Impingement Jet Cooling in Gas Turbines

International Series on Developments in Heat Transfer

Objectives

The Developments in Heat Transfer book Series publishes state-of-the-art books and provides valuable contributions to the literature in the field of heat transfer, thermal and energy engineering. The overall aim of the Series is to bring to the attention of the international community recent advances in thermal sciences by authors in academic research and the engineering industry.

Research and development in heat transfer is of significant importance to many branches of technology, not least in energy technology. Developments include new, efficient heat exchangers, novel heat transfer equipment as well as the introduction of systems of heat exchangers in industrial processes. Application areas include heat recovery in the chemical and process industries, and buildings and dwelling houses where heat transfer plays a major role. Heat exchange combined with heat storage is also a methodology for improving the energy efficiency in industry, while cooling in gas turbine systems and combustion engines is another important area of heat transfer research. Emerging technologies like fuel cells and batteries also involve significant heat transfer issues.

To progress developments within the field both basic and applied research is needed. Advances in numerical solution methods of partial differential equations, turbulence modelling, high-speed, efficient and cheap computers, advanced experimental methods using LDV (laser-doppler-velocimetry), PIV (particle-image-velocimetry) and image processing of thermal pictures of liquid crystals, have all led to dramatic advances during recent years in the solution and investigation of complex problems within the field.

The aims of the Series are achieved by contributions to the volumes from invited authors only. This is backed by an internationally recognised Editorial Board for the Series who represent much of the active research worldwide. Volumes planned for the series include the following topics: Compact Heat Exchangers, Engineering Heat Transfer Phenomena, Fins and Fin Systems, Condensation, Materials Processing, Gas Turbine Cooling, Electronics Cooling, Combustion-Related Heat Transfer, Heat Transfer in Gas-Solid Flows, Thermal Radiation, the Boundary Element Method in Heat Transfer, Phase Change Problems, Heat Transfer in Micro-Devices, Plate-and-Frame Heat Exchangers, Turbulent Convective Heat Transfer in Ducts, Enhancement of Heat Transfer, Transport Phenomena in Fires, Fuel Cells and Batteries as well as Thermal Issues in Future Vehicles and other selected topics.

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Preface

This book focuses on impingement jet cooling on gas turbine blades. The topic ranges fundamental to application of impingement jet usage for actual gas turbine blades.

The first chapter presents the basics of gas turbine impingement cooling design, the various applications within the engine, and the typical limitations imposed upon its use. Generic use and application examples for single impingement jets, in-line rows of jets, and arrays of jets are described for the hot gas flow path components of gas turbines, including the combustor system and high pressure turbine. Specific applications to airfoil aerodynamic leading and trailing edge regions, combustor liners, and rotating disks are provided, as well as emerging applications within confined channels, blade tips, and film cooling.

The second chapter deals with the experimental and numerical investigation of an impingement chamber and flow analysis for both single exit and double-exit cases. The chapter shows the dependency of local Nusselt number on the jet Reynolds number to the power of 0.78 for a Reynolds number higher than 12,000, which confirms the Reynolds number dependency for turbulent stagnation and boundary layer flows in higher ranges of the Reynolds number. The deviation of the dependence curve for a Re less than 8,000 indicated that the flow is partially mixed with a transitional turbulence condition with these Reynolds number ranges. This discovery proves useful information for the selection of the turbulence models for these heat transfer computations. The results provide useful suggestions to the gas turbine cooling technology developments.

For the single exit cases, it has been shown both experimentally and computationally that a minor reduction in the Nusselt number occurs on the even rows of the jets. This phenomenon was clarified through the extensive computational investigation that the reduction of the heat transfer was attributed to the vortex motion generated both by the surrounding jets and the side wall effects.

The third chapter presents recent development on impinging jet arrays with effects of Mach number, Reynolds number, temperature ratio, hole spacing, and jet-to-target plate distance. The experimentally obtained data cover wide-range range of those parameters. The materials presented are quite useful for understanding the effects of the factors that significantly enhance the heat transfer effectiveness, and therefore provide insight to engineers and academic community.

The fourth chapter describes an impingement application for combustor linear backside cooling technology. Jet impingement cooling is significant in gas turbine systems for cooling hot gas path components, primarily in vanes and combustor liners. In modern low NOx gas turbine combustors, cooling of the combustor liner is achieved from the backside through innovative enhanced heat transfer augmentation methods. In this chapter, an overview of jet impingement related heat transfer research and design background is presented. Additionally, some specific studies that focus on innovative cooling methods for combustor liners are presented with highlighted results. Additional comments on possible future research directions and topics under consideration are presented.

The fifth chapter focuses mainly on a combined cooling technique of impingement/effusion cooling; and with this arrangement it can be controlled by a number of factors, including the hole pattern, angle of the effusion holes, target surface configuration, and gap spacing. The classification of the principal variables affecting cooling performance are explained as well as how heat transfer and fluidic characteristics can be controlled by each variable based on thermo-physical aspects. In addition, various applied techniques involving surface modifications, such as curved surfaces and combined rib and pin-fin structures, are discussed in this chapter. The effects of the impingement/effusion cooling systems are reviewed, and a detailed account on experimental approaches as well as numerical analyses regarding heat and mass transfer are presented. The development process for an impingement/effusion cooling system is described, together with suggested directions for further advances in this field.

The sixth chapter presents flow control of impingement jets and wall jets. The main topic of this chapter is to provide useful information on the flow control technology of impingement jets in gas turbines and to discuss recent trends in the passive and active flow control of impingement jets based on recent advancements. The temperature level in a gas turbine field is so high that innovative developments in material and cooling technology are needed for usage in the hot sections. Therefore, innovative cooling systems will be employed in the future. Smart actuators for flow control of the jet impingement, which can be used under severe temperature and pressure conditions, will also be provided based on the progress in related technologies.

The seventh chapter presents a brief review of studies on swirling and non-swirling impinging jets. Also a numerical investigation of heat transfer from impinging swirling jets is described. Various turbulence models are used. Comparison with experimental data is provided. Generally the V2f model was found to perform better than other models but for small nozzle to plate distances it was hard to maintain good or sufficient accuracy. The difference in performance, in terms of the Nusselt number distribution on the impingement wall, between swirling and non-swirling impinging jets was clearly identified. The magnitude of the swirling motion has great influence on the flow field and the formation of recirculating zones and accordingly the heat transfer process

The eighth chapter presents Impingement jet cooling heat transfer with a two-dimensional and a circular nozzle enhanced by a rib. This chapter presents the effect of a rib on heat transfer enhancement in the wall jet region of impinging jet by employing mass transfer experiments using a naphthalene sublimation technique and numerical simulations by RANS and LES. By comparing the computational results obtained through various models, the authors recommend LES for its superiority in its effectiveness in predicting Nusselt number in downstream region of the channel.

All of the chapters follow a unified outline and presentation to aid accessibility and the book provides invaluable information to university professors, graduate researchers, and industrial research engineers/scientists.

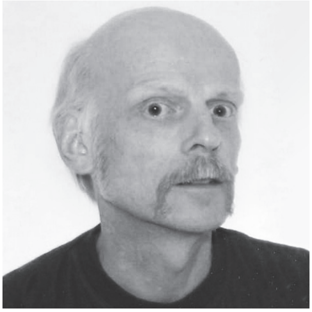
We are grateful to the authors and reviewers for their excellent contributions. We also thank ceaseless help that were provided by the staff members of WIT Press, in particular Mrs. Elizabeth Cherry, for their strong encouragement in the production of this book. Finally our appreciation goes to Professor Carlos Brebbia who gave us strong support and encouragement to complete this project.

Ryoichi S. Amano and Bengt Sundén

About the Editors

Professor Ryoichi Amano is an internationally recognized scientist in thermal engineering, experimental fluid dynamics, turbulence research, and energy systems. For a number of years he has been engaged in research related to gas turbine performance, rotating machinery, power engineering, transport phenomena, heat/mass transfer, two-phase flow, and manufacturing material processes. Dr Amano has also contributed to the development of turbulence theories, jets, combustion, heat transfer, propulsion, aerodynamics, and applications to gas turbine and aerospace-related projects. In addition, he has engaged in gas turbine flow analyses of NASA space shuttle main engines and solid rocket motor research of US Air Force Research Labs, industrial gas turbines, steam turbines, and cooling technology using impinging gas jets.

Dr Amano has more than 500 publications, including books, refereed journal papers, invited review chapters, and conference proceedings. He has conducted numerous experimental and analytical research projects with extramural funding from US governmental agencies and many industries. Dr Amano is a technical committee member, editorial board member and international advisory committee member for ASME, AIAA, WIT Conferences, ISETS conferences (Japan) and an executive member of ASME International Gas Turbine Institute, AIAA Terrestrial Energy System, and ASME Energy Systems Committee. In addition, Dr Amano has received three Best Paper awards from ASME, the Sustained Service Award from AIAA, the AIAA Energy Systems Award, a UWM Excellence of Research Award. He is a Fellow of ASME and Associate Fellow of AIAA.



Professor Bengt Sundén received his MSc in 1973, PhD in thermodynamics and fluid mechanics in 1979, and Docent in applied thermodynamics and fluid mechanics in 1980, all from Chalmers University of Technology, Goteborg, Sweden. He became Professor of Heat Transfer in 1992 at Lund University. Since 1995 he serves as the head of the Department of Energy Sciences, Lund University, Sweden, and is also a guest professor at Northwestern Polytechnical University, Xi'an, China, and an honorary professor at Xi'an Jiatong University, Xi'an China.

His research topics include compact heat exchangers, enhancement of heat transfer, gas turbine heat transfer, combustion-related heat transfer including thermal radiation, CFD-methods for laminar and turbulent fluid flow and heat transfer, liquid crystal thermography, condensation and evaporation, nanofluids, transport phenomena in fuel cells, computational modeling and analysis of multiphysics and multiscale phenomena for fuel cells (SOFC, PEMFC).

Professor Sundén was the founding and first editor-in-chief of IJHEX (International Journal of Heat Exchangers), and was Associate Editor ASME Journal of Heat Transfer. In addition, he is currently an active editor for three journals. He is also editor-in-chief for a book series, Developments in Heat Transfer (also published by WIT Press), has published over 600 papers in journals, books and conference proceedings, and has supervised 170 MSc theses, 43 Licentiate of Engineering theses and 39 PhD theses. According to ISI knowledge Web of Science, the overall number of citations is 35 per year and the total number of citations is more than 2300. The h-index is 25.

He is a fellow of the ASME and a 2011 recipient of the ASME Heat Transfer Memorial Award, and a 2013 recipient of the ASME Heat Transfer Division 75th Anniversary Medal. He is a fellow of the Wessex Institute of Technology and a holder of the WIT Eminent Scientist Medal.

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