E CONF SERIES

International Conference on Scientific Research in Natural and Social Sciences
Hosted online from New York, USA
Website: econfseries.com 2nd October, 2025

MODELING THE SYNTHESIS PROCESS OF BI–PB–SR–CA–CU–O SYSTEM-BASED HIGH-TEMPERATURE SUPERCONDUCTORS UNDER CONCENTRATED SOLAR IRRADIATION

E. B. Eshonkulov
[1]Materials Science Institute, Academy of Science,
Republic of Uzbekistan, Tashkent, Uzbekistan
e-mail: elyoreshonkulov94@mail.ru

The implementation of high-temperature synthesis processes through solar energy concentration is considered a highly efficient and environmentally friendly method. Proper selection of the optical–energetic parameters of the Large Solar Furnace (LSF) system prevents excessive overheating of the material and enables the production of high-temperature superconducting (HTS) materials with the required electrophysical properties [1]. Through the modeling process, it becomes possible to account for and minimize radiation losses, reduce experimental costs, and enhance the efficiency of synthesis [2].

The main objective of this research is to optimize and model the optical–energetic parameters of the LSF during the synthesis of high-temperature superconducting materials with the composition $Bi_{1,7}Pb_{0,3}Sr_2Ca_{(n-1)}Cu_nO_y$ (n=9-20), in order to ensure superior electrophysical characteristics of the target material.

The synthesis process of superconducting materials with the composition $Bi_{1,7}Pb_{0,3}Sr_2Ca_{(n-1)}Cu_nO_y$ (n=9-20) using solar energy depends on a number of physico-thermodynamic factors. To achieve a comprehensive understanding and evaluation of the process, an accurate mathematical model was developed. This model describes the phase transformation state resulting from the input of energy through the material surface, its distribution, and the associated temperature variations.

The model is based primarily on the first law of thermodynamics. It is applied to evaluate heating, melting, and energy losses in the material. Radiative and convective losses are determined using the Stefan–Boltzmann law and Newton's law of cooling, respectively. The main driving force of the synthesis process is the energy supplied to the material via solar irradiation. As the temperature of the

material increases over time, melting begins at a certain critical point. This process is expressed through the following energy balance equation:

$$\frac{dT}{dt} = \frac{Q_{in} - Q_{loss}}{mc_{p,eff}}. \quad (1)$$

where:

- T – temperature of the material (K),
- Q_{in} – incoming energy (W),
- Q_{loss} – total energy losses (W),
- m - (m(T)=ρ(T)V – effective mass dependent on temperature (kg),
- $c_{p,eff}$ – average specific heat capacity (J/kg·K).

Under solar furnace conditions, the portion of irradiation energy absorbed by the material is expressed as:

$$Q_{in} = E_f \cdot S \cdot (1 - R) \quad (2)$$

where E_f – irradiation flux density (W/m²), S – material surface area (m²), and R – reflection coefficient.

Energy losses occur mainly through two mechanisms: convection and radiation. The total losses are given by:

$$Q_{loss} = Q_{conv,air} + Q_{conv,water} + Q_{rad} \quad (3)$$

The melting process occurs within a finite interval. In the energy balance, the phase transformation is taken into account and is expressed using the error function (erf):

$$\beta(T) = \frac{1}{2}\left[\mathrm{erf}\left(\sqrt{2}\gamma z\right) + 1\right] \qquad z = \frac{T - T_m}{\Delta T/2} \quad (4)$$

where β(T) – degree of phase transition, T_m – average melting temperature, ΔT – phase transition interval.

As a control parameter, the minimum energy required for melting is determined by:

$$Q_{req} = m_s c_{p,s}(T_m - T_0) + m_s L, \quad m_s = \rho_s V, \quad (5)$$

Thus, the total energy needed for melting corresponds to the sum of the heat required to raise the temperature from T_0 to T_m and the latent heat necessary for the complete phase transition.

To determine whether the sample has melted completely or nearly completely, the balance between incoming and outgoing heat fluxes is considered. The condition is expressed as:

$$\int_0^{t_m}(Q_{in} - Q_{loss})\,dt \geq Q_{req} \qquad (6)$$

If the melt fraction reaches $\beta \geq 0.99$, i.e., at least 99% of the sample has melted, the sample is regarded as fully molten.

Accordingly, the minimum required solar irradiation flux density (E_f) to achieve complete melting of the sample within the specified time is determined. This optimization problem is described as:

$$\varepsilon(E_f) = \frac{|t_{melt}(E_f) - t^*|}{t^*} \qquad (7)$$

where $t_{melt}(E_f)$ – calculated melting time according to the model, and E_f – solar flux density (W/cm²).

The algorithm for modeling the melting process is depicted in Figure 1 as a block diagram. Python 3.8.12 software was used for the numerical implementation of the model [3]. To assess the accuracy and reliability of the model, the calculated results were compared with experimental data. For comparison, several phase compositions within the Bi–Pb–Sr–Ca–Cu–O system were selected: Bi-2289, Bi-221112, Bi-221415, and Bi-221920.

The radiation flux densities determined by the model (149.69; 175.42; 207.64; 258.03 W/cm²) were compared with the corresponding experimental values (156; 177; 195; 240 W/cm²). The obtained results confirm the reliability of the model. The values

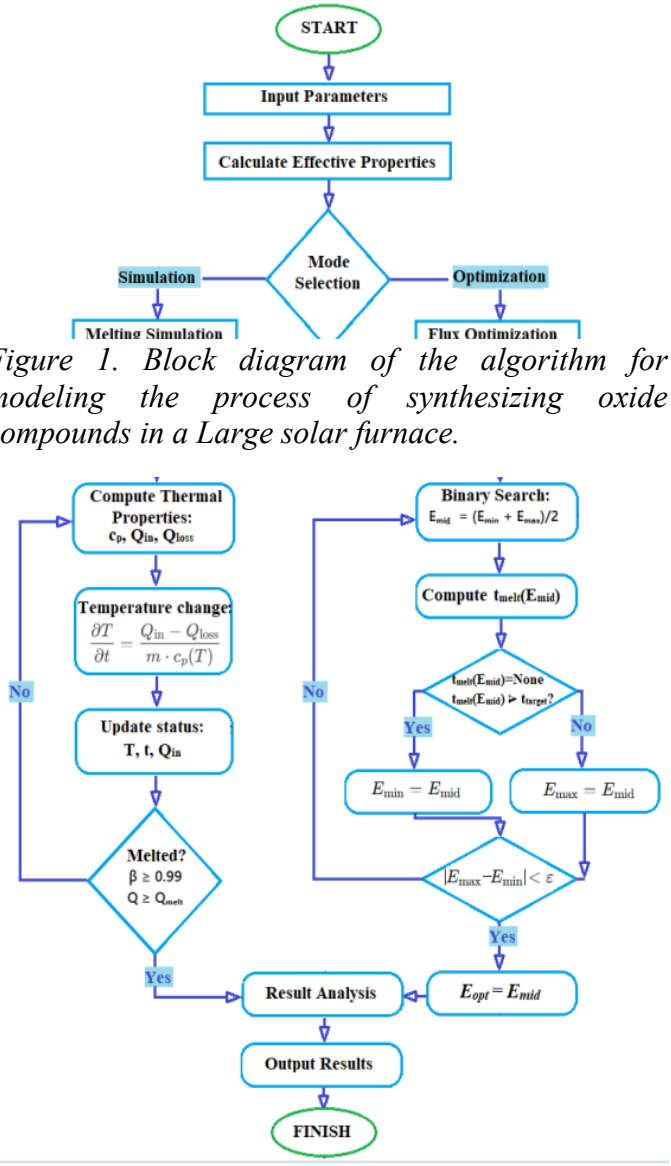

Figure 1. Block diagram of the algorithm for modeling the process of synthesizing oxide compounds in a Large solar furnace.

RMSE ≈ 11.5 W/cm² and R^2 ≈ 0.86 indicate a strong agreement between the mathematical model and the experimental results.

The results demonstrate that the developed mathematical model is highly reliable and suitable for practical application. The model adequately reflects the main experimental trends and ensures high accuracy across different compositions. At the same time, to improve accuracy in higher temperature ranges, it is advisable to recalibrate heat transfer coefficients and incorporate material parameters as temperature-dependent functions.

References

1. Payzullakhanov, M.S., Payziyev, S.D. & Suleymanov, S.K. Modeling of Processes of Heating and Cooling of Materials in a Solar Furnace. Appl. Sol. Energy 55, 404–408 (2019). https://doi.org/10.3103/S0003701X19060082

2. Akbarov, R.Y., Kuchkarov, A.A. Modeling and Calculation of Optical-Geometric Characteristics of a Solar Concentrator with Flat Fresnel Mirrors. Appl. Sol. Energy 54, 183–188 (2018). https://doi.org/10.3103/S0003701X18030027

3. P. Naik and K. Oza, Python with Spyder, no. November. 2019.