RECEIVER EFFICIENCY AS A DETERMINING CRITERION FOR THE EFFECTIVENESS OF A SOLAR TOWER

Conference paper

Cheilytko Andrii, Institute for Solar Research, November 2022

The efficiency of an open receiver as the efficiency of its elements

$$\eta_{rec}^{air} = \eta_{sp} \cdot \eta_{abs} \cdot \eta_{rad} \cdot \eta_{conv} \cdot \eta_{cond}$$

- η_{sp} is efficiencies based on receiver spillage, the unused radiation hitting the sections around the receiver aperture;
- η_{abs} is efficiencies based on receiver absorption;
- η_{rad} is efficiencies based on receiver radiation;
- η_{conv} is efficiencies based on receiver convection;
- η_{cond} is efficiencies based on receiver conduction.

Complex indicators of porous structure

- Porosity - P, %. Porosity as a general indicator of the density of thermal insulation material and thermal protection structures.
- Number of pores - n, pcs/m3. The number of pores for a homogeneous structure in combination with porosity give a general idea of the distribution of pores in the material. The change in the number of pores in time during the formation of the porous structure of heat-insulating materials expresses the dynamics of the pore formation process.
- The location of the pores in space is described by the Brave translation system (Brave lattice), in which the pore is the core of the lattice with dimensions smaller than the Wigner-Seitz cell, or the statistical distribution of pores over the volume of the insulating material.
- The pore shape is a spatial coordinate function describing the shape of the pore. It is possible to accept the description of all pores as spheres with a description of the deformation inherent in this sphere, according to the Poincaré hypothesis, or the overall dimensions of the pore, or the general coefficient of geometric characteristics of the porous structure.
- Indicators of the gas state in the pores are the temperature gradient on which convection in the pores and the physical properties of the coolant in the pore depend. It can also be represented by the product of Grasgoff number and Prandtl number
- Specific surface area porosity .

When forming the porous structure of thermal insulation materials from a raw material mixture, it is necessary to take into account the thermodynamic conditions of pore formation and the composition of the raw material mixture. Therefore, it is necessary to introduce a generalizing indicator for such materials K_0.

Problem statement

- In the porous media the heat transfer is modeled using the transient energy equation

$$\rho_s (c_p)_s \frac{\partial T_s}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda_{ef} \frac{\partial T}{\partial x}\right) - \alpha A_v (T_s - T_f) + q_{source}$$

- q_{source} – thermal energy of heat sources. It may consist of radiation energy, heat of chemical reactions, heat consumption for melting and evaporation, etc. In the case under consideration $q_{source} = q_{rad}$.

- It is interesting that the energy equation for the porous material frame which is considered as a macrostructure in the numerical solution method can be written as follows

$$\rho_s (c_p)_s \frac{\partial T_s}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda_s \frac{\partial T}{\partial x}\right) - \alpha A_v (T_s - T_f) + q_{source}$$

- The energy equation for the fluid phase is defined as

$$\rho_f (c_p)_f \left(\frac{\partial T_f}{\partial \tau} + u T_f\right) = \alpha A_v (T_s - T_f) + q_{source}$$

That is, the energy equation will depend entirely on the method of solution.

With microporous structure

In this case, the thermal conductivity of the gas is calculated by two different dependences:

- -for an optically thin layer

$$\lambda_{f\_ef} = \lambda_{f\_\lambda} + \lambda_{f\_rad} = \frac{\lambda_{f\_\lambda}}{1 + \left(\frac{4\,\gamma}{\gamma+1}\right)\left(\frac{2-a}{a}\right)\left(\frac{Kn}{Pr}\right)} + 4\varepsilon_{pr}\sigma_{SB}T^3\bar{\delta},$$

- - for the optically thick layer

$$\lambda_{f_{ef}} = \lambda_{f_\lambda} + \lambda_{f_{rad}} = \frac{\lambda_{f_\lambda}}{1 + \left(\frac{4\,\gamma}{\gamma+1}\right)\left(\frac{2-a}{a}\right)\left(\frac{Kn}{Pr}\right)} + \frac{16}{3}\frac{n_{pr}}{\sigma_a}\sigma_{SB}T^3 \cdot Y(\varepsilon_s, \tau),$$

- $Y(\varepsilon_s, \tau)$ – function of the influence of optical pore thickness τ and the degree of blackness ε_s,
- n_{pr} – refractive index,
- σ_a – volumetric spectral absorption coefficient,
- σ_{SB} – constant Stefan Boltzmann's,
- $\gamma = Cp/Cv$ – adiabatic index
- a – accommodation coefficient, characterizing the degree of completeness of energy exchange of a gas molecule with a solid material (in [41] is 0.85 for air).
- Kn – Knudens criterion,
- Pr – Prandl's criterion
- $\bar{\delta}$ – average layer thickness.

Mathematical model of heat and mass transfer in a porous absorber

Input parameters of the absorber model:

- Dislocation vector k_y, k_z
- Pore shape and size, d_1,d_2,$d_{3,}$ m
- Number of pores - n, pcs/m^3.
- Thermophysical parameters of absorber material, λ_s, c_{p_s}, ρ_s
- Thermophysical parameters of fluid, λ_f, c_{p_f}, ρ_f
- Optical parameters of the absorber material σ_β
- Optical parameters of the heat carrier σ_{af} , σ_{sf}

Input parameters of the receiver model for constructive calculation

- Geometry sizes: H_x,$H_{y,}$ $H_{z,}$
- Number of module absorber, A_{abs}/A_{rec}
- Shape of the receiver R_{xz}

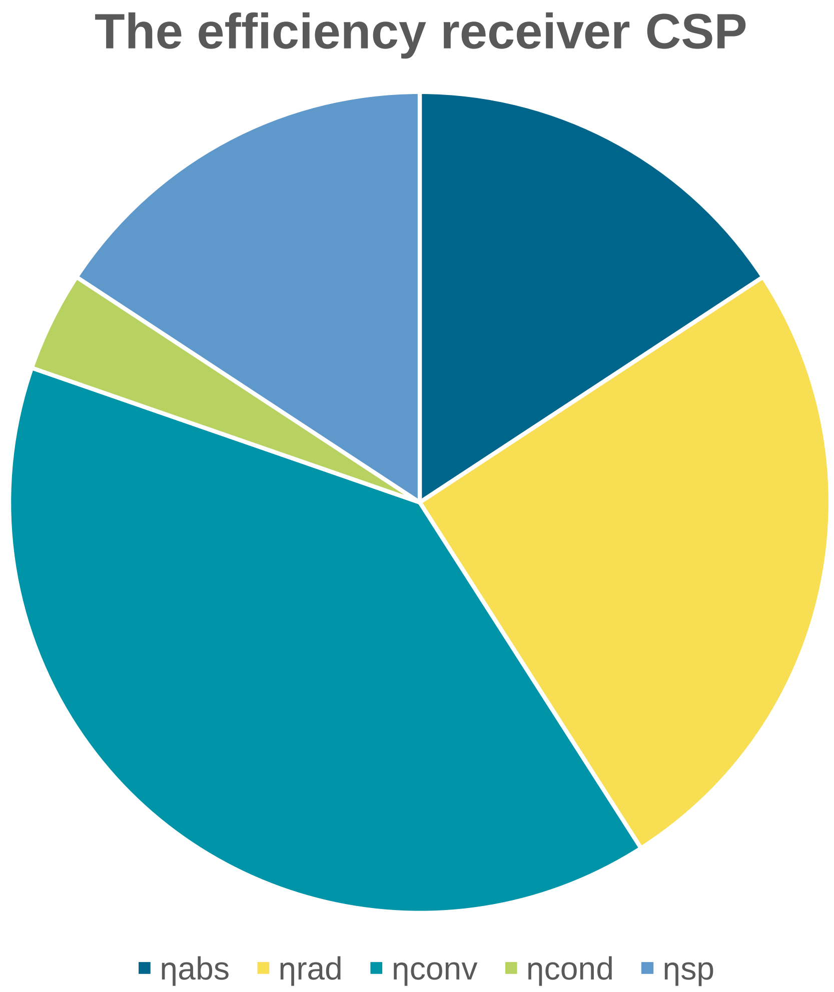
Input parameters of the receiver model for thermal calculation

- Mass flow, $\dot{M}^{air}$ kg/s
- External environment: gradP, T_o
- Air temperature T_{out}^{air}, T_{hot}^{air}

Output parameters of the model:

- efficiencies based on receiver spillage $\eta_{sp}=f(H_x, H_y, H_z, R_{xz})$;
- efficiencies based on receiver absorption $\eta_{abs}= f(d_1, d_2, d_3\ n, \sigma_\beta, R_{xz}, A_{abs}/A_{rec})$;
- efficiencies based on receiver radiation $\eta_{rad}= f(d_1, d_2, d_3, n, \lambda_s, c_{p\_s}, \rho_s, R_{xz}, A_{abs}/A_{rec}, M)$;
- efficiencies based on receiver convection $\eta_{conv}= f(R_{xz}, A_{abs}/A_{rec}, M, H_x, H_y, H_z, gradP, T_{out}^{air})$;
- efficiencies based on receiver conduction $\eta_{cond}= f(H_x, H_y, H_z, gradP, T_o, T_{hot}^{air}, T_{out}^{air})$.

New method for optimization



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