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ELECTRIC HEATING IN THERMAL PROCESSING OF GRAIN MATERIALS AS AN ENERGY-EFFICIENT METHOD OF SOLAR ENERGY CONVERSION

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Abstract

The article examines the application of electric heating in thermal processing technologies of grain materials as an energy-efficient method of utilizing electricity generated from renewable sources, particularly solar power plants. An analysis of the energy balance of the grain drying process is conducted, the main equations of heat consumption are presented, and the efficiency coefficients of electrothermal installations are determined. It is shown that electric heating reduces specific energy consumption compared to traditional convective methods. The feasibility of integrating electrothermal installations with photovoltaic systems to improve the energy efficiency of agro-industrial production and reduce CO_2 emissions is substantiated.

Keywords: electric heating, grain thermal processing, drying, energy balance, renewable energy sources.

Introduction

In the structure of energy consumption of agro-industrial production, more than 60% is attributed to thermal processes, including drying, thermal treatment, and cooling of grain raw materials [1]. The rising cost of energy resources and the necessity to reduce anthropogenic environmental impact determine the relevance of transitioning to electrothermal technologies powered by renewable energy sources.

One of the promising directions is the use of electric heating for thermal processing of grain materials integrated with photovoltaic systems.

Theoretical Foundations of the Energy Balance

The overall energy balance of the grain drying or thermal processing process is determined by the following equation [2]:

$$Q_{sup} = Q_{heat} + Q_{evap} + Q_{loss} \quad ; \tag{1}$$

where, Q_{sup}– heat supplied to the material; Q_{heat}– heat required for direct heating of the grain mass; Q_{evap}– heat required for moisture evaporation; Q_{loss}– heat losses to the environment.

Heat required for grain heating:

$$Q_{heat} = m \cdot C \cdot \frac{d\theta}{d\tau}; \tag{2}$$

where, C– specific heat capacity of grain, J/°C; m– grain mass, kg;
θ– grain temperature, °C.

Heat required for moisture evaporation:

$$Q_{evap} = -m \cdot r_0 \cdot \frac{dU}{d\tau}; \tag{3}$$

where, r_0– latent heat of vaporization of water, J/kg; U– moisture content of the material, kg/kg.

Heat losses by convection. The heat flux $q_0$transferred by convection from the grain to the surrounding air is determined by:

$$Q_{loss} = \alpha f(\theta - t_a); \tag{4}$$

where, α– heat transfer coefficient, W/m²·°C; t_a– ambient air temperature, °C;
f– grain surface area, m².

In traditional convective dryers, heat losses with the exhaust drying agent may reach up to 40% of the total supplied energy. In electric heating systems, especially with volumetric energy supply (induction and microwave heating), losses are significantly reduced due to the dependence of the heat transfer coefficient on the velocity of the drying agent flowing around the grain. In electric heating systems, heat exchange between the material and the surrounding air occurs mainly under natural convection conditions.

Efficiency of Electrothermal Installations. The efficiency (coefficient of performance) of electrothermal installations is defined as:

$$\eta = \frac{Q_{useful}}{Q_{el}}; \tag{5}$$

where,

$$Q_{useful} = Q_{heat} + Q_{evap}; \tag{6}$$

The electrical energy supplied to the installation is:

$$Q_{el} = P \cdot \tau; \tag{7}$$

where, P– electrical power of the installation, W; τ– operating time, s.

Typical efficiency values are:

- Direct electric heating: 0.90–0.95;
- Induction heating: 0.85–0.92;
- Microwave (MW) heating: 0.70–0.85;
- Convective dryers: 0.55–0.70.

Specific energy consumption for drying 1 kg of evaporated moisture is:

- 4.0–5.5 MJ/kg – convective method;
- 3.2–3.8 MJ/kg – electrothermal method;
- 2.9–3.2 MJ/kg – microwave heating.

Solar Energy Conversion in Electrothermal Processes. The conversion of solar energy in electrothermal processes can be represented as:

$$E_{solar} \rightarrow E_{el} \rightarrow Q_{useful}; \tag{8}$$

where, E_{solar}– solar irradiance incident on photovoltaic panels; E_{el}– electrical energy consumed by electrothermal equipment.

The overall efficiency of the photovoltaic system and electrothermal installation is:

$$\eta_{system} = \eta_{PV} \cdot \eta_{el} \cdot \eta_{therm}; \tag{9}$$

where, $\eta_{PV} = 0.18–0.23$– efficiency of photovoltaic panels; $\eta_{el} = 0.94–0.97$– efficiency of electrical equipment; $\eta_{therm} = 0.85–0.95$– efficiency of the electrothermal installation.

The total system efficiency is 0.14–0.21, which is acceptable considering the absence of conventional fuel consumption and the reduction of CO_2 emissions.

Conclusions.

Electric heating in grain thermal processing technologies is an effective tool for improving the energy efficiency of agro-industrial production. The use of photovoltaic systems to power electrothermal installations reduces specific energy consumption, increases process efficiency, and ensures environmental safety of production. The integration of electric heating with solar generation represents a promising direction for modernization of agricultural technologies.

References

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