The progress toward more sustainable energy, water and environmental systems approaches and applications

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From the Guest editors

THE PROGRESS TOWARD MORE SUSTAINABLE ENERGY, WATER AND ENVIRONMENTAL SYSTEMS
Approaches and Applications

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This editorial provides an overview of ten scientific articles published as the Special paper selection in Thermal Science. The papers were selected from almost six hundred contributions, presented at the 16th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES 2021), held on October 10-15, 2021 in Dubrovnik, Croatia. The topics covered in the Special paper selection include economics of electricity markets, nuclear technology, repowering of the coal-based power plant, hybrid renewable energy system, sustainable biomass handling and conversion, post-combustion emissions control, and efficient cooling technology. The editorial also emphasised the papers recently published in the Special Issues of leading scientific journals dedicated to the series of SDEWES Conferences.

Keywords: *electricity markets, nuclear technology, repowering, renewable, post-combustion, cooling technology, sustainable development*

Introduction

The Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES) [1] is an international scientific conference that gathers scientists and professionals with advanced visions and problem-solving strategies across energy, water and environment systems. Starting from the first Conference in 2002 [2] in the home venue of Dubrovnik, Croatia, the SDEWES research community continuously promoted, motivated and encouraged holistic and multidisciplinary research directions toward a more sustainable future for the world. Last year, the 16th SDEWES conference [3] brought together around 630 scientists, researchers, and experts in the field of sustainable development from 58 countries, which provided 13 special sessions, seven invited lectures, and one panel with some of the most distinguished experts in the field of sustainable development. Despite the restrictions imposed due to the ongoing COVID-19 pandemic, the organiser enjoyed the company of 223 participants in person, who presented 219 papers.

The cooperation between SDEWES Conference and one of the leading SC journal from Serbia, Thermal Science [4], have been established from the early days in 2002 and continuously expanded by launching the Special Issues [5-11] dedicated to each biannual meeting till today. The present Special paper selection published in Thermal Science, explicitly devoted to [3], provided a broad interdisciplinary insight on the various topics connected to sustainability issues. The ten selected papers propose novel approaches or remarkable advances in research studies already explored in past SDEWES Conferences. This editorial also provides an overview of the recently published papers in Special Issues of leading scientific journals dedicated to the series of SDEWES Conferences.

Background

In the last two years, the impact of the COVID-19 pandemic has become far beyond health implications; almost all aspects of society have been affected, including economic activity, global energy systems, and the environment [12]. The unknown scope and duration of the pandemic and its associated economic shocks have resulted in energy security and clean energy transition becoming highly unpredictable. Facing those challenges, following the contributions in recently published editorials by Buonomano *et al.* [13], Wolosz *et al.* [14], and Mikulčić *et al.* [15], the editors of this Special paper selection can conclude that SDEWES researchers made the remarkable agreement that the world's sustainability will evolve in the coming years under the impression of its consequences. The paper by Ćorović *et al.* (p. 4067 in this Special paper selection) documented the electricity market changes and challenges during the first year of the COVID-19 pandemic in Serbia. The study aims to improve the understanding of the techno-economic effects of unforeseen events, such as a pandemic, on the power system. In the research dataset, the authors merged the 2020 monthly information related to Serbian electricity consumption/exports, load profiles, power market prices, and daily weather records from available web-based resources. Those data are then compared on a year-over-year base against 2019 and the 2016-2019 year average to provide a fairer assessment of the key trends in the Serbian electricity market. Following the results from a comprehensive graphical and statistical analysis, the authors observed that the social distancing and lockdown measures (adopted in Serbia from March 15 to May 5, 2020) marginally affected the domestic electricity consumption and regular operation of the power system. Minimal differences in electricity consumption during the state of emergency in 2020 compared to 2019 have been explained as a result of the trade-off between economic slowdown and shallow ambient temperatures for that time of year. Still, Serbia's electricity consumption stayed low even after the lockdown-easing measures due to the slow recovery of the economy and the lingering effects of the pandemic. However, during the same analysis period, the authors recognised a significant decrease in cross-border electricity trade amplified by the low global fossil fuel demand. As a consequence, a synergy between *local* and *global* effects initiated a sharp decline in electricity prices (of about 38%) not only in the short but also in the medium term. In the last part of the paper, the authors analysed the factors influencing the Serbian electricity market in the second half of 2021, when wholesale electricity prices reached an all-time high level and concluded that electricity prices are not expected to fall to the pre-COVID level.

In past SDEWES Conferences, in the editors' opinion, little attention has been paid to the problems related to the nuclear technology and design of nuclear power plants (NPP). Only a few papers considered this topic, aiming at the environmental impact of NPP through the comparative evaluation of different energy options [16] or retiring or replacing NPP with other energy sources in the Czech republic [17]. However, in this Special paper selection, two papers investigated the thermal-hydraulic design and the thermally induced two-phase flow instabilities in NPP devices.

In the first paper, Zhang *et al.* (p. 4079 in this Special paper selection) contributed to the International Thermonuclear Experimental Reactor (ITER), the international joint experiment which started in 1985, primarily aimed to prove the feasibility of fusion as a large-scale and carbon-free energy source. Today 35 nations are collaborating to build the world's largest experimental fusion reactor (tokamak) using a combination of heating systems, strong magnets, and other devices to test the integrated technologies, materials, and physics regimes necessary for the commercial production of fusion-based electricity. The main objective of this study was the thermal-hydraulic design of a liquid lithium lead test blanket module (DFLL-TBM), the device installed in the ITER's window frame, which enables the discharge of nuclear heat from the internal structure and cools the whole breeding zone structure. To accurately simulate the broad spectrum of severe accident phenomena of DFLL-TBM, an improved version of the integrated severe accident analysis (ISAA) code, suitable for the multi-working fluid and referred to as ISAA-DFLL, was developed. The authors upgraded the existing software with two new modules: the coolant property module and heat transfer wall module, to enable the simulation of different physical properties of various coolants (helium gas, water, and liquid lithium lead) and advanced calculation of the heat transfer coefficients of natural or forced convection and boiling heat transfer. The software modifications are successfully verified using the code-to-code approach and applied to the steady-state, transient, and accident calculations of DFLL-TBM. The calculation results indicated that the new ISAA-DFLL code satisfies the ITER safety requirement in the design of the DFLL-TBM system.

The phenomenons of thermally induced two-phase flow instabilities are relevant to researchers in all fields encountering phase change heat transfer and multi-phase flow and are of significant interest for the design and safety operation of many industrial systems and equipment, such as nuclear reactor cores, steam generators, refrigeration plants, *etc*. Despite the high level of progress that has been made in this scientific area across the last decades, the SDEWES Conference series includes only a few authors who provided research studies on this topic. Masiukiewicz and Anweiler [18] used the image analysis methods for the evaluation of two-phase flow structure in mini channels, Wang *et al*. [19] reviewed recent research on multi-phase flow in gas turbines, and Anweiler and Ulbrich [20] evaluated the algorithms for the characterisation of two-phase gas-liquid flow. In the second paper related to nuclear technology, Long *et al.* (p. 4095 in this Special paper selection) provided a numerical study of two-phase flow instabilities in a simplified typical coolant open-channel system in a nuclear reactor core. To study the effect of throttling on flow instability, the authors introduced the computational model using the NUSOL-SYS code, a system code for transient safety analysis of NPP, developed based on the two-fluid seven-equation two-pressure model. The model included the control body partitions, initial and boundary conditions, throttling regions, flow oscillation characteristics, and the stability boundary map of the standard open-channel system. It has been successfully validated against data obtained by Solberg *et al.* [21] in an experimental study on flow instability in a boiling channel. The effects of throttling on flow instability are discussed based on the results obtained by sensitivity analysis of different throttling ratios, throttle locations, and the number of throttle regions in the research object. The paper was closed with the authors' opinion that the presented research study could provide a helpful engineering reference to enhance the boiling channel system's stability and eliminate or reduce the hidden danger of flow instability in boiling two-phase flow systems.

Repowering the existing coal-based power plants is one of the immense single carbon abatement opportunities for accelerating the clean energy transition. The practice involves replacing ageing heat-generating units (usually coal-firing boilers), retrofitting energy sites with more efficient components, or improving the control and operability of the plant. All cases significantly increase a power plant's output, improve its environmental performance and extend the facility's life. Mikulandrić *et al.* [22] analysed the ways of enhancing the performances of existing Western Balkans coal-fired thermal power plants by control systems modifications, particularly those based on artificial intelligence, to increase plant efficiency and lower pollutant emissions. Tanchuk *et al.* [23] proposed repowering conventional coal-fired district heating systems heat sources with gas turbine co-generation units and performed thermo-economic optimisation of such design solution. Beccali *et al.* [24] analysed several small Italian islands, aiming to assess the viability of heat recovery from the existing diesel engine-based power plants and the possible distribution of heat to supply energy loads to both residential and centralised/punctual users. Recently, Novosel *et al.* [25] investigated the possibility of implementing alternative technologies in thermal power plants to produce heat, electricity and hydrogen using RES, and Tan *et al.* [26] proposed a phase transition agglomeration system to efficiently recover the waste heat from flue gases and reduce the water consumption of the coal-fired power unit. Strušnik *et al.* (p. 4107 in this Special paper selection) considered the full repowering option in coal-based, boiler-extraction condensing steam turbine, combined heat and power (CHP) plant to improve the environmental performance and extend the plant's operating life. Based on the fuel-switching strategy, the authors proposed redesigning the plant into a gas turbine combined cycle power plant, consisting of two gas turbines with heat recovery steam generators (located downstream of each turbine) that drive the steam turbine bottoming cycle. The study's main goal was to analyse the feasibility of implementing the steam turbine in the existing CHP plant to be used in the new proposed plant configuration. Two-phase turbine testing was performed using the high pressure steam generated in the existing coal-fired boiler and under the off-design conditions with an extremely low steam flow mass rate. According to the test results, the authors concluded that despite a few unavoidable but relatively minor modifications related to the algorithm of automatic control of valves followed by hardware adaptations, the existing condensing extraction steam turbine could operate even under the off-design conditions, but at the expense of isentropic efficiency and power output. In addition, replacing the steam turbine in a future repowered plant could be avoided, as only a minor portion of yearly heat and electricity are generated in the CHP mode of operation.

During the last decade, utilising renewable energy resources in hybrid energy conversion processes became a valid approach to overall progress towards environmental sustainability. The term hybrid renewable energy system (HRES) commonly describes the energy system consisting of two or more RES with or without connecting to conventional generators. Such integration improves the overall system efficiency and reliability and overcomes the economic limitations of single RES. Due to this advantage and the multitude of possible source combinations, the HRES framework became increasingly popular among SDEWES researchers. Buonomano *et al.* [27] presented a thermo-economic dynamic simulation of an HRES system supplied by wind and solar energy coupled to an electricity storage system to determine the best system configuration and maximise the economic profitability by considering the time-dependent tariffs applied to the electricity exchanged with the grid and the possibility to store electricity. Gambini *et al.* [28] defined and validated an alternative *on-line and real-time* method to quantitatively assess fuel and solar generation within a hybrid power plant's overall electricity production. In particular, two possible plant configurations are considered, resulting in a steam power plant integrated into a solar field based on parabolic troughs and linear Fresnel reflectors, respectively. Recently, Anastasovski *et al.* [29] reviewed the system-oriented methods for heat integration of solar thermal energy in production processes. Rinaldi *et al.* [30] investigated the techno-economic performance of standalone electricity generation systems for off-grid communities located in different climatic areas of Peru. Khosravi *et al.* [31] designed a hybrid energy system comprised of a biomass power cycle combined with a solar thermal collector, and desalination unit located in Natal-RN in Brazil. Jin *et al.* (p. 4119 in this Special paper selection) designed and modelled a hybrid co-generation system comprised of geothermal power cycles combined with a solar thermal collector. The Aspen Plus-based simulation model was initially developed for a single electrical power generation system and then redesigned in the two different hybrid heat and power co-generation (CHP) systems to meet the requirements for heating energy during the winter months. The authors performed flow sheeting simulation, which enabled energy and exergy analysis of each process unit and the overall systems. The analysis results showed not only the relevant potential for heat energy production in both CHP plants but also the increase of the exergy efficiency of the system in regards to starting a single electrical power generation system.

In the SDEWES community over the years, research topics related to biomass handling and its conversion to value-added products have been seen as a critical transitioning step towards more sustainable practices. Recently, Guzovic *et al.* [32] observed that biomass is the fourth largest global primary energy carrier and the most abundant RES, accounting for 60% of RES in the EU [33]. Therefore, it is not a surprise that the guest editor, during the preparation of this Special paper selection, detected almost 10% of all papers published in SDWES SI journals contain at least one of the specific words (biomass, biodiesel, biogas, biofuel) in the titles. Castells *et al.* in (p. 4131 in this Special paper selection) presented the comparative analysis of the two thermo-chemical biomass conversion technologies, *e.g.*, pyrolysis, carried out under a nitrogen atmosphere and oxygen-enriched combustion using an atmosphere of air enriched with 30% oxygen. Following the thoroughgoing literature review, the authors observed limited scientific interest in this topic, especially regarding the biomass kinetic comparison between above mention technologies. Based on Thermogravimetric analysis, previously utilised by Song *et al.* [34], Wang *et al.* [35], and Mikulcic *et al.* [36], the experimental activity was carried out using three different lignocellulosic biomass samples, and the procedure involved testing under four different heating rates. The kinetic parameters have been evaluated from the model-free iso-conversion methods of Friedman, Kissinger-Akahira-Sunose, and Flynn-Wall-Ozawa. After an in-depth analysis of the results, the authors reported a significant difference between oxygen-enriched combustion and the pyrolysis process, followed by concluding remarks. The paper is closed with the authors' opinion that further research should consider the ultimate and/or biochemical analysis to properly define how thermal degradation affects hemicellulose, cellulose, and lignin content and the relation between process kinetic and composition.

From industrial practice, it is well known that oxidation of fuel-bound nitrogen constitutes the dominating source of nitrogen oxides, collectively termed NO_x, in most solid fuel-fired systems. Nitrogen oxides are emitted to the ambient environment mainly as nitric oxide (NO), which subsequently oxidised to nitrogen dioxide (NO_2). Nitric oxide and nitrogen dioxide are identified as acid rain precursors and participate in the generation of photochemical smog, while nitrous oxide (N_2O) is a GHG as its molecule is a strong absorber of infrared radiation at wavelengths where CO_2 is transparent. In addition, N_2O emissions in fluidised bed combustion can be significant but are negligible in most other combustion systems. The concern about NO_x emissions and the need to comply with increasingly stringent regulations have attracted the extensive interest of multiple SDEWES researchers. Nitrogen oxide abatement technologies are investigated considering the control of NO formation by: modification of operating conditions [37], (modification of combustion equipment [38-40], fuel switching [41-43], and flue gas treatment in post-combustion processes [44-46]. Paper provided by Yu *et al.* (p. 4147 in this Special paper selection) used the CARBONOX (CARBON-based NO_x reduction) process in an experimental study as a practical, highly efficient and low-cost technology for the post-combustion control of nitric oxide emissions. The technology was based on the immensely complex char-NO heterogeneous reaction, involving several processes, such as chemisorption, desorption of surface complexes, and release of products. The experiments were carried out in the denitrification reaction device consisting of: the gas supply system, the temperature control system, a heterogenous – fixed bed catalytic reactor comprised of a vertical quartz tube that is housed in an electrically heated furnace, and a flue gas analysis system to determine the concentrations of NO and other residual gas. Unlike similar studies that primarily analysed the mechanism and kinetics of char-NO heterogeneous reaction with a focus on the high temperature stage, the authors tested the effects of different char types, pre-treatment methods, additives, *etc*., on chemical reaction under a broader range of temperatures. Results are presented in terms of denitrification efficiency, showing a substantial potential for the progress of industrial applications of coal combustion.

In the paper by Sun *et al.* (p. 4157 in this Special paper selection), the authors continue the long-standing research to analyse various film cooling techniques in modern high temperature gas turbines. During the last few decades, due to design efforts toward the gas turbine with high operational efficiency and high thrust-to-weight ratio, the film cooling technology was adopted as the efficient solution to bridge the gap between the continuously increasing turbine inlet gas temperature and the allowable blade material metallurgical limit temperatures. Motivated by challenging tasks to satisfy the thermal protection requirement of turbine blades, the authors from this group contributed to film cooling enhancement by investigation of: the effects of surface deposition and droplet injection on film cooling by predicting the characteristics of two-phase flow using the discrete phase model [47], the effects of bulge configurations, blowing ratio and mist injection on the film cooling effectiveness by developing the 3-D models for numerical simulation in ANSYS FLUENT 16.0 software [48], the flow distributions and the film cooling effectiveness under different hole configurations by applying the CFD approach in ANSYS FLUENT 16.2 [49], the influence of blockage ratios and mist injection on film cooling characteristics in a rectangular channel utilising the realisable k-ε turbulence model [50], and recently, the mechanism of improving the film cooling performance by optimisation of hole configuration parameters based on the Taguchi method [51]. In the study presented in this Special paper selection, the authors applied the novel active flow control technology by using plasma actuators to improve the film cooling effectiveness of a gas turbine blade. Flow characteristics and film cooling performance were numerically investigated by a verified and validated turbulence model, which enables the comprehensive analysis of the effects regarding the blowing ratio and plasma placement of plasma actuation. Results of the study emphasised that plasma aerodynamic actuation practice enables the relevant film cooling enhancement due to an increase in adhesion performance of coolant air, significant improvement of film cooling performance under the high blowing ratios, and the weakening effect emerging on vortex structures.

The rapid increase in the power density and extreme miniaturisation of electronic packages, accompanied by the production of highly concentrated heat flux, starting from the 70's, promoted the problem of efficient cooling technology as a crucial obstacle to the further development of integrated electronic technologies. Recently, Mohd *et al.* [52] enumerated several methods to improve the cooling performance: air cooling, heat pipe, use of liquid material as a coolant, and micro-cooling method (micro-jet impingement, micro-heat pipe, micro-electro-hydrodynamic and microchannel heat sink – MCHS). The authors identified MCHS technology as the most prospective regarding its ability to provide a large heat transfer surface-to-volume ratio and to remove the heat at a very high rate. The SDEWES conferences series also highlights studies that contribute to the development of MCHS technology through advanced geometric structures and nanofluid, which can provide high thermal performance with an acceptable pressure drop in micro-cooling processes. Previously mentioned, Masiukiewicz and Anweiler [18] used stereological methods to estimate the two-phase flow structure that offers many advantages in automotive heat transfer or microelectronics for removing high heat fluxes. Shi *et al.* [53] combined CFD, surrogate model and the genetic algorithm for the optimisation of flow uniformity of a ceramic microchannel heat exchanger. Venkiteswaran *et al.* [54] considered novel water-cooled micro-channel configurations and compared them with existing arrangements using the CFD approach in ANSYS FLUENT software. Xu *et al.* [55] considered gallium as a phase change material in the thermal management of electronic devices and experimentally studied the melting mechanism of gallium heat sink in spatial distributions. Ye *et al.* in . (p. 4169 in this Special paper selection), experimentally investigated heat transfer performance and flow characteristics of three microchannels made of polydimethylsiloxane and fabricated with three different arrangements of micropillars (single, horizontal and vertical). The heat transfer performances of microchannels were investigated at different flow rates of deionised water as a working fluid. The experiments were carried out using the micro-PIV testing system, which included a flow control system and image acquisition and image processing system. Following the comprehensive results regarding the Temperature differences of fluid under various flow rates and velocity distributions in the microchannel, the authors presented a few observations related to the flow characteristics in microchannels and also concluded that the heat transfer performances of microchannels with vertical micropillars arrangement were the highest.

Biomass co-firing is widely considered the most attractive short- and long-term solution to GHG emissions in the coal power sector. The effectiveness of the co-firing application, combined with high profitability and low technical risk while maintaining the high efficiency of coal boilers, has aroused great interest among SDEWES researchers considering mitigating CO_2 emissions and saving fossil fuels. In that context, the results derived from experimental research of co-firing wooden biomass with different types of Bosnian coal were used by Kazagić and Smajević [56] to expose the synergy effects of the co-firing process, by Smajević *et al.* [57] to investigate ash-related problems and emissions during that process, and by Hodžić *et al.* [58] to present the R&D project of multi fuel concept for future coal-based power. Garsia-Galando *et al.* [59] introduced the methodology (exemplified for the Spanish sector) to carry out studies for co-firing capacity and feasibility at the country level. Mikulčić *et al.* [60] applied the CFD code FIRE to conduct a numerical analysis of co-firing of coal and biomass in a cement calciner, whereas Mehmood *et al.* [61] analysed several combinations of fuels and co-firing conditions utilising the results obtained by engineering equation solver. Finally, San Juan and Sy [62] developed a multi-objective target-oriented robust optimisation model to design biomass co-firing networks integrating uncertainty in biomass properties with investment and operations planning. Sun *et al.* in (p. 4179 in this Special paper selection) undertook the CFD modelling study to examine the co-firing of pulverised coal and biomass in the 300 MW four-corner tangential pulverised coal boiler. The CFD simulation was performed to investigate the impact of biomass co-firing with coal regarding different co-firing biomass ratios (0%, 15%, and 30%), mixing effects, and feeding temperatures. The analysis considered olive residue as blended biomass and Yulin coal, and as the research was limited to the burning part of the combustion facility, the geometry considered was up to the flue gas rising portion of the furnace. In conclusion, following the results and discussion, the authors reported a few observations about the flow field and peak temperature in the furnace, char concentration and NO_x emissions, and biomass feeding temperature. They concluded that the optimum biomass co-firing ratio is up to 20% because more than that causes corrosion, milling, collection, and transportation issues.

Conclusion

The technological advancements in the ten papers on this interdisciplinary Special paper selection beneficially augmented the research efforts within a wide range of research topics toward more efficient and sustainable energy processes. These papers, as selected among the best contributions presented at the 16th SDEWES Conference in Dubrovnik, represent the 10th set of papers of the SDEWES Conference series in the partner journal *Thermal Science*. The guest editors believe that the selected contributions considerably extend the knowledge body published in *Thermal Science* and will be of interest to readers, particularly in the areas of economics of electricity markets, nuclear technology, repowering of the coal-based power plant, HRES, sustainable biomass handling and conversion, post-combustion emissions control, and efficient cooling technology.

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