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CONTROLLED TWO-SIDED CONVECTIVE-BEAM GRAIN DRYING SYSTEM

Abstract. The system works on the principle of "layer-by-layer": intense short warm-ups on both sides alternate with pauses of thermal equilibrium and blowing, which reduces temperature and humidity unevenness in the grain thickness. For feedback, radiofrequency (dielectric) estimation of flow humidity and infrared non-contact surface temperature measurement are used. The logic of mode control, the selection of sensors and safety requirements are described. Comparative analysis shows a reduction in drying time and specific energy consumption compared to traditional convection, while reducing the risk of cracking and overheating. The practical aspects of integrating the system into small-sized and modular post-assembly lines are considered. The compliance of the approach with modern trends in intelligent drying control is shown.

Key words: energy efficiency, intelligent control, radio frequency dielectric diagnostics, infrared emitters, simulation of heat and mass transfer.

Introduction. Stabilization of grain moisture to values safe for storage remains one of the most resource-intensive agricultural processing operations. Classic convective drying provides reliable quality, but is often inferior in speed and specific energy consumption to hybrid methods where heat supply is combined (hot air + infrared radiation, etc.). Modern reviews [1-5] confirm that the combination of volumetric and surface heating speeds up moisture removal and improves process uniformity.

At the same time, the practical implementation of such solutions faces problems [1]: uneven temperature fields, risks of local overheating, lack of prompt, reliable assessment of humidity in the flow, and lack of adaptive control. A new wave of research offers intelligent systems with multidimensional data logging and real-time correction.

The purpose of the article is to substantiate and describe the system of controlled two-sided convection-beam drying with dielectric humidity control and IR pyrometry of surface temperature, to determine the requirements for sensors and algorithms, as well as to show the expected advantages in terms of speed, uniformity and energy consumption compared to basic convection. For this purpose, an analysis of the literature was performed, a functional scheme and a set of evaluation criteria were formed, control logic and typical settings were proposed.

The installation consists of a transport channel with a pseudo-layer or thin bulk of grain, two oppositely placed IR modules (top/bottom) with sectional power regulation, a ventilation circuit with heating and recirculation, a humidity measurement unit (RF dielectric probe in the channel wall or above the conveyor) and IR pyrometers or thermal chambers for surface temperature. The control system realizes alternation of short pulses of IR heating with blowing and "equalizing pauses".

The principle of two-way energy supply is as follows. Two-sided IR heating reduces the depth of the temperature gradient and accelerates the release of moisture to the surface, while controlled convection effectively removes evaporation. Compared to one-sided irradiation [2], this reduces the uneven heating, the risk of local overheating and the appearance of cracks. 1.

Table 1. Qualitative comparison of drying approaches for a batch of one crop

Approach	Cycle Duration	Specific energy consumption	Humidity uniformity	Risk of overheating
Convection (hot air)	medium / high	medium / high	Average	Low / medium
IR + convection (unilaterally)	Average	Average	Average	medium
IR (bilateral) + convection	low / medium	low / medium	High	low

Feedback on humidity and temperature is carried out as follows: humidity in the flow is estimated by the dielectric properties of the grain (radio frequency or microwave methods), sensitive to water content, the surface temperature is non-contact controlled by IR pyrometers. Such approaches provide efficiency and are suitable for closed control of air flow, conveyor speed and power of IR sections [3].

The logic of managing modes is based on a number of strategies. Thus, the basic strategy: a pulse of IR heating from above + below (5–20 s) to the maximum surface temperature; blowing and "resting" to equalize the temperature and diffuse moisture; estimation of the humidity trend; auto-correction of section power and air flow. To prevent overheating, restrictions on the maximum temperature of the shell, high-speed interlocks of fans and control of "hot spots" are used.

Due to the combination of surface and convective heat transfer, a reduction in drying time and specific energy is expected, which is consistent with the results for combined methods in cereals (hot air + IR; hot air + microwave/IR). Additionally, intelligent algorithms (adaptive or model-predictive) reduce the influence of variability in input humidity and fractional composition [4].

Dielectric humidity sensors, at the same time, need to be calibrated for the crop, bulk density range and temperature. IR pyrometers are used to correct the emissivity of the grain shell and background. Therefore, regular verification according to the laboratory standard of humidity is recommended.

Two-way IR heating allows you to reduce "unproductive" heating of air and metal structures, and recirculation allows you to reuse heat and evaporation. Review publications demonstrate significant energy saving potential for combination dryers with proper flow management [5].

Conclusions. Two-way IR heating in conjunction with controlled convection and dielectric humidity control forms a more uniform field of temperature and moisture, which increases the quality and shortens the drying time. The integration of fast sensors with adaptive control logic allows you to stabilize the process in case of changes in input parameters and reduce specific energy costs. The proposed architecture is consistent with modern trends in "smart" drying and is suitable for modular modernization of existing lines.

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