The Scope, Achievements, and Impact of the Transport Processes Research Group (TPRG)

A GLOBAL MODEL FOR INTERDISCIPLINARY ACADEMIC AND INDUSTRIAL R&D

Founded by: Professor Arun S. Mujumdar (2002)

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Preface

Knowledge becomes transformative only when it breaks free from geographic boundaries and institutional silos. In 2002, Professor Arun S. Mujumdar envisioned a borderless network of minds dedicated to the advancement of fluid mechanics, heat transfer, and drying technologies. The resulting creation—the Transport Processes Research Group (TPRG)—rewrote the textbook on international academic collaboration and industrial knowledge transfer without relying on centralized physical infrastructure.

This report compiles the multi-decade scope, technical landmarks, and socioeconomic impacts of TPRG. It stands as a testament to the power of virtual research models, demonstrating how structured global mentorship and an unwavering commitment to the democratization of science can drive real-world industrial decarbonization and enhance food security. It is shared openly with the hope that it will inspire researchers, engineers, and institutions across other scientific disciplines to forge similar global alliances to address the pressing grand challenges of our era.

— AI Research Companion, July 2026

Executive Summary

The Transport Processes Research Group (TPRG) was established in 2002 by Professor Arun S. Mujumdar during his tenure as Professor of Mechanical Engineering at the National University of Singapore (NUS). Designed as a borderless, "virtual" international research collective, TPRG was conceived to catalyze interdisciplinary research—both fundamental and applied—in fluid mechanics, heat and mass transfer, and material science.

Over nearly a quarter-century of operation, TPRG has challenged traditional, geographically constrained laboratory models. Under Professor Mujumdar's principal mentorship, the group has woven together an informal global matrix comprising hundreds of doctoral students, postdoctoral fellows, and senior academic and industry collaborators across more than twenty countries—including Canada, Singapore, China, India, Thailand, Malaysia, Brazil, France, and Poland.

By focusing on core transport phenomena and their industrial applications—most notably in thermal drying and dewatering sciences, food engineering, pharmaceutical processing, and advanced energy systems (e.g., nanofluids, fuel cells)—TPRG has achieved an extraordinary dual-impact profile. It has generated immense academic capital through over a thousand high-impact journal papers and dozens of co-authored reference text books, while simultaneously steering large-scale industrial R&D toward NetZero carbon footprints, enhanced product quality, and energy efficiency. Furthermore, through its pioneering free e-book distribution initiative, TPRG has democratized technical knowledge worldwide, leaving a profound societal and economic footprint on global food security, industrial decarbonization, and engineering education.

1. Introduction and Genesis of TPRG

At the turn of the 21st century, the field of industrial transport processes faced a dual crisis. First, classic unit operations like thermal drying—historically responsible for consuming between 10% and 25% of national industrial energy budgets in developed economies—remained heavily reliant on empirical, black-box design paradigms. Second, the rising costs of academic publishing and structural silos within universities severely bottlenecked the translation of advanced transport mathematics into viable industrial applications, especially in the rapidly developing economies of Asia and Latin America.

Recognizing that globalization could be leveraged to democratize scientific discovery, Professor Arun S. Mujumdar founded TPRG in 2002 at NUS. The group was structured not as a physical center tied to specific university walls, but as an agile, virtual network. The foundational blueprint focused on four key pillars:

- **Interdisciplinary Integration:** Merging fluid dynamics and heat/mass transfer mathematics with advanced material science and product functionality considerations.
- **Global Mentorship:** Building a continuum of talent by linking Professor Mujumdar's former research cohorts at McGill University (Canada) and NUS (Singapore) with active faculty and students across global hubs of engineering excellence.
- **Open Knowledge Dissemination:** Creating open-access pathways to complex scientific texts to circumvent the prohibitive costs of international reference books for institutions in developing nations.
- **Industry-Relevant Academic R&D:** Adhering to a philosophy that the true impact of engineering research must be measured by its capacity to improve industrial output, conserve energy, and address global issues like food security and climate change.

2. Structural Scope and Operational Architecture

TPRG operates as a flat, informal, and dynamic network. Rather than relying on a rigid administrative hierarchy, it leverages professional synergy, shared research goals, and a cross-institutional mentoring model.

PRINCIPAL MENTOR: PROF. ARUN S. MUJUMDAR	
Core Knowledge Hubs • National University of Singapore • McGill University (Canada)	**Global Collaborators** • Jiangnan University (China) • ICT Mumbai (India) • KMUTT (Thailand) • Lodz Univ. of Tech (Poland)
TRIPLE-STREAM DELIVERABLES & IMPACT MATRIX	
Archival Research • 1000+ Journal Papers • High-Impact Textbook Series	**Knowledge Democratization** • Free Technical E-Books • Open PPT Lecture Series
Industrial Applications: Scale-up & Optimization • Smart, NetZero Dryers • Food Security Solutions	

The Virtual Lab Paradigm

The group bypasses traditional geographic limitations by distributing research tasks across partner institutions based on local expertise and laboratory infrastructure. For instance, advanced computational fluid dynamics (CFD) modeling might be executed in Singapore or Canada, while large-scale experimental validation for agricultural or pharmaceutical drying is carried out simultaneously at partner facilities in China, India, or Thailand.

A Global Talent Pipeline

The group’s membership spans across some twenty nations. This cross-cultural matrix has allowed TPRG to act as an international talent incubator. Young faculty members in developing universities gain direct access to world-class peer review, editorial mentoring for high-impact journals (such as *Drying Technology*), and joint execution of complex, multi-national research grants.

3. Core Academic Achievements and Knowledge Democratization

The academic productivity of TPRG is exceptional, characterized by both high volume and rigorous peer-reviewed quality. The group's research output is balanced across fundamental transport mechanics and highly applied technology handbooks.

Archival Publications and Textual Legacy

TPRG members have contributed to thousands of research papers in top-tier journals focusing on thermal sciences, chemical engineering, and food physics. Crucially, the group has excelled in synthesizing vast bodies of scattered scientific literature into cohesive, authoritative texts. A significant portion of its research output takes the form of edited reference books, comprehensive monograms, and book series—such as the acclaimed *Advances in Drying Science and Technology* series published by CRC Press/Taylor & Francis.

The Open-Access E-Book Revolution

To counter the high financial barriers of scientific literature, Professor Mujumdar and senior TPRG members instituted a programmatic open-access e-book initiative. Group members voluntarily donate their professional time and intellectual property to author, edit, and compile specialized engineering books distributed entirely free of charge. This initiative serves thousands of students, faculty, and field engineers globally. Prominent examples of these free resources include:

- *Drying of Foods, Vegetables and Fruits* (Volumes 1, 2, and 3)
- *Industrial Drying, Principles and Practice* (Comprehensive Lecture Series)
- *Coal Dehydration: A Compilation of Relevant Publications and Technical Reports*
- *Selected Topics in Heat and Mass Transfer*

4. Advancements in Fluid Mechanics, Heat, and Mass Transfer

The cornerstone of TPRG's research program lies in translating fundamental conservation equations of mass, momentum, and energy into highly accurate predictive models for heterogeneous industrial systems.

Mathematical Modeling and Numerical Simulation

TPRG spearheaded the shift away from empirical drying curves toward multi-phase, multi-scale transport models. By integrating spatial variations in heat and mass transfer coefficients with structural mechanics, the group has accurately simulated the behavior of materials undergoing severe physical alterations during processing. This includes structural shrinkage, crust formation, case-hardening, and localized phase transitions.

$$\partial(\rho C_p T)/\partial t + \nabla\cdot(\rho C_p\, u\, T) = \nabla\cdot(k\nabla T) + Q$$

By utilizing modified Maxwell-Stefan formulations alongside localized energy balances, TPRG has mapped out how moisture migrates through complex capillary-porous media during variable thermal regimes. This foundational mathematics directly underpins the design of modern impinging jets, pulsed combustion systems, and superheated steam environments.

Nanofluids and Advanced Thermal Management

Expanding beyond dehydration science, TPRG has conducted significant foundational research into the thermal behavior of nanofluids—colloidal suspensions of nanoparticles in base liquids. The group's critical reviews and mathematical treatments of nanofluid thermal conductivity, viscosity, and convective heat transfer characteristics rank among the most highly cited works in the field of thermal sciences. These models have directly enabled the optimization of compact electronic component cooling systems, phase-change material (PCM) hybrid thermal management setups, and highly efficient heat exchangers.

5. Industrial Impact, Decarbonization, and Sustainability

Engineering research gains its truest validation when deployed on the factory floor. TPRG has systematically linked academic discovery with industrial application, addressing some of the most critical energy and climate challenges facing heavy industry.

Path to NetZero and Industrial Decarbonization

Because thermal drying is highly energy-intensive, it represents a substantial driver of industrial greenhouse gas emissions. TPRG has dedicated decades to developing and introducing decarbonization pathways for large-scale operations. Through comprehensive techno-economic assessments, Life Cycle Assessments (LCA), and exergy analyses, the group has successfully demonstrated how to reduce fossil-fuel reliance. Key interventions include:

- **Waste Heat Recovery:** Integrating high-temperature industrial heat pumps and mechanical vapor recompression (MVR) systems into drying circuits to capture and recycle latent heat.
- **Renewable Energy Integration:** Modeling and designing solar-assisted and biomass-integrated hybrid drying systems tailored for agricultural cooperatives in developing nations.
- **Superheated Steam Drying (SSD):** Eliminating air from the drying medium to allow the evaporated moisture to be fully recovered as pressurized steam, cutting net energy consumption by up to 50% in paper, sludge, and chemical processing sectors.

Digital Twins and AI Integration

In step with the Fourth Industrial Revolution, TPRG has pioneered the integration of Artificial Intelligence (AI), Machine Learning (ML), and real-time Digital Twins into thermal processing networks.

Industrial dryers are notoriously difficult to control due to the highly variable and non-linear properties of raw materials (e.g., varying moisture content in incoming food crops or mineral sludges). By layering neural networks over classic transport equations, TPRG researchers have established real-time, non-destructive control models. These digital twin frameworks continuously predict internal product moisture and temperature distributions, allowing operators to modulate energy inputs on the fly. This prevents product degradation from overheating while minimizing excess energy expenditures.

6. Industrial and Academic Case Studies

The global footprint of TPRG's multi-decade collaborative effort is best understood through real-world case studies across diverse industrial and geographical sectors.

Case Study 1: China's Food Dehydration Sector

Partners: Jiangnan University, Tianjin University of Science and Technology (TUST), and regional food processing enterprises.

Context & Intervention: Much of China's agricultural output suffered post-harvest losses or used highly inefficient coal-fired tunnel dryers. Under Professor Mujumdar’s guidance as a National High-End Foreign Expert, a multi-decade R&D program introduced advanced combined drying mechanisms (e.g., microwave-assisted vacuum drying, infrared convective drying).

Impact: The partnership scaled up high-efficiency facilities preserving nutritional value, upgraded China's food export sector tech standards, and culminated in China’s highest award for International Cooperation in Science and Technology in 2014.

Case Study 2: Sustainable Coal Dehydration Technology

Partners: Academic institutes and mining operations in Indonesia and India.

Context & Intervention: Low-rank coals contain up to 50% moisture, driving up transport costs and causing transit spontaneous combustion risks. TPRG developed intensive numerical modeling for fluidized and spouted beds, compiling outputs into open-access corporate toolkits.

Impact: Manufacturers optimized pre-combustion drying systems, boosting net thermal efficiency, reducing localized emission spikes, and mitigating self-ignition hazards.

Case Study 3: Advanced Pharmaceutical Particle Engineering

Partners: Research clusters in Singapore, Malaysia, and global pharmaceutical R&D labs.

Context & Intervention: Production of APIs requires strict control over crystalline transformations and residual solvents. TPRG deployed advanced spray drying and freeze-drying computational simulations coupling droplet evaporation with phase-change kinetics.

Impact: Designed protocols eliminated secondary drying steps, minimized solvent retention in inhaled dry powders, and successfully prevented the thermal degradation of delicate biological proteins.

7. Strategic Outlook and Future Horizons

As industrial engineering adapts to an era defined by rapid climate change and deep digital integration, TPRG’s virtual network model remains highly relevant. The group's forward-looking research agenda focuses on several key areas:

- **Global Food Security and Waste Minimization:** Developing low-cost, decentralized smart dryers for smallholder farming communities utilizing hybrid solar-biomass setups and simple smartphone-enabled AI visual tracking apps to curb post-harvest losses.
- **Advanced Electrification of Thermal Processes:** Modeling the total electrification of the drying chamber using volumetric heating technologies such as radio frequency (RF), variable-frequency microwave fields, and electro-hydrodynamic (EHD) non-thermal drying.

- **Sustaining the Open Knowledge Architecture:** Expanding the digital repository with updated curriculum modules, open-source calculation scripts, and multi-language translations of core texts.

8. Conclusion

The Transport Processes Research Group stands as an exemplary case study in how globalized, virtual networks can transform an engineering discipline. By breaking down the traditional silos that separate fluid dynamics, thermal sciences, material behavior, and industrial production, TPRG has systematically advanced both the theory and practice of industrial transport processes.

Under the visionary leadership and continuous mentorship of Professor Arun S. Mujumdar, the group has successfully struck a balance between academic excellence and industrial utility. Its legacy is etched not only in its over one thousand archival publications, highly cited reviews, and authoritative text handbooks, but also in reduced industrial carbon footprints, minimized post-harvest food waste, and the democratization of vital technical knowledge for thousands of researchers worldwide. As industry pushes toward a digitized, NetZero future, the operational philosophies and scientific frameworks pioneered by TPRG since 2002 will undoubtedly continue to guide and inspire global industrial R&D.