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DETERMINING THE OPTIMAL REGIME OF THE CONVECTIVE OPEN-CIRCUIT DRYER. CASE STUDY

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ABSTRACT

The purpose of this paper is to determine the optimal operating regime of the opencircuit convective dryer, taking into account criteria such as energy efficiency, dry product quality, and operational costs. Optimization of the drying regime contributes both to reducing energy consumption and increasing the productivity and quality of the finished product.

KEYWORDS*:* Convective dryer, drying, energy, efficiency

1. INTRODUCTION

Convective drying involves the transfer of heat from a stream of hot air to the surface of the wet material, followed by the evaporation of water and the transport of water vapors into the surrounding air.

The drying of solid materials is an essential technological process employed in a wide range of industries, like food, pharmaceutical, chemical, or textile industries. Convective open-circuit dryers are among the most widely used equipment due to their constructive simplicity, relatively low-cost, and good efficiency under correctly optimized conditions [1].

In an open-circuit convective dryer, the drying agent (usually hot air) passes through the wet material only once, removing moisture, then is discharged into the atmosphere.

This type of dryer involves several process parameters [2]:

- temperature
- the air speed
- flow of drying agent
- the exposure time

These parameters must be carefully controlled to ensure an optimal operating regime.

2. THEORETICAL CONSIDERATIONS ON CONVECTIVE DRYING WITH OPEN-CIRCUIT

Drying is a complex process of mass and heat transfer, in which moisture is removed from a material by evaporation, due to the intake of thermal energy.

Figure 1: Convective dryer

In the case of the open-circuit convective dryer, the drying agent (air or other gas) circulates in one way through the wet material, taking the water vapors and being then discharged [3].

This refers to the process of removing moisture from a material (solid or liquid) by using a stream of warm air. It is one of the most common and effective drying methods used in industry and laboratories.

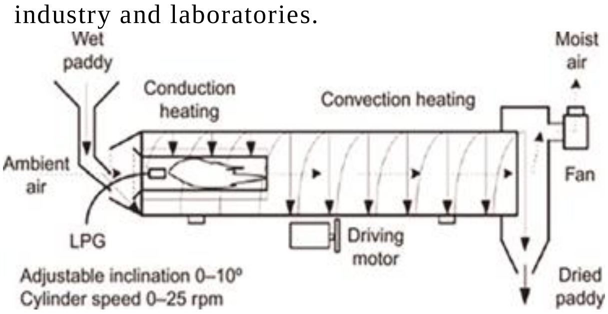

Figure 2: Convective drying – scheme

Convective drying involves the transfer of heat from a stream of hot air to the surface of the wet material, followed by the evaporation of water and the transport of water vapors into the surrounding air [4] [5].

Heat transfer occurs from the drying agent to the surface of the wet material, followed by mass transfer, as the water evaporates and is transported by the drying agent. This process is influenced by:

- temperature
- relative humidity of the air
- the movement speed of the drying agent
- thickness of the material layer
- physical characteristics of the material (porosity, diffusion, etc.).

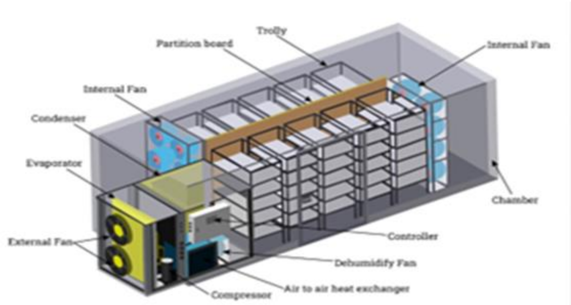

Figure 3: Inside a convective dryer

The factors that determine the influencing convective drying are:

• Air temperature - higher temperatures accelerate evaporation.

• Air speed - a higher flow rate leads to faster vapor removal.

• Relative air humidity - dry air can absorb more vapors.

• Contact surface - a larger area facilitates evaporation.

• The thickness of the material layer influences the speed at which water migrates to the surface.

To determine the optimal regime of the dryer, it is necessary to analyze the following parameters [6]:

a. Drying agent temperature - directly influences the evaporation speed

b. Air speed - affects the efficiency of heat and mass exchange

c. Drying time - determines the degree of final drying and productivity of the process

d. Air mass flow - influences the ability of the system to evacuate water vapors [7].

Constant drying period - the evaporation rate is maximum and controlled by external conditions (drying agent) as follows:

• Air heating

• The air is heated to an optimal temperature for the drying process, depending on the nature of the material

• Heat transfer (convection)

• Warm air contacts the wet surface, transferring heat to the water

• Evaporation of water from the surface

• The water at the material surface absorbs thermal energy and turns into vapors

• Diffusion of internal humidity

• The water inside the material migrates to the surface to be evaporated.

• Water vapor evacuation

• Water vapors are carried by the air current and removed from the system.

For theoretical analysis and optimization, mathematical models are based on [8] [9]:

-Heat transfer equation (conduction and convection)

-The mass transfer equation (Fick's law)

-Global energy balance of the system

-Drying curves (time-dependent water mass ratio)

- Installation components

-Materials, measured parameters, and methodology used.

3. CASE STUDY

To determine the optimal operating regime of the open-circuit convective dryer, an experimental study was carried out using a laboratory installation equipped with equipment for measuring and controlling the main process parameters [11].

The experimental stand contains the following main equipment:

- Drying chamber with forced air circulation

- Hot air source with temperature control (electric resistance or burner)

- Speed variator fan for air speed control

- Temperature, humidity, and air flow measurement system

- Electronic balance for real-time monitoring of product mass.

The material to be dried (e.g., apple slices, wet sand, porous paper) has a known moisture content.

The material was laid in a uniform layer with controlled thickness to ensure comparable conditions between the experiments.

The experiment was conducted as follows [12]:

a) A set of values has been adjusted for each parameter (temperature, air velocity, time).

b) At each set of conditions, the variation in mass over time was monitored, thereby determining the drying rate.

c) Residual humidity was determined by final drying in a reference furnace.

d) The experiment was repeated for several parameter combinations to obtain sufficient data for comparative analysis.

The following parameter values have been tested:

- Air temperature: 40-80°C;
- Air speed: 1-3 m/s
- Drying time: until a constant mass of material is reached
- Material layer thickness: 1-3 cm

3.1. Objective analysis

By comparing the results of the experiment (drying rate, estimated energy consumption, final product quality), the set of parameters that offer the best drying solution and the best compromise between energy efficiency and technological performance could be identified [13].

4. DATA ANALYSIS AND DETERMINATION OF THE OPTIMAL REGIME

Following the experiments, data series were obtained that reflect the evolution of the material mass according to time, under various conditions of temperature, air speed, and thickness of the material layer [14].

This data was used to identify:

• Drying rate (g water/min)

• Energy efficiency (report between useful energy and consumed energy)

• The final moisture of the product

• Total drying time up to a constant mass.

For each set of parameters, graphs were generated:

o Drying curves (mass vs. time)

o Drying rate according to air temperature and speed

o Estimated energy consumption according to drying conditions.

By analyzing the graphs, the following conclusions can be drawn:

-The increase in temperature leads to a significant acceleration of the drying process, but may affect the quality of the product (in the case of temperature-sensitive products)

-The air speed influences the efficiency of the heat exchange, but the effect becomes insignificant above a certain limit

-The thickness of the material layer directly affects the duration of drying and uniformity.

Based on the correlation of experimental data and performance criteria (minimum time, low consumption, good quality), it was determined that the best regime for drying is [15]:

-Air temperature: 60°C

-Air speed: 2 m/s

-Material layer thickness: 1.5 cm

-Optimum drying time: ~35 minutes

These conditions ensure efficient drying with reasonable energy consumption and without degrading the product’s quality.

Identifying the best drying regime reduces processing time by up to 30% compared to the reference regime and decreases energy consumption by about 15-20%.

Also, setting an optimal regime helps to increase repeatability and quality control in industrial drying processes.

5. CONCLUSIONS

This study focused on determining the optimal operating regime of the open-circuit convective dryer and highlighted the importance of careful control of technological parameters on the efficiency and quality of the drying process.

Based on the experimental data and the analyses performed, the following conclusions can be drawn:

-The best working regime identified (temperature 60°C, air speed 2 m/s, layer 1.5 cm) ensures a favorable balance between drying time, energy consumption, and product quality.

-The temperature rise accelerates the drying process, but above a certain threshold can adversely affect the characteristics of the product.

-The air speed positively influences the process up to a limit value, after which the effects become marginal.

-The increase of layer thickness reduces drying efficiency and leads to moisture unevenness in the final material.

In industrial applications, it is recommended to use an automated temperature and air flow control system to maintain optimal conditions. For temperature-sensitive materials, a further assessment of the thermal impact on material properties is required.

- In the case of high-capacity dryers, one can investigate the variant of a heat recovery dryer (semi-closed circuit) for energy efficiency.
- Continuing the study by numerical modelling (CFD, thermal simulations) could help optimize the process without additional experimental consumption.

REFERENCES

[1] Bratu, E.A., Unitary operations in chemical engineering, Bucharest, Ed. Technically, 1984.

[2] Carabogdan, I. Gh. ş.a., Industrial thermal installations, Bucharest, Ed. Technically, 1978.

[3] Charreau, A., Cavaillé, R., Séchage. In the Techniques de l'ingenieurs, Paris, 1995.

[4] Lîkov, A. V., Experimental and theoretical foundations of drying, Berin, 1955.

[5] McCabe, W.L., Smith, J.C., Harriott,P., Unit Operations of Chemical Engineering, McGrow-Hill, 2000.

[6] Mihăilă, C., Caluianu, V., Marinescu, M., Dănescu, Al., Industrial drying processes and installations, Bucharest, Ed. Technically, 1982.

[7] Kubasiewicz, A., Evaporators-construction and operation, Bucharest, Ed. Technically, 1981.

[8] Leca, A., Mladin, E. C. şi Stan, M., Heat and mass transfer, Bucharest, Ed. Technically, 1998.

[9] Smith, R. A., Evaporators. 1983 - Design Manual of Heat Exchangers.

[10] McCabe, W.L., Smith, J.C., Unit Operations of Chemical Engineering, McGrow-Hill, 2000.

[11] Perry, R. H., Green, D. W., Perry

[12] *** APV Dryer Handbook, 2002.

[13] www.creeaza.com/referate/ physics/Molier-Diagram-for-air-u158.php

[14] www.referatele.com/referate/fizica/online2/Heat---Specific-heat

[15] http://adrian-badea.ro/wp-content/uploads/2015/07/EIT_Capitolul-9.pdf