THE PROJECT FOR LABORATORY SCALE TUNNEL DRYER FOR CONVECTIVE-CONDUCTIVE DRYING OF FOOD MATERIALS

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Abstract: *Laboratory scale tunnel dryer for convective-conductive drying of food was designed with the ability to regulate the drying parameters by controlling the thermo-mechanical properties of the humid air and the temperature of the materials by convective-conductive methods, as well as precisely adjusting the fraction of recirculated air in the drying process. The dryer is fully automated, with the ability to operate according to temperature or humidity parameters. Automation and control of the process and drying parameters was achieved by frequency regulation of the forced air flow system, proportional-integral-differential (PID) temperature drying regulation and ON / OFF regulation of air humidity (agent), as well as PID regulation of the heating of materials by a conductive mechanism. All regulated sizes are measurable with the ability to connect to an external computer for data collection.*
Key words: *Drying, convective-conductive, recirculation, food, energy saving, automatization.*

1. INTRODUCTION

In modern industrial production it can be safely claimed that there is no product whose basic raw material at some stage has not undergone some kind of drying process. The theory and basic principles of drying were dealt with by a large number of authors, highlighting the complexity of the processes that occur during partial or complete separation of moisture from the material, Williams-Gardner (1971); Keey (1978); Strumillo (1986); Marinos-Kouris (1995); Pakowski (1996); Mujumdar (2006); Vega-Mercado (2001). In order to determine the appropriate drying parameters, different experimental techniques are used to determine the optimal moisture content in the material, the method of establishing characteristic equilibrium states in the processes of sorption and desorption, determining thermal conductivity, effective diffusion and the like. When drying foodstuffs it is necessary to know the physico-chemical properties of the material, the allowed moisture content in the material, the appropriate drying technology, the types of varieties suitable for drying, as well as the changes that occur during drying in the material, Mujumdar (2006). The general objectives of the drying experiments are: selection of suitable drying equipment, setting of the specified drying parameters, testing the efficiency and capacity of the existing drying equipment, testing the effects of drying on the final product, as well as analysis of the drying mechanism, Molnar (1995). The mathematical modeling of the complete drying process can be broken down into three parts: modeling the flow of air flow, modeling drying materials and modeling the equipment used, McMinn (1999). Model verifications are performed on different types of laboratory dryers that have the possibility of variation of all or only certain drying parameters. Ignoring some of the drying parameters avoids deeper correlation between the parameters within the model itself. One of the parameters that is often neglected is the relative humidity of the air used as a drying agent. The easiest way to control the relative humidity of the air is in drying systems in which there is some form of complete or partial recirculation, because the recirculation alone can avoid constant input of larger amounts of moisture into the process to achieve the desired initial relative humidity values, Pakowski (2007). By controlling the parameters of the entire ambient space in which the drying takes place (eg the drying room), it is possible to bring the air of the desired relative humidity to the material, Aktas (2009), Kaya (2007). The lack of this way of controlling inputs is that it can be achieved only in laboratory conditions, Saensabai (2003). The matching of the results obtained with the mathematical model and the experimental results is greater if the number of parameters covered by the model is greater. Laboratory research usually involves determining the individual or overall impact of the drying parameters on the process kinetics, Velić (2004), Uretir (1996). The overall performance of the drying system can be significantly improved if the drying process takes place with recirculated air.

Finally, this research deals with laboratory scale tunnel dryer for convective-conductive drying of food materials, that is designed to provide complete control over the drying parameters of the agent and material together by combining a convective and conductive method of heat exchange of materials and agents (combined or separated) as needed. Also, the solution provides for the possibility of automated control of recirculated air in the range of 0-100% of the recirculation.

2. DRYER PROJECT

The lack of a more fundamental approach to the research of the present processes and phenomena leads to the lack of specific data in this field and the need for additional research. Therefore, in order to obtain reliable data, which would directly or indirectly contribute to the understanding of fundamental thermomechanical processes and phenomena, there is a need for the design and development of a new laboratory drying system that would cover all relevant drying parameters. Laboratory scale tunnel dryer for convective-conductive drying of food was designed with the ability to regulate the drying parameters by controlling the thermo-mechanical properties of the humid air and the temperature of the materials by convective-conductive methods, as well as precisely adjusting the fraction of recirculated air in the drying process. The dryer is fully automated, with the ability to operate according to temperature or humidity parameters. Automation and control of the process and drying parameters was achieved by frequency regulation of the forced air flow system, proportional-integral-differential (PID) temperature drying regulation and ON/OFF regulation of air humidity (agent), as well as PID regulation of the heating of materials by a conductive mechanism. All regulated sizes are measurable with the ability to connect to an external computer for data collection.

The description of the drying system

The installation of the laboratory dryer is tunnel type (Fig.1). The dryer consists of the following sections:

- Centrifugal fan with electromotor
- Electric heaters
- Duct system with 4 implemented drying chambers
- Recirculated and fresh air regulator

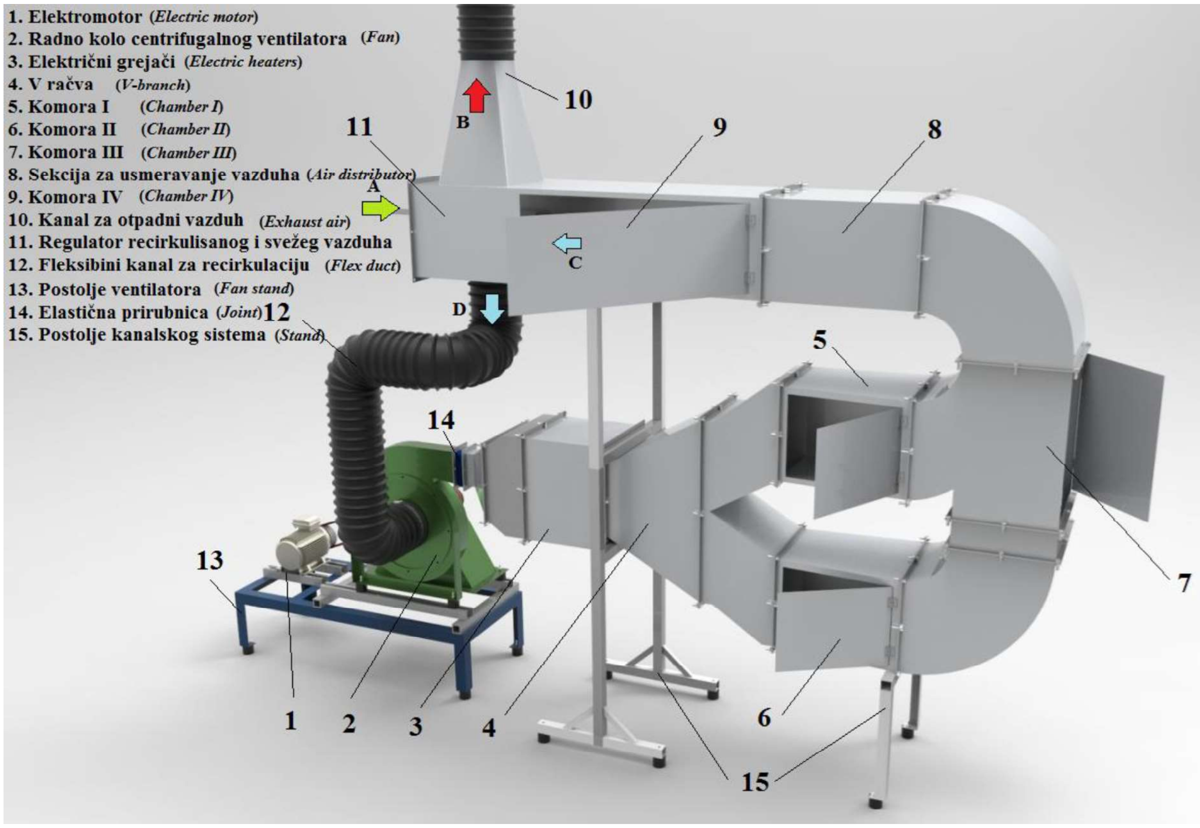

Figure 1. Laboratory dryers with adjustable air recirculation for convective and conduction drying of food materials (Model)

The centrifugal fan impeller (2) is connected to the shaft transmission (transmission ratio 1:1) by the shaft of the electric motor (1) and placed on a separate stand (13), which, due to the reduction of the vibration transmission, is leaned over the rubber-metal shock absorbers. For the same reason, this section with the rest of the dryer system is connected, on the one hand, by a flexible hose (12) and on the other by a flexible coupling (14). Electric heaters (3) are the main and only source of heat for heating the drying material. They are located directly behind the fan, at the beginning of the duct system. On them, the V-branch (4) of the duct system is connected with which the air is directed to one of the chambers I (5), ie Chamber II (6), III (7) or IV (9). The direction for the direction of air (8) is to obtain a uniform current field before encountering the chamber IV (9). Regulators (11) regulate the amount of recirculated and fresh air. The waste air is ejected through the exhaust air channel (10). The duct system is made of galvanized sheet metal flanged flanges, which are located on vertical supports (15). The carriers rely on the ground through elastic rubber pads, which significantly reduces the transmission of system vibration into the room.

The description of the drying chambers

The design of the laboratory drying facility provides space for four drying chambers:

- Chamber I (5): Conductive-convective drying in bathtubs,
- Chamber II (6): Conductive-convective drying in bathtubs,
- Chamber III (7): Convective drying with a thick layer,
- Chamber IV (9): Convective drying with a thin layer.

Chambers I (5) and II (6) are intended for combined conduction-convective drying, with the possibility to adapt in a different way. The air through the tub with the material flows in the horizontal direction. The V-section section (4) has a baffle that directs the air to the I or II chamber, and the turning of the barrier is done manually (two positions, upper and lower). Chamber III (7) is intended for convective drying of the material in the thick layer, whereby the air is fed from the bottom (through the chamber II chamber, which is not functional in this case). Chamber IV (9) is intended for convective drying in a thin layer (on wood). Before entering the chamber IV (9), the air is directed in section (8), which achieves the uniformity of the current field. The dimensions of the space of each chamber are defined in the technical part of the documentation. This technical solution only envisages the position, dimensions and purpose of the chamber, while the construction itself and the interior appearance of the chamber are not defined and determined according to the need and the specific case of drying.

The automotive control of the drying process

Controlling the operation of laboratory dryers and achieving desired drying parameters is achieved in several ways (Fig.2).

1. Frequency regulator for fan electric motor
2. Fresh/exhaust/recirculated air regulator (flow damper)
3. Electric heater regulator unit (thermostat)
4. Electric heaters fuse board
5. T/RH measurement unit (drying air parameters)
6. T/RH measurement unit (recirculated air parameters)
7. PT100 temperature sonde
8. T/RH sonde
9. Electric heaters
10. Calibration
11. Regulator display

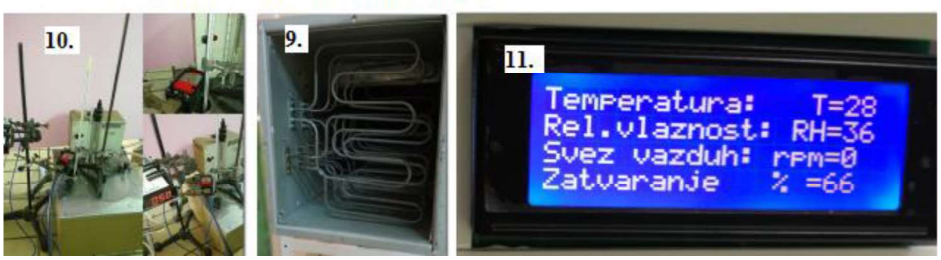

Figure 2. The components of the drying system

The flow rate of the air through the drying material is adjusted indirectly by the frequency regulator of the electric motor of the fan. By adjusting the speed of the electric motor it affects the speed of rotation of the impeller of the centrifugal fan, and therefore the air flow through the system. The temperature and relative humidity of the air coming to the material is regulated by a PID thermo-hygro-regulator that controls the operation of the electric heater according to the principle of ON/OFF regulation. The controller is assigned one of the parameters (temperature or relative humidity) to be managed. The regulation of the amount of recirculated air is carried out by a regulator driven by a signal from the probe for relative humidity of the air placed in front of the chamber. The desired relative humidity value is assigned to a microcontroller that controls the operation of the controller with an accuracy of ± 2.5% relative humidity.

3. RESULTS AND DISCUSSION

The laboratory drying system with adjustable control of air recirculation is fully automotive. It was designed and built in order to achieve and measure all relevant drying process parameters (Table 1).

Table 1. The main parameters of the drying process

Drying parameter	**Unit**	**Range**	**Accuracies**
Hot plate temperature	*°C*	*0 ÷ 120*	*± 0.1*
Air temperature	*°C*		
Air velocity	*m/s*	*0 ÷ 20*	*± 0.01*
Relative humidity	*%*	*5 ÷ 60*	*± 2.4*
Material mass	*g*	*0 ÷ 5000*	*± 0.01*

System has possibility of the full control of drying air temperature (0-120°C), relative humidity (5-60%) and velocity (0-20 m/s). It consists of a closed loop tunnel sections with four built-in drying chambers. All chambers can be adjusted to convective or conductive, or combined drying method. Chambers I, II and IV are designed for horizontal air flow, and chamber III for vertical air flow. Food material can be aligned in thin layer or in a batch bunker. The amount of introduced fresh/exhaust air can be monitored and recorded in real time, as well as the mass of the material. The energy consumption during the drying process can be monitored.

Tabela 2. The possibilities of dryer application

Drying method	**Material placement**	**Food materials**
Convective	Thin layer	Raw fruits and vegetables
Conductive	Batch bunker	Treated fruits and vegetables
Convective-Conductive	Poured into tubs	Grains
	Pomace	Mealies
		Medical plants
		Spicy herbs

In order to precisely determine and define the regime and parameters of the drying of the selected food material, it is necessary to properly combine the appropriate drying method with the method of placing the material. The laboratory drier allows a large number of these combinations, which together with the possibility of variation of all parameters of drying (shown in Table 2) and automatic control of the drying process is a serious research tool.

The simplicity of using this technical solution, as well as the ability to monitor and display different sizes and parameters of the process, contributes to further consideration and improvement of the way of studying the problem of drying food materials.

3. CONCLUSION

This research deals with laboratory scale tunnel dryer for convective-conductive drying of food materials, that is designed to provide complete control over the drying parameters of the agent and material together by combining a convective and conductive method of heat exchange of materials and agents (combined or separated) as needed. Dryer has the ability to regulate the drying parameters by controlling the thermo-mechanical properties of the humid air and the temperature of the materials by convective-conductive methods, as well as precisely adjusting the fraction of recirculated air in the drying process.

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