IOCM 2025 Conference

The 4th International Online Conference on Materials

3–6 November 2025 | Online

MDPI

Lightweight Heat Exchanger Design Using Graphene-Reinforced Ceramics: A Comparative Study of Dimensional and Material Effects

Yusuf KEPİR[1*], Holger SEIDLITZ[1], Lars ULKE-WINTER[1], Felix KUKE[1,2]

[1]Chair of Polymer-based Lightweight Design, Brandenburg University of Technology Cottbus–Senftenberg (BTU), Cottbus, Germany

[2]Research Division Polymeric Materials and Composites PYCO, Fraunhofer Institute for Applied Polymer Research IAP, Wildau, Germany

INTRODUCTION & AIM

Heat exchangers in high-temperature applications require lightweight and thermally resistant designs, as conventional metal exchangers are constrained by their density and limited thermal performance. To address these challenges, this study focuses on developing a compact heat exchanger that combines material innovation through graphene-reinforced ceramic matrix composites (G-CMCs) with geometric optimization, including channel subdivision and dimensional scaling, thereby enhancing operational efficiency at high temperatures and contributing to the energy efficiency and carbon neutrality targets of the European Green Deal.

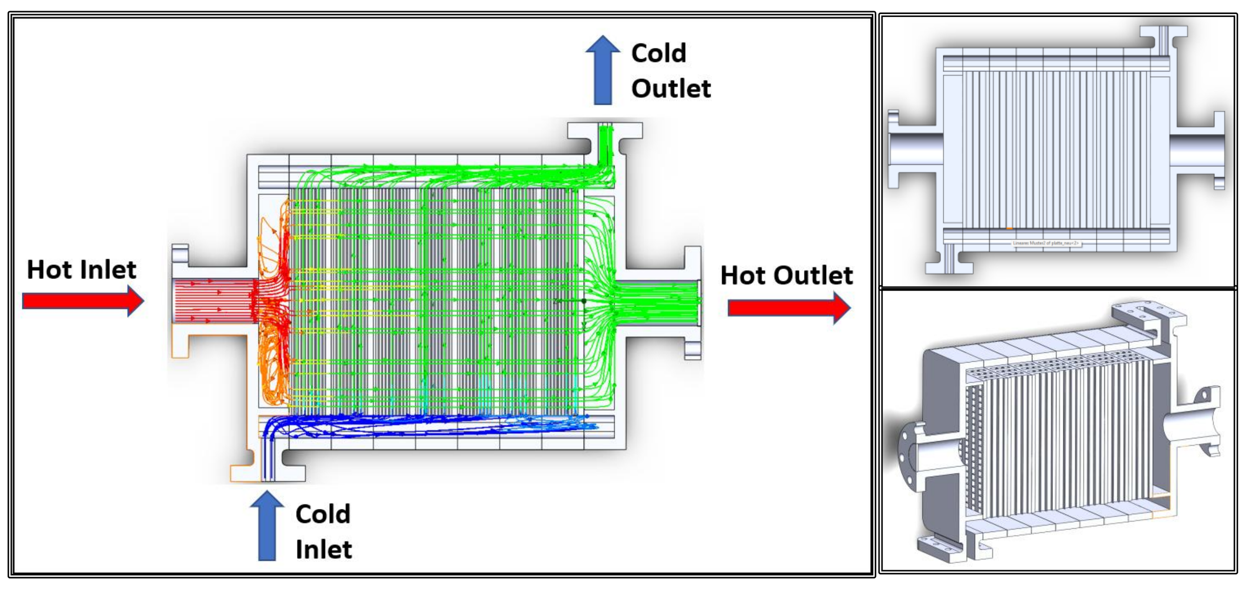

Figure 1. The compact heat exchanger model used in this study

METHOD

- A cross-flow block-type heat exchanger was modeled in SolidWorks and analyzed using the Flow Simulation module.
- Hot and cold air streams flowed perpendicularly and horizontally through rectangular channels (4×4 mm).
- Thermal and flow boundary conditions were kept constant, with inlet temperatures of 1223 K (hot) and 453 K (cold) at 0.01 kg/s.
- Heat exchanger efficiency made by stainless steel (AISI 304) and G-CMC were compared.
- Channel geometry and heat exchanger length (180-250-400–600 mm) were systematically varied to assess their effects on efficiency.

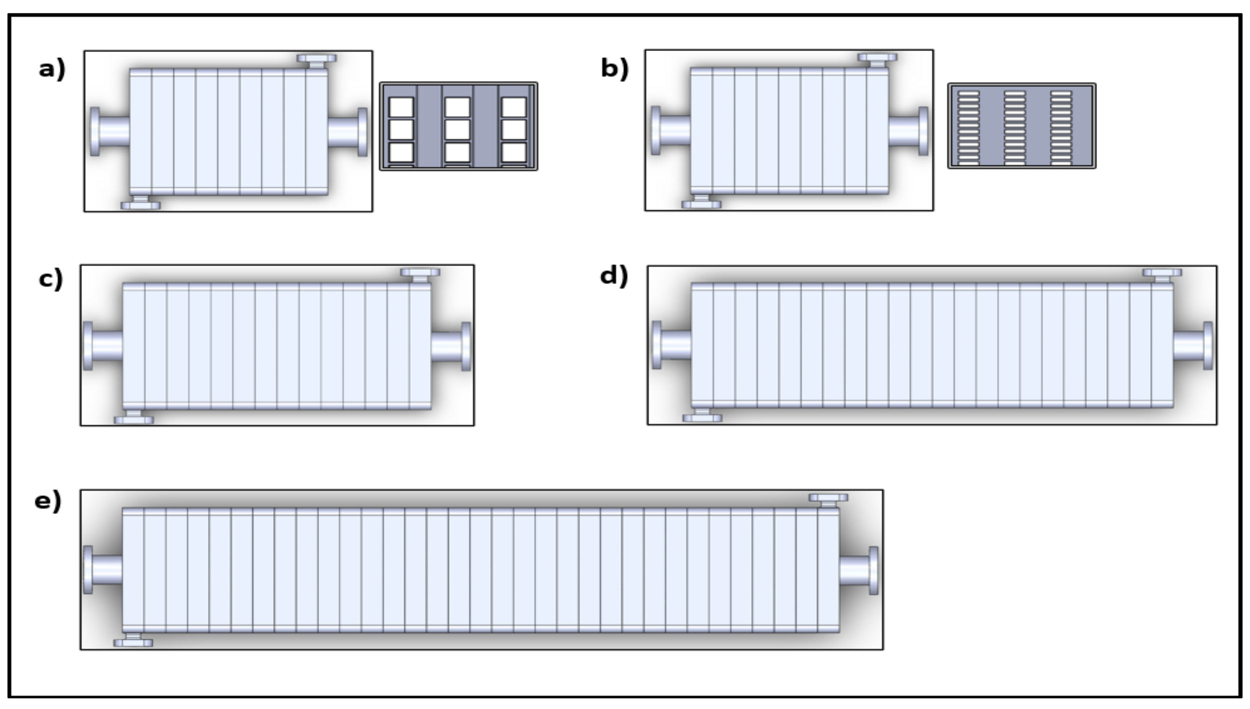

Figure 2. a) 180 mm base model with conventional channel geometry, b) 180 mm model with ¼ x subdivided channel geometry , c) 250 mm d) 400 mm e) 600 mm

Table 1. Inlet boundary conditions for the heat exchanger simulations

Inlet Parameters	Value
Inlet cold fluid mass flow rate	**0.01 kg/s**
Inlet hot fluid mass flow rate	**0.01 kg/s**
Inlet cold fluid temperature	**453.15 K**
Inlet hot fluid temperature	**1223.15 K**

ACKNOWLEDGEMENT

This project was supported by the Central Innovation Programme for SMEs (ZIM) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK), administered by AiF Projekt GmbH, under grant numbers ZF4726301CL9 (Professor Dr. Berg & Kießling GmbH) and ZF4259518CL9 (BTU Cottbus–Senftenberg)

RESULTS & DISCUSSION

- **+82%** effectiveness increase
- **–50%** lightweight with G-CMCs
- **3D printing** enables complex geometries

Simulation results showed that effectiveness increased with heat exchanger length and channel subdivision. Subdividing each 4×4 mm channel into four 1×4 mm channels raised the surface area by 2.5 times and enhanced effectiveness by 38% for the ceramic and 82% for the steel configuration. G-CMC exchangers exhibited 11% higher efficiency than steel at equal dimensions due to superior thermal conductivity and lower density. G-CMC also reduced weight by 50% and enabled complex geometries through additive manufacturing. Furthermore, temperature contour plots indicated a more uniform heat distribution across G-CMC models, suggesting reduced thermal gradients and improved heat transfer stability.

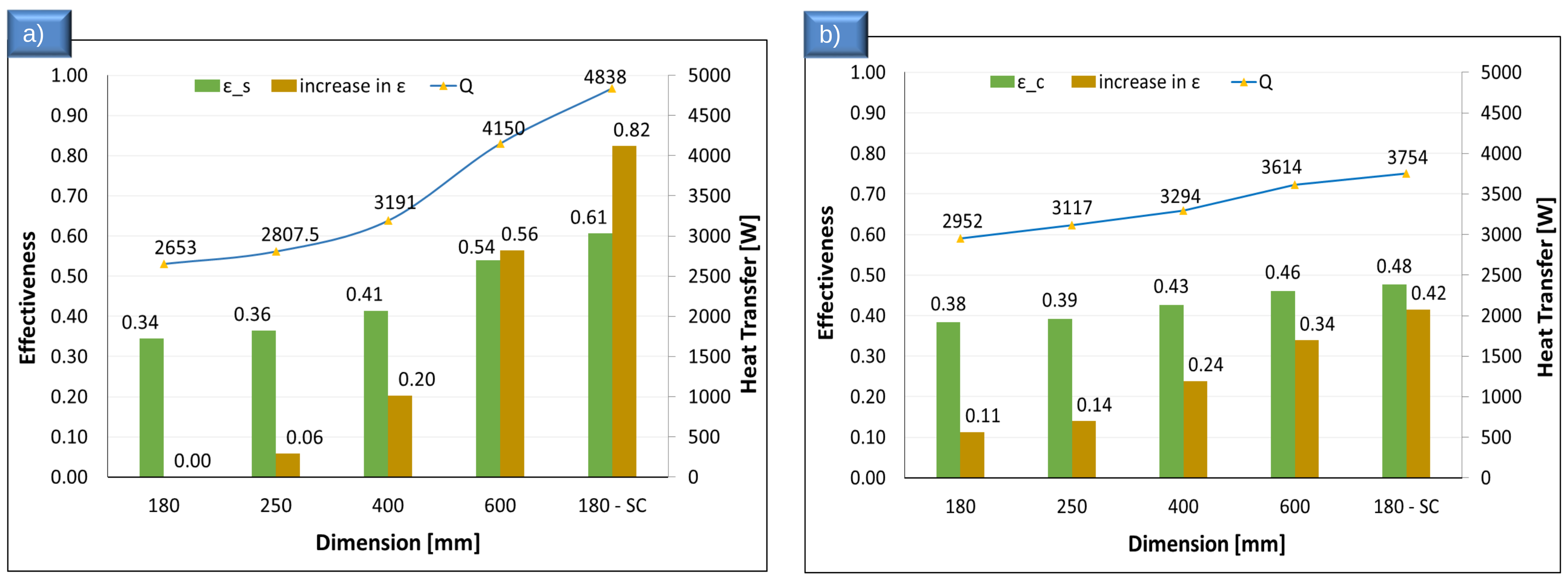

Figure 3. Effectiveness values and percentage increase rates for (a) stainless steel and (b) G-CMC composite heat exchangers

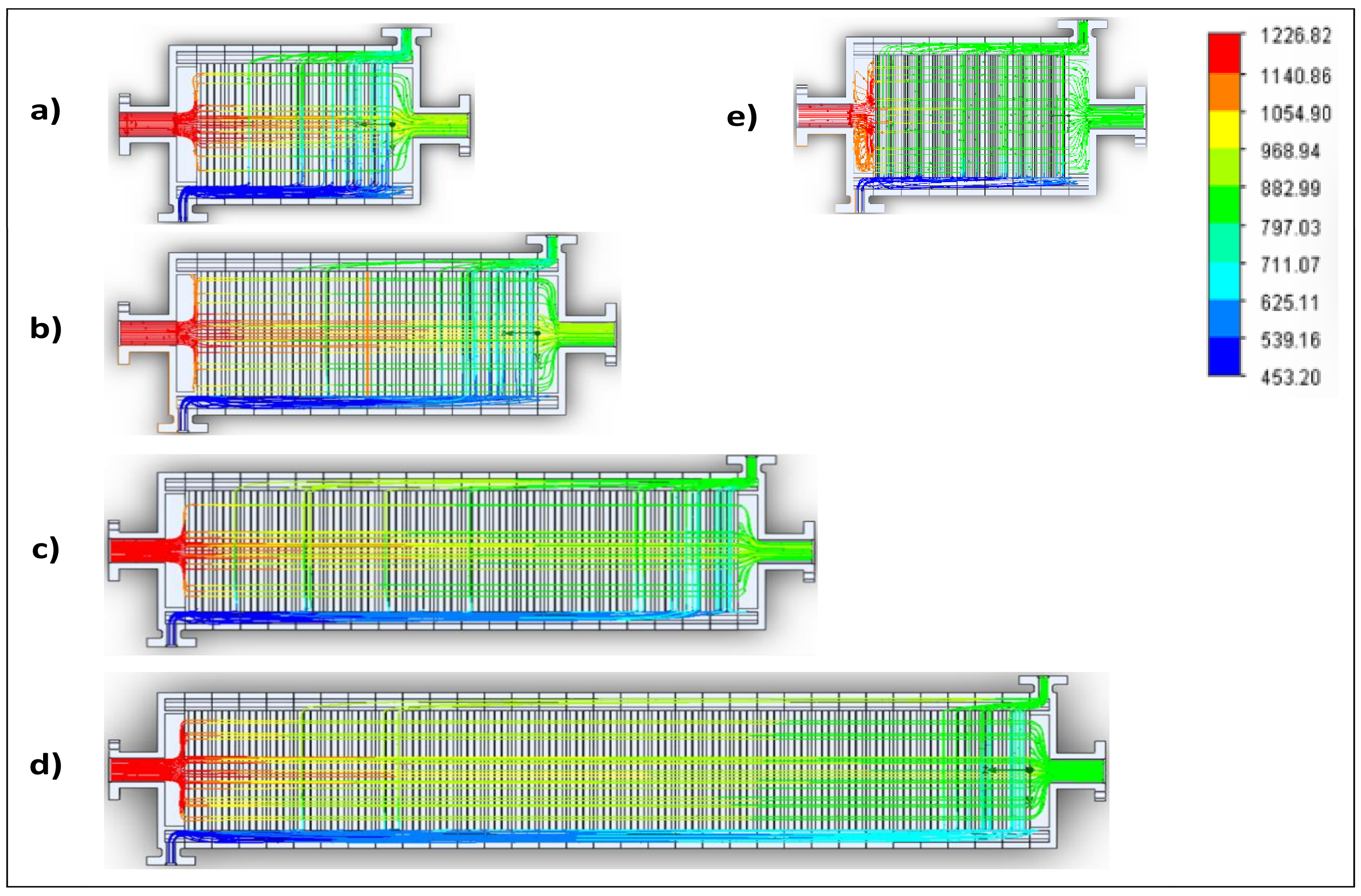

Figure 4. Temperature distribution in heat exchangers: (a) 180 mm base model, (b) 250 mm, (c) 400 mm, (d) 600 mm, (e) 180 mm - subdivided channel

CONCLUSION

- The increase in both flow path length and contact surface area resulted in higher effectiveness.
- G-CMC exchangers achieve higher efficiency and are 50% lighter than steel.
- Subdivided channels (1×4 mm) provide the most significant performance boost.
- Material selection and geometric optimization are key to sustainable high-temperature applications.