Heat conduction in complex geometric structures on the example of Neovius periodic surface

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Introduction

Heat conduction is important problem in additive manufacturing, which is main source of interest for periodic surface structures. The high energy flux, which is required for additive manufacturing to work properly, results in large temperature gradients, which can affect quality of obtained part in such properties like porosity or residual stresses.
The authors present results of heat conduction calculations in domains of complex geometric shapes expressed by a mathematical description. Such shapes are called periodic surface structures and a well known example of this type of structure is gyroid, while Neovius surface is another example. The periodic surface structures can be described by a number of factors, like thickness or number of cells, which have impact on their behavior in heat conduction problems.
The authors developed a software that allows for automatic generations of finite element meshes for Neovius surface according to a given set of parameters. Those meshes are used as an input for heat conduction simulations, which results are then base for analysis of influence of geometric factors on temperature distribution.

Neovius surface

Approximated by the equation:

$$3\left(\cos(X)+\cos(Y)+\cos(Z)\right)+4\cos(X)\cos(Y)\cos(Z)=\delta$$

where: δ is normalized thickness and X, Y, Z are spatial coordinates.

Heat transfer

Governing equation:

$$\rho c\frac{\partial T}{\partial t}-k\nabla^2 T=0$$

Neumann boundary condition:

$$q=-k\nabla T$$

where: T is temperature, c is specific heat, ρ is density, k is thermal conductivity coefficient.

Problem setup

Name	Relative thickness [·]	Volume [m^3]	Side area [m^2]	Heat flux [W/m^2]
cube	-	$6.4\cdot10^{-5}$	$16\cdot10^{-4}$	6250
Neovius - 2 cells	0.1	$1.113\cdot10^{-5}$	$2.188\cdot10^{-4}$	45694
Neovius - 2 cells	0.15	$1.678\cdot10^{-5}$	$3.578\cdot10^{-4}$	27950
Neovius - 2 cells	0.2	$2.232\cdot10^{-5}$	$5.591\cdot10^{-4}$	17882
Neovius - 4 cells	0.1	$1.117\cdot10^{-5}$	$2.027\cdot10^{-4}$	49334
Neovius - 4 cells	0.15	$1.686\cdot10^{-5}$	$3.419\cdot10^{-4}$	29251
Neovius - 4 cells	0.2	$2.244\cdot10^{-5}$	$5.532\cdot10^{-4}$	12170

Table: Parameters used for generating different variants of Neovius structure, together with value of Neumann boundary condition.

Quantity	Value	Unit
Conductivity k	260	W/(m K)
Specific heat c	1000	J/(kg K)
Density ρ	2800	kg/m^3
Initial temperature T_0	300	K

Table: Thermophysical properties together with initial condition value.

Remarks

Value of heat flux density in Neumann boundary condition was scaled to accomodate for different single side area of Neovius structures generated with different set of parameters. In general, structures with lower volume (heat capacity) will heat to higher values of temperature. However, comparison of results shows that Neovius surfaces with smaller number of cells heat up to lower values of temperature, even when volume and side area was comparable.

Temperature fields

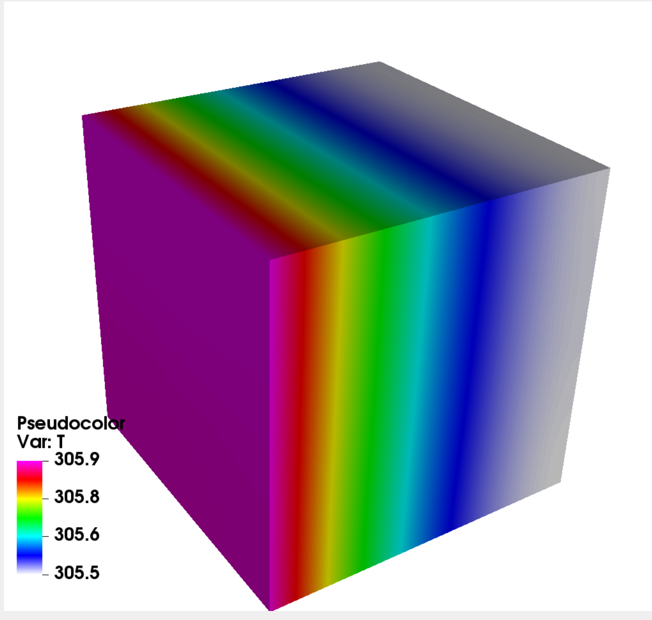

Figure: Temperature field in full cube after 100 [s].

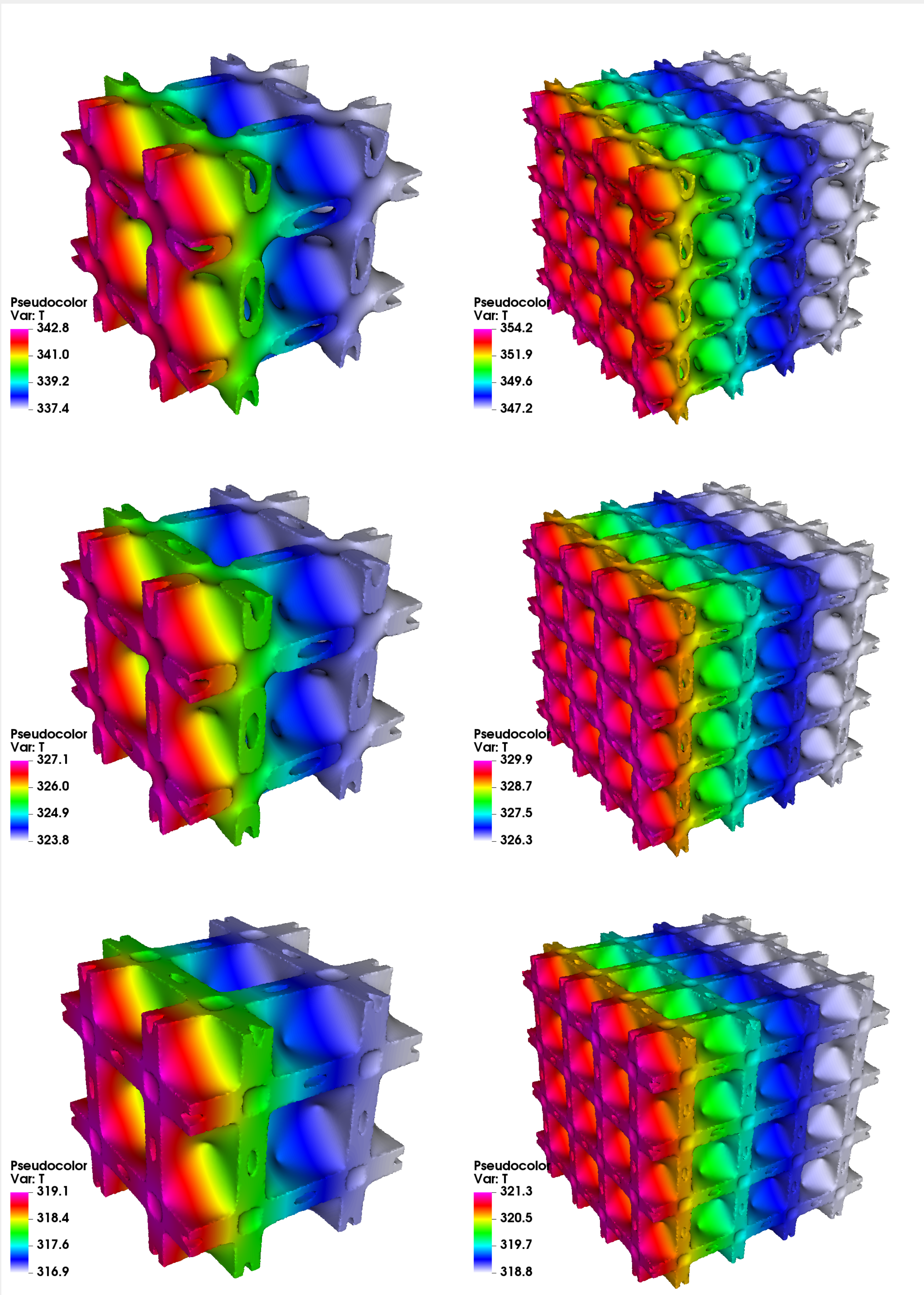

Figure: Temperature field in Neovius structures after 100 [s]. Left column: Neovius - 2 cells, right column: Neovius 4 cells. From top to bottom: relative thickness δ 0.1, 0.15, 0.2.