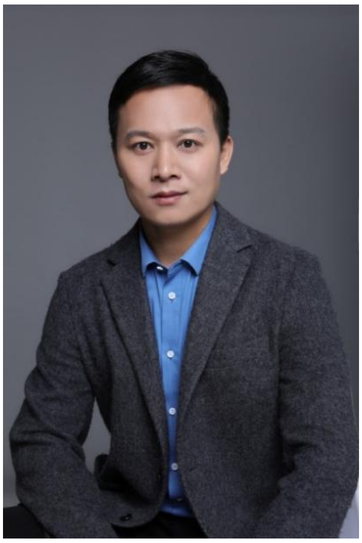
Proceedings of the 14th International Green Energy Conference
July 4-8, 2022
Paper No.: IGEC2022-211~216 (invited)

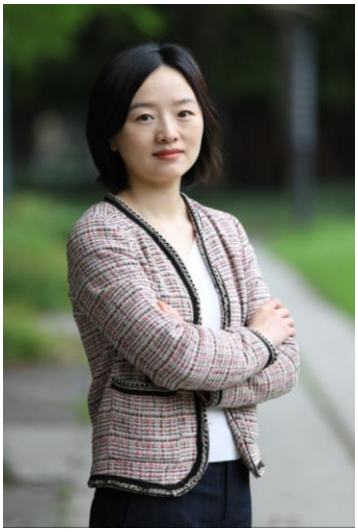
Special Session: Frosting and icing

Session Description:
Frosting and icing are widely seen in nature and industrial fields. In the real applications, they always play negative effects. For example, frosting on the surface of outdoor coil degrades the operation efficiency of air source heat pump, frosting on surface of evaporator extends the time and wastes more energy during liquid natural gas vaporization, icing on the wings' surface changes the aerodynamic profile of aircraft and may result in air crush, and ice accumulated on wind turbine blade surface reduces the power generation efficiency. Moreover, frosting and icing problems are reported in the fields of electricity cables, coal transportation, food or ice storage, etc. Droplet condensation and freezing are at the early stages of frosting and icing, and thus influence their final formation. Therefore, in this session, it is fundamental and meaningful to summarize and evaluate the existing experimental and numerical studies about frosting and icing at different stages and application backgrounds.

Session Organizers:



Mengjie SONG (Beijing Institute of Technology)

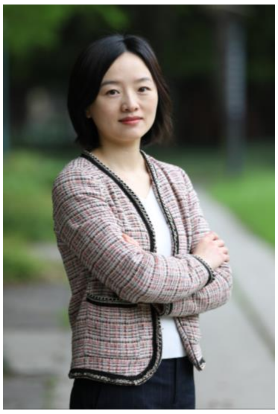


Minglu QU (University of Shanghai for Science and Technology)

Session Contents:
Topic 1: Experiments and simulations on the impact and freezing characteristics of supercooled water droplets on cold substrates
Topic 2: Droplet Collection Efficiency Distribution Laws in high speed air flows
Topic 3: Investigation on an air source heat pump system with coupled liquid-storage gas-liquid separator regarding heating and defrosting performance
Topic 4: A systematic study on the condensation frosting characteristics of a horizontal cold plate under forced convection
Topic 5: Ice breaking by a high-speed water jet impact
Topic 6: Recent challenges on the fundamental study around frosting and icing

Session Organizers:

Dr. SONG Mengjie, Professor of Department of Energy and Power Engineering, Teli Young Scholar, Director of Frost Lab, School of Mechanical Engineering, Beijing Institute of Technology (BIT), China. He is also the Editor-in-Chief of Recent Patents on Mechanical Engineering (EI, Scopus), Associate Editor of Frontiers in Energy Research (SCI, IF=2.746), DECRA Research Fellow in Sustainable Buildings Research Centre (SBRC), University of Wollongong, Australia, and Guest Professor of Tomas Bata University in Zlín, Czech Republic. Before starting the research work in BIT, he worked in the University of Tokyo as JSPS Research Fellow. Prof. SONG focuses on the mechanism study of heat and mass transfer coupled with the flow for more than 10 years. Currently, he has published 128 journal articles, in which 108 ones are SCI, with 70 ones as first/corresponding author, and 8 papers were ESI. He was selected into the World's Top 2% Scientists 2020 and 2021 (Singleyr) list.



Dr. QU Minglu, Associate Professor of Department of Building Environment and Energy Engineering, University of Shanghai for Science & Technology, China. Dr. QU received her bachelor and Ph.D degrees in from Tongji University and Hong Kong Polytechnic University in 2007 and 2012, respectively. Then she started the research work in USST. Dr. QU focuses on the defrosting process and defrosting method for air source heat pump. Dr. QU has received the funding supports from the National Natural Science Foundation of China, Shanghai Sailing Program of Shanghai Committee of Science and Technology, Key Laboratory of Refrigeration and Cryogenic Technology of Zhejiang Province. Currently, she has published 50 journal articles, in which 27 ones are SCI, and over 680 times cited.

Topic 1: Experiments and simulations on the impact and freezing characteristics of supercooled water droplets on cold substrates

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Abstract

Icing phenomena widely exist in many engineering fields, such as aviation, meteorology, power and communication, and cryogenic engineering and refrigeration. In these icing processes, impact and freezing of supercooled water droplets play a fundamental role. While some recent studies pay attention to the impact and freezing behaviors of room-temperature and supercooled droplets on cold substrates, competition between the fluid flow and heat transfer during the impact and freezing processes remains unclear. Here, we experimentally and numerically explore the impact and freezing characteristics of supercooled water droplets on cold substrates. A numerical model using the VOF (Volume of Fluid) multiphase model and the Solidification/Melting phase change model is established and validated by comparing temporal droplet profile and spreading factor with the experimental results. The contact line of a supercooled droplet spreads and retracts slower than that of a room-temperature one, inducing a smaller maximum spreading diameter. The supercooled droplets finally exhibit three morphologies including full rebound, partial rebound, and full adhesion, which is unified by correlating Weber number, supercooling degree, and contact angle. This work may deepen our understanding of the interaction mechanism between impact droplets and cold surfaces and thus advances the associated applications and technologies in anti-icing frosting and self-cleaning.

Keywords: Impact; Freezing; Supercooled water droplet; Rebound; Adhesion

Short bio:

Dr. ZHANG Xuan is an Associate Professor in the Department of Energy and Power Engineering, School of Mechanical Engineering, Beijing Institute of Technology. He received his B.S. and Ph.D. degrees from Beijing Institute of Technology and Tsinghua University in 2014 and 2019, and then worked at Tsinghua University and Nanyang Technological University as a Postdoctoral Researcher before joining Beijing Institute of Technology in 2022. He focuses on the coupling processes of heat/mass and flow, especially phase change problems (e.g., icing/frosting, boiling/evaporation/condensation). He has published/co-authored 33 SCI/EI journal papers, 2 books/chapters, and served as editors and reviewers for 20+ academic journals. He has also been granted International Postdoctoral Exchange Fellowship Program and Postdoctoral Supporting Program (Tsinghua University), and awarded Outstanding Doctoral Thesis (Tsinghua University), Wu Zhonghua Outstanding Graduate Student (Chinese Society of Engineering Thermophysics), and Star Reviewer for Physics of Fluids (AIP Publishing).

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Topic 2: Droplet Collection Efficiency Distribution Laws in high speed air flows

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Abstract

With the continuous development of aviation industry, the icing problem of aircraft and aero-engine is still a major threat to flight safety. It is crucial for the aviation safety to conduct the research of the icing of aircraft and aero-engine, analyze the formation mechanism and influencing factors of icing, so as to grasp the law of icing endangering flight safety. However, exploring the internal law of the droplet collection efficiency (DCE) distribution is still a problem, and there are some defects in existing methods, such as the unclear icing conditions of intake air, poor accuracy of numerical simulation, inadequate grasp of icing growth mechanism and so on. Aimed to the acquisition of the most important collection efficiency in the icing process, this report establishes a droplet impact model based on Euler two-phase flow model. Based on this model, the influence of different incoming flow parameters on DCE are analyzed. The mathematical regularity of DCE distribution is explored through parametric description, and the functional relation of the law between the far field condition and DCE is accomplished. The result shows a highly normal distribution. This distribution can be expressed with a good regularity of Reynolds number and droplet diameter. The research carried out in this paper provides theoretical and methodological guidance for the calculation criteria and simulation specifications of icing simulation.

Keywords: Droplet collection efficiency; Numerical simulation; Methodological guidance

Short bio:

Xu Quanyong, Associate Professor of Institute of Aero Engine, Tsinghua University (THU). He received his bachelor and doctor degree in Power and Energy Department from HEU in 2004and 2010, respectively. After graduation, he worked as a post doctor in Peking University and then worked as a teacher in THU from 2012 till now. His research interest includes aerodynamics, aero engine thermal dynamics, multiphase flows, etc. He has undertaken over 10 projects such as supported from the National Natural Science Foundation of China, and National Key R&D Program of China, etc. He has published over 30 journal/conference papers, authorized 20 invention patents and 5 software copyrights. His research achievements have made important contributions to the development of aircrafts.

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Topic 3: Investigation on an air source heat pump system with coupled liquid-storage gas-liquid separator regarding heating and defrosting performance

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Abstract

In recent years, air source heat pump (ASHP), as one of the efficient and promising technologies for space heating, has quickly expanded across the world, but frost accumulation on the outdoor heat exchanger is one of the basic concerns about its operation. Reverse cycle defrosting (RCD) is widely used for defrosting, however, when RCD begins and ends, the four-way reversing valve quickly switches and the system pressure needs to be rebalanced which will cause the incomplete evaporation of refrigerant into the compressor. Thus, it leads to the decrease of the performance of the ASHP system during RCD. In order to improve the performance of RCD, this study proposes an ASHP defrosting system with coupled liquid-storage gas-liquid separator. An obvious advantage of the proposed system is retarding frosting, reducing defrosting time and increasing the heating capacity and coefficient of performance (COP) of the ASHP system thus reducing the number of defrosting cycles. And the proposed system can improve indoor thermal comfort during defrosting. Experiments show that compared with the original system, the proposed system delays frosting by 30 min and reduces the defrosting time by 74 s (22.7%), improving the heating capacity and COP by 6.78% and 12.8% respectively. Moreover, the proposed system with the coupled liquid-storage gas-liquid separator is economically friendly, which further benefits its practical applications.

Keywords: Air source heat pump; Reverse cycle defrosting; Retard frosting; Defrosting time; Coupled liquid-storage gas-liquid separator

Short bio:

Dr. WANG Zhihua is an associate professor at the Xi’an Jiaotong University, China. He received his Ph.D at this University in 2015. His research interests are Building Energy Conservation, Air Source Heat Pump and Renewable Energy Technologies. He has published over 30 peer-reviewed journal papers in Energy and Buildings, Applied thermal and Engineering, Energy Conversion and Management etc. He has received 10 research funds from National Natural Science Foundation of China, China Postdoctoral Science Foundation Funded Projects, Shaanxi Province Postdoctoral Science Foundation Funded Projects, Xi’an Municipal Science and Technology Projects.

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Topic 4: A systematic study on the condensation frosting characteristics of a horizontal cold plate under forced convection

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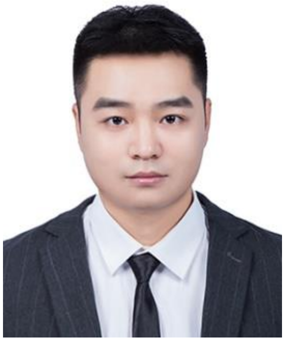
Abstract

Frosting is a common form of heat and mass transfer in nature and engineering applications, and usually brings negative effects on life and production. For a condensation frosting process, most of the related studies only focused on a part of the frosting process and ignored the edge effect of a cold plate on its frosting characteristics. Here, a systematic study on the dynamic characteristics of the entire frosting process on the edge zone of a horizontal cold plate under forced convection is experimentally carried out. In general, significant differences in droplet condensation and frozen stages between edge and inside regions can be observed. Under the condition of air velocity of 0.5 m/s, the equivalent diameter of water droplets at the end of droplet condensation stage on the edge region was around 190.2 μm, while that on the inside region was around 136.5 μm. During the droplet frozen stage, the average freezing wave propagation velocity was around 47.3 μm/s, while that on the inside region was around 18.5 μm/s. As a result, the growth of frost crystals on the frozen water droplets on the edge region was much earlier than that on the inside region. Besides, the experimental results also demonstrated that the aforementioned differences may decrease with an increase in air velocity. The results of this study can help to further understand the frosting characteristics on cold surfaces under forced convection, and hence provide insight into delaying frosting and defrosting.

Keywords: Frosting characteristic; Edge effect; Freezing wave propagation; Frost layer morphology; Forced convection

Short bio:



Dr. ZHANG Long is an assistant research fellow and postdoctoral fellow at the School of Mechanical Engineering, Beijing Institute of Technology. He obtained his dual Ph.D. degrees from The Hong Kong Polytechnic University and Harbin Institute of Technology in 2021. His research interests are focused on the frosting mechanism on cold surfaces, frosting characteristics on heat exchangers, novel defrosting methods and defrosting performances for air source heat pump systems. He has 4 authorized patents and published over 20 SCI journal papers, including 1 ESI highly-cited paper. In 2016, he was awarded the First Prize for Progress in Science and Technology by the Architectural Society of China. He serves as a guest editor of SCI journals: *Sustainability* and *Micromachines*, and EI journal: *Recent Patents on Mechanical Engineering*.

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Topic 5: Ice breaking by a high-speed water jet impact

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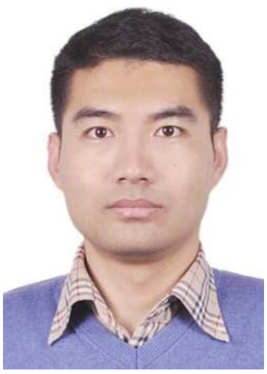
Abstract

Ice breaking has become one of the main problems faced by ships and other equipment operating in the ice-covered water region. New methods are always being pursued and studied to improve ice-breaking capabilities and efficiencies. Based on the strong damage capability, a high-speed water jet impact is proposed to be used to break an ice plate in contact with water in this paper. A series of experiments of water jet impacting ice were done in a transparent water tank, where the water jets in tens meters per second were generated by a self-designed device and circular ice plates in various thicknesses and scales were produced in the cold room. The entire evolution of water jet and ice was recorded by two high-speed cameras from the top and front views simultaneously. The focuses were the responses of the ice plate such as crack development and breakup, under the high-speed water jet loads, involving compressible pressure P_1 and incompressible pressure P_2. According to the main cause and crack development sequence, it was found that the damage of the ice could be divided into five patterns roughly. On this basis, the effects of water jet strength, ice thickness, ice plate size and boundary conditions were also investigated. Experiments validated the ice-breaking capability of the high-speed water jet, which could be a new auxiliary ice-breaking way in the future.

Keywords: Water jet impact; Ice damage; Shock wave

Short bio:



Bao-yu Ni, Professor and Doctoral Supervisor of College of Shipbuilding Engineering, Harbin Engineering University (HEU). He received his bachelor and doctor degree in Naval Architecture and Ocean Engineering from HEU in 2008 and 2012, respectively, during which he visited University College London (UCL) in UK for one year between 2010 and 2011 as a visiting PhD candidate. After graduation, he worked as a teacher in HEU and visited UCL again for two years between 2015 and 2017 as a post-doctor. His research fields of interest include ice-water-ship interaction, motion characteristics of polar ships in ice, bubble dynamics, water impact, etc. He has undertaken over 10 projects such as supported from EU Horizon 2020 Project, the National Natural Science Foundation of China, and National Key R&D Program of China, etc.. He has published 2 monographs and over 60 journal/conference papers, authorized 7 invention patents and 7 software copyrights. He has been as one of the editorial board members for the Journal of Hydrodynamics (JHD), Shock and Vibration, Journal of Marine Science and Application and Chinese JHD. He has been selected into "Youth Talent Promotion Project" of China and "Postdoctoral International Exchange Program" of China, etc.

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Topic 6: Recent challenges on the fundamental study around frosting and icing

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Abstract

Frosting and icing are widely seen in nature and industrial fields. In the real applications, they always play negative effects. For example, frosting on the surface of outdoor coil degrades the operation efficiency of air source heat pump, frosting on surface of evaporator extends the time and wastes more energy during liquid natural gas vaporization, icing on the wings' surface changes the aerodynamic profile of aircraft and may result in air crush, and ice accumulated on wind turbine blade surface reduces the power generation efficiency. Moreover, frosting and icing problems are reported in the fields of electricity cables, coal transportation, food or ice storage, etc. Droplet condensation and freezing are at the early stages of frosting and icing, and thus influence their final formation. Therefore, it is fundamental and meaningful to summarize and evaluate the existing experimental and numerical fundamental studies about frosting and icing at different stages and application backgrounds. Based on the summary, recent challenges around frosting and icing will be reported in this talk. It is expected that more scholars could be attracted to frosting and icing investigations, and thus solve the stated problems in real applications.

Keywords: Wind turbine icing; icing numerical computation; icing wind tunnel experiment

Short bio:

Dr. SONG Mengjie, Professor of Department of Energy and Power Engineering, Teli Young Scholar, Director of Frost Lab, School of Mechanical Engineering, Beijing Institute of Technology (BIT), China. He is also the Editor-in-Chief of Recent Patents on Mechanical Engineering (EI, Scopus), Associate Editor of Frontiers in Energy Research (SCI, IF=2.746), DECRA Research Fellow in Sustainable Buildings Research Centre (SBRC), University of Wollongong, Australia, and Guest Professor of Tomas Bata University in Zlín, Czech Republic. Before starting the research work in BIT, he worked in the University of Tokyo as JSPS Research Fellow. Prof. SONG focuses on the mechanism study of heat and mass transfer coupled with the flow for more than 10 years. Currently, he has published 128 journal articles, in which 108 ones are SCI, with 70 ones as first/corresponding author, and 8 papers were ESI. He was selected into the World's Top 2% Scientists 2020 and 2021 (Singleyr) list.