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Additives for a Complex energetic analysis of convective crop drying

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Abstract

An important area of rational energy management is the analysis of the use of available energy sources. Rational management of energy sources is important in connection with the implementation of production technology and the technical and operational quality of the equipment used.

One of the most important ways to reduce energy costs is to improve process efficiency. Analyzing the energy demand for the drying of crops, it can be concluded that some of the motivating factors are increasing the energy consumption, while others act in the direction of decrease.

However nowadays there is not an accepted complex method, which is able to present the real energetic features of convective crop dryers.

The aim of this study is to provide methodological assistance for the complex energy analysis of practical crop drying and the basis for objective process regulation.

Keywords: *drying; energetics; grain; modelling*

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1. Introduction

The diversity of agricultural materials, their complex, dependent on the production site biological structure, variations of material laws makes it very difficult to develop general relationships and design methods. At the present stage of the research practice, the large number of experiments carried out and their in-depth examination have resulted in practical drying [6].

The aim of this study is to provide methodological assistance for the complex energy analysis of practical crop drying and the basis for objective process regulation.

2. Materials and Methods

In drying, the greatest role is played by the equilibrium moisture content, the specific heat capacity, the thermal conductivity and diffusivity, and the density of the raw material [1]. Therefore, depending on the physical properties of the material and parameters of the applied drying technology, the energy demand of the process may vary significantly (Figure 1).

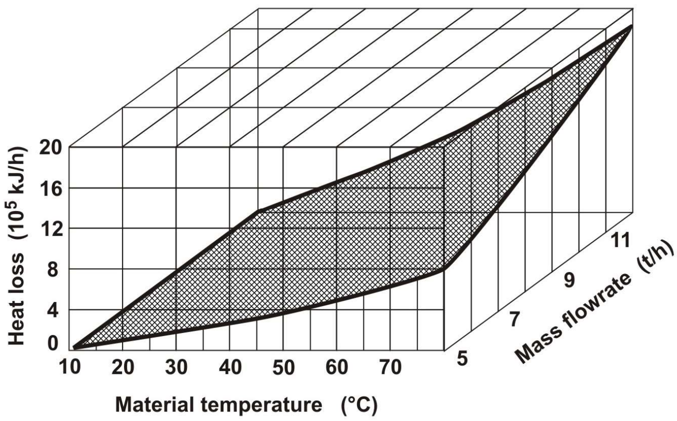

Fig. 1. The heat taken away by the dried material depending on dry matter performance when corn is dried [1]

Climatic heat losses occur mostly due to surface heat losses and material warming (Figure 2), which confirms the necessity of thermal insulation and the recovery of the amount of heat absorbed by the material.

In a convective process, increasing the temperature (t) of the drying medium results in a reduction in the specific energy requirement. At a lower drying medium temperature (t <80 ^{o}C), the heat demand depends to a large extent on the relative humidity of the exhaust air. For real drying, the theoretical limit can be determined on the basis of equilibrium moisture curves. As a result, the value of φ_2<1 and, apart from the warm-up phase, gradually decreases with real process as the drying progresses. [3].

The modernization of drying equipment and technologies, the partial introduction of preservation processes that do not require drying, the putting into production of plant varieties with a lower moisture content, the automation of the drying process, the

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improvement of the skills and working conditions of the operators, the observance of technological discipline, etc. help to reduce energy consumption.

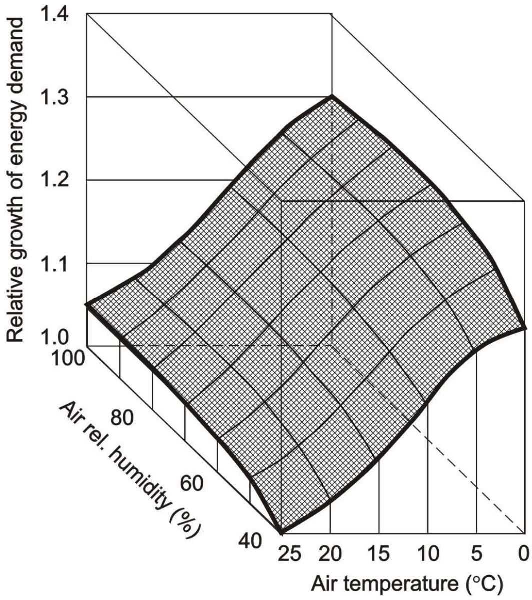

Fig. 2. The effect of climatic characteristics on the specific energy demand of drying

The components of energy rationalization can be divided into three major groups.

The first group includes the factors that fundamentally determine the objective conditions of drying. There are relatively few possibilities for influencing them in the drying plant. This group includes meteorological conditions, crop characteristics, and technological characteristics such as storage moisture content.

The second group includes the characteristics defined by operating and technological conditions. Alternative decisions within the plant that define the entire production activity from plant production to livestock production and sales can be included in this issue. For example, the cultivation of shorter breeding varieties for maize is an option. In addition to the factors of cultivation, the characteristics of harvesting and pre-processing technologies, the technological parameters of drying and the human factors should be included in this question group. These factors can be more or less accurately determined and controlled in the desired direction by controlling the cultivation conditions. Assuming the equipment of the applied drying process is given, the energy consumption of the drying can be reduced by optimizing the operating conditions.

The third group is the issue of applied drying technology. These include design, selection and technical development issues, such as drying technology, machine equipment and facilities, heating mode, and automation that excludes subjective factors. Energy-saving operation of the drying equipment can be provided relatively easily. To achieve this, it is sufficient to calculate some operating indicators using a small number of technological features [6].

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3. Results and Discussion

3.1. Specific heat consumption of dryers

In the drying plant, the following parameters can be measured simply and reliably:

- moisture content on wet basis before (w_1) and after (w_2) drying, [kg/kg],
- mass flow-rate of the crop before (G_2) and after (G_1) drying, [kg/h],
- fuel consumption (B) [kg/h].

Taking into account the total heat loss of the dryer, the amount of heat needed to remove 1 kg of water can be calculated as follows:

$$q = \frac{BH_i}{G_v} \tag{1}$$

or

$$q = \frac{BH_i}{G_2}\frac{1-w_1}{w_1-w_2} \tag{2}$$

and

$$q = \frac{BH_i}{G_1}\frac{1-w_2}{w_1-w_2} \tag{3}$$

where H_i is the calorific value of the fuel (kJ/kg), G_v is the water evaporating capacity of the dyer (kg/h).

The amount of heat per 1 kg of dried end product can be calculated by the formula:

$$q_2 = \frac{BH_i}{G_2} \tag{4}$$

After substitution, the specific heat consumption of the dryer can be determined by the following equation:

$$q = q_2\frac{1-w_1}{w_1-w_2} \tag{5}$$

The specific fuel consumption (b) characteristic of the energy quality level of the dryers is given by the following relationship.

$$b = \frac{q}{H_i}1000 \quad \text{(kg/t water removed)} \tag{6}$$

In practice, it is customary to use fuel consumption for one ton of dried end products for cost-benefit purposes:

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$$b_2 = \frac{B}{G_2} \quad \text{(kg/t dried material)} \qquad (7)$$

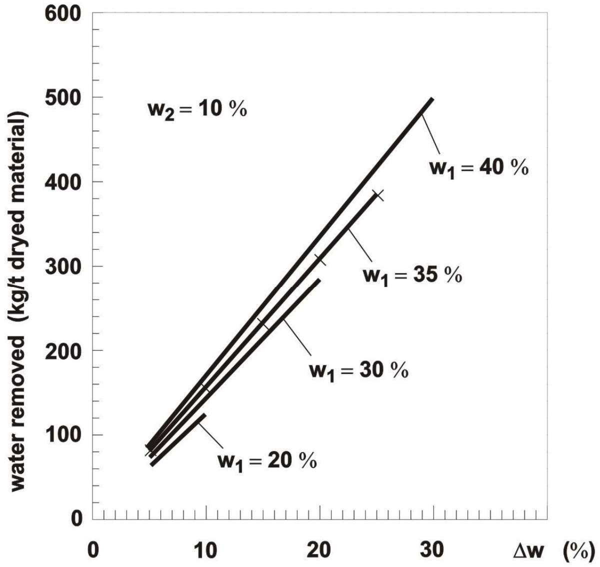

Fig. 3. Specific dewatering depending on the moisture content reduction

Fuel consumption per ton of end product is greatly influenced by the moisture content of the crop before drying. Therefore, it does not in itself show the energy quality of the operation of the dryer. However, it can help you determine the energy performance of a dryer:

$$q = b_2 H_i \frac{1 - w_1}{w_1 - w_2} \quad \text{(kJ/kg water removed)} \qquad (8)$$

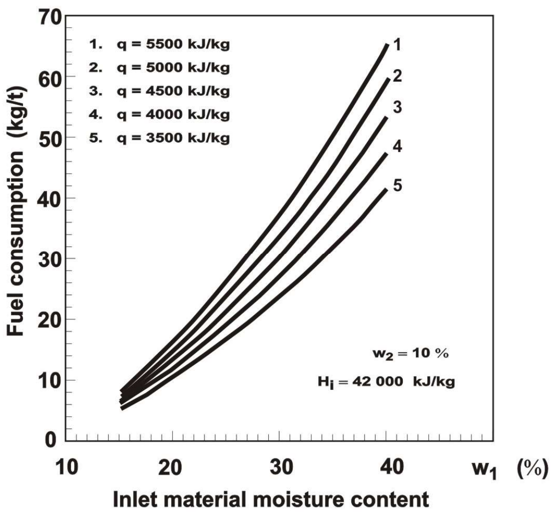

Fig. 4. Specific fuel consumption as a function of the initial moisture content.

Figure 4 shows the amount of fuel required to dry one ton of grain (b_2) as a function of the moisture content before drying (w1) and the specific heat consumption (q).

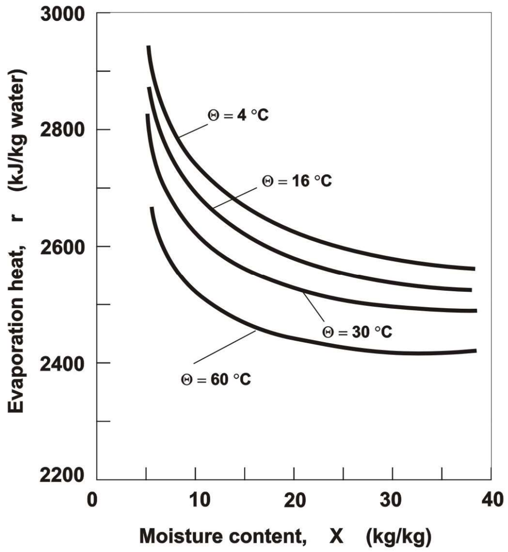

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Fig. 5. The evaporation heat of moisture in corn

A significant part of the value of specific heat consumption in convection dryers is the of evaporation (hidden) heat in the liquid phase. The amount of evaporative heat (r) in the final stage of drying increases significantly as the moisture content decreases. Figure 5 shows the evaporation heat demand of the moisture of the corn maize as a function of the moisture content. Water removal below X = 0.2 (w = 16.3%) requires an increasing amount of heat. If this marginal moisture content is taken into account, 85% of the evaporated total moisture can be removed with reasonable low energy from the product if corn is dried from w1 = 30% initial to w2 = 13.8% (X = 0.16) moisture content. More energy is needed to evaporate the remaining 15% of moisture. For example, if the final moisture content w2 = 13.8% (X = 0.16) is reduced to w2 = 9.1% (X = 0.10); then the higher part of total energy consumption is required by only the 0.30 part of the total moisture. In addition, increased moisture removal (compared to drying from 30% to 13.8%) increases the total evaporation of moisture by 20% unreasonably for long-term storage.

3.2. The efficiency of the drying equipment

In addition to the specific heat consumption, the energy standard of the operation of the drying equipment is also characterized by the thermal efficiency.

The thermal efficiency, assuming the process of dewatering is isobaric state change, is the ratio of the temperature of the inlet and outlet drying medium:

$$\eta_t = \frac{t_1 - t_2}{t_1 - t_n} \tag{9}$$

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Therefore, in order to achieve maximum thermal efficiency, it is necessary to strive to achieve a minimum average outlet temperature for the given inlet drying medium temperature. Changes in operational conditions (i.e. inlet moisture content, dry matter, drying medium temperature) - due to the drying time of several hours - are followed by the temperature of the outlet drying medium at an appropriate rate. Therefore, the outlet temperature of the fluid, along the length of the drying zone, provides information about the energy standard of the operation.

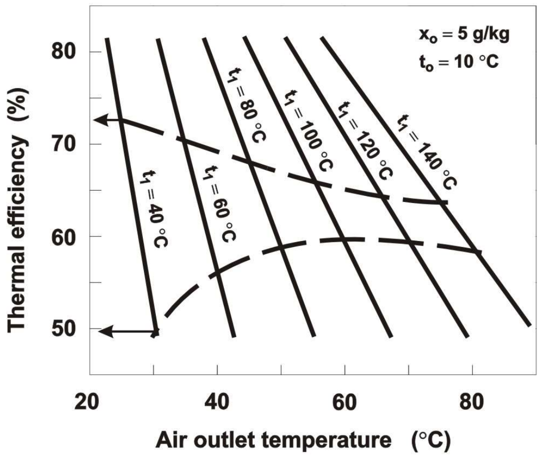

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Fig. 6. The theoretical thermal efficiency of the dryer as a function of the temperature of the drying medium.

Figure 6 shows the relationships between η_t and (t_1-t_2). The slope of the lines shown on it decreases as the inlet air temperature increases. For this reason, the change in the outlet drying air temperature for each of the inlet temperatures has a significantly different efficiency change. The two dashed lines show the change in efficiency for the temperature change $\Delta t_2=5\ ^oC$.

The formulaic formulation of thermal efficiency considers drying to be a simple heat transport process, ignoring the heat demand of material transfer and the resulting losses. More realistic values are provided if the efficiency of the drying equipment can be expressed by the ratio of utilized and total heat. Useful Heat Quantity (q_h) refers to the theoretical amount of heat required to evaporate the abstract moisture content of the crop, which can be calculated by knowing the evaporation heat (r) and the inlet (X1) and outlet (X2) moisture content of the drying medium:

$$q_h=r(x_2-x_1) \qquad (10)$$

With the use of the two formulas above, and not taking the losses of the heat source into account, the efficiency of the dryer is:

$$\eta_o = \frac{r(x_2 - x_1)}{c_{pnl}(t_1 - t_o)} \qquad (11)$$

Losses of the heat generator can be taken into account by its thermal efficiency (η_h).

$$\eta_h = \frac{c_{pnl}\left(t_1 - t_o\right)}{b_k H_i} \tag{12}$$

where b_k=B/L is the fuel consumption per 1 kg of drying medium (kg/kg), and c_{pnl} is the specific heat capacity of mist air at constant pressure (kJ/kgK). With the help of these two equations, the drying efficiency (η) taking into account all losses can also be determined:

$$\eta = \frac{r}{b_2 H_i} \frac{w_1 - w_2}{1 - w_1} \tag{13}$$

For the practical implementation of the above-described energy analyzes, the technological conditions and ways of operating the dryers should be examined. Their creation and implementation can be varied depending on the purpose of the dryer or its type and can be achieved by different interventions. The most common is the control of the temperature, possibly the amount of the drying medium, the mass flow of the material to be dried, the thickness of the layers and, last but not least, the final moisture content of the dried material.

4. Conclusion

In the process engineering the diversity of agricultural materials, as well as the permanent changes of materials features definitely hinder the application of a generally valid method. For this purpose the semi-empirical solutions seem more practical.

The multifaceted stochastic nature of agricultural crops in the process simulation makes it possible to apply general-purpose correlations only in special cases, instead it is more appropriate to use the results of a large number of experiments and their in-depth examination.

In order to rationalize the energy consumption of crop driers complex process analysis is needed, including the investigation of objective, technological, operation and technical conditions. The manual control system should be substituted by such an automatic process control that is based on the theory and practice of drying. To derive a model system, which is directly usable in the practice, such a database is needed that comes from the plant operation, including the measurements of most important practical parameters during the drier operation.

In order to rationalize energy consumption, the complex analysis of all three influencing factors (objective conditions of drying, operational and technological conditions, issues of design, selection and technical development) is required.

A particular type of dryer provides a wide range of desired drying parameters. To do this, instead of the manual control, which still can be found today, an automatic control system that excludes subjective factors is desirable.

Improving the operating conditions of the drying equipment, monitoring the energy consumption during operation, accurate recording of the actual data, and precise processing of the energy consumption of the annual drying season, characterized by the different harvest time crop moisture content, helps to create a database that can be used to develop a modeling method that can be used directly for practice.

5. Acknowledgements

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