available from this study are minimal so that no meaningful correlations can be developed.

Information on pressure drop in U-bends is available in the literature for various refrigerants [4,5]. ASHRAE recently concluded a research project studying the pressure drop in U-bends for HFC refrigerants. RP-1444 resulted in a significant data bank for pressure drop in U-bends for HFC refrigerants in use today [6,7].

The overall review of existing literature indicates that there is a significant gap in our understanding of two-phase pressure drop phenomenon for this important low GWP refrigerant, which limits the ability of equipment manufacturers to accurately model and design ammonia evaporators and condensers.

Advancement to the State-of-the-Art:

The proposed work is a follow-up to the very successful RP-1444 which investigated two-phase pressure drop in U-bends for the HFC refrigerants R134a and R410A. This work will fill the research gap discussed in the previous section and will provide a fundamental understanding of how two-phase ammonia behaves as it flows through U-bends. This work will also provide design information and correlations that system designers can use to properly size U-bends to optimize the pressure drop (which will reduce energy consumption) and equipment size (which will promote stewardship of manufacturing and environmental resources). Ammonia is already in wide use as a refrigerant, and as environment regulations continue to encourage the use of Low GWP refrigerants, ammonia use will likely increase. Thus, the fundamental and design information that will be generated from this work is quite timely.

Justification and Value to ASHRAE:

Ammonia, notwithstanding its toxicity, is a popular refrigerant in industrial refrigeration applications. Due to its wide use, the design community is in need of better prediction tools. ASHRAE members and equipment suppliers who are employed in the design of air-to-refrigerant heat exchangers to be used with ammonia will directly benefit from this study. They will be better equipped to design more compact, reliable, and economically competitive heat exchangers.

Objectives:

Ammonia has historically been the preferred refrigerant in industrial refrigeration systems. However, due to increasing interest in natural refrigerants engineers are investigating its use in commercial refrigeration and HVAC systems as well. A good estimate of refrigerant pressure drop is important to design a compact and effective heat exchanger. Heat exchangers used for ammonia are of the conventional fin and tube type which has return bends and U-bends. The objective of this project is to generate data regarding the pressure drop in U-bends in fin and tube heat exchangers used in ammonia applications. The data generated will be used to develop pressure drop correlations and associated void fraction models for U-bends.

Scope/Technical Approach:

The project is anticipated to consist of four major sub-tasks as listed below.

1. Perform a detailed literature review on existing correlations for pressure drop in U-bends. The PI (Principal Investigator) should discuss and explain how the correlations perform for various refrigerants.
2. Developing the test matrix. The test matrix will consist of two-phase pressure drop points that need to be collected in order to develop pressure drop correlations. The test matrix will need to be designed such that relevant parameters can be changed to cover a range of design and operating conditions so that their effect on the two phase pressure drop can be determined. The range that needs to be covered by the test setup is given below. Please note that condensers are not in the scope of this project. The PI is expected to propose the extent of the test matrix in the proposal. The PMS will work with the PI to finalize the experimental conditions for the proposed test points.
    a. Refrigerant: Ammonia
    b. Tube Nominal OD: 3/8", 5/8", 7/8"
    c. U-bend orientation: Horizontal and Vertical
    d. Mass velocities [kg/m2-s]: 10 to 150, with a minimum of 5 mass velocities tested.
    e. Vapor Quality: 0.1 to 0.9, with a minimum of 4 vapor qualities tested.
    f. Saturation temperature: -40 C to 10 C, with a minimum of 4 temperatures tested.
    g. U-bend R/D ratio: 1.2 to 2.5, with a minimum of 3 R/D ratios tested.
3. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend as required by the test matrix. The pressure measurement will be made at both far and near upstream and downstream locations for each point in the test matrix. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1]. The proposal should document the method proposed to measure pressure drop, mass flow, vapor quality, and stability of the system. The PI will also undertake the required uncertainty analysis on the test setup. Location and types of various transducers for pressure temperature and refrigerant flow rate will be agreed upon by the PMS. Please provide details on the flow visualization/flow mapping methodology you are proposing. The purity of the ammonia circulating through the test section is also of key interest. PI should provide a plan for checking the purity of the circulating ammonia documenting that it is free from contaminates and

circulating oil.

Due to the toxic nature of ammonia, it is important that all safety guidelines in the event of a leak of ammonia be followed. The PI should explain in the proposal how the experimental facility will handle Ammonia and previous experience with Ammonia.

4. Perform tests as defined by the test matrix. In the proposal, the PI should provide evidence that a low evaporator temperature of -40 C can be maintained in the proposed facility.
5. The PI is required to compare the experimental results obtained from above task to the results from correlations identifed in Task 1. In case of big deviation, The PI will develop a new correlation (or pressure drop model) which can be used to predict the pressure drop introduced due to a U-bend. The work will also help develop and record the flow patterns near and within U-bend. Such observations will help in formulating an explanation of the behavior and will enable future researchers in developing an analytical pressure drop model. It is highly recommended that proposals follow the approach taken to data reduction and correlation used by Lima and Thome in their work on RP-1444 [2].

<u>Scope/Technical Approach (Continued 3)</u>:

Deliverables/Where Results Will Be Published:

The deliverables are defined with each task and described above. In addition, the contractor shall prepare monthly progress reports and other reports as described below:

Progress, Financial, Interim, and Final Reports, Research or Technical Paper(s), and Data shall constitute required deliverables ("Deliverables") under this Agreement and shall be provided as follows:

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 committee at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

Interim Reports. An interim report at the completion of Task 2 and an interim report at the completion of Task 4 shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services. An electronic copy of each report in Microsoft Word or PDF format shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS). Each report must be approved by the PMS prior to subsequent work.

Final Report. A written report ("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. An electronic copy of the Final Report in Microsoft Word or PDF format shall be furnished for review by the PMS.

Following approval by the PMS and the sponsoring committee, 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 bound copies
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on CD-ROM; one in PDF format and one in Microsoft Word.

Deliverables/Where Results Will Be Published (Continued):

HVAC&R Research or ASHRAE Transactions 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 publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for 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 paper. The paper title shall contain the research project number (XXXX-RP) at the end of the title in parentheses, e.g., (XXXX-RP).

Note: A research or technical paper describing the research project must be submitted after the TC has approved the Final Report. Research or technical papers may also be prepared before the project's completion, if it is desired to disseminate interim results of the project. Contractor shall submit any interim papers to MORTS and the PMS for review and approval before the papers are submitted to ASHRAE Manuscript Central for review.

Data. The Institution agrees to maintain true and complete books and records, including but not limited to notebooks, reports, charts, graphs, analyses, computer programs, visual representations etc., (collectively, the "Data"), generated in connection with the Services. Society representatives shall have access to all such Data for examination and review at reasonable times. The Data shall be held in strict confidence by the Institution and shall not be released to third parties without prior authorization from the Society, except as provided by GENERAL CONDITION VII, PUBLICATION. The original Data shall be kept on file by the Institution for a period of two years after receipt of the final payment and upon request the Institution will make a copy available to the Society upon the Society's request.

Project Synopsis. A written synopsis totaling approximately 100 words in length and written for a broad technical audience shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights. The synopsis should document the main findings of research project, why findings are significant, and 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.

All Deliverables under this Agreement and voluntary 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:

It is estimated that the project will require two (2) professional months of the PI and thirty (30) months effort of research assistants. The project duration is expected to be thirty (30) months including the time to build the experimental facility. The total project cost is estimated at $150k. The cost for the project is itemized as below: 1. Principal Investigator (~2 months) $20k 2. Research Assistants/Technician (~30 months) $105k 3. Lab expense $25k The required time and expenditures to complete the project will of course be dependent on the availability of existing facilities.

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	Contractor's understanding of Work Statement as revealed in proposal based on 1. Knowledge of previous research experimental work 2. Knowledge of previous modeling efforts 3. Explanation of the application of the research	15%
2	Quality of methodology proposed for conducting research based on 1. Proposed method for modeling 2. Proposed data analysis techniques 3. Estimated uncertainties in the data obtained from the system	20%
3	Contractor's capability in terms of facilities based on 1. Design of facility matching current project needs 2. Ability to achieve desired conditions: flow, quality, purity, and pressure. 3. Description of and experience handling ammonia 4.	25%
4	Qualifications of personnel for this project based on: 1. Completion of previous ASHRAE projects 2. Experience managing funded project work with timely completion 3. Evidence of timely publication of project results.	15%
5	Student Involvement	10%
6	Likelihood of meeting the objectives and schedule of the Work Statement based on: 1. Level of operation of current facility 2. Explanation of time schedules 3. Discussion of modeling effort	15%

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month

1	Complete Literature review and identify gaps in current correlations	Month 3
2	Design of the test rig approved by PMS	Month 5
3	Development of test matrix in consultation with PMS	Month 8
4	Construction of test rig and shake down tests complete – Ready for testing (proceeds in parallel with previous task)	Month 13
5	Perform tests from the test matrix developed in Task 3	Month 25
6	Comparison of data against existing correlations and development of new correlations as applicable	Month 28
7	Submission of Final report approved by PMS	Month 30

Authors:

Sankar Padhmanabhan, Chad Bowers, Steven Eckels

References:

1. Shah, M. M., 1974. "Heat Transfer and Pressure Drop in Ammonia Evaporators". ASHRAE Transactions 80(2) 2. Lima, R. J., Quiben, J. M., Kuhn, C., Boyman, T., Thome, J. R. 2009. "Ammonia two-phase flow in a horizontal smooth tube: Flow pattern observations, diabatic and adiabatic frictional pressure drops and assessment of prediction methods". Int. Journam of Heat and Mass Transfer, vol 52, pp:2273-2288.
2. Cotter, D. 2009. “Improvement of the Heat Transfer Performance of and Ammonia Air Cooler”. PhD Thesis.London South Bank University.
3. Tran, C. C., Gupta, S., Chato, J. C., Newell, T.A. 2000. "An Experimental Study of Return Bend Effects onPressure Drop and Void Fraction". Proc. of International Refrigeration and Air-Conditioning Conference, Purdue University.
4. Geary, D. F. 1975. Return Bend Drop in Refrigeration Systems. ASHRAE Transactions, 81:250-265.
5. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN:1078-9669 print/1938-5587 online.
6. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous StraightTubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN:1078-9669 print/1938-5587 onlin

Other Information for Bidders (Optional):

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1683-TRP, Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

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: TC1.3, Liquid to Refrigerant Heat Exchangers
Co-sponsored by: TC 8.4, Air to Refrigerant Heat Transfer Equipment

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

Scheduled Project Start Date: **TBD** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, TBD. 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: 1683-TRP, Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia, 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
Sankar Padhmanabhan
Danfoss
11655 Crossroads Circle
Baltimore, MD 21220-9914
Phone: 410-513-1149
Email: sankar@danfoss.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: 678-539-2111
E-Mail: MORTS@ashrae.net

Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by TBD 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. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, TBD.**
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 Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

Ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. In addition, the saturation vapor pressure curve for ammonia is steeper than other comparable refrigerants such as R22, especially at lower evaporating temperatures. Thus, the saturation temperature will drop significantly with pressure drop in the evaporator. It is important that an accurate prediction of pressure drop in the evaporator be obtained so as to not operate at evaporating temperatures lower than designed, which will result in inefficient compressor operation.

Performance of ammonia evaporators is very sensitive to pressure drop due to the steep saturation temperature curves. This is especially true at lower evaporating temperatures. Due to this, it is important that the pipe diameter in the ammonia heat exchanger be as large as possible. Another factor that influences the performance of ammonia evaporators is the fact that the liquid density to vapor density for ammonia is significantly higher than for other refrigerants. This means that as quality changes in the evaporator, the void fraction in the evaporator increases significantly. The designer must thus choose the diameter of the pipe carefully so as not to fall into the stratified flow regime. This consideration requires that the pipe diameter be small.

Pressure drop in heat exchangers employing ammonia as the refrigerant has been studied and reported previously [1,2]. All the reported pressure drop studies for ammonia have been done on straight sections of pipe and typically with a single inside diameter of the pipe.

Recent research [3] has focused on visualization and qualitative analysis of two-phase flow of ammonia in U-bends. The study was focused on the visualization of flow regime upstream and downstream of the U-bend and did not capture the changes in the bend itself. Also, experimental data and correlations available from this study are minimal so that no meaningful correlations can be developed.

Information on pressure drop in U-bends is available in the literature for various refrigerants [4,5]. ASHRAE recently concluded a research project studying the pressure drop in U-bends for HFC refrigerants. RP-1444 resulted in a significant data bank for pressure drop in U-bends for HFC refrigerants in use today [6,7].

The overall review of existing literature indicates that there is a significant gap in our understanding of two-phase pressure drop phenomenon for this important low GWP refrigerant, which limits the ability of equipment manufacturers to accurately model and design ammonia evaporators and condensers.

Justification and Value to ASHRAE

Ammonia, notwithstanding its toxicity, is a popular refrigerant in industrial refrigeration applications. Due to its wide use, the design community is in need of better prediction tools. ASHRAE members and equipment suppliers who are employed in the design of air-to-refrigerant heat exchangers to be used with ammonia will directly benefit from this study. They will be better equipped to design more compact, reliable, and economically competitive heat exchangers.

Objective

Ammonia has historically been the preferred refrigerant in industrial refrigeration systems. However, due to increasing interest in natural refrigerants engineers are investigating its use in commercial refrigeration and HVAC systems as well. A good estimate of refrigerant pressure drop is important to design a compact and effective heat exchanger. Heat exchangers used for ammonia are of the conventional fin and tube type which has return bends and U-bends. The objective of this project is to generate data regarding the pressure drop in U-bends in fin and tube heat exchangers used in ammonia applications. The data generated will be used to develop pressure drop correlations and associated void fraction models for U-bends.

Scope:

The project is anticipated to consist of four major sub-tasks as listed below.

1. Perform a detailed literature review on existing correlations for pressure drop in U-bends. The PI (Principal Investigator) should discuss and explain how the correlations perform for various refrigerants.

2. Developing the test matrix. The test matrix will consist of two-phase pressure drop points that need to be collected in order to develop pressure drop correlations. The test matrix will need to be designed such that relevant parameters can be changed to cover a range of design and operating conditions so that their effect on the two phase pressure drop can be determined. The range that needs to be covered by the test setup is given below. While the parameters shown in the table cover a wide range, the exact test matrix will be evaluated by the PMS and the PI, and test points will be established. Please note that condensers are not in the scope of this project. The final test matrix must be approved by the PMS before testing beings.

   a. Refrigerant: Ammonia
   b. Tube Nominal OD: 3/8", 5/8", 7/8"
   c. U-bend orientation: Horizontal and Vertical
   d. Mass velocities [kg/m2-s]: 10 to 150, with a minimum of 5 mass velocities tested.
   e. Vapor Quality: 0.1 to 0.9, with a minimum of 4 vapor qualities tested.
   f. Saturation temperature: -40 C to 10 C, with a minimum of 4 temperatures tested.
   g. U-bend R/D ratio: 1.2 to 2.5, with a minimum of 3 R/D ratios tested.

3. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend as required by the test matrix. The pressure measurement will be made at both far and near upstream and downstream locations for each point in the test matrix. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1]. The PI will also undertake the required uncertainty analysis on the test setup. Location and types of various transducers for pressure temperature and refrigerant flow rate will be agreed upon by the PMS. Since the objective of this project is to isolate the pressure drop and flow regime in the U-bends, it is important that enough care be given to visualize the flow in addition to measuring the pressure drop.

   Due to the toxic nature of ammonia, it is important that all safety guidelines in the event of a leak of ammonia be followed.

4. Perform tests as defined by the test matrix.

5. The PI is required to compare the experimental results obtained from above task to the results from correlations identifed in Task 1. In case of big deviation, The PI will develop a new correlation (or pressure drop model) which can be used to predict the pressure drop introduced due to a U-bend. The work will also help develop and record the flow patterns near and within U-bend. Such observations will help in formulating an explanation of the behavior and will enable future researchers in developing an analytical pressure drop model. It is highly recommended that proposals follow the approach taken to data reduction and correlation used by Lima and Thome in their work on RP-1444 [2].

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. Interim Reports

An interim report at the completion of Task 2 and an interim report at the completion of Task 4 shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services. An electronic copy of each report in Microsoft Word or PDF format shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS). Each report must be approved by the PMS prior to subsequent work.

c. 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.

d. *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 Research Papers for HVAC&R Research or Technical Paper(s) for 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 (1683-RP) at the end of the title in parentheses, e.g., (1683-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.

e. Data

Data is defined in General Condition VI, "DATA"

f. 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

It is estimated that the project will require two (2) professional months of the PI and thirty (30) months effort of research assistants. The project duration is expected to be thirty (30) months including the time to build the experimental facility. The total project cost is estimated at $150k. The cost for the project is itemized as below:

Principal Investigator (~2 months) $20k;
Research Assistants/Technician (~30 months) $105k
Lab expense $25k

The required time and expenditures to complete the project will of course be dependent on the availability of existing facilities.

Project Milestones:

Project milestones, the expected month of completion, and the expected funds required for the milestone are listed below. At the beginning of the project, it will likely be necessary to work on tasks in parallel to maintain the project timeline. At the completion of each milestone, the results from that milestone will be submitted to the PMS. The PMS will review and approve the results submitted for that milestone before the investigator can move to the next milestone.

No.	Major Project Completion Milestone	Deadline Month
1	Complete literature review and identify gaps in current correlations	3
2	Design of the test rig and approval by PMS	5
3	Development of test matrix in consultation with PMS	8
4	Finish construction of test rig and shake down tests complete – Ready for testing (proceeds in parallel with previous task)	13
5	Perform tests from the test matrix developed in Task 3	25
6	Comparison of data against existing correlations and development of new proposed correlations as applicable	26
7	Finalization of correlations	28
8	Submission of Final Report and approval by PMS	30

Proposal Evaluation Criteria

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

No.	Proposal Review Criterion	Weighting Factor
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

1. Shah, M. M., 1974. "Heat Transfer and Pressure Drop in Ammonia Evaporators". ASHRAE Transactions 80(2)
2. Lima, R. J., Quiben, J. M., Kuhn, C., Boyman, T., Thome, J. R. 2009. "Ammonia two-phase flow in a horizontal smooth tube: Flow pattern observations, diabatic and adiabatic frictional pressure drops and assessment of prediction methods". Int. Journam of Heat and Mass Transfer, vol 52, pp: 2273-2288.
3. Cotter, D. 2009. "Improvement of the Heat Transfer Performance of and Ammonia Air Cooler". PhD Thesis.London South Bank University.
4. Tran, C. C., Gupta, S., Chato, J. C., Newell, T.A. 2000. "An Experimental Study of Return Bend Effects onPressure Drop and Void Fraction". Proc. of International Refrigeration and Air-Conditioning Conference, Purdue University.
5. Geary, D. F. 1975. Return Bend Drop in Refrigeration Systems. ASHRAE Transactions, 81:250-265.
6. Lima, R. J. D, Thome, J. R., 2012. "Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)". HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN: 1078-9669 print/1938-5587 online.
7. Lima, R. J. D, Thome, J. R., 2012. "Two-Phase Frictional Pressure Drops in U-bends and Contiguous StraightTubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)". HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN: 1078-9669 print/1938-5587 online.

WORK STATEMENT COVER SHEET

Date: May 12, 2017

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	✔
B Executive Summary	✔
C. Applicability to ASHRAE Research Strategic Plan	
D. Application of the Results	✔
E. State-of-the-Art (background)	✔
F. Advancement to State-of-the-Art	✔
G. Justification and Value to ASHRAE	✔
H. Objective	✔
I. Scope	✔
J. Deliverables/Where Results will be Published	✔
K. Level of Effort	
Project Duration in Months	✔
Professional-Months: Principal Investigator	✔
Professional-Months: Total	✔
Estimated $ Value	✔
L Proposal Evaluation Criteria & Weighting Factors	✔
M. References	✔
N. Other Information to Bidders (Optional)	

Title:
Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

WS# 1683-WS
(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

- Fundamentals: Chapter 5 (Two-phase flow)
- Systems & Equipments: Chapter 23 (Air-Cooling and Dehumidifying coils), Chapter 39 (Condensers)

Responsible TC/TG: 1.3 Heat Transfer & Fluid Flow

Date of Vote: 5/12/2017 email ballot

For		10
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	2
Total Voting Members		12

This W/S has been coordinated with TC/TG/SSPC (give vote and date):
TC 8.4: vote was (for-against-abstain-not voting) 5-0-2-3; email

Has RTAR been submitted? YES
Strategic Plan
Theme/Goals

Work Statement Authors: **
SANKAR PADHMANABHAN, CHAD BOWERS

Proposal Evaluation Subcommittee:
Chair: Sankar Padhmanabhan
Members:
Chad Bowers
Kashif Nwaz
Marios Georgiou
Evraam Gorgy

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)
SAME

Recommended Bidders (name, address, e-mail, tel. number): **

Lorenzo Cremaschi, Ph.D., Associate Professor
Department of Mechanical Engineering
Auburn University
2446 Wiggins Hall, Auburn, AL, 36849
Phone: 334-844-3302
Fax: 334-844-3307
Email: lorenzo.cremaschi@auburn.edu

Prof. Dr. Ricardo Lima
HEDIA

(**Three qualified bidders must be recommended, not including WS authors.)**

Potential Co-funders (organization, contact person information):

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		✔	
Has an electronic copy been furnished to the MORTS?	✔		
Will this project result in a special publication?		✔	
Has the Research Liaison reviewed work statement?	✔		

* Reasons for negative vote(s) and abstentions

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1683

Title:

Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

Sponsoring TC/TG/MTG/SSPC:

TC1.3 Liquid to Refrigerant Heat Exchangers

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

TC8.4 Air to Refrigerant Heat Transfer Equipment

Executive Summary:

The refrigeration community worldwide depends on ASHRAE to provide basic information and knowledge for all types of working fluids, including ammonia. Ammonia is already a preferred refrigerant in many industrial refrigeration applications. Because ammonia is a natural refrigerant with near-zero GWP, it is currently being considered for use in many non-traditional commercial refrigeration and air-conditioning applications as well. In traditional air-to-refrigerant heat exchangers the refrigerant passes through a series of tubes connected through a U-bend or a return bend. The pressure drop caused by this U-bend is not properly studied in the case of ammonia as refrigerant. The work statement described here proposes basic research to develop correlations for pressure drop in U-bends with ammonia. Engineers working to design ammonia evaporators and condensers will be able to make use of this new information to predict refrigerant pressure drop more accurately thereby improving equipment designs for increased efficiency and performance.

Applicability to the ASHRAE Research Strategic Plan:

The proposed research will support the following goals of the 2010-2018 ASHRAE Strategic Research Plan:

Goal 8: Facilitate the use of natural and low global warming potential (GWP) synthetic refrigerants and seek methods to reduce their charge.

Ammonia is, of course, a natural refrigerant with extremely low GWP (near zero). The proposed research project will better quantify frictional pressure drop in 180 degree U-bends for this very important refrigerant. Providing heat exchanger designers with accurate two phase pressure drop correlations will allow more accurate predictions of performance for evaporators and condensers, and hence more compact

Application of Results:

The results of the project are to be disseminated to ASHRAE and general society. A technical paper is a specified deliverable from the work. The technical paper is expected to divulge the facts and knowledge acquired as a result of the study. It is expected that a designer will be able to directly apply the results contained in the technical paper. In addition, progress will be periodically reviewed by members of TC 1.3 and other interested parties at the ASHRAE annual and winter meetings for the duration of the project. It is likely that the results will be presented in an ASHRAE seminar or symposium to a wider audience. The correlations developed will be added to the ASHRAE Fundamentals Handbook. Information could also be incorporated in Systems & Equipment Chapters 23 and 39.

State-of-the-Art (Background):

Ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. In addition, the saturation vapor pressure curve for ammonia is steeper than other comparable refrigerants such as R22, especially at lower evaporating temperatures. Thus, the saturation temperature will drop significantly with pressure drop in the evaporator. It is important that an accurate prediction of pressure drop in the evaporator be obtained so as to not operate at evaporating temperatures lower than designed, which will result in inefficient compressor operation.

Performance of ammonia evaporators is very sensitive to pressure drop due to the steep saturation temperature curves. This is especially true at lower evaporating temperatures. Due to this, it is important that the pipe diameter in the ammonia heat exchanger be as large as possible. Another factor that influences the performance of ammonia evaporators is the fact that the liquid density to vapor density for ammonia is significantly higher than for other refrigerants. This means that as quality changes in the evaporator, the void fraction in the evaporator increases significantly. The designer must thus choose the diameter of the pipe carefully so as not to fall into the stratified flow regime. This consideration requires

Advancement to the State-of-the-Art:

The proposed work is a follow-up to the very successful RP-1444 which investigated two-phase pressure drop in U-bends for the HFC refrigerants R134a and R410A. This work will fill the research gap discussed in the previous section and will provide a fundamental understanding of how two-phase ammonia behaves as it flows through U-bends. This work will also provide design information and correlations that system designers can use to properly size U-bends to optimize the pressure drop (which will reduce energy consumption) and equipment size (which will promote stewardship of manufacturing and environmental resources). Ammonia is already in wide use as a refrigerant, and as environment regulations continue to encourage the use of Low GWP refrigerants, ammonia use will likely increase. Thus, the fundamental and design information that will be generated from this work is quite timely.

Justification and Value to ASHRAE:

Ammonia, notwithstanding its toxicity, is a popular refrigerant in industrial refrigeration applications. Due to its wide use, the design community is in need of better prediction tools. ASHRAE members and equipment suppliers who are employed in the design of air-to-refrigerant heat exchangers to be used with ammonia will directly benefit from this study. They will be better equipped to design more compact, reliable, and economically competitive heat exchangers.

Objectives:

Ammonia has historically been the preferred refrigerant in industrial refrigeration systems. However, due to increasing interest in natural refrigerants engineers are investigating its use in commercial refrigeration and HVAC systems as well. A good estimate of refrigerant pressure drop is important to design a compact and effective heat exchanger. Heat exchangers used for ammonia are of the conventional fin and tube type which has return bends and U-bends. The objective of this project is to generate data regarding the pressure drop in U-bends in fin and tube heat exchangers used in ammonia applications. The data generated will be used to develop pressure drop correlations and associated void fraction models for U-bends.

Scope/Technical Approach:

The project is anticipated to consist of four major sub-tasks as listed below.

1. Perform a detailed literature review on existing correlations for pressure drop in U-bends. The PI should discuss and explain how the correlations perform for various refrigerants.

2. Developing the test matrix. The test matrix will need to be designed such that relevant parameters can be changed to cover a range of design and operating conditions. The range that needs to be covered by the test setup is given below. While the parameters shown in the table cover a wide range, the exact test matrix will be evaluated by the PMS and the PI, and test points will be established. Please note that condensers are not in the scope of this project.

   a. Refrigerant: Ammonia

   b. Tube Nominal OD: 3/8", 5/8", 7/8"

   c. U-bend orientation: Horizontal and Vertical

   d. Mass velocities [kg/m2-s]: 10 to 150

   e. Vapor Quality: 0.1 to 0.9

   f. Saturation temperature: -40 C to 10 C

   g. U-bend R/D ratio: 1.2 to 2.5

3. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend. The pressure measurement will be made at both far and near upstream and downstream locations. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1]. The PI will also undertake the required uncertainty analysis on the test setup. Location and types of various transducers for pressure temperature and refrigerant flow rate will be agreed upon by the PMS. Since the objective of this project is to isolate the pressure drop and flow regime in the U-bends, it is important that enough care be given to visualize the flow in addition to measuring the pressure drop.

Due to the toxic nature of ammonia, it is important that all safety guidelines in the event of a leak of ammonia be followed.

4. Perform tests as defined by the test matrix.

5. The PI is required to compare the experimental results obtained from above task to the results

<u>Scope/Technical Approach (Continued 2)</u>:

<u>Scope/Technical Approach (Continued 3)</u>:

Deliverables/Where Results Will Be Published:

The deliverables are defined with each task and described above. In addition, the contractor shall prepare monthly progress reports and other reports as described below:

Progress, Financial, Interim, and Final Reports, Research or Technical Paper(s), and Data shall constitute required deliverables ("Deliverables") under this Agreement and shall be provided as follows:

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 committee at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

Interim Reports. An interim report at the completion of Task 2 and an interim report at the completion of Task 4 shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services. An electronic copy of each report in Microsoft Word or PDF format shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS). Each report must be approved by the PMS prior to subsequent work.

Final Report. A written report ("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. An electronic copy of the Final Report in Microsoft Word or PDF format shall be furnished for review by the PMS.

Following approval by the PMS and the sponsoring committee, 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 bound copies
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on CD-ROM; one in PDF format and one in Microsoft Word.

HVAC&R Research or ASHRAE Transactions 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 publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE

Deliverables/Where Results Will Be Published (Continued):

Level of Effort:

It is estimated that the project will require two (2) professional months of the PI and thirty (30) months effort of research assistants. The project duration is expected to be thirty (30) months including the time to build the experimental facility. The total project cost is estimated at $150k. The cost for the project is itemized as below:

1. Principal Investigator (~2 months) $20k
2. Research Assistants/Technician (~30 months) $105k

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	1. Contractor's understanding of Work Statement as revealed in proposal: 20%	
2	2. Quality of methodology proposed for conducting research: 20%	
3	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%	

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	1. Complete literature review and identify gaps in current correlations, Month 3, $10,000	
2	2. Design of the test rig and approval by PMS, Month 5, $10,000	
3	3. Development of test matrix in consultation with PMS, Month 8, $20,000 4. Finish construction of test rig and shake down tests complete – Ready for testing (proceeds in parallel with previous task), Month 13, $30,000 5. Perform tests from the test matrix developed in Task 3, Month 25, $60,000	

Authors:

SANKAR PADHMANABHAN, CHAD BOWERS

References:

1. Shah, M. M., 1974. "Heat Transfer and Pressure Drop in Ammonia Evaporators". ASHRAE Transactions 80(2)
2. Lima, R. J., Quiben, J. M., Kuhn, C., Boyman, T., Thome, J. R. 2009. "Ammonia two-phase flow in a horizontal smooth tube: Flow pattern observations, diabatic and adiabatic frictional pressure drops and assessment of prediction methods". Int. Journam of Heat and Mass Transfer, vol 52, pp:2273-2288.
3. Cotter, D. 2009. “Improvement of the Heat Transfer Performance of and Ammonia Air Cooler”. PhD Thesis.London South Bank University.
4. Tran, C. C., Gupta, S., Chato, J. C., Newell, T.A. 2000. "An Experimental Study of Return Bend Effects onPressure Drop and Void Fraction". Proc. of International Refrigeration and Air-Conditioning Conference, Purdue University.
5. Geary, D. F. 1975. Return Bend Drop in Refrigeration Systems. ASHRAE Transactions, 81:250-265.
6. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN:1078-9669 print/1938-5587 online.
7. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous StraightTubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN:1078-9669 print/1938-5587 online.

Other Information for Bidders (Optional):

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

To: Michael Vaughn, MORTS

From: Joseph Huber, Research Subcommittee Chair TC 1.3

Date: May 2, 2017

Subject: Response to RAC comments for 1683-WS

The work statement authors have provided the following responses to most recent RAC comments for this project.

1. The individual tasks require additional description. Not enough specificity regarding number of tests.
Additional tasks have been added to provide more detail. Specific test points will be decided during discussions with PMS. The test matrix mentioned in the WS covers is a wide range to allow flexibility for the PMS and investigator.

2. Provide a better list of milestones need for PMS to manage this research.
The list of milestones has been expanded and enhanced to include the target month when the task is expected to be completed and an estimation of the funding amount required.

3. Check to see if co-funding can be secured with IIAR.
We are in discussion with IIAR. A change in the governing structure within IIAR is slowing down the process. We will continue to engage IIAR and see if any co-funding can be secured for this project.

4. In task 5, need to change the work "expected" to required.
The recommended change has been incorporated into Task 5.

5. Why is Advancement to the State-of-the-Art blank.
This section has been added.

6. Needs better description of intermediate milestones.
This comment seems to be the same as #2, and has been addressed above.

Shaping Tomorrow's Built Environment Today

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Michael R. Vaughn, P.E.
Manager
Research & Technical Services

mvaughn@ashrae.org

TO: Raymond Rite, Chair TC 1.3, ray.rite@irco.com
Joseph Huber, Research Subcommittee Chair TC 1.3, joe.huber@alfalaval.com
Shinsuke Kato, Research Liaison Section 1.0, kato@iis.u-tokyo.ac.jp

FROM: Michael Vaughn, MORTS, MORTS@ASHRAE.net

DATE: February 10, 2017

SUBJECT: Work Statement (1683-WS), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

During their recent winter meeting, the Research Administration Committee (RAC) reviewed the subject Work Statement (WS) and voted to return with comments.

Below are the issues, concerns, and questions that must be addressed in your next submission of the WS if you choose to resubmit.

1. The individual tasks require additional description. Not enough specificity regarding number of tests.
2. Provide a better list of milestones need for PMS to manage this research.
3. Check to see if co-funding can be secured with IIAR.
4. In task 5, need to change the work "expected" to required?
5. Why is Advancement to the State-of-the-Art blank?
6. Needs better description of intermediate milestones.

Please coordinate changes to this Work Statement with your Research Liaison, Shinsuke Kato, kato@iis.u-tokyo.ac.jp or RL1@ashrae.org prior to resubmitting it to the Manager of Research and Technical Services for further consideration by RAC.

Also, it is necessary that you provide a new TC vote on the revised Work Statement, and a letter describing how each of the above items were addressed in the revision.

If you wish for this work statement to be reconsidered at the next RAC meeting, the revised Work Statement must be sent (electronically) to Mike Vaughn, Manager of Research and Technical Services (morts@ashrae.net) by May 15, 2017. The next opportunity for consideration after this deadline is August 15, 2017.

Project ID	**1683**	
Project Title	**Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia**	
Sponsoring TC	Co-sponsored: TC 8.4 (Air-to-Refrigerant Heat Transfer Equipment)	
Cost / Duration	$150,000 / 30M	
Submission History	**4th WS Submission, 3rd Submission Nov. 2015, 2nd Submission Oct. 2013, 1st Submission Oct. 2012**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2017 Winter Meeting Review	**RTAR STAGE FOLLOWED**	
Check List Criteria	**Voted NO**	**Comments & Suggestions**
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		#9 - 5 bidders referenced #3 - 8 potential bidders provided. #14 - 8 bidders listed with complete contact information. SK - Good list of potential bidders, well known, well respected. HS - 8 bidders!
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		**#9** - WS and project description are well written **#3** - Straightforward, if minimal, description of the required tasks **#14** - he authors cite RP1444 and justify the need for the present project on the basis of the large differences between the thermophysical properties of ammonia and HFCs. Although water is not suitable as a refrigeration working fluid, its thermophysical properties are even farther from those of HFC than ammonia's, and there are probably a lot more 2-phase flow data on water/steam than any other fluid. Shouldn't data on water and steam be considered to guide this research? Advancing the SOA is empty. **#10** - Missing section on "Advancement to the State-of-the-Art, but expected content in prior sections. Scope/Technical Approach is brief, with detail to be provided by negotiation between PMS and contractor. Is this a problem? Should the WS contain an example test matrix to illustrate expectations within which there can be flexibility and trade-offs? I tend to think so.
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.	**#9**	**#9** - Task are defined but would like to see approval by PMS on tasks 1, 4 and 5 before proceeding. Task 1, the PMS should approve literature review. Task 4 PMS should be involved and approved performance tests. PMS should approve the the beginning and end of task 5. **#14** - 5 Tasks described in sufficient detail.The literature search should also consider water correlations. **#7** - There is uncertainty in the task test matrix since the PMS will work with the PI to develop, but will be following RP1444, so likely ok. Is an baseline know refrigerant should be conducted so that the rig can be debugged or previous work replicated. Due to the toxic nature of Ammonia, should there be an FMEA conducted as one of the tasks and reviewed by the PMS. Should more $$ go to building the rig because of this? Monitors can be expensive . **#10** - No uncertainty/experimental quality evaluation found. How do we know how confident we can be of the results?
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.	**#3, #7**	**#3** - Page 11 says Project Milestones associated with Tasks 1, 2 and 5. But these are not very descriptive. WS mentions interim reports after Tasks 2 and 4. Are those the real milestones? TC needs to go think this through. **#14** - Deliverables of each technical task are not specifically listed. They are embedded in the task descriptions. They should be listed explicitly. Reporting deliverables are explicit and detailed.
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		**#3** - Overall the projects seems well thought out and achievable.
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		**#9** The comments from the RTAR was that 36 months seems a bit long. Not sure is 30 months addresses this comment **#3** - Overall the projects seems well thought out and achievable. #3 - 30 months seems like a long time given the cost. **#7** - Maybe need for $$ for ammonia safety. Should there be a co-funding from IIAR to bring this to the attention of their members. HS - I am not an experimentalist, but looks reasonable. #14 -I don't see the value of listing budget distribution in a SoW. The SoW should state that the bidders need to provide a break-up of the budget among PI, assistants, materials, equipment, etc, but not prescribe the actual split.
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**#14** - After changes have been made as described above.
Decision Options	**Initial Decision**	**Final Approval Conditions**
ACCEPT		**#11** - The individual tasks require additional description. Not enough specificity regarding number of tests. Not all sections of the WS form have been completed. **#9** - I would like to see approval of each task be included in the WS before proceeding to the next task. This is especially important in task 5 which is the summary of the project. In task 5, need to change the work "expected" to required? Also in this task is "highly recommended" correct? Make sure TC 8.4 is invited to join the PES/PMS. Why is Advancement to the State-of-the-Art blank? **#3** - Cover sheet explains one abstention, what about the other? And why 3 not voting? Needs better description of intermediate milestones. #7 - More breakdown of tasks and deliverables with specifically calling out the deliverable at each step. Also there should be a call out for a go-no go under the test rig development in case there is a large amount of rework needed that would cause it to go over budget or the safety protocol cause the project to go over budget. Should there be a co-funding from IIAR to bring this to the attention of their members. #10 - In my opinion, the TC has satisfactorily responded to concerns that the proposed project overlaps too much with a recent Ph.D. dissertation by Cotter. I think the project would be much better if a proposed test matrix were included in the bid document, or at least the estimated number of trials stipulated. As it is, the bidder faces huge uncertainties about the extent of the experimental work to be required. #14 - TC1.3 (10/0/1/1). Co-sponsored by TC8.4 (5/0/2/3).
COND. ACCEPT	**#9, #3, #14, #10**	
RETURN	**#11**	
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

WORK STATEMENT COVER SHEET

Date: May 12, 2017

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	✔
B Executive Summary	✔
C. Applicability to ASHRAE Research Strategic Plan	
D. Application of the Results	✔
E. State-of-the-Art (background)	✔
F. Advancement to State-of-the-Art	✔
G. Justification and Value to ASHRAE	✔
H. Objective	✔
I. Scope	✔
J. Deliverables/Where Results will be Published	✔
K. Level of Effort	
Project Duration in Months	✔
Professional-Months: Principal Investigator	✔
Professional-Months: Total	✔
Estimated $ Value	✔
L Proposal Evaluation Criteria & Weighting Factors	✔
M. References	✔
N. Other Information to Bidders (Optional)	

Title:
Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

WS# 1683-WS
(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

- Fundamentals: Chapter 5 (Two-phase flow)
- Systems & Equipments: Chapter 23 (Air-Cooling and Dehumidifying coils), Chapter 39 (Condensers)

Responsible TC/TG: TC1.3 Liquid to Refrigerant Heat Exchangers

Date of Vote: 5/12/2017 email ballot

For		10
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	2
Total Voting Members		12

This W/S has been coordinated with TC/TG/SSPC (give vote and date):
TC 8.4: vote was (for-against-abstain-not voting) 5-0-2-3; email

Has RTAR been submitted? YES
Strategic Plan
Theme/Goals

Work Statement Authors: **
SANKAR PADHMANABHAN, CHAD BOWERS

Proposal Evaluation Subcommittee:
Chair: Sankar Padhmanabhan
Members:
Chad Bowers
Kashif Nwaz
Marios Georgiou
Evraam Gorgy

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)
SAME

Recommended Bidders (name, address, e-mail, tel. number): **

Lorenzo Cremaschi, Ph.D., Associate Professor
Department of Mechanical Engineering
Auburn University
2446 Wiggins Hall, Auburn, AL, 36849
Phone: 334-844-3302
Fax: 334-844-3307
Email: lorenzo.cremaschi@auburn.edu

Prof. Dr. Ricardo Lima
UFPIA

Potential Co-funders (organization, contact person information):

(**Three qualified bidders must be recommended, not including WS authors.)**

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		✔	
Has an electronic copy been furnished to the MORTS?	✔		
Will this project result in a special publication?		✔	
Has the Research Liaison reviewed work statement?	✔		

* Reasons for negative vote(s) and abstentions

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1683

Title:

Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

Sponsoring TC/TG/MTG/SSPC:

TC1.3 Liquid to Refrigerant Heat Exchangers

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

TC8.4 Air to Refrigerant Heat Transfer Equipment

Executive Summary:

The refrigeration community worldwide depends on ASHRAE to provide basic information and knowledge for all types of working fluids, including ammonia. Ammonia is already a preferred refrigerant in many industrial refrigeration applications. Because ammonia is a natural refrigerant with near-zero GWP, it is currently being considered for use in many non-traditional commercial refrigeration and air-conditioning applications as well. In traditional air-to-refrigerant heat exchangers the refrigerant passes through a series of tubes connected through a U-bend or a return bend. The pressure drop caused by this U-bend is not properly studied in the case of ammonia as refrigerant. The work statement described here proposes basic research to develop correlations for pressure drop in U-bends with ammonia. Engineers working to design ammonia evaporators and condensers will be able to make use of this new information to predict refrigerant pressure drop more accurately thereby improving equipment designs for increased efficiency and performance.

Applicability to the ASHRAE Research Strategic Plan:

The proposed research will support the following goals of the 2010-2018 ASHRAE Strategic Research Plan:

Goal 8: Facilitate the use of natural and low global warming potential (GWP) synthetic refrigerants and seek methods to reduce their charge.

Ammonia is, of course, a natural refrigerant with extremely low GWP (near zero). The proposed research project will better quantify frictional pressure drop in 180 degree U-bends for this very important refrigerant. Providing heat exchanger designers with accurate two phase pressure drop correlations will allow more accurate predictions of performance for evaporators and condensers, and hence more compact

Application of Results:

The results of the project are to be disseminated to ASHRAE and general society. A technical paper is a specified deliverable from the work. The technical paper is expected to divulge the facts and knowledge acquired as a result of the study. It is expected that a designer will be able to directly apply the results contained in the technical paper. In addition, progress will be periodically reviewed by members of TC 1.3 and other interested parties at the ASHRAE annual and winter meetings for the duration of the project. It is likely that the results will be presented in an ASHRAE seminar or symposium to a wider audience. The correlations developed will be added to the ASHRAE Fundamentals Handbook. Information could also be incorporated in Systems & Equipment Chapters 23 and 39.

State-of-the-Art (Background):

Ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. In addition, the saturation vapor pressure curve for ammonia is steeper than other comparable refrigerants such as R22, especially at lower evaporating temperatures. Thus, the saturation temperature will drop significantly with pressure drop in the evaporator. It is important that an accurate prediction of pressure drop in the evaporator be obtained so as to not operate at evaporating temperatures lower than designed, which will result in inefficient compressor operation.

Performance of ammonia evaporators is very sensitive to pressure drop due to the steep saturation temperature curves. This is especially true at lower evaporating temperatures. Due to this, it is important that the pipe diameter in the ammonia heat exchanger be as large as possible. Another factor that influences the performance of ammonia evaporators is the fact that the liquid density to vapor density for ammonia is significantly higher than for other refrigerants. This means that as quality changes in the evaporator, the void fraction in the evaporator increases significantly. The designer must thus choose the diameter of the pipe carefully so as not to fall into the stratified flow regime. This consideration requires

Advancement to the State-of-the-Art:

The proposed work is a follow-up to the very successful RP-1444 which investigated two-phase pressure drop in U-bends for the HFC refrigerants R134a and R410A. This work will fill the research gap discussed in the previous section and will provide a fundamental understanding of how two-phase ammonia behaves as it flows through U-bends. This work will also provide design information and correlations that system designers can use to properly size U-bends to optimize the pressure drop (which will reduce energy consumption) and equipment size (which will promote stewardship of manufacturing and environmental resources). Ammonia is already in wide use as a refrigerant, and as environment regulations continue to encourage the use of Low GWP refrigerants, ammonia use will likely increase. Thus, the fundamental and design information that will be generated from this work is quite timely.

Justification and Value to ASHRAE:

Ammonia, notwithstanding its toxicity, is a popular refrigerant in industrial refrigeration applications. Due to its wide use, the design community is in need of better prediction tools. ASHRAE members and equipment suppliers who are employed in the design of air-to-refrigerant heat exchangers to be used with ammonia will directly benefit from this study. They will be better equipped to design more compact, reliable, and economically competitive heat exchangers.

Objectives:

Ammonia has historically been the preferred refrigerant in industrial refrigeration systems. However, due to increasing interest in natural refrigerants engineers are investigating its use in commercial refrigeration and HVAC systems as well. A good estimate of refrigerant pressure drop is important to design a compact and effective heat exchanger. Heat exchangers used for ammonia are of the conventional fin and tube type which has return bends and U-bends. The objective of this project is to generate data regarding the pressure drop in U-bends in fin and tube heat exchangers used in ammonia applications. The data generated will be used to develop pressure drop correlations and associated void fraction models for U-bends.

Scope/Technical Approach:

The project is anticipated to consist of four major sub-tasks as listed below.

1. Perform a detailed literature review on existing correlations for pressure drop in U-bends. The PI should discuss and explain how the correlations perform for various refrigerants.

2. Developing the test matrix. The test matrix will need to be designed such that relevant parameters can be changed to cover a range of design and operating conditions. The range that needs to be covered by the test setup is given below. While the parameters shown in the table cover a wide range, the exact test matrix will be evaluated by the PMS and the PI, and test points will be established. Please note that condensers are not in the scope of this project.

   a. Refrigerant: Ammonia

   b. Tube Nominal OD: 3/8", 5/8", 7/8"

   c. U-bend orientation: Horizontal and Vertical

   d. Mass velocities [kg/m2-s]: 10 to 150

   e. Vapor Quality: 0.1 to 0.9

   f. Saturation temperature: -40 C to 10 C

   g. U-bend R/D ratio: 1.2 to 2.5

3. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend. The pressure measurement will be made at both far and near upstream and downstream locations. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1]. The PI will also undertake the required uncertainty analysis on the test setup. Location and types of various transducers for pressure temperature and refrigerant flow rate will be agreed upon by the PMS. Since the objective of this project is to isolate the pressure drop and flow regime in the U-bends, it is important that enough care be given to visualize the flow in addition to measuring the pressure drop.

Due to the toxic nature of ammonia, it is important that all safety guidelines in the event of a leak of ammonia be followed.

4. Perform tests as defined by the test matrix.

5. The PI is required to compare the experimental results obtained from above task to the results

Scope/Technical Approach (Continued 2):

Scope/Technical Approach (Continued 3):

Deliverables/Where Results Will Be Published:

The deliverables are defined with each task and described above. In addition, the contractor shall prepare monthly progress reports and other reports as described below:

Progress, Financial, Interim, and Final Reports, Research or Technical Paper(s), and Data shall constitute required deliverables ("Deliverables") under this Agreement and shall be provided as follows:

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 committee at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

Interim Reports. An interim report at the completion of Task 2 and an interim report at the completion of Task 4 shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services. An electronic copy of each report in Microsoft Word or PDF format shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS). Each report must be approved by the PMS prior to subsequent work.

Final Report. A written report ("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. An electronic copy of the Final Report in Microsoft Word or PDF format shall be furnished for review by the PMS.

Following approval by the PMS and the sponsoring committee, 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.
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HVAC&R Research or ASHRAE Transactions 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 publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE

Deliverables/Where Results Will Be Published (Continued):

Level of Effort:

It is estimated that the project will require two (2) professional months of the PI and thirty (30) months effort of research assistants. The project duration is expected to be thirty (30) months including the time to build the experimental facility. The total project cost is estimated at $150k. The cost for the project is itemized as below:

1. Principal Investigator (~2 months) $20k
2. Research Assistants/Technician (~30 months) $105k

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
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2	2. Quality of methodology proposed for conducting research: 20%	
3	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%	

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	TASK 1	DEC
2	TASK 2	MAR
3	TASK 5	JUN

Authors:

SANKAR PADHMANABHAN, CHAD BOWERS

References:

1. Shah, M. M., 1974. "Heat Transfer and Pressure Drop in Ammonia Evaporators". ASHRAE Transactions 80(2)
2. Lima, R. J., Quiben, J. M., Kuhn, C., Boyman, T., Thome, J. R. 2009. "Ammonia two-phase flow in a horizontal smooth tube: Flow pattern observations, diabatic and adiabatic frictional pressure drops and assessment of prediction methods". Int. Journam of Heat and Mass Transfer, vol 52, pp:2273-2288.
3. Cotter, D. 2009. “Improvement of the Heat Transfer Performance of and Ammonia Air Cooler”. PhD Thesis.London South Bank University.
4. Tran, C. C., Gupta, S., Chato, J. C., Newell, T.A. 2000. "An Experimental Study of Return Bend Effects onPressure Drop and Void Fraction". Proc. of International Refrigeration and Air-Conditioning Conference, Purdue University.
5. Geary, D. F. 1975. Return Bend Drop in Refrigeration Systems. ASHRAE Transactions, 81:250-265.
6. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN:1078-9669 print/1938-5587 online.
7. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous StraightTubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN:1078-9669 print/1938-5587 online.

Other Information for Bidders (Optional):

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

Response to RAC Comments for 1683-RTAR

1. **Appears to be a high cost relative to value to ASHRAE based upon description provided. Define better in WS the 'benefits' that ASHRAE is likely to receive from this research.** More detailed information has been provided in the work statement. It is our understanding that the purpose of the RTAR was not to obtain detailed information, but rather was to be an overview to gauge RAC's interest in the research topic.

2. **Reevaluate estimated project duration in WS development phase - 36 months seems a bit long.** The TC membership has several experienced researchers who feel the 36-month duration is realistic. Also, URP-1444, which conducted similar tests for HFC refrigerants, required 48 months to complete. However, the techniques and lessons learned from URP-1444 should enable this project to be completed in a shorter time frame.

3. **Curious - Why ammonia only? Why not test other two-phase refrigerants too?** 1444-URP investigated HFC refrigerants. However due to molecular differences between ammonia and HFC refrigerants, the results from 1444-URP cannot be used to predict ammonia performance, which is why this project is being proposed.

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Michael R. Vaughn, P.E.
Manager Research & Technical Services
mvaughn@ashrae.org

TO: Justin Kauffman, Chair TC 1.3, justin.p.kauffman@jci.com
Joseph Huber, Research Subcommittee Chair TC 1.3, joe.huber@alfalaval.com

CC: Shinsuke Kato, Research Liaison Section 1.0, kato@iis.utokyo.ac.jp

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

DATE: November 20, 2015

SUBJECT: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

During their annual meeting, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to accept it with comments for further development into a work statement (WS) provided that the key comment(s) and question(s) below are addressed to the satisfaction of your Research Liaison, Shinsuke Kato, kato@iis.utokyo.ac.jp, or RL1@ashrae.net, in the work statement draft.

1. Appears to be a high cost relative to value to ASHRAE based upon description provided. Define better in WS the 'benefits' that ASHRAE is likely to receive from this research.

2. Reevaluate estimated project duration in WS development phase - 36 months seems a bit long

3. Curious - Why ammonia only? Why not test other two-phase refrigerants too?

The work statement draft must be approved by the Research Liaison prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers require additional information or rewording for clarification.

The first draft of the work statement should be submitted to RAC no later than **August 15, 2017** or it will be dropped from display on the Society's Research Implementation Plan. The next likely submission deadline for a new work statement on this topic is **May 15, 2016** for consideration at RAC's 2016 Annual meeting. The submission deadline after that for work statements is **August 15, 2016** for consideration at the RAC's 2016 fall meeting.

Project ID	**1683**	
Project Title	**Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia**	
Sponsoring TC	TC 1.3, (Instruments and Measurements)	
Cost / Duration	$150k 24M-36M	
Submission History	**3rd Submission, 2nd Submission Oct. 2013, 1st Submission Oct. 2012**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2015 Fall Meeting Review		
Essential Criteria	**Voted NO**	**Comments & Suggestions**
Background: The RTAR should describe current state of the art with some level of literature review that documents the importance/magnitude of a problem. References should be provided. If not, then note it in your comments.		**9**- Two experts assure us of the significance of this research.
Research Need: Based on the background provided is the need for additional research clearly identified? If not, then the RTAR should be rejected.		**9** - Ammonia is a popular natural refrigerant, however, further research is required for its optimal use.
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject.	**13**	**13** - The purpose of this research is well defined, but it is not clear how ASHRAE will benefit from it. Low GWP refrigerants is a legitimate goal, but it is not clear how this work will directly contribute or how this work will be incorporated into ASHRAE literature. **9** - Two experts assure us that the proposed research will cover the important missing information. **10** - I take 'benefits to ASHRAE' broadly, in terms of benefits to the broader society if industry has better tools in areas where publically available design tools have good potential to help designers improve performance/reduce energy use. This would qualify for me.
IF ABOVE THREE CRITERION ARE NOT ALL SATISFIED - MARK "REJECT" BELOW & CONTINUE REVIEW BELOW		
Other Criteria	**Voted NO**	**Comments & Suggestions**
Project Objectives: Based on the background and need, evaluate whether the project objectives are: 1. Aligned with the need 2. Specific 3. Clear without ambiguity 4. Achievable If not, then appropriate feedback should be provided.		**13** - Project objectives are clear. **9** - The research method is clearly stated and few problems are likely to occur to conduct the research. **10** - objectives clear and well-defined. Should be: this is third submission.
Expected Approach and Budget: Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision. Anticipated funding level and duration:	**13**	**13** - Appears to be a high cost relative to value to ASHRAE based upon description provided. **9** - The research will be conducted with the re-use of existing apparatus. **6** - The project duration seems a bit long if 36 months.
References: Are the references provided?		**10** - yes
Decision Options	**Initial Decision?**	**Final Approval Conditions**
ACCEPT AS-IS		**7**- Authors have provided justification that the proposed work does not duplicate the Ph.D. thesis research. **13** - Define better in WS the 'benefits' that ASHRAE is likely to receive from this research. **6** - Reevaluate estimated project duration in WS development phase - 36 months seems a bit long. **3 -** Why ammonia only? Why not other Two-phase refrigerants?
ACCEPT W/COMMENTS		
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
ACCEPT W/COMMENTS Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: May 12, 2017

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	✔
B. Applicability to ASHRAE Research Strategic Plan	✔
C. Application of the Results	✔
D. State-of-the-Art (background)	✔
E. Advancement to State-of-the-Art	✔
F. Justification and Value to ASHRAE	✔
G. Objective	✔
H. Estimated Duration	✔
I. References	✔

Title:
Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

RTAR# 1683
(To be assigned by MORTS)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

• Fundamentals: Chapter 5 (Two-phase flow)
• Systems & Equipments: Chapter 23 (Air-Cooling and Dehumidifying coils), Chapter 39 (Condensers)

Responsible TC/TG: TC1.3 Liquid to Refrigerant Heat Exchangers

Date of Vote: 5/12/2017 email ballot

For		Sankar Pa
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	4
Total Voting Members		12

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date):
TC 8.4 voting on 6/30/2015 : 5-0-1-2

RTAR Lead Author: Sankar Padhmanabhan
Expected Work Statement Lead Author: Bruce Nelson/Sankar Padhmanabhan

Potential Co-funders (organization, contact person information):
IIAR

Research Classification:
☑ Basic/Applied Research
☐ Advanced Concepts
☐ Technology Transfer

	Yes	No
Has an electronic copy been furnished to the MORTS?		✔
Has the Research Liaison reviewed the RTAR?	✔	✔

* Reasons for negative vote(s) and abstentions

The one abstention in the co-sponsorship vote was due to a job change of one voting member such that Trane had two voting members (until an emergency roster change goes into effect on 1 July) so one of these individuals abstained.

DRAFT RTAR Template

Title: Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia

Summary

Describe in summary form the proposed research topic, including what is proposed, why this research is important, how it will be conducted, and why ASHRAE should fund it (50 words maximum)

The RTAR described here proposes a basic research to develop correlations for pressure drop in U-bends with ammonia. The refrigeration community depends on ASHRAE to provide basic information and knowledge for all types of working fluids, including ammonia. Ammonia being a natural refrigerant increases the impact of proposed research.

Background

Provide the state of the art with key references (at the end of this document) substantiating it (300 words maximum)

The proposed work is follow-on to the very successful RP-1444 which investigated two-phase pressure drop in U-bends for the HFC refrigerants R134a and R410a. It is suspected that ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. While recent research [3] has focused on visualization and qualitative analysis of 2-phase flow of Ammonia in U-bends, experimental data and correlations do not currently exist. This represents a significant gap in our understanding of two-phase pressure drop phenomenon for this important low GWP refrigerant and limits the ability of equipment manufacturers to accurately model and design ammonia evaporators and condensers.

Research Need

Use the state of the art described above as a basis to specify the need for the proposed effort (250 words maximum)

A typical evaporator or condenser designed for use with ammonia has multiple passes, each with an accompanying U-bend on each pass. An air-cooling ammonia evaporator, for example, may have as many as 12 to 24 passes and U-bends. The pressure drop incurred by the U-bends therefore represents a significant portion of the total frictional pressure drop for the evaporator. At lower evaporating temperatures (i.e. in refrigeration applications) ammonia evaporator performance is particularly sensitive to the frictional pressure drop since dT/dP becomes quite large (approx. 2 deg F/psi at -20 deg F). Most refrigeration evaporators operate with a TD (air on temperature minus evaporating temperature) in the range of 10 deg F. In the case of a -20 deg F evaporator operating with a 10 deg F TD, if the pressure drop estimate is off by only 1 psi, the performance of the evaporator can be reduced by as much as 30 to 35%. This unexpected reduction in evaporator performance causes the system compressor(s) to operate at lower than expected suction pressure with accompanying increased power consumption.

U-bends in a heat exchanger contributes significantly towards the total pressure drop. While correlations exist for other refrigerants (from RP 1444 and other research), none exists for ammonia. Moreover, ammonia being a highly polar molecule exhibits different thermophysical properties which eliminates the possibility of using correlations developed for other refrigerants.

Project Objectives

Based on the identified research need(s), specify the objectives of the solicited effort that will address all or part of these needs (150 words maximum)

The project is anticipated to consist of three major sub-tasks as listed below.
1. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend. The pressure measurement will be made at both far and near upstream and downstream locations. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1].
2. Developing the test matrix which will cover the parameters and ranges of operating conditions as listed in Table 1.
3. Develop a correlation (or pressure drop model) which can be used to predict the pressure drop introduced due to a U-bend. The work will also help develop and record the flow patterns near and within U-bend. It is highly recommended that proposals follow the approach taken to data reduction and correlation used by Lima and Thome in their work on RP-1444 [2].

Expected Approach

Describe in a manner that may be used for assessment of project viability, cost, and duration, the approach that is expected to achieve the proposed objectives (200 words maximum).

Check all that apply: Lab testing ☑, Computations ☐, Surveys ☐, Field tests ☑, Analyses and modeling ☐, Validation efforts ☐, Other (specify) ( )

Table 1: Expected range of test conditions

Refrigerant: Ammonia
Tube Nominal OD: 3/8", 5/8", 7/8"
U-bend orientation: Horizontal & Vertical
Mass velocities [kg/m2-s]: 10 to 150
Vapor Quality: 0.1 to 0.9
Saturation temperature: -40 C to 10 C
U-bend R/D ratio: 1.2 to 2.5

Relevance and Benefits to ASHRAE

Describe why this effort is of specific interest to ASHRAE, its impact, and how it will benefit ASHRAE and the society. How does it align with ASHRAE Strategic Plans and Initiatives? How does it advance the state of the art in this area in general? Are there other stakeholders that should be approached to obtain relevant information or co-funding? (350 words maximum)

Goal 8 of the 2010-2015 Research Strategic Plan encourages us to “Facilitate the use of natural and low global warming potential (GWP) synthetic refrigerants and seek methods to reduce their charge.” Ammonia is, of course, a natural refrigerant with extremely low GWP (near zero). The proposed research project will better quantify frictional pressure drop in 180 degree U-bends for this very important refrigerant. Providing heat exchanger designers with accurate two phase pressure drop correlations will allow more accurate predictions of performance for evaporators and condensers and hence more compact and efficient designs having less internal volume and reduced charge. The project will also contribute to Goal 9 (Improved HVAC&R components) and specifically the 12th research topic identified in Goal 9 (Conduct studies and experiments to support the proper evaluation of low GWP refrigerants, including exploration of methods for developing compact heat exchangers around the properties of these refrigerants and the impact of low GWP refrigerant heat exchanges on equipment sizing).

Anticipated Funding Level and Duration

Funding Amount Range: $ 150,000

Duration in Months: 24-36 months

References

List the key references cited in this RTAR

1. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN:1078-9669 print/1938-5587 online.

2. Lima, R. J. D, Thome, J. R., 2012. “Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)”. HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN:1078-9669 print/1938-5587 online.

3. Cotter, D. 2009. “Improvement of the Heat Transfer Performance of and Ammonia Air Cooler”. PhD Thesis. London South Bank University.

Re: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"
From: Yirong Jiang <yrjiang71@yahoo.com>
To: Joe Huber <joe.huber@alfalaval.com>
Cc: Amir Jokar <ajokar@exponent.com>

Dear Mr. Huber:

I have reviewed RTAR-1683 and Cotter Thesis. I do not believe RTAR-1683 duplicates the research done in the dissertation. Here are my thoughts:
The research proposed in RTAR-1683 is to measure the pressure drop of U-bends, both near and far upstream and downstream to address local, entrance and exit effect of the U-bend. In Cotter's research, instead of measuring the pressure drop of a U-bend at near upstream and downstream, he measured a long tube with a U-bend in the middle. In his work, two identical pressure drop test sections were made, with one of them bend to U-shape in the middle. Both test sections were made of 15.34 mm ID (5/8" OD x 0.02" wall) tubes. For the bent test section, the bend R/D ratio was 1.6. The total lengths of both pressure drop test sections were 1291 mm, where the upstream and downstream pressure measurement points were 863 mm apart. Therefore, the pressure drop measured in the bent test section was the sum of pressure drops from significant straight lengths upstream and downstream as well as the U-bend. By comparing the pressure drop measurements between the straight and bent test sections, the author concluded that no measureable pressure drop effect was found with the U-bend. This may be true for applications where the straight tube section is long and the pressure drop contribution from the U-bend is small compared to the total pressure drop. However, in applications where the straight tube sections are short, the pressure drop from U-bends may be significant to the total pressure, and this conclusion may not be applicable.

There are overlaps between the RTAR and Cotter thesis on test tube dimension, U-bend orientation, mass flux range, vapor quality range, saturation temperature range, and U-bend R/D ratio.

Please let me know if you have any questions.

Regards,

Yirong Jiang

To: Jiang, Yirong
Cc: Amir Jokar
Subject: Fw: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

Hello!

Amir Jokar informed me that you would be interested in reviewing 1683-RTAR. As was discussed during the TC 1.3 meeting, during the evaluation of the subject RTAR, ASHRAE Research Activities Committee (RAC) has indicated concerns that the research proposed by this RTAR would significantly overlap the work covered by a recently completed Ph.D. dissertation. RAC has provided us a copy of the dissertation (which is included below) for careful review of duplication. I've also included the comments from RAC.

Would you be able to review the dissertation and RTAR and provide your thoughts regarding whether the RTAR duplicates the research done in the dissertation?

Let me know.

Thank you!

Joe Huber
Senior Research and Development Engineer/Packaged Chiller Support
Tel direct: +1 682 777 8374
joe.huber@alfalaval.com
Contact me on MS Lync/Communicator: sip:joe.huber@alfalaval.com

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From: Thome John richard <john.thome@epfl.ch>
To: Joe Huber <joe.huber@alfalaval.com>
Date: 01/21/2014 06:43 AM
Subject: Re: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

Joe,

I have gone over the thesis in detail and offer the following comments:

1. The thesis does not go to high vapor qualities in measuring pressure drops except at the lowest mass flux, stopping before the characteristic peak before the characteristic rapid decrease…for direct-expansion applications with ammonia, these data at high vapor quality are important but were NOT taken in the thesis.

2. Pg. 97 in thesis: only ONE differential pressure transducer was used with a 200 mbar range…hence, this is TOO large for measuring pressure drops at the smaller mass fluxes and smaller vapor qualities…(in my ASHRAE U-bend project that the student won the Homer Award we used two differentials for low and medium and then the two absolute for the larger ones, so always had an accurate measurement over the entire range).

3. Fig. 5.7 on page 122: the pressure drop in a horizontal U-bend equals a straight tube and secondly a vertical U-bend is less than the straight tube…quite unexpected results. From the thesis, not clear if the static head was removed from the measured pressure drop for the vertical U-bend…has to be. In our tests in our ASHRAE project, the U-bend pressure gradients were 3-5 times higher than those in the straight lengths…other u-bend tests (not on ammonia) at Lyon and Brussels in recent years found multiplies like ours.

4. Thesis does not follow the flow pattern based modeling that has been shown to work very well to capture all the various trends and peaks in the pressure drop (and heat transfer coefficients)…the analysis of the data was quite light in the thesis.

5. Pg 78 in thesis figs 3.8 and 3.9: the "U-bend" pressure drop is actually measured for a very long u-tube with long straight lengths before and after the bend…there is not pressure drop measurement at the u-bend! Hence, the pressure drop in the U-bend is backed out by subtracting the two long straight length pressure drops (with point 2 to consider), losing sensitivity to get the U-bend pressure drop. While I think the student did a good quality PhD thesis, the value of the results are limited by the test section design used to get U-bend data.

ASRHAE project: this project will use a much better U-bend test section I am sure with PMS to check/monitor this.

Summary: I think there is need for more and better quality U-bend pressure drop data for ammonia…temperature approaches in heat exchangers are getting smaller and smaller to get better energy efficiency…two-phase pressure drops give the local Tsat in the local incremental LMTD in the stepwise thermal simulation of heat exchangers…hence the pressure drop accuracy is becoming more and more important. Thus, I support these new ammonia U-bend tests proposed in the RTAR.

Also, please note: I can guarantee that I will not be a bidder on the eventual project as I no longer have ammonia test capabilities.

Regards,

Prof. John Thome

From: Joe Huber <joe.huber@alfalaval.com>
Date: Tuesday, January 21, 2014 6:04 AM
To: John Richard Thome <john.thome@epfl.ch>
Subject: Fw: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

Hello John!

Per our discussion at the research review meeting on Sunday, during the evaluation of the subject RTAR, RAC has indicated concerns that the research proposed by this RTAR would significantly overlap the work covered by a recently completed PH.D. dissertation. RAC has provided us a copy of the dissertation for careful review of duplication. I've also included the comments from RAC.

Would you be able to review the dissertation and RTAR and provide your thoughts regarding whether the RTAR duplicates the research done in the dissertation?

Let me know.

Thanks!

Joe Huber
Senior Research and Development Engineer/Packaged Chiller Support
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Michael R. Vaughn, P.E.
Manager Research & Technical Services mvaughn@ashrae.org

TO: Amir Jokar,, Chair TC 1.3, amirjokar@gmail.com

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

CC: Arthur Giesler, Research Liaison 1.0, art.giesler@att.net
Joseph Huber, Research Subcommittee Chair TC 1.3, joe.huber@alfalaval.com

DATE: November 19, 2013

SUBJECT: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

During their recent teleconference, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to return it. The following list summarizes the mandatory comments and questions that need to be fully addressed in the RTAR re-submission:

1. Suggest that the RTAR author and Research liaison contact Dr. Cotter to discuss his PhD thesis results, and determine if additional research is justified.

Please address or incorporate the above information into the RTAR with the help of your Research Liaison prior to resubmitting it to the Manager of Research and Technical Services for further consideration by RAC. In addition, a separate document providing a point by point response to each of these mandatory comments and questions must be submitted with the RTAR. The response to each item should explain how the RTAR has been revised to address the comment, or a justification for why the technical committee feels a revision is unnecessary or inappropriate. The RTAR and response to these comments and questions must be approved by the Research Liaison prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers may require additional information or rewording for clarification.

The next submission deadline for RTARs and WSs is **December 15, 2013** for consideration at the Society's 2014 winter meeting. The submission deadline after that is May15, 2014.

Project ID	**1683**	
Project Title	**Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia**	
Sponsoring TC	TC 1.3, Heat Transfer and Fluid Flow	
Cost / Duration	$150,000/ 36 Months	
Submission History	**RTAR 2nd Submission, 1st Submission returned Oct. 2012**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2013 Fall Meeting Review		
Check List Criteria	**VOTED NO**	**Comments & Suggestions**
Is there a well-established need? The RTAR should include some level of literature review that documents the importance/magnitude of a problem. If not, then the RTAR should be returned for revision.	**3, 7, 1, 4**	**3** - The RTAR does not properly credit the research already completed on this topic published in the PhD thesis of Dr. Dermot Cotter, 2009, London South Bank University. **7** - Not convinced there is a need, this is work seems to have already been done. **1** - Thesis by Dermott Cotter did have pressure drops. Committee needs to review. **4** - Is there still disagreement between Giesler & the TC re Dermot Cotter? Is this really new work?
Is this appropriate for ASHRAE funding? If not, then the RTAR should be rejected. Examples of projects that are not appropriate for ASHRAE funding would include: 1) research that is more appropriately performed by industry, 2) topics outside the scope of ASHRAE activities.	**7.8**	**7** - Not if the data is already available. **4** - Probably yes. **8** - The topic of this research has some value to ASHRAE, but I am not convinced it should be funded by ASHRAE. The pressure drop through U-Bends is part of a refrigerating system. It should be the chiller manufacturers instead of design engineers who want to study this pressure drop, if it constitutes significant part of the overall pressure loss of the system.
Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision.	**7, 4, 8**	**7** - If most of the funds will be utilized for developing a test facility, then this research should be co-funded with another organization. **4** - p.2, Objective 1: can one measure pressure gradient within the U-bend? In 2-phase flow that might be fast and turbulent? **8** - A large portion of the budget seems to develop a test rig in order to obtain the pressure loss data. This is not a smart way of spending ASHRAE money.
Is the budget reasonable for the project scope? If not, then RTAR could be returned for revision or conditionally accepted with a note that the budget should be revised for the WS.	**7, 8**	**10** -Budget and length of time are high for the work to be done. 4 - not qualified to comment. **8** - The project duration seems too long.
Have the proper administrative procedures been followed? This includes recording of the TC vote, coordination with other TCs, proper citing of the Research Strategic Plan, etc. If not, then the RTAR could be returned for revision or possibly conditionally accepted based on adequately resolving these issues.		**4** - as far as I can tell

Decision Options	**Initial Decision**	**Approval Conditions**
ACCEPT		**3** - Suggest that the RTAR author and TC liaison contact Dr. Cotter to discuss his PhD thesis results, and determine if additional research is justified. **7** - Do not feel that the TC has adequately addressed the concerns of RAC or this project is worthy of funding. 10 - This research should be funded with the condition that most of the funds will be utilized for testing and not for developing a test lab. **4** - Cannot be accepted w/o first resolving perceived disagreement between RL and the TC on whether this really is new work not adequately covered by Cotter's dissertation.
COND. ACCEPT		
RETURN		
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
COND. ACCEPT Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
RETURN Vote - Topic is probably acceptable for ASHRAE research, but RTAR is not quite ready.
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: **August 14, 2013**

(Please Check to Insure the Following Information is in the RTAR)

A. Title	X
B. Applicability to ASHRAE Research Strategic Plan	X
C. Application of the Results	X
D. State-of-the-Art (background)	X
E. Advancement to State-of-the-Art	X
F. Justification and Value to ASHRAE	X
G. Objective	X
H. Estimated Duration	X
I. References	X

Title: **Experimental Evaluation of Two-Phase Drop and Flow Pattern in U-Bends with Ammonia**

RTAR# **1683**

(To be assigned by MORTS)

Results of this Project will affect the following Handbook Special Publications, etc.:

Fundamentals Chapter 5

Systems & Equipment Chapters 23, 39, 48

Responsible **TC 1.3**

Date of Vote: **August 05-13, 2013 (email ballot)**

For	12
Against	0
Abstaining	0
Absent or not returning	1
Total Voting	13

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date):

t

RTAR Lead Author: **Sankar Padhmanabhan**

Expected Work Statement Lead **Sankar Padhmanabhan**

Research Classification: (Basic/Applied Research; Advanced Concepts; or Technology Transfer)

Basic/Applied Research

Potential Co-funders (organization):

	Yes	No
Has an electronic copy been furnished to the MORTS?	X	
Has the Research Liaison reviewed the RTAR?	X	

* Reasons for negative vote(s) and abstentions

Dated: 06/25/2013

To: Mike Vaughn, MORTS

From: Sankar Padhmanabhan

Sub: Response to mandatory comments by RAC regarding RTAR 1683 (Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia).

Following are the responses to mandatory comments raised by RAC regarding RTAR 1683(Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia)

1. Evaluate the information sent to the TC by the Research Liaison, Art Giesler regarding recent research done in this area and make any determination on action they may wish to take regarding this RTAR due to the information sent.
    a) *While the thesis by Dermot Cotter sent by Art Giesler is a study on the flow of Ammonia, it was more qualitative and about visualization. The study did not concentrate rigorously on pressure drop in U-bends. The work is of interest and will be included as a reference in RTAR.*

2. The budget seems excessive for the amount of work proposed; needs more justification. Elaborate on the uniqueness of ammonia in determining two-phase pressure drop versus the data already collected from RP-1444.
    a. *In the experience of RP-1444 PMS chair Bruce Nelson, the proposed budget amount is reasonable, considering the special materials required for Ammonia compatibility along with health & safety considerations, due to toxicity. In addition, the original test rig at EPFL at Luzern has been dismantled.*
    b. *The data taken and correlated during RP 1444 is based on HFC refrigerants (R134a & R410a). Ammonia as a highly polar molecule exhibits significantly different thermophysical and thermodynamic properties, implying the need for data and correlations specific to this fluid.*

3. Does this data possibly exist already through other sources? What role, if any, has IIAR played in the development of this RTAR? Have international experts in ammonia, such as Dr. Andy Pearson of the Institute of Refrigeration, been consulted?
    a) *This type of frictional 2-phase pressure drop data for ammonia in U-bends does not exist. Bruce Nelson, co-author of RTAR is the chair of IIAR research committee and has provided valuable input from an IIAR perspective. Mr. Nelson is recognized as an international*

expert in Ammonia heat exchangers and has contacted Dr. Pearson and others during the course of the RTAR development.

4. Are there any existing laboratories have the capability to do this research? Most of the funding for this project appears to be allocated to developing a test facility.
   a) *Potential bidders capable of conducting this work include*
      - *Highschool for Engineering and Architecture, Friebourg, Switzerland*
      - *Creative Thermal Solutions, Urbana, IL.*
      - *Kansas State University, Manhattan, KS*

   Unique material compatibility and safety considerations of Ammonia will require significant portion of funding to be directed towards facility construction.

Respectfully Submitted

Sankar Padhmanabhan
Author, RTAR 1683
Member TC 1.3

RESEARCH TOPIC ACCEPTANCE REQUEST <u>1683-RTAR</u>

Sponsoring TC/TG/MTG/SSPC/EHC/REF: TC1.3 Heat Transfer and Fluid Flow

Title:
"Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

Applicability to ASHRAE Research Strategic Plan:
Goal 8 of the 2010-2015 Research Strategic Plan encourages us to "Facilitate the use of natural and low global warming potential (GWP) synthetic refrigerants and seek methods to reduce their charge." Ammonia is, of course, a natural refrigerant with extremely low GWP (near zero). The proposed research project will better quantify frictional pressure drop in 180 degree U-bends for this very important refrigerant. Providing heat exchanger designers with accurate two phase pressure drop correlations will allow more accurate predictions of performance for evaporators and condensers and hence more compact and efficient designs having less internal volume and reduced charge. The project will also contribute to Goal 9 (Improved HVAC&R components) and specifically the 12^{th} research topic identified in Goal 9 (Conduct studies and experiments to support the proper evaluation of low GWP refrigerants, including exploration of methods for developing compact heat exchangers around the properties of these refrigerants and the impact of low GWP refrigerant heat exchanges on equipment sizing).

Research Classification:
Basic/Applied Research

TC/TG/MTG/SSPC Vote:
12 For, 0 Against, 0 Abstain, 1 no response
(08/05/2013 email ballot)

Reasons for Negative Votes and Abstentions:
None

Estimated Cost:
USD150,000

Estimated Duration:
24 to 36 Months

RTAR Lead Author
Sankar Padhmanabhan / sankar@danfoss.com

Expected Work Statement Lead Author
Bruce Nelson / bruce.nelson@colmaccoil.com

Co-sponsoring TC/TG/MTG/SSPCs and votes:

Possible Co-funding Organizations:
IIAR

Application of Results:
The results of this chapter will be included in the following Handbook chapters

- Fundamentals: Chapter 5 (Two-phase flow)
- Systems & Equipments: Chapter 23 (Air-Cooling and Dehumidifying coils), Chapter 39 (Condensers) & Chapter 48 (Heat Exchangers)

State-of-the-Art (Background):
The proposed work is follow-on to the very successful RP-1444 which investigated two-phase pressure drop in U-bends for the HFC refrigerants R134a and R410a. It is suspected that ammonia, a highly polar molecule with its unique thermophysical and thermodynamic properties, will exhibit two-phase flow

characteristics and frictional pressure drop which are not predicted accurately by the previous HFC-derived correlation. While recent research [3] has focused on visualization and qualitative analysis of 2-phase flow of Ammonia in U-bends, experimental data and correlations do not currently exist. This represents a significant gap in our understanding of two-phase pressure drop phenomenon for this important low GWP refrigerant and limits the ability of equipment manufacturers to accurately model and design ammonia evaporators and condensers.

Advancement to the State-of-the-Art:
A typical evaporator or condenser designed for use with ammonia has multiple passes, each with an accompanying U-bend on each pass. An air-cooling ammonia evaporator, for example, may have as many as 12 to 24 passes and U-bends. The pressure drop incurred by the U-bends therefore represents a significant portion of the total frictional pressure drop for the evaporator. At lower evaporating temperatures (i.e. in refrigeration applications) ammonia evaporator performance is particularly sensitive to the frictional pressure drop since dT/dP becomes quite large (approx. 2 deg F/psi at -20 deg F). Most refrigeration evaporators operate with a TD (air on temperature minus evaporating temperature) in the range of 10 deg F. In the case of a -20 deg F evaporator operating with a 10 deg F TD, if the pressure drop estimate is off by only 1 psi, the performance of the evaporator can be reduced by as much as 30 to 35%. This unexpected reduction in evaporator performance causes the system compressor(s) to operate at lower than expected suction pressure with accompanying increased power consumption.

Justification and Value to ASHRAE:
The refrigeration community worldwide depends on ASHRAE to provide this type of basic information and knowledge for all types of working fluids, including ammonia. Engineers working to design ammonia evaporators and condensers will be able to make immediate use of this new information to improve industrial equipment designs for increased efficiency and performance. Because ammonia is a natural refrigerant with near-zero GWP, it is currently being considered for use in many non-traditional commercial refrigeration and air-conditioning applications. This obviously increases the potential audience of users of this new information and raises the importance and urgency of the work.

Objectives:
Ammonia has historically been the preferred refrigerant in industrial refrigeration systems. However, due to increasing interest in natural refrigerants engineers are investigating its use in commercial refrigeration and HVAC systems. The project is anticipated to consist of three major sub-tasks as listed below.

1. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend. The pressure measurement will be made at both far and near upstream and downstream locations. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic. It is highly recommended that proposals follow the approach to designing the test rig used by Lima and Thome in their work on RP-1444 [1].
2. Developing the test matrix which will cover the parameters and ranges of operating conditions as listed in Table 1. While the parameters shown in the table cover a wide range, the exact testing matrix will be evaluated by the PMS and the PI, and test points will be established.
3. Develop a correlation (or pressure drop model) which can be used to predict the pressure drop introduced due to a U-bend. The work will also help develop and record the flow patterns near and within U-bend. Such observations will help in formulating an explanation of the behavior and will enable future researchers in developing an analytical pressure drop model. It is highly recommended that proposals follow the approach taken to data reduction and correlation used by Lima and Thome in their work on RP-1444 [2].

Table 1: Range of test conditions

Parameter	Values
Refrigerant	Ammonia
Tube Nominal OD	3/8", 5/8", 7/8"
U-bend orientation	Horizontal & Vertical
Mass velocities [kg/m2-s]	10 to 150
Vapor Quality	0.1 to 0.9
Saturation temperature	-40 C to 10 C
U-bend R/D ratio	1.2 to 2.5

Key References:

1. Lima, R. J. D, Thome, J. R., 2012. "Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 1. Experimental Results (RP-1444)". HVAC&R Research, vol. 18(6), pp. 1047-1071. ASHRAE, ISSN:1078-9669 print/1938-5587 online.
2. Lima, R. J. D, Thome, J. R., 2012. "Two-Phase Frictional Pressure Drops in U-bends and Contiguous Straight Tubes for Different Refrigerants, Orientations, Tube, and Bend Diameters: Part 2. New Models (RP-1444)". HVAC&R Research, vol. 18(6), pp. 1072-1097. ASHRAE, ISSN:1078-9669 print/1938-5587 online.
3. Cotter, D. 2009. "Improvement of the Heat Transfer Performance of and Ammonia Air Cooler". PhD Thesis. London South Bank University.

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Michael R. Vaughn, P.E.
Manager Research & Technical Services
mvaughn@ashrae.org

TO: Samuel Yana Motto, Chair TC 1.3, samuel.yanamotta@honeywell.com

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

CC: Arthur Giesler, Research Liaison1.0, artgiesler@permapipe.com
Joe Huber, Research Subcommittee Chair, joe.huber@alfalaval.com

DATE: November 1, 2012

SUBJECT: Research Topic Acceptance Request (1683-RTAR), "Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

During their fall teleconference, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to return it. The following list summarizes the mandatory comments and questions that need to be fully addressed in the RTAR re-submission:

1. Evaluate the information sent to the TC by the Research Liaison, Art Giesler regarding recent research done in this area and make any determination on action they may wish to take regarding this RTAR due to the information sent.
2. The budget seems excessive for the amount of work proposed; needs more justification. Elaborate on the uniqueness of ammonia in determining two-phase pressure drop versus the data already collected from RP-1444.
3. Does this data possibly exist already through other sources? What role, if any, has IIAR played in the development of this RTAR? Have international experts in ammonia, such as Dr. Andy Pearson of the Institute of Refrigeration, been consulted?
4. Are there any existing laboratories have the capability to do this research? Most of the funding for this project appears to be allocated to developing a test facility.

Please address or incorporate the above information into the RTAR with the help of your Research Liaison prior to resubmitting it to the Manager of Research and Technical Services for further consideration by RAC. In addition, a separate document providing a point by point response to each of these mandatory comments and questions must be submitted with the RTAR. The response to each item should explain how the RTAR has been revised to address the comment, or a justification for why the technical committee feels a revision is unnecessary or inappropriate. The RTAR and response to these comments and questions must be approved by the Research Liaison prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers require additional information or rewording for clarification.

The next submission deadline for RTARs and WSs is **December 15, 2012** for consideration at the Society's 2013 winter meeting. The submission deadline after that is May15, 2013.

Project ID	**1683**	
Project Title	Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia	
Sponsoring TC	TC 1.3, Heat Transfer and Fluid Flow	
Cost / Duration	$150,000 / 24M	
Submission History	**1st submission**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC FALL 2012 (Web) Meeting Review	**REVIEW SUMMARY**	
Check List Criteria	**VOTED NO**	**Comments & Suggestions**
Is there a well-established need? The RTAR should include some level of literature review that documents the importance/magnitude of a problem. If not, then the RTAR should be returned for revision.	**#15, #6**	**#15** - Justification is weak. There is a lack of literature review and what does currently exist? How equipment manufacturers are designing these equipments without these correlations. **#3** - Data on Ammonia will assist the industry. **#5** - The following may be only a minor issue......The justification based on applicability to 2010-2015 ASHRAE Research Plan quotes improvements and technology development for compact heat exchangers. If compact heat exchangers are defined as micro channel heat exchangers, the tube diameters will be in the range of 0.5 to 1 mm (0.02 to 0.04 inches). The RTAR specifies tube diameters of 0.375 to 0.875 inches. Do compact heat exchangers include tube diameters of 0.375 to 0.875 inches? **#7**- Feel more elaboration is needed as to why Engineers need this data: i.e. large systems are designed and field erected and cannot be lab tested for performance or efficiency. **#6** - Two-phase pressure drop in U bends is important. However, the authors have not explained why, if there was recent ASHRAE funded research conducted on this topic with other working fluids, the results would be different for ammonia, and why results of the previous study, e.g., correlations from that study, cannot be used for ammonia. This needs to be better established. **#11-** what organizations might have information of interest in this project?
Is this appropriate for ASHRAE funding? If not, then the RTAR should be rejected. Examples of projects that are not appropriate for ASHRAE funding would include: 1) research that is more appropriately performed by industry, 2) topics outside the scope of ASHRAE activities.		**#15** - The funding should be supported by OEMs It seems most of the funding will be utilized for developing a laboratory. **#7** - The budget seems excessive for the amount of work proposed; needs more justification.
Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision.	**#15, 5**	**#15**- Needs details about the approach and instrumentation. Existing laboratories and their capabilities in conducting such research. **#9 -** Add data from RP-1444, **#5-** Timing and cost estimates for each of the three major sub-tasks not provided. The first sub-task is developing an instrumented test facility for measuring pressure drop inside the tubes. The third sub-task mentions recording the flow patterns near and within the U-bends. Does this imply the heat exchanger is to be constructed of a transparent material of construction which is compatible with ammonia? Also note there is no sub-task for operating the test facility. **#7-** More detail is needed in the output; will the results of the research be used for anything other than Handbook updates? **#6** - It appears that this testing has already been conducted in prior ASHRAE research and it would most likely be follow on effort to that project, so the methodology should be well established.
Is the budget reasonable for the project scope? If not, then RTAR could be returned for revision or conditionally accepted with a note that the budget should be revised for the WS.	**#15, #9, #7**	**#15** - Budget seems to be high. If the work is done in the labs with existing facilities, it can be done at reduced cost. **#9** - May be overpriced. Review cost from RP-1444. Why was Ammonia removed from RP-1444? Cost overrun? **#7** -The budget seems excessive for the amount of work proposed; needs more justification. **#6** - Perhaps a little on the high side for a lab already possessing the needed test facility. Also, this work should not take 24 months.
Have the proper administrative procedures been followed? This includes recording of the TC vote, coordination with other TCs, proper citing of the Research Strategic Plan, etc. If not, then the RTAR could be returned for revision or possibly conditionally accepted based on adequately resolving these issues.		

Decision Options	**Initial Decision**	**Additional Comments or Approval Conditions**
ACCEPT		**#15** - Author needs to find an OEM to co-sponsor the research. This research Phase I may involve just a detailed literature review to find the correlations and may not need subsequent funding if such correlations already exist. Not only one doing this with U-send, ammonia, etc. Phase 1 literature search? Using funds to set up lab not nest us of funds **#5** - Need timing and cost estimates for each sub-task, and note there is no sub-task for operating the experimental test facility. Also a question about heat exchanger material of construction, as one task is to record the ammonia flow patterns near and within the U-bends. Write up is weak given they did RP-1444. **#7**- RTAR needs more detail to justify the research and the budget. The output is also not clearly defined. #6 - Need elaboration on the uniqueness of ammonia in determining two-phase DELTA. Budget seems a little high, duration is high. **#11** - Need more due diligence on co-funders and related date sources.
COND. ACCEPT		
RETURN	**X**	
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
COND. ACCEPT Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
RETURN Vote - Topic is probably acceptable for ASHRAE research, but RTAR is not quite ready.
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: **August 14, 2012**

(Please Check to Insure the Following Information is in the RTAR)

A. Title	**X**
B. Applicability to ASHRAE Research Strategic Plan	**X**
C. Application of the Results	**X**
D. State-of-the-Art (background)	**X**
E. Advancement to State-of-the-Art	**X**
F. Justification and Value to ASHRAE	**X**
G. Objective	**X**
H. Estimated Duration	**X**
I. References	**X**

Title: **Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia**

RTAR# **1683**

(To be assigned by MORTS)

Results of this Project will affect the following Handbook Special Publications, etc.:

Fundamentals Chapter 5

Systems & Equipment Chapters 38 and 47

Responsible **TC 1.3**

Date of Vote: **August 14, 2012 (email ballot)**

For	**11**
Against	**0**
Abstaining	**0**
Absent or not returning	**3**
Total Voting	**11**

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date):

None at this time

RTAR Lead Author: **Sankar Padhmanabhan**

Expected Work Statement Lead **Sankar Padhmanabhan**

Research Classification: (Basic/Applied Research; Advanced Concepts; or Technology Transfer)

Basic/Applied Research

Potential Co-funders (organization):

IIAR

	Yes	No
Has an electronic copy been furnished to the MORTS?	**X**	
Has the Research Liaison reviewed the RTAR?	**X**	

* Reasons for negative vote(s) and abstentions

RESEARCH TOPIC ACCEPTANCE REQUEST (RTAR) 1683-RTAR

Sponsoring TC/TG/MTG/SSPC: TC 1.3

Title:
"Experimental Evaluation of Two-Phase Pressure Drop and Flow Pattern in U-Bends with Ammonia"

Applicability to ASHRAE Research Strategic Plan:
2010-2015 Research Plan: Better correlations for U-bend pressure drop will help achieve improved prediction of the power required by the prime-moving device in a refrigeration machine. The results of this project will directly contribute to Goal 8- Facilitate the use of natural and low global warming potential synthetic refrigerants and specifically the 5th research topic identified in Goal 8 (Study the heat transfer and pressure drop performance of compact heat exchanges with naturally occurring refrigerants). The project will also contribute to Goal 9 (Improved HVAC&R components) and specifically the 12th research topic identified in Goal 9 (Conduct studies and experiments to support the proper evaluation of low GWP refrigerants, including exploration of methods for developing compact heat exchangers around the properties of these refrigerants and the impact of low GWP refrigerant heat exchanges on equipment sizing).

Research Classification:
Basic/Applied Research

TC/TG/MTG/SSPC Vote:
11 For, 0 Against, 0 Abstain, 3 no response (email ballot)

Reasons for Negative Votes and Abstentions:
None

Estimated Cost:
US$ 150,000

Estimated Duration:
24 months

RTAR Lead Author
(Sankar Padhmanabhan)
(Sankar.padhmanabhan@jci.com)

Expected Work Statement Lead Author
TBD

Co-sponsoring TC/TG/MTG/SSPCs and votes:
No co-sponsoring TCs at this time

Possible Co-funding Organizations:
IIAR

Application of Results:
The results of this chapter will be included in the following Handbook chapters

- Fundamentals: Chapter 5 (Two-phase flow)
- Systems & Equipments: Chapter 38 (Condensers) & Chapter 47 (Heat Exchangers)

State-of-the-Art (Background):
U-bends are common components in air cooled heat exchangers to create a serpentine path for refrigerant. Such U-bends cause the boundary layer to break and redevelop along with causing secondary swirl flows. The immediate effect of the U-bend is an increase in pressure drop compared to a straight pipe section. Significant amount of research has been done in correlating the pressure drop in U-bends for single phase

flow [1-6]. For two-phase fluids most of the research has been focused on straight tube sections [7, 8] and the amount of experimental literature for two-phase flow through U-bends is limited. Two-phase flow in U-bends is difficult to study theoretically due to the mixing of vapor and liquid phase due to the turbulence caused by U-bend. As such it is necessary that experimental studies be carried out to correlate the pressure drop for two-phase fluids.

With the popularity of small diameter tubes increasing, the need is even more pronounced since the U-bends in small diameter coils tend to have smaller bend radius due to closer tube spacing. The reduction in the bend radius results in further increase in pressure drop in U-bends [9, 10]. Pressure drop in U-bends for other popular refrigerants such as R-134a and R-410 [11] was carried out recently as part of an ASHRAE research project (RP-1444). One of the main conclusions of this study was that while two-phase flows behaved similarly to single-phase in far upstream and downstream sections, the pressure gradient is significantly affected in the neighborhood of the U-bend. As a result it was concluded that there is a need to develop the database of two-phase pressure drop data for U-bends which will allow improved prediction capability. While such data has been recently developed for many refrigerants, there is a lack of such data for Ammonia. Ammonia has been historically used in large industrial refrigeration applications where U-bends are not very common. However, with the increased awareness in using natural refrigerants, ammonia is starting to emerge as a choice in small refrigeration systems using air-to-refrigerant heat exchangers where U-bends are common. As such the need to develop the datasets is relevant.

Advancement to the State-of-the-Art:
Proper estimation of pressure drop in U-bends will allow designers to correctly size the compressors and pumps. Without the knowledge of an accurate estimate the designers tend to oversize the components thus leading to increased energy consumption. It is expected that the results from this project will be available for the ASHRAE community as correlations covering a wide range of conditions.

Justification and Value to ASHRAE:
Engineers worldwide in the commercial and industrial air conditioning and refrigeration industries are examining the use of ammonia as a natural refrigerant in many types of vapor compression machines (packaged chillers and rooftop equipment, low charge air conditioning units, industrial refrigeration evaporators and condensers, industrial heat pumps). The energy efficiency and performance of this equipment is directly affected by tube-side pressure drop in the evaporators and condensers. The contribution of the pressure drop through return bends to the total pressure drop through a heat exchanger with multiple passes is significant. The results of this research will be practically and immediately applied by engineers and designers in the air conditioning and refrigeration industries to better model and predict pressure drop through return bends in coils and shell-and-tube heat exchangers. More accurate prediction of tube-side pressure drop will result in optimized and more energy efficient equipment designs.

Objectives:
Ammonia has been the preferred refrigerant in big industrial refrigeration systems historically. However, due to increasing interest in natural refrigerants engineers are looking to use ammonia in smaller systems. The project is anticipated to consist of three major sub-tasks as listed below.

1. Developing a fully instrumented test facility to measure the pressure gradients in the flow field at upstream, downstream and within the U-bend. The pressure measurement will be made at both far and near upstream and downstream locations. Since the facility is aimed at measuring the pressure drop alone, the test section is intended to be designed as adiabatic.

2. Developing the test matrix which will cover the parameters and ranges of operating conditions as listed in Table 1. While the parameters shown in the table cover a wide range, the exact testing matrix will be evaluated by the PMS and the PI, and test points will be established.
3. Develop a correlation (or pressure drop model) which can be used to predict the pressure drop introduced due to a U-bend. The work will also help develop and record the flow patterns near and within U-bend. Such observations will help in formulating an explanation of the behavior and will enable future researchers in developing an analytical pressure drop model.

Table 1: Range of test conditions

Parameter	Values
Tube Nominal OD	3/8", 5/8", 7/8"
U-bend orientation	Horizontal & Vertical
Mass velocities [kg/m2-s]	10 to 150
Vapor Quality	0.1 to 0.9
Saturation temperature	-20 C to 10 C
U-bend R/D ratio	1.2 to 2.5

Key References:

1. Popiel, C.O., Wojtkowiak, J., 2000, Friction factor in U-type undulated pipe flow, Journal of Fluids Engineering, vol. 122, pp. 260-263.
2. Wojtkowiak, J., Popiel, C.O., 2000, Effect of cooling on pressure losses in U-type wavy pipe flow, International Communication on Heat and Mass Transfer, vol. 27, pp. 169-177.
3. Abou-Arab, T.W., Aldoss, T.K., Mansour, A., 1991, Pressure drop in alternating curved tubes, Applied Scientific Research, vol. 48, pp. 1-9.
4. Ito, H., 1959, Friction factors for turbulent flow in curved pipes, Journal of Basic Engineering, vol. 81, pp. 123-134.
5. Ito, H., 1960, Pressure losses in smooth pipe bends, Journal of Basic Engineering, vol. 82, pp.131-143.
6. Chen, I.Y., Lai, Y.K., Wang, C-C., 2003, Frictional performance of U-type wavy tubes, Journal of Fluids Engineering, vol. 125, pp. 880-886
7. Wang, C-C., 2005, Tons of two-phase data and correlations: what's next?, Heat Transfer Engineering, vol. 10, pp. 1-2.
8. Thome JR., 2004, Wolverine Engineering Databook III, Wolverine Tube Inc., Huntsville, AL, USA, 2004, http://www.wlv.com/products/databook/db3/DataBookIII.pdf.
9. Dean, R., 1928, The streamline motion of fluid in curved pipe, Philosophical Magazine, vol. 5, pp. 671-695.
10. Dean, R., 1928, Note on motion of fluids in curved pipes, Philosophical Magazine, vol. 4, pp. 208-223.
11. Lima, R. J. D, Thome, J. R., 2010. Two-Phase Pressure Drops in Adiabatic Horizontal Circular Smooth U-Bends and Contiguous Straight Pipes (RP-1444). HVAC&R, vol. 16(3), pp. 383-398.