EDITORIAL

Editorial: Convergence at the Crossroads-Charting the Future of Thermo-Fluid Systems for a Sustainable Energy Transition

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As we stand at a pivotal juncture in the global effort to mitigate climate change and secure a resilient energy future, the role of fundamental engineering sciences has never been more critical. The *International Journal of Thermo-Fluid Systems and Sustainable Energy* (IJTFSSE) serves as a dedicated forum at the very heart of this challenge: the intersection of thermodynamics, fluid mechanics, heat transfer, and the urgent imperative for sustainable energy solutions. This editorial reflects on the evolving landscape of our field and the key frontiers where transformative research is unfolding.

For decades, advancements in thermo-fluid systems have been the bedrock of industrial progress, from aerospace propulsion and power generation to HVAC&R and automotive engineering. Today, however, the performance metrics have dramatically expanded. Efficiency remains paramount, but it is now inextricably linked with new imperatives: carbon neutrality, circularity, integration with intermittent renewables, and environmental impact minimization. This shift from purely performance-driven design to sustainability-driven innovation defines our era. It is no longer sufficient to make a gas turbine more efficient; we must ask how it can run on green hydrogen or ammonia, facilitate carbon capture, or provide grid flexibility to support solar and wind power.

We identify several interconnected thematic pillars that are shaping the current and future research agenda of this journal:

1. **Decarbonization of Thermal Power and Propulsion**. The transition away from fossil fuels demands fundamental re-engineering of prime movers. Research on gas turbines and internal combustion engines operating on sustainable aviation fuels (SAFs), hydrogen, and other carbon-free energy carriers is vital. This involves tackling profound challenges in combustion dynamics (e.g., flashback, lean blow-off), material compatibility, and the re-optimization of entire cycles (Brayton, Rankine) for new working fluids. Concurrently, Carbon Capture, Utilization, and Storage (CCUS) technologies rely heavily on novel separation processes, sorbent materials, and thermo-fluid integration to become energy- and cost-effective.

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2. **The Rise of Next-Generation Renewable Thermal Systems**. Beyond photovoltaics and wind turbines, the sustainable energy portfolio requires advanced thermal solutions. This includes concentrated solar power (CSP) with high-temperature molten salt or particle receivers, where heat transfer and thermal energy storage at extreme conditions are key. Similarly, geothermal energy extraction, enhanced by advanced closed-loop wellbore heat exchangers and supercritical CO_2 cycles, represents a rich area for thermo-fluid analysis. Ocean thermal energy conversion (OTEC) and advanced waste-heat recovery technologies also fall within this realm, demanding innovations in heat exchangers and working fluids.

3. **The Critical Enabler: Advanced Thermal Management and Energy Storage**. The electrification of everything-from vehicles to data centers-places unprecedented demands on thermal management. High-flux cooling using micro-channel flows, two-phase systems, and immersion cooling are essential for power electronics, batteries, and computing infrastructure. Furthermore, the integration of variable renewables necessitates large-scale, long-duration energy storage. Here, thermo-fluid systems excel in the form of pumped thermal electricity storage, liquid air energy storage, and advanced sensible/latent heat storage systems, where fluid dynamics and phase change phenomena dictate performance and cost.

4. **The Fluids of the Future: Nanofluids, Supercritical Fluids, and Bio-Fluids**. The working fluid itself is a primary research variable. Nanofluids continue to promise enhanced thermal conductivity for cooling applications, though stability and pragmatic implementation challenges remain. Supercritical CO_2 has emerged as a transformative working fluid for power cycles, offering high efficiency in compact turbomachinery, but requiring precise handling near the critical point. The development of low-GWP (Global Warming Potential) refrigerants and biodegradable hydraulic fluids further underscores the need for fundamental property characterization and system compatibility studies.

5. **The Digital Revolution: AI/ML and High-Fidelity Simulation**. Our field is being reshaped by digital tools. High-fidelity simulations (DNS, LES) provide unprecedented insight into turbulent reacting flows, multiphase phenomena, and conjugate heat transfer. Machine learning and data-driven models are accelerating design optimization, enabling predictive maintenance of complex assets, and discovering new materials or correlations from vast datasets. The synergy between high-performance computing, artificial intelligence, and fundamental thermo-fluid physics is creating a new paradigm for discovery and design.

Call for Interdisciplinary, Holistic Research

The grand challenges we face do not respect traditional disciplinary boundaries. Authors submitting to IJTFSSE are encouraged to embrace this interconnectedness. We seek studies that not only present a novel thermo-fluid analysis but also articulate its impact on system-level sustainability metrics-be it exergy efficiency, life-cycle carbon footprint, levelized cost of energy, or grid stability. Collaboration between fundamental fluid dynamicists, heat transfer specialists, materials scientists, chemists, and energy systems modelers are crucial.

Furthermore, we emphasize the importance of bridging scales-from molecular interactions governing new refrigerant properties, to micro-scale heat transfer in battery electrodes, to macro-scale performance of a full-scale wind farm or geothermal reservoir. Papers that make these connections are particularly valuable.

Conclusion

The mission of the *International Journal of Thermo-Fluid Systems and Sustainable Energy* is to publish rigorous, innovative research that pushes the boundaries of our understanding and application of thermo-fluid sciences in service of a sustainable planet. We are interested in both fundamental advances and applied engineering breakthroughs, provided they are grounded in sound science and address the pressing needs of the energy transition.

We extend our gratitude to our authors, reviewers, and editorial board for their continued commitment to excellence. Together, through the dissemination of high-quality research, we can equip the global engineering community with the knowledge needed to design the efficient, resilient, and clean thermo-fluid systems of the future.

We invite you to contribute your pioneering work to this ongoing endeavor.

Sincerely,

Muhammad Ijaz Khan

Editor-in-Chief

On behalf of the Editorial Board

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