Designing the infrared drying machines of cylindrical type with an active reflector

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Abstract. The theoretical substantiation for choosing a rational geometry parameter of “irradiator – object” system is presented. Selecting it is crucial for designing infrared drying machines for solid bodies, in the form of two concentric infinitely long bodies, when one body covers the other. Also, the effectiveness validation of this system is presented in practice using a laboratory stand in the form of two cylinders. An infrared flexible membranous electric heater is sprayed and fixed on the walls of cylinders, an optical sensor was installed between them in order to determine the reflection of the radiation flux. Positive results make it possible to obtain recommendations for designing infrared installations to dry solid bodies.

1. Introduction

The energy is understood as the electromagnetic radiation energy when designing infrared drying plants. It goes through the generation stages during the technological process, propagation in space and absorption in volume. The energy of electromagnetic radiation is characterized by various parameters of optical radiation and their distribution (Figure 1).

![Figure 1. The distribution parameters of the optical radiation characteristics.](image-url)

According to the classification of optical electrical technologies presented in the works of scientists from different countries, drying of agricultural products and materials refers to the photophysical action process, in which optical radiation should produce useful heat in order to remove moisture.
The main classification parameters affecting the biological object are the surface density of radiation flux and the spectral distribution of flux energy [3].

Surface irradiation of an object is carried out by one or several radiation sources. Moreover, the most rational geometry parameters of the “irradiator – object” system are selected based on the required irradiation values and its uniform distribution over the object surface.

The selection of such system in the paper is presented in the form of a theoretical justification for the radiant heat transfer of two radiating concentric infinitely long bodies, when one body covers the other. In this case, the object located between these concentric bodies will receive a uniform distribution of electromagnetic radiation energy. This, in turn, is confirmed by the experimental part, where the object located between the concentric bodies will be an optical infrared sensor, which allows registering the radiation flux density.

These studies will provide recommendations for designing infrared drying plants with the most rational geometry parameter of the “irradiator – object” system. Such knowledge will reduce the energy supply and energy consumption of installations for drying solid bodies.

2. Materials and methods

Researchers have always paid much attention to the design of infrared drying plants. The results of such studies are widely presented in the scientific researches of Altukhov I.V., Tsuglenok N.V., Popova V.M., Afonkina V.A. et al. [4-7]. Calculations of drying plants are presented in these studies, in which flat or point IR radiation generators were considered. Optimal solutions were found regarding the placing of heaters relative to raw materials, their number, reflector area, energy supply regulation. Optimal drying conditions were determined according to the type and specificity of the raw material, layer thickness, grinding options for subsequent drying. As a rule, all calculations were aimed at designing drying plants for raw materials with a small structure and small volume that did not change during the drying process, or raw materials that were subjected to preliminary processing like grinding, which made the methods equal. No infrared drying unit was calculated for solid raw materials, which significantly change their volume during the drying process.

Based on the well-known laws of Planck, Wien, Stefan-Boltzmann radiation, the radiation of an elementary area of the body surface into the surrounding space (the hemisphere) is considered (Figure 2) [8].

\[
\frac{d\Omega}{\cos\varphi} = d\Omega_0 = \frac{1}{\pi} C \left( \frac{T}{100} \right)^4 dF d\Omega \cos \varphi
\]

(1)

Here, \(dq_\phi\) is normal radiation, \(\pi\) times less than the radiation in the hemisphere;  
\(d\Omega\) - elementary solid angle;  
\(\varphi\) is the angle between the direction of radiation and the normal to the radiating area.
According to the abovementioned laws, it is possible to obtain the calculated formulas for radiant heat transfer between individual bodies.

Radiant heat transfer between two bodies with infinitely large plane-parallel surfaces with temperatures T1 and T2 (°K) and radiation coefficients C1 and C2 is expressed by the following formula

\[ q_0 = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_s}} \left[ \left( \frac{T_1}{100} \right)^4 - \left( \frac{T_2}{100} \right)^4 \right] \text{[kcal/m}^2\text{h]} \]  

(2)

The expression \( \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_s}} \) is called the reduced coefficient of radiation.

Since \( C_1 = \varepsilon_1 C_S \) and \( C_2 = \varepsilon_2 C_S \), then

\[ C_{re} = \frac{C_S}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \quad \text{or} \quad C_{re} = \varepsilon_{re} C_S. \]

The radiant heat transfer formula has the following form for two concentric infinitely long cylinders having radiant heat transfer surfaces \( F_1 \) and \( F_2 \):

\[ q = \frac{C_F}{\frac{1}{\varepsilon_1} + \frac{F_1}{F_2} \left( \frac{1}{\varepsilon_1} - 1 \right)} \left[ \left( \frac{T_1}{100} \right)^4 - \left( \frac{T_2}{100} \right)^4 \right]; \]

(3)

where \( C_s \) is the radiation coefficient for the black body; \( F_1 \) is the area of the inner cylinder; \( F_2 \) is the area of the outer cylinder; \( \varepsilon_1 \) is the blackness degree of the inner cylinder; \( \varepsilon_2 \) is the blackness degree of the outer cylinder; \( T_1 \) is the surface temperature of the inner cylinder; \( T_2 \) is the surface temperature of the outer cylinder.

This formula can be applied in the case of radiant heat transfer between two bodies, when one body covers the other, and \( F_1 \) should always be a smaller surface.

For designing the infrared drying plants, the expression (3) is true if a flat IR emitter is placed on the walls of the inner and outer cylinders, which could take the form of a cylinder. In this case, the object located between the cylinders will receive a uniform distribution of electromagnetic radiation energy for a given irradiation value from the heater. This will become the most rational geometry parameters of the “irradiator – object” system when designing infrared installations for solid raw materials [9].

Implementing this expression for the design of infrared drying plants became possible with the advent of flexible sprayed membranous infrared electric heaters MEH (Figure 3), developed and patented by scientists of the South Ural State Agrarian University. MEHs are able to create a high energy flux density in the wavelength range from 8 to 9.5 microns and this is the only infrared emitter capable of changing its geometric shape. The blackness degree \( \varepsilon \) is 0.96 for a given electric heater, and this fact allows us to consider it as a completely black body [10, 11].
In order to confirm the effectiveness of the “iradiator – object” system in the form of two cylinders, experiments were carried out to determine the reflection of the radiation flux. A laboratory bench was made, it consists of two cylinders, one of which covers the other (Figure 4). A flexible membranous infrared heater was mounted on the cylinder walls (position 4, Figure 4). The radiation flux was measured using an optical infrared sensor, the principle of which is based on the assessment of the product volt integral sensitivity (position 2, Figure 4) [12]. Subsequently, the obtained indices of integral sensitivity are mathematically converted to a unit of radiation flux density. The sensor was located between the cylinders, and data were recorded on the three sensor positions, position 3 indicates the direction of its sensing element. Positions 4 and 5 show the direction of radiation and reflection of the infrared heater.

The tests were carried out in several stages. The first stage was to measure the integral sensitivity over the three positions of the sensor with the external cylinder turned on and the internal cylinder not working. That is, the internal cylinder was considered as a reflector. At the second stage, the measurements were also made according to the three positions of the sensor, but with the inner cylinder turned on and it was considered as an active reflector. The third stage repeated the scenario of the second, only the bottom and the top with a reflective surface were installed on the laboratory bench (two cylinders), similar to the surface of a flexible membranous infrared electric heater.

3. Results and discussion
According to the results of all test stages, the correlations between the radiation flux density and time are plotted (Figure 5,6,7).
Figure 5. The correlation between the radiation flux density and time. First stage.

Figure 6. The correlation between the radiation flux density and time. Second stage.
Figure 7. The correlation between the radiation flux density and time. Third stage.

It was noted in the researches [7, 10] that an infrared membranous electric heater of the correct rectangular shape is able to create a radiation flux density from 34 to 80 W/m². Taking this range of radiation flux density values as a guideline, the results of the tests can be analyzed.

The first stage, with the inner cylinder turned off and acting as the reflector, the maximum value on the “a” sensor turned out to be 10% higher than the maximum value of the considered range. The location of the “b” sensor turned out to be close to the maximum value of the range. The location of the “c” sensor turned out to be the same as the minimum value of the considered range, but provided that it did not possess radiative energy and only was able to reflect, and not to concentrate considering its bending, and to scatter the rays incident on it. The optical sensor with the small area of the sensitive part of the receiver froze a value included in the range of considered values.

The second stage was conducted using an active reflector with an internal cylinder connected to the electric network, which received the ability to radiate energy in addition to reflectivity. The maximum radiation flux density value turned out to be at the “a” sensor, it was 53% higher than the considered range, and 36% higher than the values of the first stage for this location of the sensor. For the “b” sensor location, the maximum flow was 30% higher than the value of the first stage and 25% higher than the maximum value of the considered range. The maximum effect from the use of an active reflector affected the values at the “b” sensor. It turned out to be 164% higher than the first stage value, and it was 10% higher than the maximum considered range of values.

In the third stage, test results with an active reflector, a bottom and a cover with a reflective surface were obtained. A comparative analysis was carried out with the results obtained during the second stage. The location of the “a” sensor turned out to be maximal and was 30% higher comparing with the second stage. There is an equalization tendency for the location of the “b” and “c” sensors, while an increase in flux density for “b” is by 40% and for “c” by 55% in comparison with the previous testing stage.

4. Conclusion
The obtained practical results fully represent the theoretical justification for selecting the rational geometry parameter of the “irradiator – object” system for designing infrared drying systems for solid bodies in the form of two concentric infinitely long bodies, when one body covers the other. They also allow obtaining design recommendations for infrared drying systems for solid bodies, such as the following:
1) The dryer casing should have the geometric shape of a cylinder of a larger diameter and a cylinder of small diameter placed inside, on the walls of which a flexible sprayed membranous infrared electric heater MEH should be placed. This is the only IR emitter capable of changing its geometric shape, while able to create a high energy flux density, which will be concentrated on the body by the geometric shape of casing.

2) In addition to the reflectivity of the inner cylinder, it is necessary to presume the possibility of its emissivity, thus increasing the efficiency of the radiation flux acting on the solid body located between the cylinders. Also, the concept of an active reflector should be introduced for the first time for a shorter explanation in subsequent studies of infrared installations.

3) The surface of the bottom, cover and all the enclosing parts of the infrared installation of a cylindrical type should be reflective, which will also contribute to the concentration of the radiation flux on the solid body.

4) These studies allow making a slightly different calculation of installed power while designing the infrared drying systems for solid bodies. It will be underestimated in comparison with drying plants analogues of this class. While maintaining the technical capabilities of the dryer, leveling will be carried out due to the proper selection of optical radiation parameters and their propagation.

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