Heat transfer evaluation in TPMS and Lattice inserts for structured packed beds

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Highlights

- Additive manufacturing allows us to tailor complex internal structures by selectively melting layers of metal alloys.
- Structured inserts provide an organized network of conductive pathways that overcome the poor solid-solid contact typical for random packed beds.
- The insert thermal properties can be improved by adjusting parameters like cell size, solid fraction and geometric parameters
- TPMS have proven superior thermal efficiency, due to their smooth continuous surfaces and high surface area to volume ratio that improve convective heat transfer.

1. Introduction

Fixed-bed tubular reactors are widely used in industry, yet their reliance on randomly packed catalyst particles limits their thermal performance due to poor solid–solid contact and low effective thermal conductivity. These shortcomings produce radial temperature gradients and hot spots that result in catalyst deactivation, sintering, coking, and reduced product yield. Improving reactor efficiency therefore requires enhanced radial heat transport, optimized wall heat transfer, and controlled pressure drop—factors closely tied to particle geometry, porosity, and flow conditions. Structured reactor concepts have emerged as promising alternatives to previous traditional solutions such as honeycombs and foams, which improve conduction but often suffer from structural irregularities and high pressure drops.

Latest advances in additive manufacturing now enable the fabrication of architected metallic lattices with precise geometries, including Periodic Open Cellular Structures (POCS) and Triply Periodic Minimal Surfaces (TPMS). These structures provide tunable porosity, continuous conductive pathways, and enhanced convective mixing, while TPMS offer smooth curvature, high surface-area-to-volume ratios, and superior thermal and mechanical properties. Reported heat exchanger studies show TPMS can deliver 48–61% higher heat transfer than conventional foams.

2. Methods

In this work, lattice and TPMS inserts with varied geometries and cell sizes were fabricated under identical manufacturing constraints and evaluated in a wall-jacketed tubular reactor. Axial and radial temperature profiles were measured and used to determine overall heat transfer coefficients for structured and conventional packed beds.

3. Results and discussion

The overall heat-transfer analysis revealed clear performance differences between the TPMS and lattice structures, driven largely by variations in their solid fraction. Structures with higher solid fractions exhibited improved conductive pathways, resulting in higher overall heat-transfer coefficients. This balance between solid connectivity and open-pore volume governed the observed thermal behavior, demonstrating that optimal heat-transfer performance emerges from carefully tailored solid fractions rather than geometry alone. These findings highlight how the interplay between structure density and thermal transport mechanisms can be leveraged to design next-generation structured reactors with superior temperature control and efficiency.

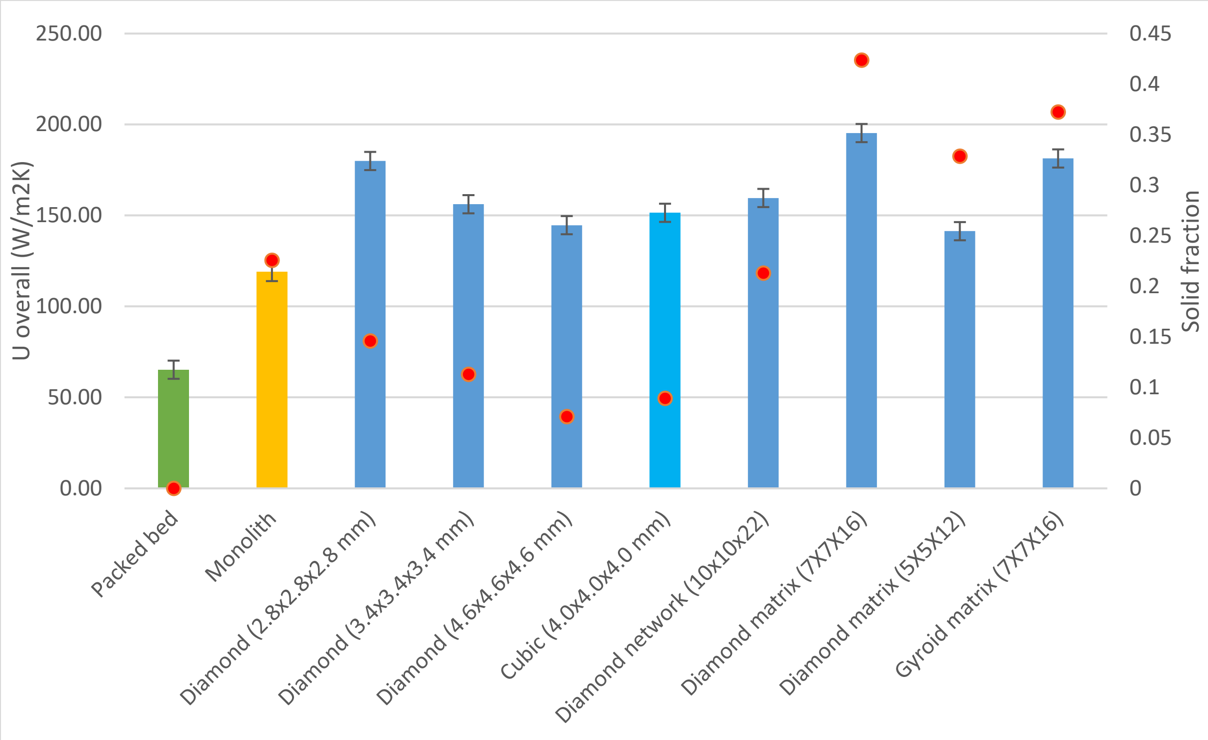

Figure 1. Overall heat transfer of regular packed bed (green color), monolith (orange color), TPMS (dark blue color), diamond TPMS of 2.8, 3.4- and 4.6-mm cell size, diamond network TPMS, diamond matrix 7x7x16 and 5x5x12 TPMS, and gyroid 7x7x16 matrix TPMS, and POCS (light blue color) cubic strut-node lattice. All structures evaluated against their corresponding solid fraction.

4. Conclusions

- Structured inserts outperform conventional packed beds, offering higher radial heat transfer and more uniform temperature profiles.
- Solid fraction strongly dictates heat-transfer performance, with higher solid content improving conduction while lower fractions enhance permeability.
- Wall contact is a key driver of efficiency, as better contact significantly boosts overall heat-transfer coefficients.
- Geometry matters: TPMS and lattice types excel under different flow conditions, and topology must be chosen to match operating regimes.

References

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Keywords
TPMS, POCS, Additive Manufacturing, Heat transfer