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Editorial

Advances in Fuel Energy

Leszek Chybowski

Department of Marine Propulsion Plants, Faculty of Marine Engineering, Maritime University of Szczecin, ul. Willowa 2, 71-650 Szczecin, Poland; l.chybowski@pm.szczecin.pl

Ongoing climate change, the depletion of fossil fuel resources, and the continuously growing demand for energy have made the development and implementation of new types of fuels for energy systems one of the key challenges of modern engineering [1]. This is particularly relevant for internal combustion engines, boilers, and other thermal machines used in maritime, road, rail, and air transport, as well as in stationary power and heat generation systems. Alternative fuels such as biofuels, alcohols, synthetic fuels, gaseous fuels, ammonia, and hydrogen are increasingly being considered both as direct substitutes for conventional fuels and as additives to traditional fuels [2]. While their application may lead to significant environmental benefits, it also reveals complex technical and operational consequences.

The research results presented in this collection clearly demonstrate that even small shares of alternative fuels in fuel blends can substantially alter the combustion process. These changes include extended ignition delay, increased peak in-cylinder temperatures, and intensified pressure rise rates, which consequently lead to higher thermal and mechanical loads on the engine [3]. At the same time, it has been observed that increases in combustion temperature on the order of several tens of degrees Celsius may result in elevated nitrogen oxide emissions. This highlights the need for further research focused on optimizing injection strategies and combustion control when oxygenated fuels and their blends are used.

In parallel, this Special Issue presents research findings related to the evaluation of the physicochemical properties of alternative fuels, which directly affect the durability and reliability of fuel supply systems. The reported results indicate that alcohol fuels are characterized by low viscosity and very limited lubricity. The estimated lubricity values obtained suggest that, without appropriate additives or design modifications, long-term operation using such fuels may be problematic. At the same time, the development of models describing the temperature dependence of fuel viscosity and density presented in this collection represents an important step toward improved design and performance prediction of fuel supply systems.

Another important research direction addressed here involves emulsified fuels and fuels with modified physical structures, which enable substantial reductions in pollutant emissions without a radical deterioration in performance. Experimental results show that properly designed fuel emulsions can lead to nitrogen oxide emission reductions of nearly 50% and smoke reductions exceeding 80% at selected engine operating points. In addition, cases of improved thermal efficiency have been observed, indicating that these solutions may represent a viable alternative in the short- and medium-term energy transition [4].

From the perspective of practical implementation of alternative fuels, particularly significant are the results obtained from studies conducted on in-use engines and vehicles without introducing structural modifications. It has been demonstrated that low shares of biocomponents in gasoline fuels can lead to improvements in thermal efficiency on the order

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of 1–2%, while simultaneously reducing hydrocarbon and nitrogen oxide emissions, even in older power units. At the same time, the increase in specific fuel consumption resulting from the lower heating value of the blends remains moderate, which is of particular importance for developing countries and regions with limited opportunities for fleet modernization.

The energy transition, however, extends beyond the combustion process itself and also involves the development of auxiliary systems and infrastructure. Research on new exhaust gas cooling systems indicates that replacing conventional water-based solutions with dry systems can improve safety, reduce fuel consumption by several percent, and lead to very significant reductions in CO, HC, NOx, and CO_2 emissions. Equally important are issues related to the compatibility of alternative fuels with existing measurement and control systems, as exemplified by the dielectric properties of next-generation aviation fuels, which are critical for the proper operation of onboard fuel quantity indication systems.

In the long term, carbon-free fuels play a particularly important role, especially in the maritime and aviation sectors. Analyses of current market and regulatory trends indicate that transitional fuels such as LNG, LPG, and biofuels will not be sufficient to meet increasingly stringent requirements beyond 2030 [5]. As a result, growing interest is being directed toward ammonia and hydrogen, the implementation of which is associated with significant technological challenges, including storage safety, fuel flow control, purging processes, and control of combustion byproduct emissions. Research on optimizing fuel supply systems and control strategies shows that precise management of fuel and auxiliary gas flows can significantly reduce operational risks.

In light of the presented findings, it is evident that a key research gap remains the lack of an integrated approach to the assessment of alternative fuels that simultaneously considers emissions, efficiency, component durability, safety, and life-cycle costs. Future research should focus on the development of adaptive control systems for fuels with variable composition, further refinement of numerical models for combustion and mixing processes, and long-term operational studies conducted under real-world conditions. Equally important will be the integration of alternative fuels with hybrid technologies and energy recovery and storage systems.

It is hoped that this Special Issue constitutes a meaningful contribution to advancing knowledge on alternative fuels for thermal machines and helps define directions for further interdisciplinary research that will enable a safe, efficient, and economically viable energy transition in the decades ahead.

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