INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1909-TRP, In-Tube Condensing Flue Gas Heat Transfer and Pressure Drop with Enhancements for Residential Furnaces

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

Sponsoring Committee: TC 1.03, Heat Transfer and Fluid Flow
Co-sponsored by: TC 6.03, Residential and Ligh Commercial Forced Air Heating and Cooling Systems

Budget Range: $245,500 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2025,** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, December 16th, 2024. 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: 1909-TRP, In-Tube Condensing Flue Gas Heat Transfer and Pressure Drop with Enhancements for Residential Furnaces, 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
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For Administrative or Procedural Matters:
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Contractors intending to submit a proposal should notify, by mail or e-mail, the Manager of Research by December 1st, 2024 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. In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, December 16th, 2024.
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)

Residential gas fired central furnaces are rated per the Department of Energy test procedures as outlined in the Code of Federal Regulations (10 CFR Part 430, Subpart B, Appendices N and AA) and ANSI/ASHRAE 103. Furnaces are rated for Annual Fuel Utilization Efficiency (AFUE) and output heating capacity. High efficiency furnaces (>90 AFUE) are condensing-type furnaces and are widely used in residential and light commercial equipment today in order to minimize fuel consumption/operating costs and thus reduce CO2 generation from the burning of fossil fuels.

In order to be condensing, in addition to the primary heat exchanger where heat is transferred from the just combusted fuel-air mixture to the return air stream from the conditioned space, there is a second heat exchanger downstream of the primary to extract additional heat from the combustion products.

This secondary heat exchanger is a finned tube design. It is typically constructed with stainless steel tubes (3/8" and 1/2" nominal diameter tubes are most common) with plain or wavy aluminum plate fins. These heat exchangers are multi-circuit, multirow. Residential furnace capacity ranges are from 40,000 Btu/hr to 120,000 Btu/hr. The capacity of the secondary heat exchanger is on the order of 20%-30% of that. Depending on secondary heat exchanger circuiting this would translate into approximately 10-100 ft3/hr (4.7-47 Lpm) of flue gas and from 0.05-0.4 lbm/hr (0.05-0.1kg/hr) of condensate per tube. This condensate will collect in the bottom of the tubes due to gravity but will continually drain from the heat exchangers which are pitched to promote this. Since the flue gas flow rate is quite low, inserts such as twisted or bent tapes are used to increase the tube-side convective heat transfer coefficients. The inserts also serve to increase the internal surface area. In addition to extracting sensible heat from the flue gas, latent heat is also extracted via condensation of the "wet" flue gas products.

It is desired to model both the sensible and latent heat components such that both the overall capacity as well as the condensation production can be predicted. The condensation prediction is especially important since the furnace rating standard calls for measuring and reporting out this value. It is crucial to be able to model these types of heat transfer processes for design purposes such that alternate configurations may be explored via math models rather than expensive and time-consuming laboratory testing.

GTI Energy personnel highlighted the growing trends and importance of hydrogen blended natural gas fuels at the ASHRAE Winter Conference in Atlanta. Fridlyand et al. (2023) presented burner design considerations for hydrogen blended gas fuels, Zhao et al. (2023) researched hydrogen sensors and Glanville et. al. (2023) presented the infrastructure transition for hydrogen blended gas distribution. The effects of flue gas condensation may be even greater for hydrogenated natural gas and thus the models developed will be even more helpful designing the next generation high efficiency furnaces.

Advancement of the Arts

The flue gas side of the secondary heat exchanger presents an extremely challenging heat transfer and pressure drop problem. During the process, there is sensible cooling of the flue gas as its heat is given up to the return air. Further downstream in the heat exchanger, the inner tube wall temperature becomes equal to the local dew point of the flue gas and condensate will then form.
This condensate will drain out of the heat exchanger eventually but there will be some level of condensate in the tube.

Due to the low velocity of the flue gas in tube, there will usually be an internal enhancement feature.
The current enhancements of choice are twisted tape or bent tape/tab inserts.

Seminal published work on twisted tape inserts was done by Manglik and Bergles (1994) for single- phase water flows. ASHRAE Fundamentals (2021) provides correlations for convective heat transfer and pressure drop with these inserts in a single-phase situation. In addition, an equation set to calculate convective heat transfer coefficients is presented by Watanabe and Taira (1984) for the twisted tape insert in the primary heat exchanger in a combustion situation. The method outlined by Watanabe and Taira accounts for convection and radiation exchange between the tape and the tube wall and applies to single-phase flows of combustion gas. Recently, a film condensation model was made available in ANSYS Computational Fluids Dynamics software. The film condensation model was validated specifically for ANSYS CFD modeling by Zschaeck et al. (2014). However, the model may not be reliable for complex geometries found in secondary heat exchanger tubes and is computationally intensive. Recently, Zhang et al. (2019) provided an overview of existing insert tape designs as well as a proposing a new self-rotating twisted insert. The work here was applied to single-phase flows only. Preliminary single tube flue gas condensation experimentation and CFD is on-going at Oklahoma State University. Description of the experiment and some data were provided by Devlin et al (2022).

Only one of the references cited above addresses the condensing flue gas scenario specifically and that very recent study is very geared toward a CFD approach. Further experimental and model development work to enable the refinement of furnace designs is required. If proper modeling was available, new insert geometries could be explored resulting in more compact secondary heat exchanger designs and less energy intensive manufacturing processes as well as a greater penetration of super high efficiency furnaces in the marketplace. This would help achieve goals on reducing greenhouse gas emissions.

Justification and Value to ASHRAE

Improved modeling of HVAC&R systems is an important part of ASHRAE's mission. Furnaces in some form will be a part of our built environment heating strategy for the near-term. In order to minimize the energy usage/carbon footprint of these appliances, improved understanding of the physics that takes place in their heat exchangers is necessary. Applying this improved modeling understanding coupled with addressing the application of hydrogenated fuels to residential furnaces will assist us in reaching our decarbonization goals.

Objectives

Develop fundamental mathematical models of condensing flue gas in-tube. The models should be able to describe both plain tube configurations as well as allow for the addition of enhancements on the tube side. The enhancements would be using the twisted or bent tape variety commonly used in the industry. Model development should be based on literature search as well as new empirical data acquired specifically during this project.

2.) Conventional fuels (natural gas and propane) as well as hydrogen mixtures should be addressed in the modeling.

3.) Verify the models with experimental data across a range of appropriate flue gas flow rates, heat fluxes, and condensate rates. Additionally, a range of enhancement surface area (density) will be verified. These data should include some amount of actual combustion data but may also be supplemented with data using surrogate fluids.

Scope:

The recommended approach for this project involves the following tasks:

Task 1: Literature survey (both directly related combustion gas research including hydrogenated natural gas combustion as well as adjacent mass transfer/psychrometric, and film condensation work).

Activity	Time Duration	Milestone
Literature Survey	3 Mo.	Report out to PMS

Task 2: Empirical data will be required to develop and verify the new correlations to be developed. Since we are interested in the process of flue gas condensation in-tube, it is recommended that a single-tube type facility be designed. The measurements of interest would be tube-side heat transfer coefficient and pressure drop as well as the rate of condensate generation. The approximate flow ranges to be tested over are 10-100 ft^3/hr (4.7-47 Lpm) of flue gas and from 0.05-0.4 lbm/hr (0.05-0.1kg/hr) of condensate per tube. Inlet temperatures and pressures will depend on the working fluid selected and test facility designed.

The tube geometries that will be tested are as below:

Nominal Tube Diameter	3/8 in. (9.5mm)	1/2 in. (12.7mm)
Tube Internal configuration	No insert, plain tube	No insert, plain tube
	Twisted tape insert pitch #1 (selected by PMS)	Twisted tape insert pitch #1 (selected by PMS)

	Twisted tape insert pitch #2 (selected by PMS)	Twisted tape insert pitch #2 (selected by PMS)

The milestone for this task:

Activity	Time Duration	Milestone
Test Facility Design	2 Mo.	PMS Approval of proposed test facility

Task 3: This task will involve initial data collection with the no insert, 3/8” and 1/2" tubes.

Activity	Time Duration	Milestone
No insert testing	4 Mo.	PMS Review of data

Task 4: This task will cover the data collection of both tubes with the two insert designs selected by the PMS. Each design will be tested and then the PMS will review the data to ensure they address the goals of the project.

Activity	Time Duration	Milestone
Insert #1 testing	6 Mo.	PMS Review of data
Insert #2 testing	6 Mo.	PMS Review of data

Task 5: The main deliverables of the project are appropriate fundamental math models of condensing flue gas in-tube that may be programmed into larger total heat exchanger models. The models should be able to describe both plain tube configurations as well as allow for the addition of enhancements on the tube side. The enhancements would be the twisted tape variety commonly used in the industry. Model development should be based on the literature search discoveries as well as the new empirical data acquired specifically during this project. Conventional fuels (natural gas and propane) as well as hydrogen mixtures should be addressed in the modeling.

Activity	Time Duration	Milestone
Correlation development	9 Mo.	Report out to PMS

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. 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.

b. 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.

The following deliverables shall be provided to the Project Monitoring Subcommittee (PMS) as described in the Scope/Technical Approach section above, as they are available:

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.

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 (1909-RP) at the end of the title in parentheses, e.g., (1909-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 four professional-months for the Principal Investigator and thirty months effort of research assistants, with a total project duration of thirty (30) months at a cost of $245.5k.
Approximately itemized as below:
$/Mo Months Total
Principal Investigator $12,000 4 $48,000
Graduate Student $3,500 30 $105,000
Tuition $50,000
Technician $10,000 1 $10,000
Lab Expense (facility upgrades and samples as required) $25,000
Miscellaneous items (travel, etc.): $7,500
Total $245,500

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Task 1: Literature Review	3rd Mo,
2	Task 2: Design and Build Verification Facility	5th Mo.
3	Task 3: Test Matrix (Plain tube testing)	9th Mo.
4	Task 4: Complete Execution of Test Matrix (Insert testing)	21st Mo.
5	Task 5: Final Correlation Development for Heat Transfer, Pressure Drop and Mass Transfer, and Final Report	30th Mo.

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.	15%
2	Quality of methodology proposed for conducting research.	25%
3	Contractor's capability in terms of facilities.	20%
4	Qualifications of personnel for this project.	15%
5	Probability of contractor's research plan meeting the objectives of the Work Statement	25%

References

1. ANSI/ASHRAE Standard 103-2007, "Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnace and Boilers."
2. ANSYS FLUENT 2020 R1 user's guide, Section 25.4.6. Film Condensation Model
3. ASHRAE, 2021, Handbook of Fundamentals, pp. 4.27-4.28.
4. ASHRAE, 2021, Handbook of Fundamentals, pp. 28.1-28.21.
5. ASHRAE, 2020, Handbook of HVAC Systems and Equipment, pp. 33.1-33.10.
6. Devlin, Simon Bear; Bach, Christian K; Alexander, Aaron S; Park, Hyunjin; Cook, James; Nguyen, Tien; and Board, Aaron, "Toward Optimal Secondary Furnace Heat Exchanger: Acquisition of Heat Transfer Correlations" (2022). International Refrigeration and Air Conditioning Conference. Paper 2383
7. Fridlyand, Aleksandr; Zhao, Yan; Asher, William; Glanville, Paul; 2023, "Burner Design Considerations for Hydrogen-blended Gas Operation", ASHRAE Transactions Volume 129, Part 1 [AT-23-C-010]

8. Glanville, Paul; Fridlyand, Aleksandr; Zhao, Yan; 2023, “From Town Gas to Hydrogen: Historical and Modern Perspectives on Transitions Between Delivered Fuels in the Built Environment”, ASHRAE Transactions Volume 129, Part 1 [AT-23-C-011]
9. Manglik, R.M. and Bergles, A.E., 1993, “Heat Transfer and Pressure Drop Correlations for Twisted-Tape Inserts in Isothermal Tubes: Part I—Laminar Flows,” J. Heat Transfer, Vol.115(4): 881-889.
10. Manglik, R.M. and Bergles, A.E., 1993, “Heat Transfer and Pressure Drop Correlations for Twisted-Tape Inserts in Isothermal Tubes: Part II—Transition and Turbulent Flows,” J. Heat Transfer, Vol.115(4): 890-896.
11. Watanabe, K. and Taira, T., 1984, “Heat Transfer Augmentation in Tubular Flow by Twisted Tapes at High Temperatures and Optimum Performance,” Heat Transfer Japanese Research, Vol.12, No.3.
12. Zhang, S., Lu, L., Dong, C., and Cha, S.H., 2019, “Performance evaluation of a double-pipe heat exchanger fitted with self-rotating twisted tapes,” Applied Thermal Engineering, Vol.158, No.113770.
13. Zhao, Yan; Glanville, Paul; Fridlyand, Aleksandr; 2023, “Inline Hydrogen Sensor Monitoring of a Tankless Water Heater Operating up to 30% Hydrogen Blending”, ASHRAE Transactions Volume 129, Part 1 [AT-23-C-012]
14. Zschaeck, G., Frank, T., Burns, A.D., 2014, “CFD modeling and validation of wall condensation in the presence of non-condensable gases”. Nuclear Engineering and Design, 279. 137–146.