Special Session: Advances in Energy Recovery

Session Description:

The last decade has witnessed significant advances in energy recovery technology for supplying part of the world's energy needs and thus reduce the rate of consumption of fossil fuels and other non-renewable resources. As one of the green energy solutions, energy recovery can reduce greenhouse gas emissions generated with traditional energy sources. This special session is aimed at evaluating the existing energy recovery systems and methods, and is devoted to the latest development and R&D achievements for the energy recovery technology, ranging from components to systems, and from modeling, simulations and analyses to experimental investigations.

Session Organizers:

Guopeng Yu (SunYat-Sen University)   Youcai Liang (South China University of Technology)

Session Contents:

Topic 1:   Evaluation system for thermal-cycle based energy recovery system
Topic 2:   Modeling and control for heat transfer process based on deep reinforcement learning
Topic 3:   CO2-based thermodynamic cycle for engine waste heat recovery
Topic 4:   Combined CO2 Power-Ejector based refrigeration system driven by waste heat of engine
Topic 5:   Sorption thermal battery governed by reaction wave model
Topic 6:   Absorption thermal batteries for high-efficiency and high-density energy storage

Topic 1: Evaluation system for thermal-cycle based energy recovery system

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Abstract

For effective utilization of sustainable resources, evaluation systems based on innovative optimization algorithms and decision-making methods are of great significance. This talk presents a systematic and generic design method, which integrates the modelling, optimizing, scheme comparing and decision-making process. This method is developed by emphasizing on mobile systems in which the working condition is complex and ever-changing, it actually provides a general-adapted approach to get the final optimal solution, which can be widely employed in industrial energy recovery, co-generation systems, geothermal energy/biomass energy utilization, etc. In this topic, multi-objective optimization models are constructed for typical thermal-cycle-based energy recovery systems, and thirteen decision criteria including environmental, thermodynamic, and techno-economic perspectives are evaluated for the performance analysis. Four decision-making methods including Shannon Entropy, modified LINMAP (combined with Relative entropy), modified TOPSIS (integrated with Shannon entropy and Relative entropy), and TLFDM (Three-level fuzzy decision method) are employed to determine Pareto-optimal solutions, which are finally evaluated by Taylor method to identify the optimization target.

Keywords: Evaluation system; Multi-objective optimization; Decision-making method

Dr Guopeng Yu is now working as associate professor in Sino-French Institute of Nuclear Engineering and Technology (IFCEN) of Sun Yat-Sen University. She received her Ph.D degree in 2017 from Tianjin University, and was appointed as associate researcher from 2017 to 2021 in James Watt School of Engineering in University of Glasgow before joining Sun Yat-Sen University. The main research interests of Dr Yu are heat management of advanced thermal system, heat and mass transfer of innovative and high-performance energy technologies, efficient and cost-effective utilization of renewable energy and waste heat. As the main author, she has published more than 20 SCI papers, including 3 ESI top1% highly-cited papers. She has received provincial government awards for Outstanding PhD Degree Dissertation. She is in the editorial board of SCI journal *Frontiers in Energy Research*, *International Journal of Green Energy*, and EI journal *Transactions of CSICE*.

Topic 2: Modeling and control for heat transfer process based on deep reinforcement learning

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Abstract

Heat exchangers have been widely used in various thermodynamic systems, and precise tracking control of important parameters of the heat transfer process, such as temperature and pressure, is vital for ensuring safety and highly efficient operation of the entire system. Owing to the high degree of nonlinearity of the heat-transfer process, not only the dynamic model of heat exchanger is difficult to accurately established, but also the important parameters are difficult to control, especially under highly fluctuating operating conditions. In view of the strong perception and decision-making capabilities of deep reinforcement learning (DRL), this study proposes a DRL-based modeling method and DRL-based control method for heat transfer process.

This study proposes to use the most basic mechanism as the model skeleton to establish the stability of the model and reduce the computation of the model, while deriving some physically meaningful characterization parameters to ensure the accuracy of the model, and using DRL to obtain the exact values of these parameters.

Besides, we use the DRL agent to learn the control strategy of the temperature in heat transfer process. The results of our research indicate that the DRL agent can satisfactorily perform the control task under the trained and untrained transient heat source. A case study shows that the DRL control can track the reference temperature with an average error of only 0.19 K, whereas that of the traditional PID control is 2.16 K.

Keywords: Modeling; Control; Thermodynamic system; Deep reinforcement learning

Dr. **Xuan Wang** received his Ph.D. degree in Power Machinery and Engineering from the Tianjin University in 2019. In 2017-2018, he worked at Lawrence Berkeley Laboratory, the United States as a visiting scholar. Currently he is an associate Professor at Tianjin University, China. His research focuses on the aspects of design, modeling and control of thermodynamic system, including (1) energy management of hybrid electric vehicle system; (2) waste heat recovery of internal combustion engine; (3) modeling and control for CO_2 Brayton Cycle; (4) thermal energy management of battery. He has received several relative funds from National Natural Science Foundation of China, Ministry of Science and Technology of the People's Republic of China, China Postdoctoral Foundation etc. He has published over 50 SCI journal papers and more than 10 patents.

## Topic 3: CO2-based thermodynamic cycle for engine waste heat recovery

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Abstract

The bottoming thermodynamic cycle is of great significance to recover waste heat from the ICE and improve the overall efficiency of it. Therein, CO_2 transcritical power cycle is regarded as a promising energy conservation means for its effectiveness in concurrently recovering both waste heat from the jacket water and exhaust gas. In this report, the development process of CO_2 power cycle used in ICE waste heat recovery are deeply discussed, including different aspects namely the specific thermodynamic characteristics of the ideal working fluid, design & optimization of the bottoming cycle, development on expander and micro heat exchanger, and finally the safe operation & control of the prototype system. Additionally, a multi-mode operation scheme of CO_2–based combined cooling and power cycle is further proposed to satisfy the special cooling and power requirements in practical scenarios of refrigerated vehicles and shipboards.

Keywords: carbon dioxide, thermodynamics cycle, waste heat recovery
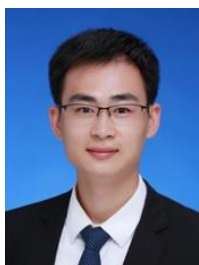
Dr. **Lingfeng Shi** received his Ph.D. degree in Power Machinery and Engineering from the Tianjin University in 2019. After graduation, he has acquired support from the Postdoctoral Innovative Talent Support Program and worked as a postdoctoral researcher at Department of Thermal Science and Energy Engineering in the University of Science and Technology of China. Currently, he is serving as an Associate Research Fellow in the University of Science and Technology of China, and is elected as the member of Youth Innovation Promotion Association of Chinese Academy of Sciences (2022). He has published over 44 peer-reviewed international journal publications in energy field. His research focuses on four different aspects of CO_2-based thermodynamics cycles, including (1) design of advanced power/refrigeration cycle, (2) composition tuning in CO_2-based binary mixtures, (3) key component development in waste heat recovery, (4) dynamic simulation and intelligent controls.

Topic 4: Combined CO2 Power-Ejector based refrigeration system driven by waste heat of engine

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Abstract

With the increasing demand of residents for fresh food, refrigerated trucks have become an indispensable part of cold chain transportation. For a typical diesel engine, nearly 60% of the energy is lost to the atmosphere via exhaust gas and jacket coolant, leading to a low fuel utilization rate. Considering the demand multi-variety and small-batch transportation in the current cold chain logistics, a heat driven ejector-based refrigeration combined cycle with two evaporators was proposed to meet the dual temperature requirement of both refrigerator compartment and freezer compartment. The comprehensive performance evaluation on the construction of both single ejector and dual ejectors are conducted. The results shows that both proposed systems can satisfy the basic cooling capacity requirements of refrigerator compartment and freezer compartment. To obtain the maximum refrigeration capacity, the exergy efficiency, cost per exergy unit of product, and dynamic payback period of the system with two ejectors are 17.70%, 94.60 \$/GJ, and 6.12 years, respectively. The exergy efficiency is 8.32% higher than that of the system with single ejector, while the cost per exergy unit of product and dynamic payback period are reduced by 2.8% and 0.218 years, respectively.

Keywords: Waste heat recovery; supercritical CO2 cycle; Compression/ejection refrigeration cycle;

Short bio:

Dr. **Youcai Liang** received his Ph.D. degree in Power Machinery and Engineering from State Key Laboratory of Engine (Tianjin University) in 2015, and started his academic career as a lecturer in Tianjin University of Commerce, and then worked as a postdoctoral researcher in University of Glasgow from 2016 to 2019. He joined in South China University of Technology in 2020 and he is currently a Professor in School of Electric Engineering. He has published over 50 peer-reviewed journal papers with more than 1100 citations. He has received 7 research funds from National Natural Science Foundation of China, Guangdong Basic and Applied Basic Research Foundation etc., and made contributions in the areas of design and optimization of thermodynamic cycle, including Advanced Power system, Heat Pump/Refrigeration system, Distributed energy system etc.

Topic 5: Sorption thermal battery governed by reaction wave model

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Abstract

Adsorption thermal battery has attracted burgeoning attention which is considered as a promising method to reduce energy consumption for space heating. Adsorption "reaction wave" model could be used to remain the stable output. However, internal mechanism between reactor and material is still not clear. The presentation will introduce a new definition of "reaction wave" model which could bring more insights of adsorption thermal battery from heat and mass transfer perspective. Also response surface methodology is adopted to evaluate key parameters e.g. humidity, flow rate, temperature of inlet air o stable output temperature and duration. Results indicates that wave length of reaction is negatively correlated with heat and mass transfer efficiency. Velocity of reaction wave increases with the increase of flow rate. To achieve stable output over long period, shorter wave lengths and slower wave velocity are needed. The expected stable output time can be calculated according to "Reaction wave" model. However, the lower limit of air flow should meet the minimum output power requirement of adsorption thermal battery. Therefore, the proposed "Reaction wave" model is expected to guide sorbent selection and reactor design for adsorption thermal battery.

Short bio:

Professor Long Jiang is a professor (research track) in the department of energy engineering, Zhejiang University. Before that, he worked as a lecturer and assistant professor (research) in University of Aberdeen and Durham University. He is a member of International Institute of Refrigeration and editorial board member of energy and environmental materials, energy and built environment and advanced powder materials. His research interest lies in sorption related thermal conversion technologies e.g. sorption thermal energy storage, sorption refrigeration and power. He has published 102 research articles across energy storage, sorption trigeneration and CCUS with more than 1500 citations. Besides, Prof. Jiang work as a PI of project on thermochemical desorption for power generation, refrigeration and thermal storage based on low-grade waste heat utilization, and Co-I on projects on regional energy system optimization from NSFC.

Topic 6: Absorption thermal batteries for high-efficiency and high-density energy storage

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Abstract

Thermal energy storage is important for renewable energy utilization towards carbon neutrality. Absorption thermal battery (ATB) is a promising solution due to its excellent energy storage performance and flexibility. There are different ATB cycles to cover a wide range of design options, including single-effect cycle, compression-assisted cycle, double-stage cycle, double-effect cycle, and double-effect compression-assisted cycle. To reveal the advantages and shortcomings of different ATB cycles, comparative investigations are conducted from a multi-criteria perspective, including energy storage efficiency, energy storage density, exergy efficiency, charging temperature, and initial cost. The effects of charging/discharging/cooling temperatures on the storage performance are analyzed in three scenarios, i.e., short-term cold storage, short-term heat storage, and long-term heat storage. The double-effect, compression-assisted, and single-effect cycles respectively achieve the maximum energy storage efficiency (1.53), energy storage density (365.4 kW/m^3), and exergy efficiency (0.61). The compression-assisted and double-stage cycles require the lowest charging temperatures (<70 °C). This work aims to facilitate the rational development of ATB cycles for high-efficiency and high-density thermal energy storage during low-carbon energy transition.

Short bio:

Dr. Wei Wu obtained his Ph.D. degree from Tsinghua University in 2016. He was a visiting scholar at the University of Maryland in 2013. Since 2016, he served as a guest researcher at the National Institute of Standards and Technology. He joined the City University of Hong Kong as an assistant professor in 2018. Dr. Wu's research is focused on sustainable energy technologies, including absorption heating/cooling, thermochemical energy storage, thermal management, renewable/waste energy utilization, advanced heat pump, alternative refrigerants, and net-zero energy buildings. He has obtained/filed 18 patents, published a book by Springer Nature, and published around 90 SCI journal papers. He received the IIR Willis H. Carrier Young Researcher Award, the NIST Distinguished Associate Award, and the Excellent Young Scholar Award of Energy and Built Environment. He serves as an editorial board member or guest editor of 6 SCI journals. He is among the Top 2% Scientists Worldwide by Stanford University. He is an expert of IEA-HPT and IEA-SHC Annex.