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COMPUTATIONAL DOMAIN DISCRETIZATION IN NUMERICAL ANALYSIS OF FORCED CONVECTIVE HEAT TRANSFER WITHIN PACKED BEDS OF GRANULAR MATERIALS

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Abstract: *Computational Fluid Dynamics (CFD) is a very effective research tool in the analysis of heat transfer within backed beds of granular materials. Computational domain discretization is the pre-processing stage in CFD analysis and it highly contributes to reducing the level of solution error as well as increasing the numerical stability of the model. The discretization of domain representing a packed bed of granular material is a demanding task due to the topology of the model consisting of spherical granules contacting tangentially. Therefore the aim of the carried out research was to define guidelines to effectively discretize the computational domain representing the packed bed of granular material. Two methods of contact point representation between granules and two mesh types (tetrahedral and polyhedral) are investigated. Differences between the analyzed cases are discussed.*

Keywords: computational domain discretization, polyhedral mesh, granular materials, heat transfer

1. Introduction

Packed beds of granular materials are the focus of numerous experimental and theoretical studies due to their widespread prevalence in nature and common application in industry (Hu et al., 2017; Oschmann and Kruggel-Emden, 2017; Więcek, Parafiniuk and Stasiak, 2017; Krzywanski et al., 2017).

Computational Fluid Dynamics (CFD) has become a very effective research tool (Sosnowski, 2017a; Gnatowska and Sosnowski, 2017; Jamrozik et al., 2017) in the analysis of heat transfer within granular materials (Hu et al., 2017). CFD applies numerical methods of solving nonlinear differential equations describing the investigated physical phenomenon. Most of these equations do not have analytical solutions, therefore approximate numerical methods are used to solve them. Contemporary commercial CFD codes accomplish the above mentioned task in a very effective manner but the round-off errors, as well as truncation errors, influence the solution accuracy. Computational domain discretization is the initial stage in CFD analysis and it highly contributes to reducing the level of solution error as well as increasing the numerical stability of the model (Gnatowska, Sosnowski and Uruba, 2017; Sosnowski, 2017b). The resolution of generated mesh and the type of mesh elements strongly influence the numerical diffusion as well as the model convergence.

The discretization of the computational domain can be achieved with the application of three different mesh types: hexahedral (HEX), tetrahedral (TETRA) and polyhedral (POLY). The numerical diffusion of each mesh type is different and strongly influences the result quality. HEX elements are least diffusive while TETRA elements are most diffusive (Bailey, 2017). Unfortunately, the geometric complexity of a packed bed of granular material makes it impossible to apply structured HEX mesh. POLY elements are worth investigating as their numerical diffusivity is at a level comparable to HEX and in addition, POLYs can easily by applied to describe even very complicated geometries (Sosnowski et al., 2017; Sosnowski, Krzywanski, and Gnatowska, 2017).

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Moreover the discretization of computational domain representing a packed bed of granular material is a demanding task due to the topology of the packed bed consisting of spherical granules contacting tangentially. It leads to mesh elements of extremely low quality because the cells in direct vicinity of the contact point are highly skewed. The common discretization method used by researchers (Bu et al., 2014) is to reduce the granule radius (GRR – granule radius reduction) but the drawback of this method is the flow disturbance and heat transfer within said domain. Another method is the extension of the contact point (CPE – contact-point extension) between two individual granules to the cylindrical volume (Bu et al., 2014) which guarantees contact between granules and simultaneously allows the generation of a high-quality mesh.

Therefore the aim of the carried out research is to define guidelines to effectively discretize the computational domain representing a packed bed of granular material by investigating different mesh types and different approaches to discretization of the contact region between granules.

2. Methods

The research object was a section of a packed bed of solid granular material submerged in fluid domain. The parametric geometry was generated using SolidWorks with ANSYS plugin. It was prepared in two configurations. The first (Fig. 1ab) represents the section of the packed bed with granules of reduced diameter (GRR method) – the gap between granules was defined as $\frac{1}{100}d$ (where: d – granule diameter) on the basis of findings described in (Bu et al. 2014) and (Sosnowski 2017b). The second configuration (Fig. 1cd) represents the full-size granules with contact point extended to the cylindrical volume (CPE method) of diameter equal $\frac{3}{20}d$.

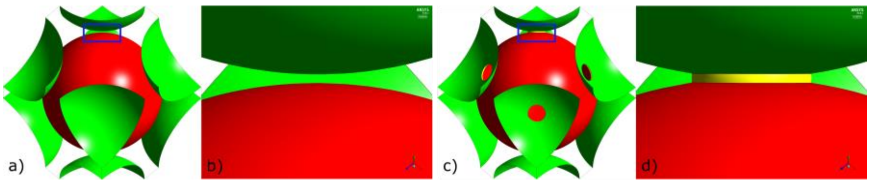

Fig. 1: Research object in two configurations: GRR – a and b (zoom), CPE – c and d (zoom).

The mesh was generated using ANSYS Meshing with uniform size function in order to create regular mesh size distribution in the entire domain. In the case of TETRA mesh, the element sizes on the granules surfaces, as well as within the domain, were defined as $\frac{3}{80}d$ which resulted in 90526 mesh cells (GRR) and 85578 mesh cells (CPE). POLY generation is a two-step process: TETRA mesh generation and conversion of the TETRA mesh to a POLY mesh. The conversion algorithm uses the agglomeration process and therefore the initial TETRA mesh sizes were set to $\frac{1}{40}d$. It resulted in 298710 mesh cells (GRR) and 281533 mesh cells (CPE). The final POLY mesh obtained after conversion consisted of 58364 and 55671 mesh cells respectively. Mesh quality was analyzed for all cases. The quality metric ranges from 0 to 1 where the value of 1 indicates a perfect element and the value of 0 describes the element of zero or negative volume. The mesh element of the worst quality generated throughout the entire research was characterized by the quality index 0.13. Therefore it was assumed that the mesh quality was at least at the acceptable level and did not affect the numerical stability of the model.

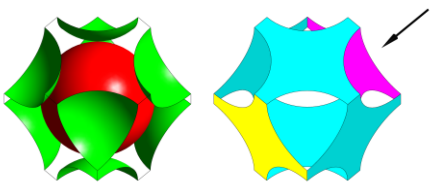

Fig. 2: Boundary conditions.

The solver was configured as pressure-based and the analysis was performed for steady state. The pressure-velocity coupling algorithm was used as a solution method. The fluid medium was air at normal conditions. Velocity-inlet boundary condition type was assigned to the inlet (magenta surface in Fig. 2). The outlet of the computational domain (yellow surface in Fig. 2) was defined as outflow. Wall with no slip shear condition with constant heat flux was assigned to the surfaces of granules (red and green surfaces in Fig. 2) whereas symmetry was assigned to the side-surfaces (cyan surfaces in Fig. 2).

3. Results

The obtained results concerning porosity of the investigated packed bed of granular material is 0.320 while the porosity of the domain is 0.340 in the case of GRR (6.25% relative error) and 0.319 in the case of CPE (0.3125% relative error).

Temperature distributions obtained for both analyzed methods (GRR and CPE) and both analyzed mesh types (TETRA and POLY) are depicted in Figs. 3 to 6. Some differences are noticeable mostly on the outlet surfaces, but the average values of temperature on outlet, XY, XZ and granules surfaces do not differ among the analyzed cases more than 0.03%.

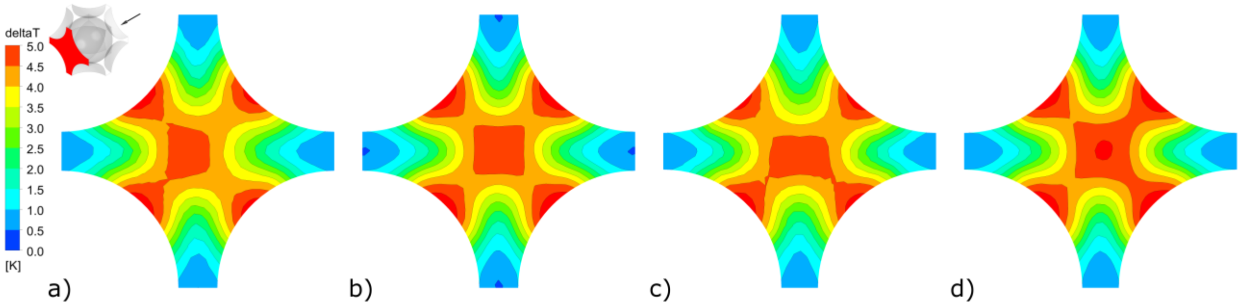

Fig. 3: Temperature on outlet: a - GRR TETRA, b - GRR POLY, c - CPE TETRA, d - CPE POLY.

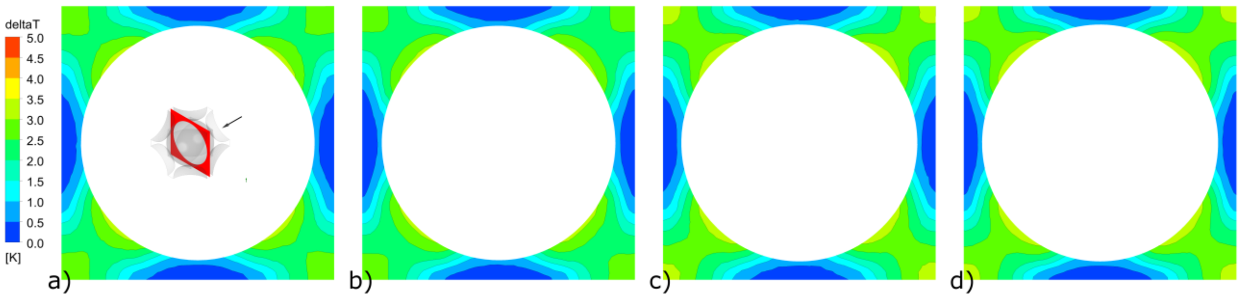

Fig. 4: Temperature on XY surface: a - GRR TETRA, b - GRR POLY, c - CPE TETRA, d - CPE POLY.

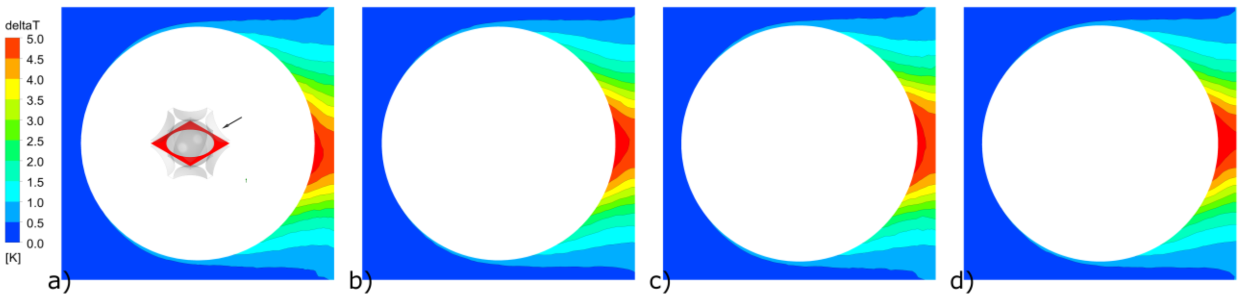

Fig. 5: Temperature on XZ surface: a - GRR TETRA, b - GRR POLY, c - CPE TETRA, d - CPE POLY.

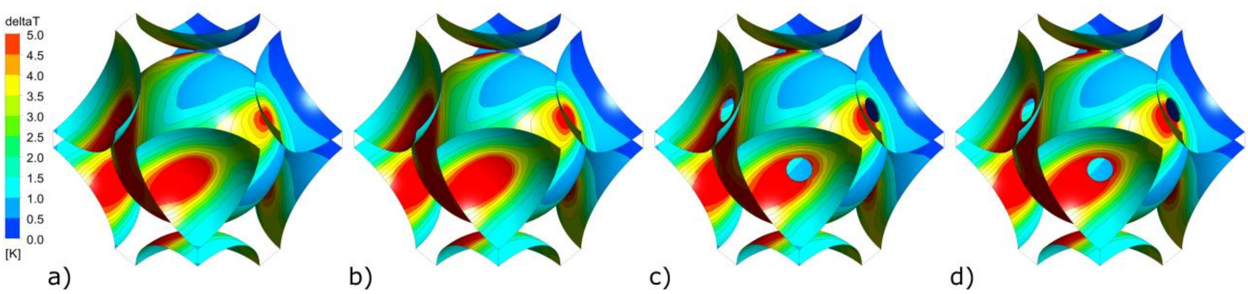

Fig. 6: Granule temperature: a - GRR TETRA, b - GRR POLY, c - CPE TETRA, d - CPE POLY.

4. Conclusions

- The main difference between the analyzed methods of the computational domain discretization which represents the packed bed of granular materials, is revealed in the porosity of the model – the CPE method is preferable due to insignificant relative error of porosity equal to 0.3125%.
- Slight variations of temperature distribution on the outlet surface exist not only between the analyzed methods but also the mesh types. GRR method and POLY mesh generate the most symmetric results.
- Average temperature can be assumed as constant for all analyzed cases (relative error equal 0.03%).
- Experimental research is necessary in order to properly define the applicability of the discretization method and mesh type in CFD analysis of packed beds of granular materials.

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