University of Illinois at Urbana-Champaign

ACRC

Air Conditioning and Refrigeration Center A National Science Foundation/University Cooperative Research Center

ACRC Research Program

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Fundamental Processes

An Experimental and Computational Study of Disperse Two-Phase Flow in Headers

P. S. Hrnjak, S. P. Vanka

A combined experimental and computational study will be undertaken to develop better understanding and control of dispersed two-phase flow in headers. First, we will examine misty flow regimes in headers using the refrigeration setup from Project 96 for which the liquid and vapor phase flow rates can be individually measured from five tubes distributed along the length of a header. A model of two-phase flow in headers will be developed which will be directly compared to experiments. Second, a more fundamental understanding of dispersed two-phase flow over a backward step, which simulates the sudden expansion at the inlet of a typical header, will be conducted using LDV/PDPA. The particle size, particle volume fraction and Reynolds number will all be varied over ranges applicable to headers and their effects noted. A Large Eddy Simulation (LES) code will be developed which will predict dispersed two-phase flow and corresponding comparisons with the experiments will be made.

Fundamental Investigation on the Tribological Failure Mechanisms of Compressor Surfaces-Scuffing

A. A. Polycarpou, T. F. Conry

The focus of this research project is to investigate further the cause of catastrophic failures, viz., scuffing for realistic compressor surfaces. The project will have two major components: (a) The detailed characterization of the changes in surface topography and physical structure of mating surfaces from their initial state up to the point of scuffing. (b) After we understand the material properties and surface topography, a modeling effort will be initiated to describe the essential coupled processes of deformation and heat transfer and the resulting effects of stress and temperature at points in a contact interface.

Three-Dimensional Computational Modeling Of Augmented Louver Geometries for Air-side Heat Transfer Enhancement

D. K. Tafti

The objective is to explore means by which one can use the three-dimensionality of the louver geometry or variants of the base louver geometry to enhance heat transfer not only on the louver but also on the adjoining tube surface. We first propose to model the conventional multilouvered geometry and the fluid flow and heat transfer which occurs as the angled louver transitions to the flat landing at its junction with the tube surface. In the second phase, we will examine modified louver geometries, which will attempt not only to enhance heat transfer on the louver itself but also on the adjoining tube surface. The proposed shape of the louver is similar to a modified delta wing.

Investigation of Refrigerant/Oil Mixtures in Horizontal Tubes and Flat Plate Condensers and Evaporators

T. A. Newell, J. C. Chato

This project will investigate oil holdup under condensation conditions in round tubes (smooth, axially finned, and 18 degree helically finned) and flat plate heat exchangers (chevroned and bumpy). R134a and R410A refrigerants will be used with 32 and 68 mm2/s viscosity POEs and an automotive PAG (R134a only). An oil (alkylbenzene) immiscible with R134a will also be examined under evaporation conditions with round tubes.

The primary activity for collecting data related to oil holdup during condensation follows a similar test matrix as ACRC project 100 that is examining oil holdup in evaporation. "Low" (0.1 to 0.3%) and "high" (3 to 5%) concentrations of oil in circulation with refrigerant are examined over a mass flux range of 75 to 500 kg/m2-s and a quality range from 10 to 90%. 32 and 68 mm2/s viscosity POEs and an automotive PAG will be used as lubricants. R134a will be examined with all three oils, while R410A will be examined with the POEs.

A New Approach to Interrupted-Fin Design, with a Focus on Wake Management, Vortex Shedding and Boundary-Layer Effects

A. M. Jacobi

Recent manufacturing developments allow unprecedented freedom in array layout in interrupted-fin construction with. With this freedom, the question is how to exploit the physics of wake management, vortex shedding, and boundary layer re-starting for an optimal deployment of interrupted-fin surface. This project is focused on answering that question for offset-strip (zero attack angle) arrays. We will use experiments to characterize the flow and heat transfer behavior of a new offset-strip array. Flow visualization, anemometry, and convective data will be used to understand the roles of wake management, vortex shedding, and boundary-layer re-starting on this canonical interrupted-fin array. The results will be used to develop a near-optimal array design and to develop guidelines for other interrupted fin arrays.

A Study of the Application of Vortex Generators to Enhance the Air-Side Thermal Performance of Heat Exchangers

A. M. Jacobi

Passively generated streamwise vortices can enhance air-side heat exchanger performance in refrigeration and air-conditioning systems. Recent Center research showed that vortex generation applied to a plain fin-and-tube heat exchanger with a large fin spacing will increase the area-goodness factor, j/f, by up to 34% at relatively high air flow rates. The work now underway will address critical questions related to vortex enhancement of refrigerator evaporators (under frosting conditions) and will explore the development of a viable generator geometry for more compact heat exchangers typical to those used in AC systems. This project will be completed using full-scale heat exchanger experiments and techniques developed in earlier Center research.

Void Fraction and Pressure Drop in Microchannels

T. A. Newell,, P. S. Hrnjak

The objective of the project is the investigation of pressure drop in microchannel tubes by extending the current investigation range by examining R123, carbon dioxide and ammonia. These fluids in combination with the refrigerants previously investigated (air/water, R134a, R410A) will cover a broad property range, including important hydrocarbons such as isobutane. The carbon dioxide property region should be one in which homogenous flow dominates the flow conditions. Ammonia (very similar to isobutane in fluid mechanics characteristics) is in a region where annular flow tends to be dominant. R123 represents another extreme in which liquid density is high while vapor density is low. The tests would include oil with refrigerants to determine the effects of oil on pressure drop.

Tribological Studies on Scuffing Due to the Influence of CO_2 Used as a Refrigerant in Compressors

A. A. Polycarpou, T. F. Conry

The overall objective of this project is to determine how surface topography and material(s) properties relate to scuffing in a CO_2 refrigerant/lubricant environment. The major components of the study are to: establish a common testing protocol with CO_2; investigate, under High Pressure Tribometer (HPT) conditions, the miscibility of CO_2 with different lubricants (POE and PAG), percent weight, pressures, and temperatures; screen and analyze tribo-pairs (cast iron on cast iron and aluminum alloy against 1018 steel); and use the analysis tools established in ACRC 127, viz. the characterization of surface topography and the characterization of the physical, chemical, and mechanical properties of the surface and near sub-surface material(s). This would be the first comprehensive investigation of tribological behavior in a CO2 environment.

Microfinned Microchannel and Flat Plate Heat Exchangers

T. A. Newell, J. C. Chato

Microfin surfaces applied to microchannel passageways will be investigated in this project. Microfins are structures that are lower in height than the average liquid film thickness in a two-phase flow. These surfaces have been found to significantly enhance heat transfer in round and flattened tubes by adding surface area in the viscous sublayer and buffer regions of the liquid film adjacent to the wall of a refrigerant passageway. Test sections will be constructed for experimental measurement of heat transfer and pressure drop. Also, numerical modeling of the fins and wall base metal will be performed in order to examine the wall material's ability to move heat across the passageway wall material.

Study of Multilouvered Heat Exchangers at Low Reynolds Numbers

D. K. Tafti

The project will study the low Reynolds number flow regime (Re< 500) in louvered fin heat exchangers. It will focus on the following issues:

1. Flow efficiency and transition from duct to louver directed flow. Reconcile and explain differences in experimental measurements with aid of computations. Provide a comprehensive understanding of flow efficiency.
2. Augmentation techniques focused on increasing flow efficiency for large fin pitches. We will study the effect of modifications on inlet and redirection louvers and selective use of large louver angles.
3. Effect of flow perturbations on flow and heat transfer. Study effects of inflow perturbations on flow and heat transfer. Study type of perturbations required to induce unsteadiness and augmentation at low Reynolds numbers.
4. Effect of flow angle on heat transfer. Study how the inlet and first few louvers react to flow angles and should they be modified to account for the flow angle. Study combined effect of flow perturbations and flow angle.

Maldistribution and Bundle-Depth Effects on Falling-Film Flow

A. M. Jacobi

In falling-film heat exchangers, a liquid is sprayed onto the top of a tube bundle, and as it falls from one horizontal tube to another below it, the flow may take the form of discrete droplets, jets, or a continuous sheet. The falling-film mode plays an important role in the wetting, heat transfer, and mass transfer characteristics of the heat exchanger. Center research is underway to develop new regime maps that will include the effects of vapor shear on the falling film behavior. Once those new maps are complete, work is planned to consider liquid-flow maldistribution effects on the local falling film mode. We will conduct experiments with imposed restrictions in the liquid feeding system to cause liquid maldistribution along the top tube. We will measure the flow maldistribution, relate it to mode observations, and assess the rate at which flow uniformity is achieved in the bundle. We will also incorporate the maps into bundle simulation programs to predict the falling-film regimes at various locations within the bundle, and with these simulations to study (analytically) the overfeed rates required to meet flow regime requirements throughout a bundle.

Components

Evaporator Frosting and Defrosting Strategies

P. S. Hrnjak, C. W. Bullard

This project builds upon earlier frost-related research conducted at the Center. The goal is to further understand the mechanisms by which frost degrades evaporator performance in various types of commercial or transport refrigeration systems, and to design strategies for minimizing such degradation. By identifying design variables that can affect the start and termination of defrost, it may be possible to choose defrost techniques in a way that allows the system to operate closer to the overall system optimum. The defrost criterion could be to maximize COP, but it could also be expressed in terms of capacity or air flow rate or any combination of such parameters. Another objective is to develop heat exchanger design guidelines and insights that could lead to more effective defrosting strategies.

To determine the optimal time to defrost a particular system, it is necessary to understand how the frost affects evaporator heat transfer, reduces air flow rate, capacity, and ultimately the COP and capacity by reducing suction pressure and air flow rate. Experiments are measuring performance degradation (e.g. capacity, air flow rate) for a carefully selected set of heat exchangers, to validate a model that will represent explicitly the density and conductivity of the frost layer and its effects on fin spacing, etc. Then it will be used to devise strategies for minimizing performance degradation in various types of commercial or transport refrigeration systems.

Design Tradeoffs in Microchannel Heat Exchangers

C. W. Bullard

The purpose of this project is to exploit knowledge gained in earlier experiments and analyses of microchannel condensers and evaporators, and to apply it to the problem of optimizing their design. Research is focused on finding ways to avoid or offset the adverse effects of refrigerant maldistribution, both tube-to-tube and port-to-port. There are three basic types of tasks: 1) rough order-of-magnitude calculations to establish design constraints to avoid such deleterious effects as gravity-induced maldistribution; 2) detailed calculations focused narrowly to help understand such phenomena as the as the non-unique dependence of mass flow rate on inlet quality, or to investigate ways in which tube wall thickness could help equalize the thermal loads among parallel ports; 3) use heat exchanger simulation models to quantify performance improvements achievable through use of multi-slab construction, or the pressure drop implications of maximizing air-side area by using more thick tubes or fewer thin tubes.

An Empirical Study of Frost Accumulation Effects on Louvered-Fin, Microchannel Heat Exchangers

A. M. Jacobi, P. S. Hrnjak, J. G. Georgiadis

The focus in the project is on frost growth on folded louvered fins with microchannel tubes. The emphasis is on experimental study over the complex parameter space of louvered fins. The research will provide an assessment of frost growth and its effects on overall heat transfer and pressure drop behavior for microchannel heat exchangers. The project will result in performance correlations useful for the design of microchannel heat exchangers with folded, louvered fins in frosting applications. This study will be pursued through a broad experimental program to measure heat transfer and pressure drop under frosting conditions for a range of louvered-fin designs. Wind tunnel experiments will be conducted using a specimen design that allows for relatively quick and easy changes in fin shape to be studied.

Closed-Loop Control for a Smart Refrigeration Air Curtain

E. Loth

It is proposed to develop and test closed-loop control for the fluid dynamics of a refrigeration air curtain, i.e. a "smart" air curtain. The objective of employing this control is to minimize the entrainment mass flow rate of ambient air while maintaining a constraint of sufficiently low curtain temperature. This objective will result in a minimization of both the thermal load to the compressor (which reduces power consumption) and the amount of water vapor in the return air (which minimizes frost formation rates and thus defrost requirements). This will be achieved in the laboratory by a monitoring of thermal entrainment as the feedback signals and variable fan speed or duct louvers as the system actuator. An integrated experimental program will investigate and quantify the most promising and robust control-loop strategies.

Flow Distribution and Pressure Drop in Microchannel Manifolds

T. A. Newell, P. S. Hrnjak

The primary objective of this project is to establish an understanding of the flow field in a manifold distributing two-phase refrigerant flow into a series of microchannels. Successful implementation of microchannel tubes in evaporators requires controlled distribution of refrigerant to the microchannel tubes. The reasons for maldistribution of refrigerant flow may be due to manifold design or to a natural preference of the flow field. Maldistribution effects may be spatial, temporal, or a combination. Flow visualization combined with experiments in a microchannel heat exchanger will be used to determine flow field parameters important for controlling refrigerant flow.

Systems

Investigation of Refrigerator Heat and Mass Transfer Cabinet Loading during Open Door Conditions

T. A. Newell

This investigation will determine moisture transport into a refrigerator cabinet during open door conditions. The open door moisture loading activities will investigate both overall cabinet loading and local cabinet loading. A second activity will determine sensible and latent heat loads due to objects (food containers) temporarily removed from a cabinet.

Moisture loading of a cabinet during open door conditions will consist of two studies. First, an investigation of the overall moisture loading (average mass transfer coefficient) will be conducted. The approach will use a full-scale cabinet cavity model that is cooled and then exposed to a warmer, more humid surrounding environment. The model will be weighed as the overall moisture collection monitored. The cavity walls will be covered with calorimeter plates that will allow the energy loading to be determined. A study examining localized moisture loading in a refrigerator cabinet will also be conducted. The localized study will use a light refraction technique for measuring the thickness of a liquid film deposited on the cavity surface. A simple weighing technique will also be used to determine local water mass condensation amounts.

Container loading (food packages) will be investigated by constructing calorimetered models of common food package shapes. The models will be weighed in order to determine moisture buildup. A model for determining sensible and latent cabinet loads due to the temporary removal of containers will be developed.

Investigation of Electrochemical Processes for Refrigeration

T. A. Newell

Electrochemical processes can be combined into thermodynamic cycles that can produce refrigeration effects. These systems generally make use of fuel cell and electrochemical cells combined into a thermodynamic cycle. Refrigeration effects may be achieved by either "internally" or "externally" driven processes.

This project will begin with an extensive review of potential chemical candidates for electrochemical reaction processes. Candidate components will be used as the basis for designing electrochemical refrigeration cycles. The cycles will be analyzed on a thermodynamic and transport basis in order to determine the potential cycle performance limits and capacity limits.

Prototypes of the most promising candidates will be constructed and tested in order to compare performance with predicted levels.

Designing and Optimizing Systems for Compressor Short-Cycling

C. W. Bullard, P. S. Hrnjak

The purpose of this project is to explore the system design implications of compressor short-cycling. A project initiated last year has produced promising results, showing that on/off cycle periods as long as 10-25 seconds can produce COP's comparable to those achievable with variable-speed compressors. This project builds on those results, and aims to develop ways of designing heat exchangers and receivers to fully capitalize on this technology. The experimental program will be expanded to include microchannel evaporators and condensers, and automotive a/c applications. Those results will be used to validate heat exchanger models that can quantify tradeoffs among such parameters as cycle period, runtime fraction, thermal mass, refrigerant inventory, and surface/volume ratio.

Modular Simulation Model for Air Conditioning Systems

C. W. Bullard

The purpose of the project is to develop a detailed air conditioner simulation model with a modular structure that can accommodate the various types of heat exchangers, expansion devices used in a wide variety of stationary and mobile air conditioning and refrigeration applications. The work builds on an existing model/solver structure that enables the user to exchange input and output variables without rewriting or recompiling the program.

Strategies for Improving Operation and Reliability of Vapor Compression Systems

A. G. Alleyne, N. R. Miller, P. S. Hrnjak, C. W. Bullard

The purpose of this project is to develop a dynamic simulation model for stationary and mobile a/c, and to commercial and domestic refrigeration systems. It will retain enough detail to accurately predict system dynamic response while also being simple enough to be of value in determining appropriate control strategies. The focus is on controlling quasi-steady transitions between operating states by modulating flow rates of both air and refrigerant, to meet changing constraints on capacity, efficiency, compressor reliability, noise, etc., not startup and shutdown transients. It will build upon the best published empirical/lumped parameter models, by making more extensive use of physical parameters, based on results from other research projects. The model development is supported by a parallel set of experiments conducted in a breadboard test facility that can handle both automotive-type and conventional heat exchangers. The sensitivity of the control strategies to variations in operating conditions will be related to physical design parameters.

Design Methods for Reducing Refrigerant Induced Noise

N. R. Miller

This project carries on work begun in projects 72 and 105. Project 72 experimentally investigated the flow noise from a variety of expansion devices over a wide range of operating conditions. We also examined the propagation and attenuation of the acoustic signal within the refrigerant flow and through the tube walls. Semi analytical models were shown to reliably predict the sound propagation. Project 105 concentrated primarily on the “popping” noise reported to occur in capillary tubes under certain operating conditions. A basic understanding of the causes of the phenomenon has been developed.

This project will focus on developing design guidelines for low noise expansion devices and refrigeration components that minimize the propagation of refrigerant flow noise and shocks.

Charge Minimization in Components and Refrigeration Systems that use Hydrocarbons as a Refrigerant

P. S. Hrnjak

The objective is exploring options for charge reduction in hydrocarbon systems and their effects on performance. A similar project initiated two years ago for ammonia resulted in ten folds charge reduction in the system with air cooled condenser and microchannel tubes compared to existing systems of this type. The major contribution in charge reduction comes from the channel and headers size and shape. Further steps will be based on models and approaches developed in earlier ACRC projects to balance air and refrigerant sides related to volume and void fraction. Effect of oil in the (low volume) compressor will be investigated as well as Charge distribution issues in heat exchangers and its migration in transient conditions.

Contract Research

Dual Evaporator Refrigerators

T. A. Newell, C. W. Bullard

Two-evaporator refrigerators can offer higher energy efficiency and improved control of conditions in the fresh food and freezer compartments. This project examines two types of systems: 1) a two evaporator system in which a single compressor simultaneously drives both evaporators in either a series or parallel arrangement would be developed; and 2) a system in which either a capacity modulated compressor or a dual compressor system supplies independently operated evaporators.

Integrated Mesoscopic Cooler Circuits

M. L. Philpott, M. A. Shannon

A distributed system of light-weight, ultra-efficient mesoscopic coolers will be developed which can be economically mass-produced to create a flexible cooling system. By combining innovative layered mesoscopic fabrication techniques with a scale-efficient vapor-compression cycle, an integrated mesoscopic cooler circuit (or IMCC) could provide significant improvements in cooling performance. The process combines polyimide/thin film layers with silicon-based electro-mechanical device fabrication. A network of flexible, electrically powered IMCCs approximately 120 mm (4.7") square and 3 mm (<1/8") thick may be used to create a cooling system for a wide range of military and commercial applications that require low-temperature lift cooling. An important potential application is the cooling of military personnel on active duty in hot climates. Other potential applications include cooling of microelectronics and infrared sensors, and weapon systems that can benefit from robust distributed cooling.

Transcritical Cycles for Mobile and Stationary Air Conditioning Using Carbon Dioxide Refrigerant

P. S. Hrnjak, C. W. Bullard

Transcritical carbon dioxide cycles are being compared to state-of-the-art vapor compression cycles that use hydroflurocarbon refrigerants. Experiments are being conducted in test facilities specifically designed to span a wide range of indoor and outdoor psychrometric conditions for both mobile a/c and residential-scale heat pumps. The resulting data will provide the basis for comparing the total impact on global warming, directly and indirectly, resulting from the operation of CO2-based systems designed to compete with R-134a based mobile a/c systems, and with residential heat pumps using R-410A. Tradeoffs involving volume, weight, efficiency, and reliability are being investigated.

Condensate Accumulation Effects on the Air-Side Thermal Performance of a Slit-Fin Surface

A. M. Jacobi

For heat exchangers in air-conditioning applications, water retention and shedding have an important effect on air-side flow and heat transfer. Previous research has shown that at high Reynolds numbers, sensible heat transfer can be enhanced by condensate on the heat transfer surface; however, at low Reynolds numbers, retained condensate can accumulate and act as an added resistance to air flow and heat transfer. The overall thermal impact-beneficial or detrimental-of retained condensate is highly dependent on exchanger geometry and operating conditions and is not well understood. Few studies of water retention have been reported in the open literature, and no models are available for predicting condensate retention and its effects on flow and heat transfer in slit-fin geometries. The purpose of this project is to obtain measurements of water retention and shedding effects and to develop and validate an empirical model for predicting these effects for slit-fin heat exchangers.

Heat Transfer Enhancement in Copper Tubing

T. A. Newell, J. C. Chato

A research project is proposed that would examine a copper tube passageway that combines the effects of interior surface groove and small passageway effects. The goal of the project would be the development of a copper tube that enhances air-side and refrigerant-side heat transfers, minimizes pressure drop, and minimizes refrigerant inventory. A two year effort in which refrigerant condensation is examined is proposed. The project would be primarily experimental, utilizing the ACRC's refrigerant condensation heat transfer facility. A cooperative effort between Copper Development Association representatives and ACRC personnel is envisioned in which CDA representatives' expertise in materials and manufacturing are combined with the ACRC's expertise in refrigerant heat transfer and fluid mechanics.

Technical Testing Agreements

The Center's faculty and students occasionally perform short-term tests of systems or components and provide the data to the sponsoring companies.