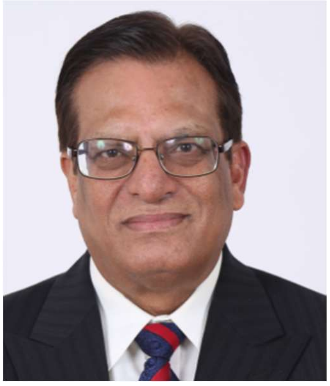
The Third Pacific Rim Thermal Engineering Conference
December 15-19, 2024, Honolulu, Hawaii, USA

PRTEC-PL01

Plenary Lectures



SUPERCRITICAL FLUIDS: POTENTIAL AND CHALLENGES

Prof. Vish Prasad
Department of Mechanical Engineering
University of North Texas, USA

ABSTRACT

Industrial fluids, such as the natural gas, under supercritical (SC) conditions can be transported to ultra-long distances with very-large mass flow rates and much lower pumping power. The pipeline transport of two important fluids, hydrogen and helium will certainly be at the SC pressures and temperatures. In a CCS process, CO_2 from the place of capture to a (temporary) storage, and finally, to the permanent place, such as the ocean bottom or a geological reservoir, will experience the SC conditions. Moreover, the use of CO_2 in energy conversion systems that are being extensively investigated, would require SC transport via pipelines as well as within the heat exchangers. Efforts are also being made to take advantage of the SC pressures and temperatures of water in geothermal reservoirs for the renewable energy recovery. Furthermore, the next generation thermal power plants are expected to use the SC water that can significantly enhance its power and efficiency and reduce the cooling water requirement. Indeed, two to three orders-of-magnitude increase in heat transfer is possible by using the working fluid at SC pressures; the effect being more pronounced at low temperatures. Although not fully realized thus far, there is an unlimited scope of the use of SC fluids for super-enhanced heat transfer in heat exchangers and other thermal systems.

However, one of the major challenges facing the SC fluids is that they all exhibit anomalous behavior near their critical points (CP). In the anomalous region, the thermophysical/transport properties show large scale variations, e.g., the specific heat first increases with temperature, achieves a peak, and then decreases to a monotonic behavior. Furthermore, this region is prone to flow oscillations, thermal instabilities and deteriorated heat transfer. It is also now well established that the SC state is divided into “liquid-like” (SCLL) and “gas-like” (SCGL) regions. Interestingly, the research on the anomalies and the crossover from SCLL to SCGL have been primarily focused on the conditions beyond the CP, but not on the subcritical sides. Indeed, the anomaly starts in the subcritical liquid, peaks at the CP, and finally vanishes at high SC conditions. From the applications point of view, the anomalous region needs to be identified and, in most applications, avoided, though there may be some advantages in using the anomalous states in some specific cases. All of the above, physical, thermodynamic, transport, and applications aspects of the supercritical fluids will be elaborated during the presentation.

PRTEC-PL02

Plenary Lectures

THE FUTURE OF HEAT PUMPS: PIONEERING THE PATH TO A SUSTAINABLE TOMORROW

Prof. Yongchan Kim
Department of Mechanical Engineering, Korea University, South Korea

ABSTRACT

Transitioning to sustainable energy is critical for mitigating climate change and reducing carbon emissions. Among renewable technologies, heat pumps have garnered strong attention for their potential for high efficiency in residential, commercial, and industrial heating and cooling. These energy-efficient devices, powered by low-emission electricity, provide significant energy savings and reduce fossil fuel reliance with high cooling and heating performance. Environmentally, heat pumps offer substantial benefits by utilizing renewable energy sources such as air, water, and geothermal heat, significantly cutting greenhouse gas emissions. Notably, as electricity grids incorporate more renewable energy, the carbon footprint of heat pumps will further decrease. Additionally, the development of low-GWP refrigerants addresses environmental concerns, and hybrid heat pump systems provide flexibility in diverse climates. High initial installation costs remain challenges to be solved. Nevertheless, heat pumps are alternative systems for reducing climate change and promoting sustainable development owing to their efficiency and environmental benefits.

PRTEC-PL03

Plenary Lectures

THERMAL ENERGY STORAGE FOR PLUS ENERGY BUILDING APPLICATION: SORPTION THERMAL BATTERY

Yong Tae Kang
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ABSTRACT

A key strategy to realize the plus-energy building beyond the net-zero energy building is to employ the renewable energy so that the amount of generated energy is larger than that of energy consumption. It is inevitable to apply the high-performance energy storage system for the effective usage of renewable energy due to the mismatch between the supply and demand. This study suggests a daily sorption thermal battery to store the thermal energy in the form of the chemical potential difference, which can compensate the incompatibility of the renewable thermal energy. The sorption thermal battery involves van der Waals interaction between the sorbent and the sorbate. If the sorbate obtains sufficient momentum to overcome the bonds with the sorbent, the sorbate changes its phase so that the thermal storage is achieved by separating the sorbate from the sorbent, which is called "charging process". The discharge of the sorption thermal battery provides the useful energy for application when the sorbate undergoes the phase change that releases heat upon contact with the sorbent. This type of the thermal energy storage system doesn't require the thermal insulation to prevent the heat loss of the storage tanks and has an advantage of the small volume with high energy storage density. There are two strategies suggested in this study to apply the daily sorption thermal battery for plus-energy building: one is an absorption thermal battery using the H_2O-LiBr as working fluid, the other is an adsorption thermal battery employing the composite adsorbent consisting of LiOH salt hydrate impregnated into Zeolite 13X and H_2O as a sorbate. The absorption thermal battery can supply the cooling output to relieve the cooling demand that can operate repeatedly with the same performance without any additional manipulation. The numerical investigation is conducted to optimize the discharging process of absorption thermal battery in the aspect of the mass flow rate and the total charge amount of the LiBr solution, in which the optimized point derives the minimum value of difference between the cooling output of absorption thermal battery and the cooling demand of the building. The optimum solution charge and solution flow rate are quantified based on the four different building types (residential, hotel, hospital, and office) and the most suitable cooling load response is observed in the case of the hotel. The building cooling demand can be relieved as much as 91.31% with optimized absorption thermal battery and the energy storage density is estimated as 101.99 kWh/m^3 under the solution charge of 1440 kg and the solution flow rate of 0.51 kg/s. The maximum COP and energy storage density are estimated as 0.74 and 207.73 kWh/m^3 with the solution charge of 1440 kg and the solution flow rate of 1.0 kg/s. The adsorption thermal battery with composite adsorbent of LiOH salt hydrate and Zeolite 13X can serve the hot water supply with temperature of 55 °C to the plus-energy building and it achieves the energy storage density of 2219.21 kJ/kg by measuring with the simultaneous thermogravimetric analyzer. This result should be applicable to the reactor-scale. However, since adsorption only takes place on the surface of the adsorbent, the adsorbent with a large ratio of surface area to volume will assist to maximize the amount of the water vapor adsorbed. The hydrodynamic resistance is also considered to guarantee the inner surfaces of the composite adsorbent to be accessible for the water vapor, which means a large specific volume, sufficient passages between the composite adsorbent, and a large amount of heat released. The experimental investigation is conducted with cylindrical reactor filling with composite adsorbent to observe the breakthrough curve and temperature distribution of the reactor. The breakthrough curve is also predicted with the numerical investigation by varying the length of the reactor, the velocity of the water vapor flow, and the relative humidity of the inlet water vapor so that the appropriate charging time and length of the reactor for the daily adsorption thermal battery can be estimated.

KEYWORDS: Charging and discharging, Energy storage density, Plus-energy building, Sorption thermal battery, Thermal energy storage.

PRTEC-PL04

Plenary Lectures

GAS ADSORPTION IN CONFINED NANOSPACES AND ITS APPLICATION TO HVAC TECHNOLOGY

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ABSTRACT

Porous materials with confined nano-spaces are widely used as gas adsorbents. In particular, metal-organic frameworks (MOFs) are highly porous crystalline structures composed of metal nodes and organic linkers that are excellent adsorbents due to their mesoporous structure. Additionally, altering their structure and central metal atoms allows tailoring to different applications. Furthermore, MOFs have been developed for a wide range of applications from gas storage and separation, heterogeneous catalysis, drug delivery, sensors, and desalination, due to their tunability and large surface area. We are conducting theoretical and experimental studies on water vapor adsorption and carbon dioxide adsorption on MOFs with a view to their application in heating, ventilation, and air conditioning (HVAC) technology. We have studied in detail not only the fundamental structural, dynamic, and thermodynamic properties of molecules adsorbed in confined nano-spaces, but also the effects of temperature and material flexibility on gas adsorption. Recently, we proposed the concept of a new heat pump cycle utilizing the carbon dioxide adsorption properties of MOFs, namely a hybrid compression-adsorption heat pump cycle. In this presentation, I will describe the prospects of this heat pump cycle and discuss the necessary component technologies and suitable materials for this heat pump cycle.

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PRTEC-PL05

Plenary Lectures

RECENT NEW COMBINATION EXAMPLES IN OUR APPLICATION-ORIENTED HEAT AND MASS TRANSFER PROBLEMS

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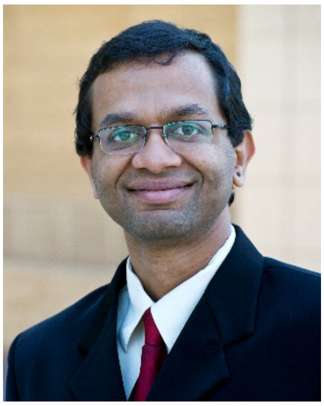
ABSTRACT

Heat and mass transfer is one of the most important academic disciplines to address the problems in various industrial applications. Current research and development activities enjoy the fruitful results of research history. For the research and development phase of actual industrial applications, heat and mass transfer requires new combination with ideas and/or tools from different disciplines.

One of the research topics I would like to discuss is inkjet technology. The recent trend in the printing industry is the transformation from analog to digital, and inkjet is the key technology in digital printing. Evaporation and permeation on the print media determine the print quality. Understanding the heat and mass transfer process of ink droplet on printing media requires additional tools to achieve. The other topic to be presented is related to electronic packaging. Especially the thermal issues in electronic packaging are crucial for reliability and the technology is continuously evolving due to the increasing demand for thermal management. This presentation summarizes our research experience on these topics.

PRTEC-PL06

Plenary Lectures



THERMAL TRANSPORT IN LITHIUM-ION CELLS AND BATTERY PACKS

Ankur Jain
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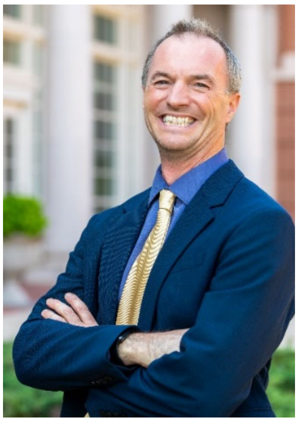
ABSTRACT

High-efficiency electrochemical energy storage in Li-ion cells may play a key role in meeting the energy challenges of the future such as in electric vehicles and the storage of renewable energy. Li-ion cells pose several interesting scientific questions related to thermal and fluid transport that directly affect their performance and safety. Understanding these questions and optimizing the nature of multiscale heat transfer in Li-ion cell materials, components and systems remain critical research challenges.

This talk will first present an overview of the key thermal transport phenomena and challenges that occur in a Li-ion cell, including performance deterioration at low temperatures and thermal runaway hazards at elevated temperature. The talk will then discuss ongoing experimental and theoretical research towards meeting some of these challenges. Multiscale thermal conduction measurements that identify poor thermal transport across the cathode-separator interface as the fundamental root cause of the low thermal conductivity of Li-ion cells will be discussed. A molecular bridging technique that improves this interfacial thermal transport by 4X will be discussed. System-level multiphysics simulations that model and predict the highly non-linear thermal runaway phenomenon in a battery pack will be discussed. Finally, motivated by thermal runaway in Li-ion cells, stability analysis of multilayer diffusion-reaction problems will be discussed, including recent work on the use of Heaviside functions for solving problems with a very large number of layers. Key outcomes of this theoretical work include derivation of a new non-dimensional number to predict the occurrence of thermal runaway, and analysis of the existence of multiple but finite number of imaginary eigenvalues in such problems.

PRTEC-KL01

Keynote Lectures



NAVIGATING THE JOURNEY TO DECARBONIZATION IN REFRIGERATION SYSTEMS: FROM LOW-GWP REFRIGERANTS TO NATURAL ALTERNATIVES AND BEYOND VAPOR COMPRESSION TECHNOLOGIES

Lorenzo Cremaschi
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ABSTRACT

Energy security, the pressing threat of climate change, and the imperative to meet escalating energy demands collectively present formidable challenges for decision-makers in the energy sector. Notably, buildings are projected to account for more than 40 percent of primary energy consumption in the United States, with industry and transportation following closely. Among these energy-intensive structures, Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC & R) systems stand out as the largest energy consumers.

To pave the way toward a sustainable energy future and swiftly reduce CO2 emissions, enhancing energy efficiency and mitigating the environmental impact of HVAC & R systems take center stage. In this context, the upcoming presentation will delve into the ongoing journey toward decarbonization within the HVAC & R industry. Recent research plays a pivotal role in this endeavor, particularly in the adoption of refrigerants with lower global warming potential.

One innovative approach involves spray evaporation on tube bundles, which significantly reduces the refrigerant charge while maintaining system efficiency. Additionally, the session will spotlight emerging trends related to natural refrigerants, including noteworthy developments in ammonia research. Lastly, we'll explore in-kind non-vapor compression technologies and focus on an intriguing long-term solution for separating sensible and latent loads in building humidity control, contributing to sustainable thermal systems.

PRTEC-KL02

Keynote Lectures

LATEST ON-ORBIT SOLID COMBUSTION EXPERIMENTS ON THE ISS/KIBO: EVALUATING FIRE SAFETY IN MICROGRAVITY ENVIRONMENTS

Shuhei Takahashi
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ABSTRACT

Since 2012, FLARE, the international research project on space fires involving 11 universities and research institutions, including JAXA, NASA, and ESA, has been conducted. The goal of this project is to evaluate fire safety in environments with different gravity levels from those on Earth, including microgravity and reduced-gravity environments such as lunar bases and Mars. On Earth, buoyant flow exists around flames, significantly influencing flame spread over solid materials. However, in low-gravity environments, the influence of buoyancy decreases, resulting in increased heat loss from the preheated zone to the surroundings, significantly altering the flammability limits. The FLARE project aims to quantitatively model the flame spread over solid materials to predict their flammability in microgravity environments using data obtained on Earth. Since 2022, long-term combustion experiments have been conducted using the Solid Combustion Experiment Module (SCEM) installed in the Kibo laboratory on the International Space Station. Many intriguing phenomena unique to microgravity environments have been observed. In this lecture, based on these findings, we will present the latest on-orbit experimental results and introduce methods for evaluating the fire safety of solid materials in microgravity environments.

PRTEC-KL03

Keynote Lectures

EFFECTIVE INTERFACE CONTROL IN ALL-SOLID-STATE BATTERIES TO PREVENT MIXED IONIC-ELECTRONIC CONDUCTING INTERPHASE FORMATION

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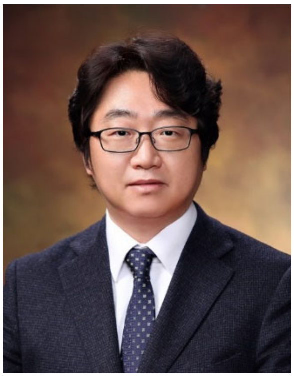
ABSTRACT

$Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$ (LATP) (LATP) is recognized for its excellent stability in ambient conditions and cost-effectiveness, making it a promising solid electrolyte material. Its high shear modulus also prevents lithium dendrite growth in lithium metal batteries. However, an adverse reaction between lithium metal and LATP can lead to battery degradation. To address this issue, we suggest a straightforward method to incorporate zinc oxide into LATP to improve the stability of the lithium metal and LATP interface. This process involves soaking the LATP electrolytes in a zinc nitrate precursor solution and then calcining them, resulting in a zinc oxide grain interlayer. This ZnO grain interlayer at the lithium metal interface creates an ion-conductive Li_2O solid electrolyte interphase, which significantly reduces the unwanted reaction between lithium and LATP. Furthermore, the ZnO grain interface enhances the movement of Li+ ions and prevents the formation of lithium dendrites. The Li/ZnO-LATP/Li symmetric battery demonstrates stable cycling performance for over 120 hours without noticeable degradation, whereas the pure LATP configuration (Li/LATP/Li) shows significant performance decline within a few hours at a current density of 0.05 mA cm^{-2}. Overall, our findings highlight a new zinc oxide infiltration technique to create a protective grain interlayer, thereby effectively improving the stability of solid-state electrolytes.

PRTEC-KL04

Keynote Lectures



VAPOR ACCUMULATION AND EVAPORATION CHARACTERISTICS OF MULTIPLE BINARY MIXTURE DROPLETS

Seong Hyuk Lee
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ABSTRACT

This study investigates the evaporation characteristics of the multiple-binary mixture droplets (M-BMDs) by analyzing vapor distributions and local evaporation fluxes. The surface plasmon resonance imaging (SPRi) technique, a sensitive, nonintrusive, and real-time detection method, is employed to examine temporal variations of liquid concentrations during evaporation. Numerical simulations are also conducted to compare the vapor distributions and local evaporation fluxes of each component. The results indicate that the evaporation rate of multiple droplets is suppressed due to vapor accumulation, which impedes the diffusion of vapor molecules into the ambient air. A higher vapor density region appears for the multiple droplets, whereas the single droplet exhibits axisymmetric distributions. The local evaporation flux of each component is significantly reduced in the region of neighboring droplets, leading to a liquid concentration gradient along the liquid-air interface. Selective evaporation and vapor accumulation cause locally higher liquid concentrations near neighboring droplets, resulting in surface tension gradients that affect internal flow motions. The M-BMDs show distinct flow patterns with two large vortices for side droplets due to these surface tension gradients. Furthermore, based on both experimental and numerical results, a new evaporation rate model is proposed, considering local vapor distributions. This model provides accurate estimations of the evaporation rate for both single-component and binary-component droplets.

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PRTEC-KL05

Keynote Lectures

HIGH-PRESSURE TORSION (HPT) PROCESSING OF Si, Ge AND SiGe COMPOSITE AND ITS THERMAL/ELECTRICAL PROPERTIES

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Kyushu University, Japan

ABSTRACT

Si and Ge exist as Si-I and Ge-I with diamond (dc) structures at normal pressure. However, it is known that high-pressure torsion processing results in the formation of metastable phases, such as the bc8-structured Si-III, r8-structured Si-XII, and st12-structured Ge-III, in addition to the dc-structured Si-I and Ge-I. Si-III and Si-XII are known to be a semimetal and a narrow-gap semiconductor, respectively, while Ge-III is known to be a semiconductor. These metastable phases have different properties, such as bandgaps, compared to the dc structure, and thus their application to new functional materials is anticipated.

SiGe crystals, an alloy of Si and Ge, are expected to be applied to electronic device substrates, infrared lenses, thermoelectric conversion elements, and more. Since SiGe alloys form a complete solid solution, they can be mixed in various ratios. By varying the Ge composition in $Si_{1-x}Ge_x$, the lattice constant and bandgap can be continuously varied. Although SiGe crystals have a dc structure, if the metastable phases with different crystal structures can be utilized, the development of semiconductor materials with various bandgaps ranging from semimetal to semiconductor is expected. However, the properties of these metastable phases are largely unknown. This study focused on High-Pressure Torsion (HPT) processing, one of the Severe Plastic Deformation (SPD) methods, as a way to obtain the metastable phases of Ge and SiGe crystals in bulk form. It has been reported that applying HPT processing to Si results in Si-III and Si-XII, and in the case of Ge, Ge-III is formed at room temperature and Ge-IV at low temperatures. In this study, we also applied high-pressure torsion processing to Ge and SiGe crystals produced by the Traveling Liquidus-Zone (TLZ) method, which allows for the production of single crystals with uniform composition, and examined their structure, thermal conductivity, and electrical conductivity.

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PRTEC-KL06

Keynote Lectures

OPTIMAL DESIGN OF A FIN-TUBE HEAT EXCHANGER FOR HEAT PUMP USING LOW GWP REFRIGERANTS

Young Soo Chang
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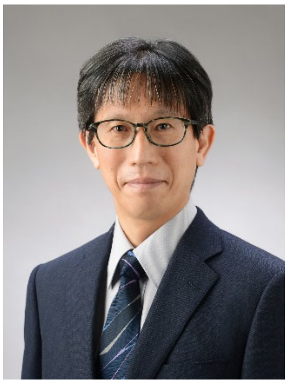
ABSTRACT

Due to concerns over the environmental impact of refrigerants, there is a global initiative to phase out high Global Warming Potential (GWP) refrigerants. This effort involves developing and implementing Low GWP refrigerants in refrigeration and air conditioning systems. It is crucial to optimize system components based on the characteristics of these new refrigerants to achieve maximum performance. Fin-tube heat exchangers have a significant impact on system performance, particularly when designing compact, cost-effective, and environmentally friendly heat pump systems. Optimizing factors like geometrical dimensions, working conditions, and refrigerant circuitry configurations can enhance heat transfer performance, thus optimal design for fin-tube heat exchangers is essential for enhancing overall system efficiency. Different thermophysical properties of low GWP refrigerants demand optimization techniques that minimize pressure drop and enhance heat transfer. Each refrigerant has unique characteristics in terms of heat transfer coefficient, pressure drop, and temperature glide that must be accounted for in optimal design. The lack of reasonable development in accommodating the diverse characteristics of various refrigerants can limit the practical application of low GWP alternatives in heat pump systems. Optimizing refrigerant circuitry is a complex task that involves exploring numerous potential configurations and utilizing techniques such as Genetic Algorithms for efficient solution discovery. The optimal number of circuits in multiple circuit configurations can be determined by considering the balance between pressure drop and heat transfer. Employing multiple circuits with split-and-merge tubes could enhance the performance of the heat exchanger. The optimal circuitry, which contains multiple circuits with split/merge tubes has a higher capacity, with a 13 % increase in total heat capacity compared to the reference circuitry.

PRTEC-KL07

Keynote Lectures



UNDERSTANDING AND DESIGNING MESOSCALE STRUCTURE IN SOLID OXIDE CELLS

Hiroshi Iwai
Kyoto University, Japan

ABSTRACT

Solid oxide cells have been attracting attention in recent years not only as conventional fuel cells for power generation, but also as steam electrolyzers for generating hydrogen. In either mode of operation, a higher current density will lead to a more compact system, improved dynamic characteristics due to lower heat capacity of the stack, and lower costs. The most common options for the current density enhancement are to devise the macroscopic cell shape and/or the microstructure of the porous electrodes. Particularly in the latter category, advances in nanoscale three-dimensional imaging techniques, such as focused ion beam scanning electron microscopy (FIB-SEM) and nano-X-ray computed-tomography, have provided access to the details of the complex microstructure of porous electrodes, deepening our understanding of the reactions and transport phenomena therein. Numerical analysis based on the obtained three-dimensional structure revealed a trade-off relationship, in which the reaction activity increases as the structure size decreases, while diffusion resistance also increases. It was also found that the reaction region is concentrated near the electrode-electrolyte interface. In this talk, on the basis of the findings from the microstructural analysis, we introduce the concept of structural modification in mesoscale, which is larger than the electrode microstructure and smaller than the macroscopic cell scale. Among the various techniques for mesostructural modification, we first discuss the role of large pores formed with pore formers in enhancing gas transport in electrodes. Optimization of the electrolyte-electrode interface and thin film electrolyte geometries will also be resented. The mesostructure-modified cell, realized by a combination of optimization simulation and micro-extrusion-based additive processing, achieved a significant increase in power density in the fuel cell mode.

PRTEC-KL08

Keynote Lectures

RESONANCE-DRIVEN HEAT TRANSFER ENHANCEMENT IN A NATURAL CONVECTION

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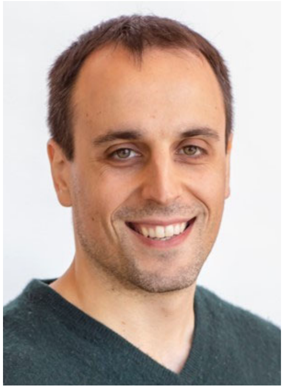
ABSTRACT

Heat transfer by natural convection is typically enhanced by installing fin arrays and other devices increasing the heat transfer surface area, but the implementation of large surfaces sometimes causes various problems. In contrast, the impact of a jet on a natural convection thermal boundary layer has been reported to produce periodical disturbance, which may yield flow resonance with the periodic flows present in the transition length of the natural convection thermal boundary layer. The flow resonance triggered by an impinging jet can enhance convective heat transfer without the need of increased surface area. The control of instability waves, including flow resonance, is expected to have applications in enhancing local and total convective heat transfer over large surfaces. In this study, a resonance-driven convective heat transfer enhancement downstream of a natural convection boundary layer is reported, which is perturbed by a moderate impinging jet. Flow resonance is experimentally and numerically confirmed between the thermal boundary layer and a periodic flow driven by the unbalance of jet momentum and buoyant force. When the oscillation frequency in the impinging region is a submultiple of the characteristic frequency of natural convection, downstream heat transfer enhancement, E, from the baseline of natural convection exceeds 40%. In contrast, further increasing the jet momentum fourfold yields $E < 20\%$. These results suggest that there would be optimal impinging jet condition to generate the flow resonance inside of natural convection thermal boundary layer. Hence this study furthermore focuses on varying the impinging location near the leading edge of the vertical heated plate, the momentum of the impinging planar jet, and the net buoyancy of the thermal boundary layer. Instability waves were estimated and observed downstream over the heated surface via simulations and experiments, resulting in a downstream heat transfer enhancement compared to that of pure natural convection of about 40% to 60% depending on the impinging position for plates shorter than 1 m. A combination of flow resonance generation and boundary layer thinning around the impinging region yields a low-energy activation method for enhancing convective heating and cooling performance.

PRTEC-KL09

Keynote Lectures



TAILORING SURFACES FOR OPTIMIZED STEAM CONDENSATION And REFRIGERANT EVAPORATION

Nenad Miljkovic
Founder Professor, Mechanical Science and Engineering
Director, Air Conditioning and Refrigeration Center
University of Illinois, USA

ABSTRACT

Almost a century ago, dropwise condensation of steam on a hydrophobic surface was shown to have a 10X higher condensation heat transfer coefficient when compared to filmwise condensation on hydrophilic surface. The resulting overall heat transfer enhancement has the potential to result in a 2% overall energy efficiency increase for steam-based power plants, which are responsible for the majority of global electricity production. The potential of dropwise condensation has driven researchers to design thin (≈100 nm-thick) hydrophobic coating materials. However, the lack of long-term (> 3 year) durability has been the main hindrance to coating utilization. In this talk, I will present our recent progress in designing thin and durable hydrophobic coating materials that enable stable dropwise condensation. First, I will discuss our fundamental studies probing the origin of hydrophobic coating degradation. We show that nanoscale pinhole defects in the coating are the source of steam penetration during condensation, where the condensate forms water blisters that pressurize and delaminate the coating. Understanding the mechanics of water blister formation and growth enables us to develop quantitative guidelines for rational coating design and selection. Next, we use these guidelines to develop fluorinated-diamond like carbon (F-DLC) with polymer-like low surface energy and metal-like exceptional mechanical properties. We show experimentally that the high bending stiffness and coating adhesion makes F-DLC durable to 5,000 cycles of mechanical abrasion and enables more than 3 years of continual stable dropwise condensation. I end my talk by shifting focus to refrigerant evaporation and present our most recent efforts to both understand the fundamentals mechanisms governing nucleation and heat transfer on textured surfaces, and to use this understanding to develop scalable electrochemical texturing techniques with optimized surface roughness for flow boiling.

PRTEC-KL10

Keynote Lectures

ELECTRICITY RECOVERY BY ELECTRIC CHARGE SEPARATION OF AIR-WATER TWO-PHASE FLOW IN CHANNELS

Jaeseon Lee
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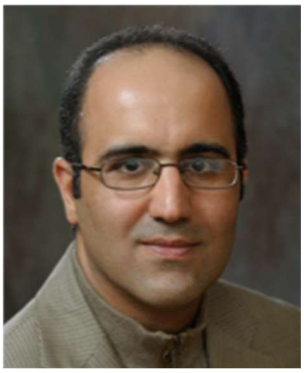
ABSTRACT

Static electricity generated by friction is one of the most common natural phenomena observed around us. When a fluid flows through a tube, the flow friction between the tube wall and the fluid causes the phenomenon of flow electrificaton. The difference in electron affinity between the fluid and the tube wall causes an exchange of electrons between the two substances, and the tube wall becomes charged, resulting in a difference in potential. Charges in the fluid that have an opposite charge to the tube wall are attracted to the tube wall potential and are held in the fluidized bed close to the wall. The remaining charges in the fluid are free from the wall potential and are present in the diffusion layer, but are subject to an electrical imbalance equal to the fixed charges. Due to this electrical double layer effect and the phase interference of two-phase flow, we are looking for a way to independently separate the charges in electrical imbalance.This lecture will introduce several research activities related to the recovery of electrical energy from these separated charges and the amplification of charge separation by continuous air-water two-phase flow.

PRTEC-KL11

Keynote Lectures



OPPORTUNITIES AND CHALLENGES IN IMPLEMENTING PHASE-CHANGE COOLING FOR NEXT-GEN AI CHIPS AND ULTRA-EFFICIENT DATA CENTERS

SAEED MOGHADDAM
UNIVERSITY OF FLORIDA, USA

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ABSTRACT

With the burgeoning demand for data centers driven by the rapid growth of AI and IoT applications, the need for efficient cooling solutions to mitigate escalating energy consumption has become critical. As chip power and server densities increase, reliance on air cooling is increasingly unsustainable, resulting in the growing adoption of liquid cooling solutions that provide enhanced thermal management capabilities. To fully realize the benefits of liquid cooling, there is an urgent need for more efficient systems, particularly those utilizing phase-change heat transfer, which can significantly improve energy efficiency and sustainability in data center operations.

Phase-change cooling has emerged as a promising alternative to single-phase methods, enabling more efficient cooling and higher computational capabilities at the chip, server, and rack levels. However, implementing phase-change cooling in data centers presents challenges due to the complex fluid dynamics and the highly coupled nature of flow hydrodynamics and phase-change processes, which are not yet fully understood. This complexity complicates optimization efforts and hinders accurate prediction and modeling.

In this talk, an overview of current trends in computational power and data center energy demand will be provided, followed by a presentation on the state-of-the-art in liquid cooling technologies. The physics of two-phase flow and phase-change heat transfer at small scales will then be explored, addressing intricate phenomena such as critical heat flux (CHF), two-phase flow in microchannels and microgaps, and the rapid formation and instability of thin liquid films. By discussing these complexities, it will be highlighted how advancements in two-phase flow dynamics can significantly contribute to development of next generation thermal management solutions reducing energy consumption in data centers, ultimately paving the way for a more resilient infrastructure capable of meeting the escalating demands of AI and IoT applications while minimizing environmental impacts.

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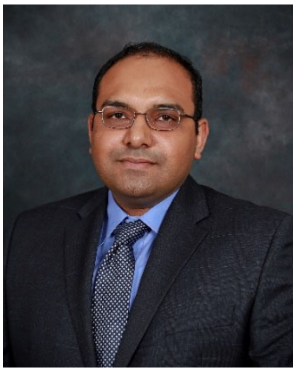
PRTEC-KL12

Keynote Lectures



HIGH-TEMPERATURE HEAT PUMPS AND THEIR ROLE IN THE DECARBONIZATION OF BUILDINGS AND INDUSTRY

Kashif Nawaz
Oak Ridge National Laboratory, Country

ABSTRACT

Heat pumps have been sought as a promising technology for air and water heating processes in buildings. Several OEMs have been commercializing heat pumps with varying capacities; However, the application has been limited to lower temperatures. With the recently growing interest in replacing gas-fired equipment for buildings and industrial processes, a new class of heat pumps is gaining substantial interest where the target temperatures are higher than the conventional heat pump technology. The speaker aims to provide a holistic overview of state-of-the-art technology while highlighting major challenges and opportunities. The discussion will focus on technology availability to enable higher sink temperatures, deployment-based applications, waste heat recovery, and process integration and controls.

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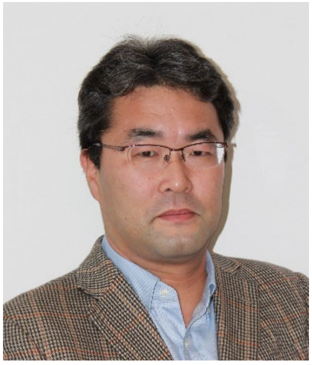

COMPARISON OF HEAT TRANSFER PERFORMANCE OF PHASE CHANGE SLURRIES

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ABSTRACT

In recent years, latent heat type thermal fluids, such as phase change slurries, have attracted more attention than sensible heat type fluids, such as water and oil. The phase change slurries are mixture of fine phase change material (PCM) particles and liquid. Thus, the phase change slurries provide not only high thermal energy storage density by using the latent heat of the PCM particles but they also show good heat transportation, because the phase change slurries include fine PCM particles. Therefore, the phase change slurries are expected to use as secondary refrigerants in the air-conditioning and food refrigeration systems. The phase change slurries can be classified by the kind of the PCM particles. Ice slurry is a mixture of fine ice particles and aqueous solution. Hydrate slurry is a mixture of hydrate crystals and the solution. Phase change emulsion is a mixture of an aqueous surfactant solution and fine particles of PCM dispersed inside it. In the case of O/W phase change emulsion, hydrocarbons such as paraffin are used as the PCM. However, the flow and heat transfer characteristics of the phase change slurries are different depending on the dispersed phase, and it is very important to reveal each characteristic of the phase change slurries. In this lecture, the comparison of the heat transfer performance of the phase change slurries was attempted. At first, the flow characteristics of the slurries were clarified. Generally, the phase change slurries are not Newtonian-fluids. Thus, the rheological behavior of the phase change slurries was investigated, and the pressure drop of the slurries in the circular tube under laminar and turbulent flow condition was measured. After that, the heat transfer characteristics of the slurries was revealed. The inner surface temperature of the tube and the temperature of the slurries under constant heat flux condition were measured, and the Nusselt number was calculated from the results. Finally, the results of the flow and heat transfer characteristics were used to evaluate their respective characteristics and the comparison of the heat transfer performance of the phase change slurries were carried out.