III International Scientific Conference “Sustainable and efficient use of energy, water and natural resources – SEWAN-2021”

EVALUATION OF THE POSSIBILITY AND RANGE OF INCREASING THE THERMOPHYSICAL PROPERTIES OF COMPOSITES PARAFFIN + HIGHLY THERMAL CONDUCTIVE FILLERS

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Saint-Petersburg, April 19-24, 2021

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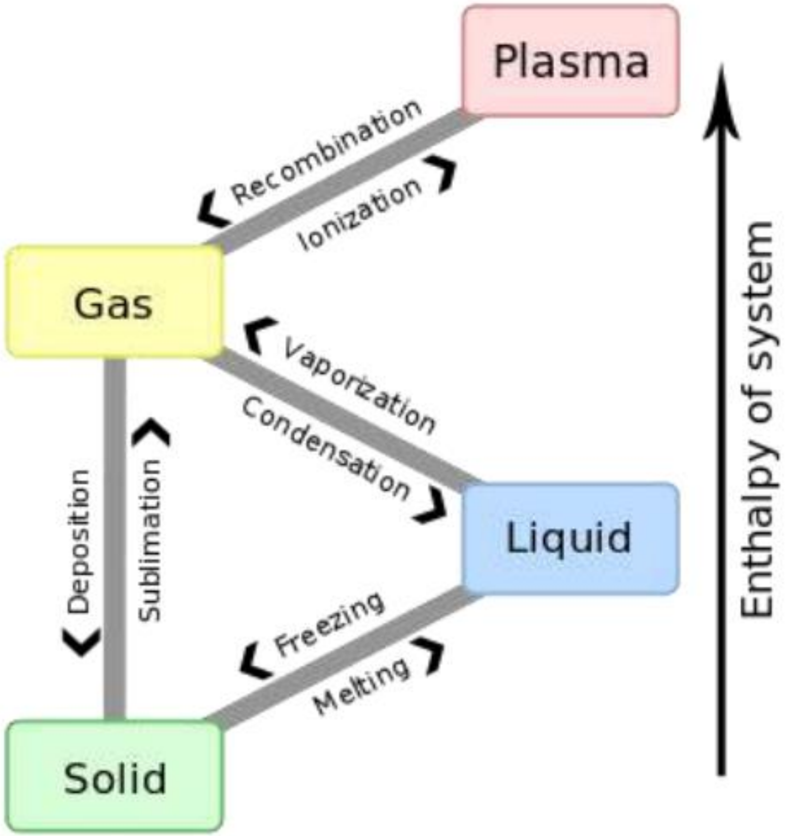
Affiliations: **ITMO University**

Keywords: inhomogeneous systems with phase transitions, thermophysical properties, heat capacity, thermal conductivity,

Research Objective:

The purpose of the work is to evaluate the possibility and potential range of increasing the thermophysical properties of composite materials with phase transitions - paraffin + high-thermal conductivity fillers, which will be promising for use in thermal energy storage systems.

Shopping center Aquarelle, Volgograd
Energy center using cold accumulators



Latent heat storage is the use of a storage material that undergoes a phase change as it stores and releases energy

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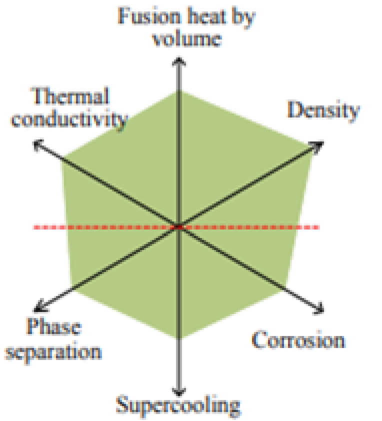
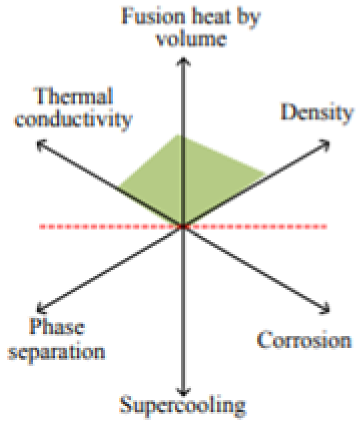
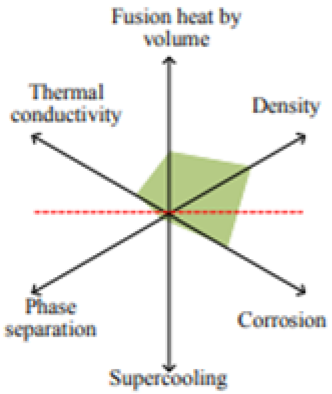


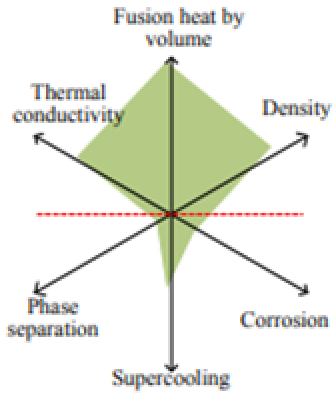
Salt hydrates and eutectics



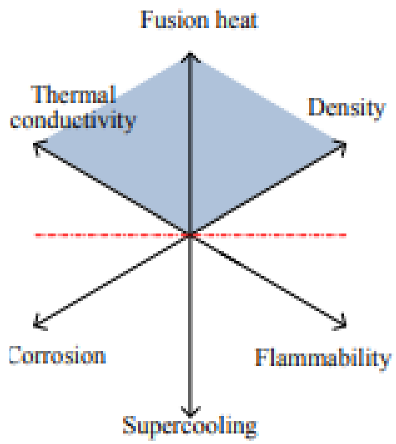
Paraffin waxes



Fatty acids



Refrigerant hydrates

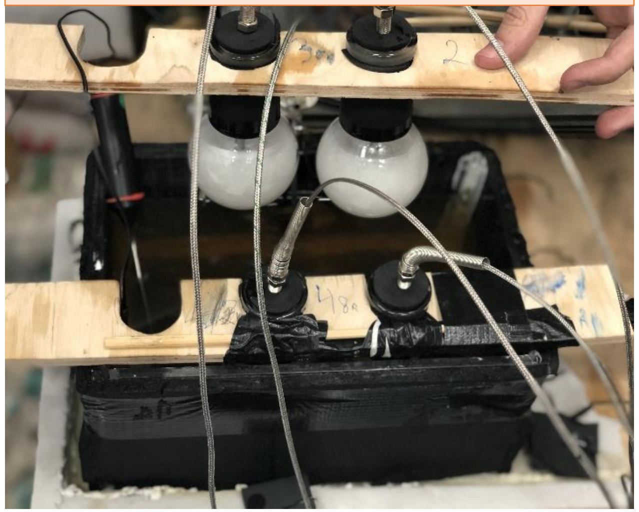


Ideal properties [1]

Paraffin wax…

… is a soft colorless solid derived from petroleum, coal or oil shale that consists of a mixture of hydrocarbon molecules $C_{18}H_{38} – C_{35}H_{72}$

Experimental stand



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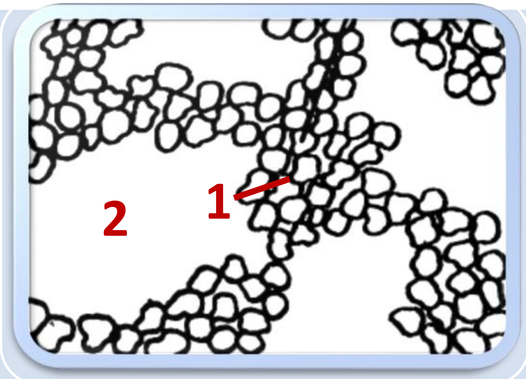
Structures and models of a heterogeneous system - paraffin with highly thermal conductive fillers [3]

$$a_{ef} = \frac{\lambda_{ef}}{c_{ef}, \rho_{ef}}$$

$a_{ef}, \lambda_{ef}, c_{ef}, \rho_{ef}$ – thermophysical properties of the filled matrix (thermal diffusivity, thermal conductivity, heat capacity, density)

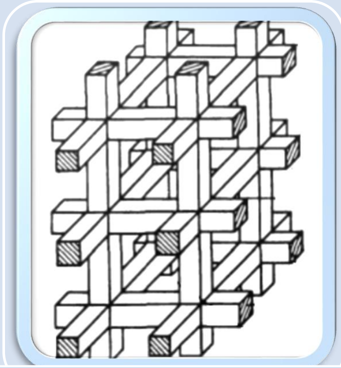
Structure with non-contacting inclusions

1 – binder (paraffin)
2 – inclusions



Frame with contacting particles and a net of large pores penetrating it

1 – structural frame with contacting parts
2 – large pores



Structure with interpenetrating components

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Structure with non-contacting inclusions

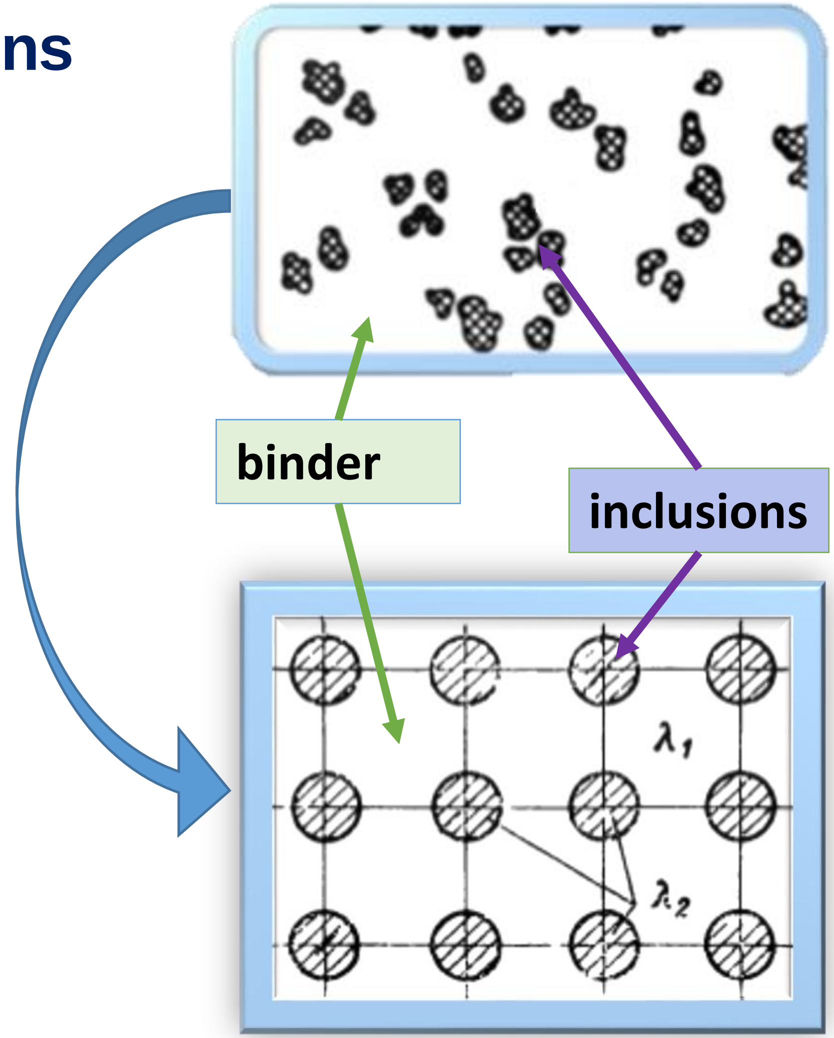
Formula V.I. Odelevsky [2]:

$$\frac{\lambda_{ef}}{\lambda_1} = 1 - \frac{V_2}{\frac{1}{1-\lambda_r} - \frac{1-V_2}{3}}, \quad \lambda_r = \frac{\lambda_2}{\lambda_1}$$

V_2 - volume fraction of aluminum

λ_1 - thermal conductivity of paraffin

λ_2 - thermal conductivity of aluminum



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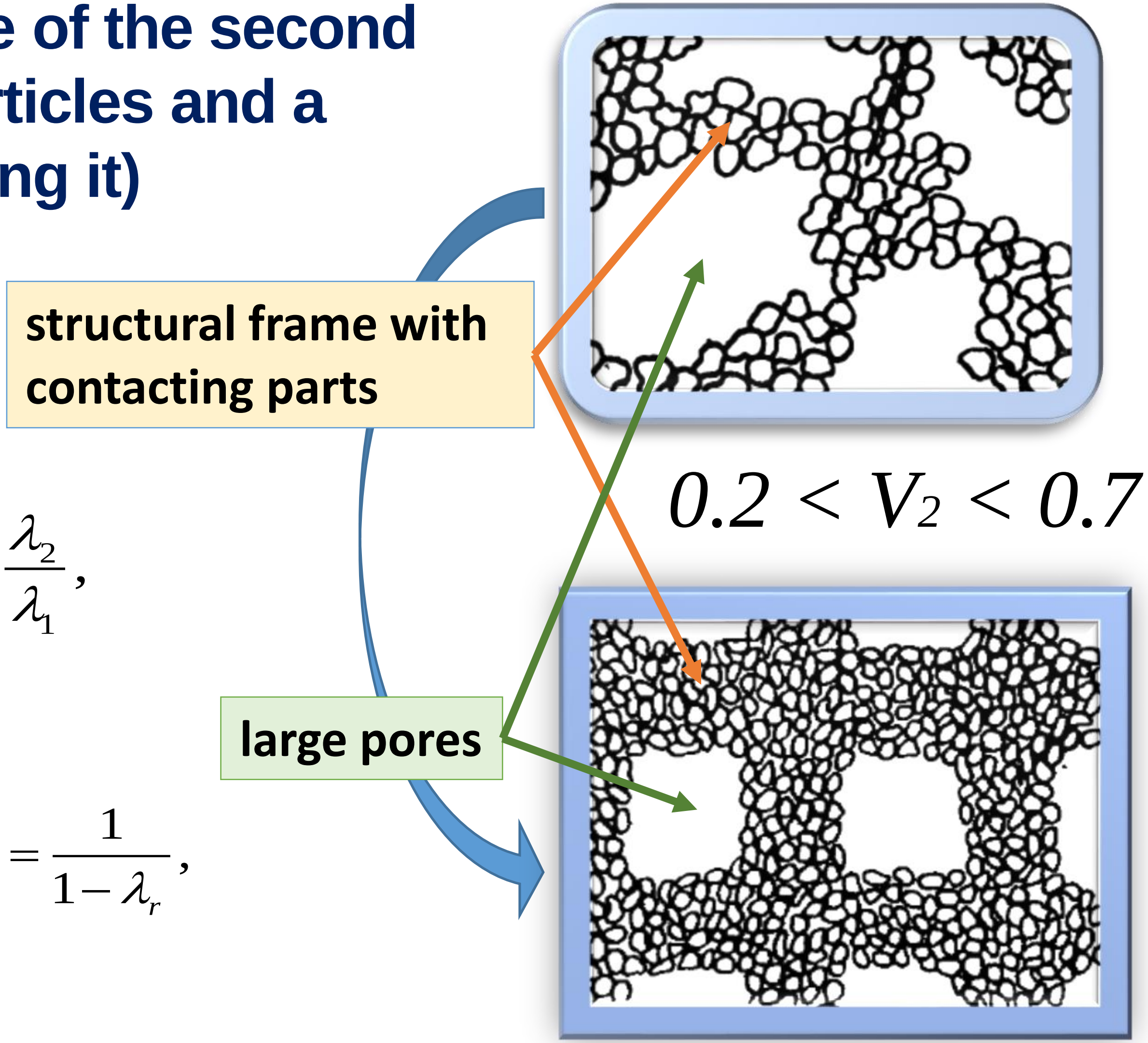
A granular system as a structure of the second order (frame with contacting particles and a network of large pores penetrating it)

Thermal conductivity of the frame with dense packing of contacting particles [2]:

$$\lambda_c = \frac{\lambda_1}{y_4^2}\left[\frac{2\lambda_r}{1-\lambda_r}\cdot D + \lambda_r\left(y_4^2 - y_3^2\right)\right], \qquad \lambda_r = \frac{\lambda_2}{\lambda_1},$$

$$D = \sqrt{1-y_3^2} - 1 + F\ln\frac{F-\sqrt{1-y_3^2}}{F-1},$$

$$y_3 = \frac{r_3}{r} = \frac{2\sqrt{N_c - 1}}{N_c}, \quad y_4 = \frac{r_4}{r} = \frac{y_3}{\sqrt{1-V_{2c}}}, \quad F = \frac{1}{1-\lambda_r},$$



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A granular system as a structure of the second order (frame with contacting particles and a network of large pores penetrating it)

$$\frac{\lambda_{ef}}{\lambda_c} = C_c^2 + (1-C_c)^2 \lambda_{rc} + \frac{2\lambda_{rc} C_c (1-C_c)}{(\lambda_{rc} C_c + 1 - C_c)}, \quad \lambda_{rc} = \frac{\lambda_{22}}{\lambda_c}$$

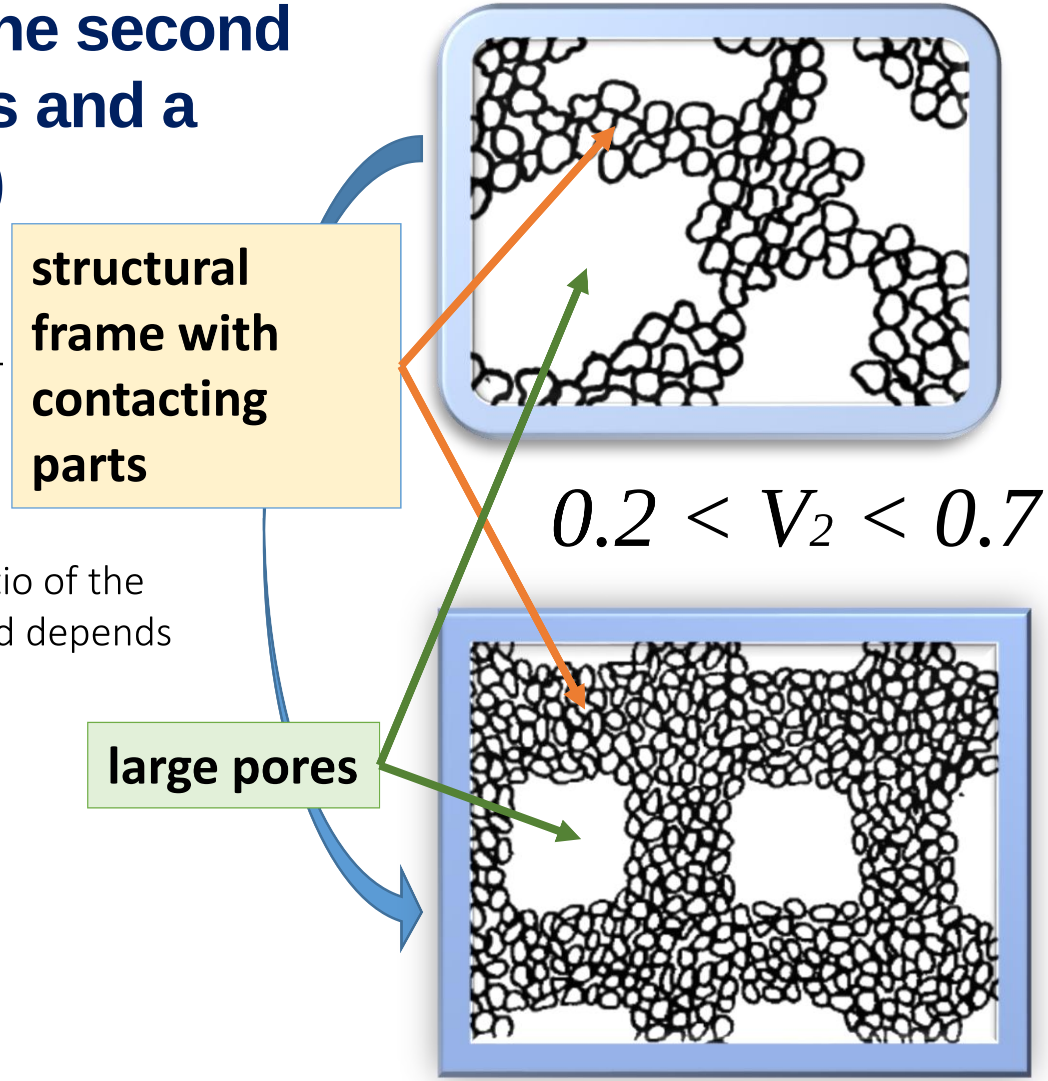
λ_{22} - large pore conductivity

C_c - characterizes the dimensional parameters (the ratio of the thickness of the bar to the size of the unit cell) and depends on the porosity of the second-order structure V_{22}

$$C_c = 0,5 + A\cos\frac{\alpha}{3}, \quad 270^0 \le \alpha \le 360^0,$$

$$0 \le V_{22} \le 0,5 \quad A = -1, \quad \alpha = \arccos(1 - 2V_{22}),$$

$$0,5 < V_{22} \le 1 \quad A = 1, \quad \alpha = \arccos(2V_{22} - 1),$$



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Structure with interpenetrating components

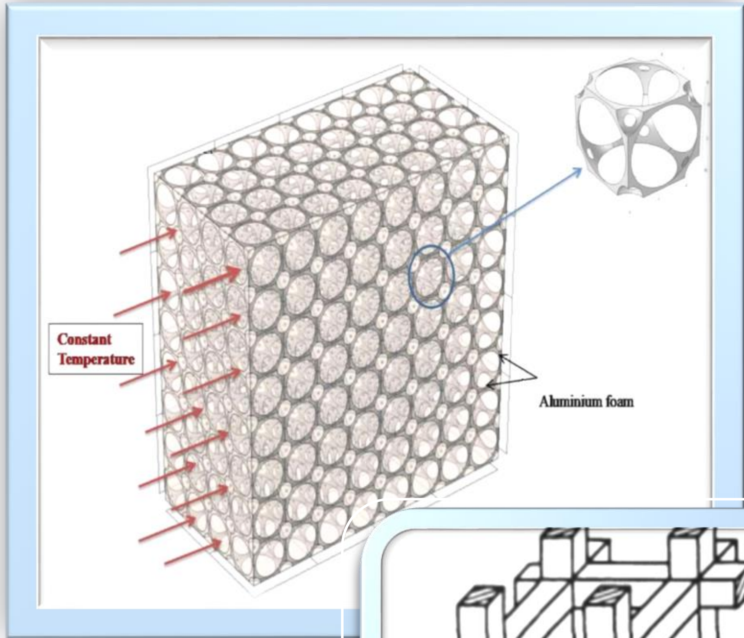
$$\frac{\lambda_{ef}}{\lambda_1} = C^2 + (1-C)^2\lambda_r + \frac{2\lambda_r C(1-C)}{(\lambda_r C + 1 - C)}, \qquad \lambda_r = \frac{\lambda_2}{\lambda_1}$$

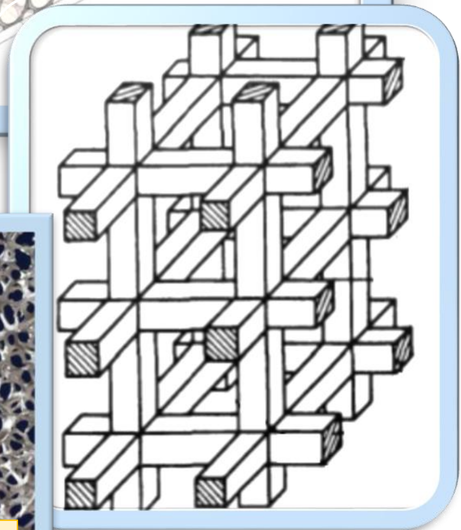
C - characterizes the dimensional parameters (the ratio of the thickness of the bar to the size of the unit cell) and depends on the porosity of the filler

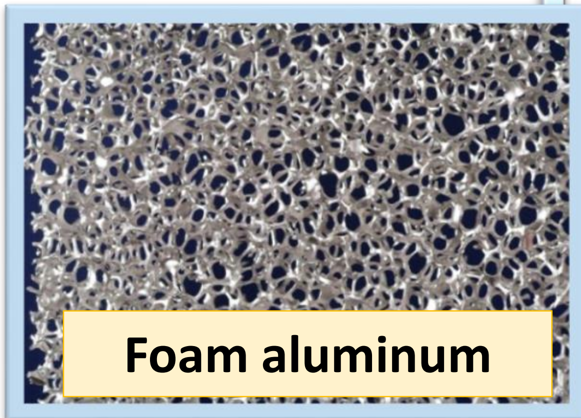
$$C = 0,5 + A\cos\frac{\alpha}{3}, \quad 270^0 \le \alpha \le 360^0,$$

$$0 \le V_{22} \le 0,5 \qquad A = -1, \quad \alpha = \arccos(1 - 2V_{22}),$$

$$0,5 < V_{22} \le 1 \qquad A = 1, \quad \alpha = \arccos(2V_{22} - 1),$$







Foam aluminum

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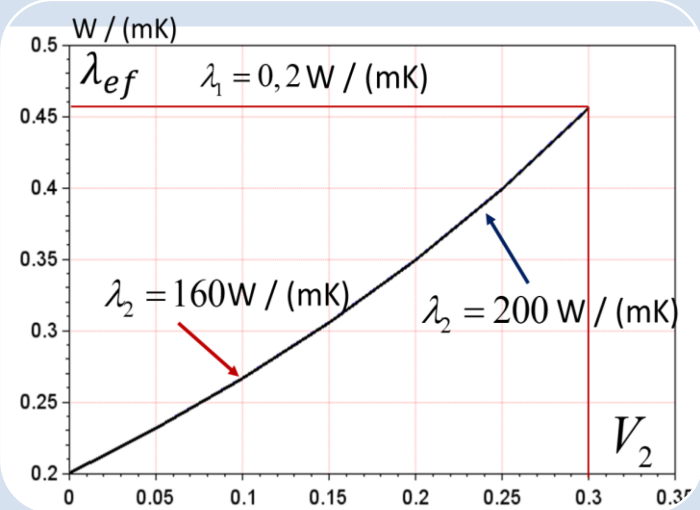
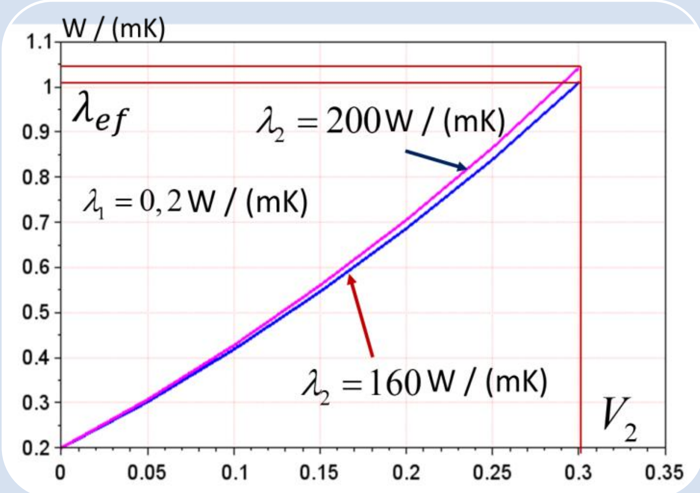
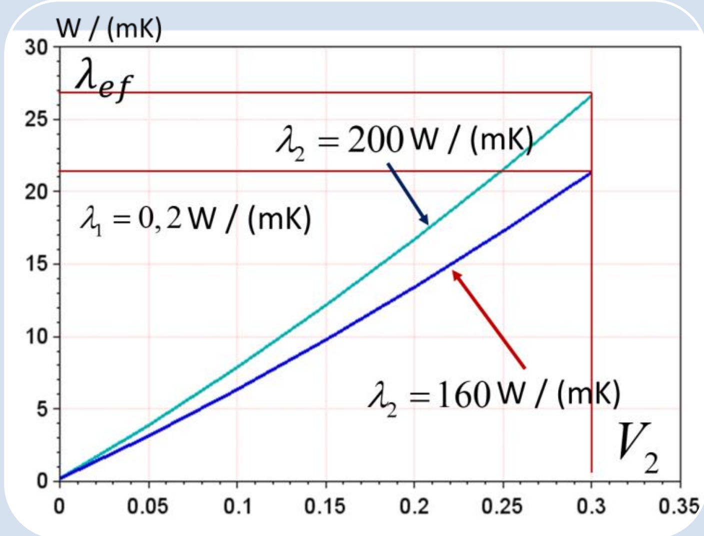
Results



Structure with non-contacting inclusions



Frame with contacting particles and a net of large pores penetrating it



Structure with interpenetrating components

V_2 - volume fraction of aluminum

λ_1 - thermal conductivity of paraffin

λ_2 - thermal conductivity of aluminum

λ_{ef} - effective thermal conductivity

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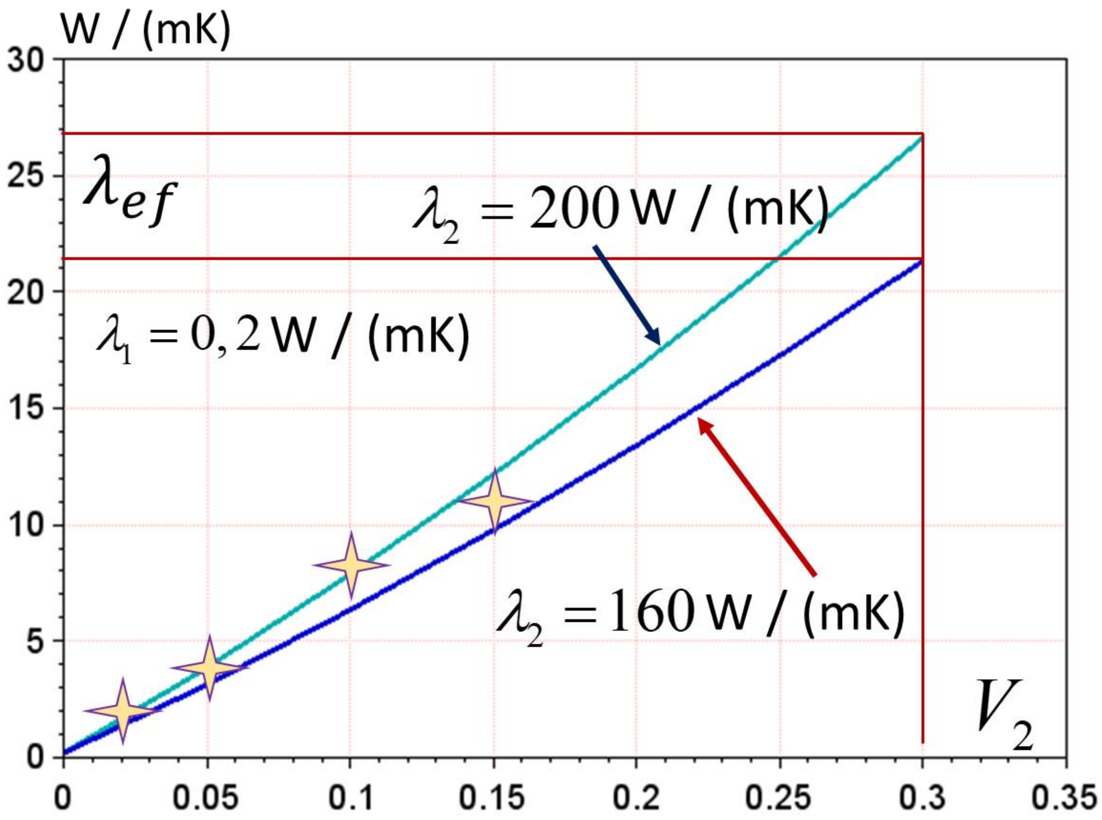
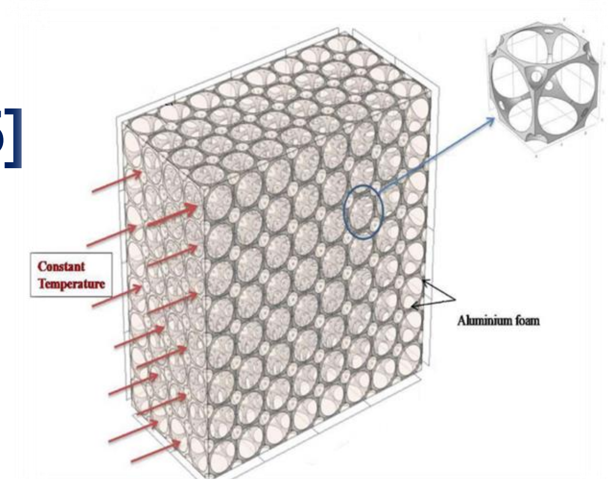
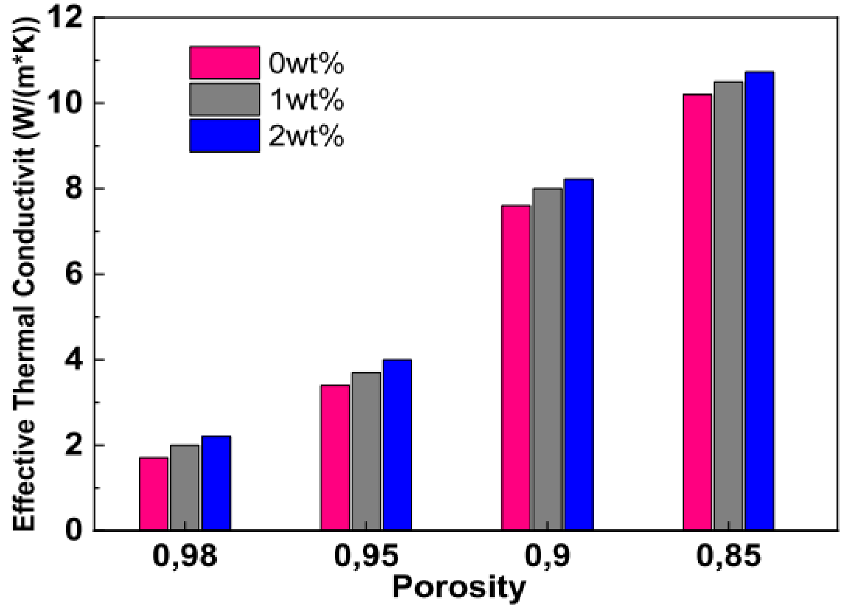
Results
Structure with interpenetrating components [4, 5]







✦ numerical solution for calculating conductivity

V_2 - volume fraction of aluminum

λ_1 - thermal conductivity of paraffin

λ_2 - thermal conductivity of aluminum

λ_{ef} - effective thermal conductivity

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Conclusions

- The results of analytical and numerical estimates of the effective thermal conductivity of a composite material paraffin + high-thermal conductivity filler are compared on various models of its structure. The results of calculations showed that in structures with interpenetrating components, the thermal conductivity of the filler has a much stronger effect on the effective thermal conductivity of the composite.
- The scale of a possible increase in the effective thermal conductivity of the composite in the range of variation of the volume fraction of the highly heat-conducting filler from units to tens of percent is estimated.

The considered models of composite structures and calculation methods can be used to assess the effective thermal conductivity of compositions even at the design stage of promising compositions with phase transitions, reducing the time and money spent on planning and conducting experiments.

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Thank you for your attention!

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