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

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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.

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

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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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Research Objective:

Paraffin wax…

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

Ideal properties

[1]
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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

Keywords: inhomogeneous systems with phase transitions, thermophysical properties, heat capacity, thermal conductivity, thermal diffusivity
Structure with non-contacting inclusions

Formula V.I. Odelevsky [2]:

\[
\frac{\lambda_{ef}}{\lambda_1} = 1 - \frac{V_2}{1 - \lambda_1} \left( 1 - \frac{1 - V_2}{1 - \lambda_r} \right), \quad \lambda_r = \frac{\lambda_2}{\lambda_1}
\]

- \(V_2\) - volume fraction of aluminum
- \(\lambda_1\) - thermal conductivity of paraffin
- \(\lambda_2\) - thermal conductivity of aluminum

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

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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]:

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

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

$$y_3 = \frac{r_3}{r} = \frac{2\sqrt{N_c - 1}}{N_c}, \quad y_4 = \frac{r_4}{r} = \frac{y_3}{\sqrt{1 - V_{2c}}}, \quad F = \frac{1}{1 - \lambda_r},$$
A granular system as a structure of the second order (frame with contacting particles and a network of large pores penetrating it)

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

- \(\lambda_{22}\) - large pore conductivity
- \(C_c\) - charactersizes 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 \(V_{22}\)

\[
C_c = 0.5 + A \cos \frac{\alpha}{3}, \quad 270^0 \leq \alpha \leq 360^0,
\]

\[
0 \leq V_{22} \leq 0.5 \quad A = -1, \quad \alpha = \arccos(1 - 2V_{22}),
\]

\[
0.5 < V_{22} \leq 1 \quad A = 1, \quad \alpha = \arccos(2V_{22} - 1),
\]
Structure with interpenetrating components

\[
\frac{\lambda_{ef}}{\lambda_1} = C^2 + (1 - C)^2 \lambda_r + \frac{2 \lambda_r C (1 - C)}{(\lambda_r C + 1 - C)}, \quad \lambda_r = \frac{\lambda_2}{\lambda_1}
\]

\(C\) - 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

\(C = 0.5 + A \cos \frac{\alpha}{3}, \quad 270^0 \leq \alpha \leq 360^0,\)

\(0 \leq V_{22} \leq 0.5 \quad A = -1, \quad \alpha = \arccos(1 - 2V_{22}),\)

\(0.5 < V_{22} \leq 1 \quad A = 1, \quad \alpha = \arccos(2V_{22} - 1),\)
Results

Structure with non-contacting inclusions

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

Structure with interpenetrating components

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

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\[ V_2 - \text{volume fraction of aluminum} \]

\[ \lambda_1 - \text{thermal conductivity of paraffin} \]

\[ \lambda_2 - \text{thermal conductivity of aluminum} \]

\[ \lambda_{ef} - \text{effective thermal conductivity} \]
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Results
Structure with interpenetrating components [4, 5]

\[ \lambda_{ef} \]
\[ \lambda_2 = 200 \, \text{W} / (\text{mK}) \]
\[ \lambda_1 = 0.2 \, \text{W} / (\text{mK}) \]
\[ \lambda_2 = 160 \, \text{W} / (\text{mK}) \]

Effective Thermal Conductivity (W/(m*K))

- \( V_2 \) - volume fraction of aluminum
- \( \lambda_1 \) - thermal conductivity of paraffin
- \( \lambda_2 \) - thermal conductivity of aluminum
- \( \lambda_{ef} \) - effective thermal conductivity

Numerical solution for calculating conductivity
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.

References

Thank you for your attention!

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