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THE INNOVATIVE SOLUTIONS AND THE DEVELOPMENT OF A LOW-ENERGY AIR DRYER

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SUMMARY

Drying is one of the most energy-intensive industrial processes, regardless of the processing material. In the industrial food production, drying can be used as the only step for food preservation and/or as a preparation stage in food processing. However, the quality of final dried product is a priority that needs to be accomplished. This study presents the innovative solution and the development of a low-energy air dryer based on heat pump for application in food drying with a closed circulation of relatively low temperature air (up to 70 °C).

Keywords: low-energy air dryer, energy efficiency, food

INTRODUCTION

The tasks of the drying technique and technology are primarily to preserve the quality of agricultural products through the drying process with minimum energy inputs and environmental impacts. Drying is an energy-intensive process, and for cost-effectiveness, it needs to be carried out in the shortest possible time with as less energy consumption as possible. The complexity of the drying process is reflected throughout the simultaneous transfer of heat and matter (moisture), and in changes in the physical and structural properties of the material being dried. That is particularly evident in the drying of food materials that are mutually significantly different in composition and structure. Dried fruits and vegetables of high quality can only be obtained by carefully selecting the variety within each species.

Drying can take place as a natural process or as an industrial unit operation. The natural process cannot be controlled while the industrial process is more or less controlled. The natural process depends on the season and applied conditions in terms of temperature and air humidity that agricultural products are exposed to. However, such dried products have a relatively high final moisture content (Tiwari et al., 2016.). Industrial processes are mostly based on the indirect removal of moisture

by hot air, which flows over the foodstuff, after which it is released into the environment with high relative humidity and lower temperature compared to the beginning of the process.

In order to analyse the drying process and determine the design parameters of the dryers, it is necessary to know the static and kinetics of drying process (Budin and Mihelić-Bogdanić, 2013). Drying statics implies the correlation of the initial and final parameters of the material and the drying agent based on the balance of matter and energy, while the drying kinetics implies a relationship between the change in material humidity with time and the process parameters.

Improved conditions of the drying process and better utilization of air heat can be achieved by different methods that simultaneously fulfil the material properties and are more energy efficient. The combination of heat regeneration and circulation of drying air is applied in industrial driers to achieve better results and greater usability. The workflow needs to be managed in such a way as to increase productivity and reduce energy consumption. In order to reduce energy consumption, an optimization needs to be carried out, which involves a combination of recirculation (air circulation) and heat regeneration. In that way, the drying air returns its efficiency and it can be reused for drying without discharging into the environment (Minea, 2013; Moses et al., 2014).

This study presents the innovative solution and the development of a low-energy air dryer based on heat pump for application (Budžaki et al., 2019) in food drying with the heat regeneration and circulation of drying hot air.

Design and development of a lower-energy air dryer

The dryer is a machine with the purpose of drying that is, reducing the moisture of raw material to a desired value. This can be achieved by means of hot air circulating through the dryer.

Low-energy condensing dryers *SINAI* and *THAR* spend 3-4 times less energy than conventional dryers. With regard to the technology used, they provide better controllability of the drying process, which is particularly important when drying agricultural products.

Materials that will be dried (clothes, fruits or vegetables) are placed into the drying chamber. The user selects the desired drying mode (depending on the materials ready to be dried) on the control panel located on the air-drying device. The drying mode has an enormous effect on the speed and quality of drying, regardless of whether the production mode or the modified mode is used. The most important part of this type of a low-energy dryer is the air-drying device which prepares the air (heats it up), after which the heated air enters the drying chamber and passes through the materials being dried. When the air returns into the drying device, air circulation in the system is completed, and the process is repeated until the materials are dry. The drying device is extremely economical and does not deplete the ozone layer because it uses refrigerant R134a.

During running, process parameters can be read via the control panel, including relative air humidity, temperature, air enthalpy, absolute humidity, etc. During the process, there is no contact with fresh air from the outside. The entire process includes the flow of an equal amount of air in a closed system.

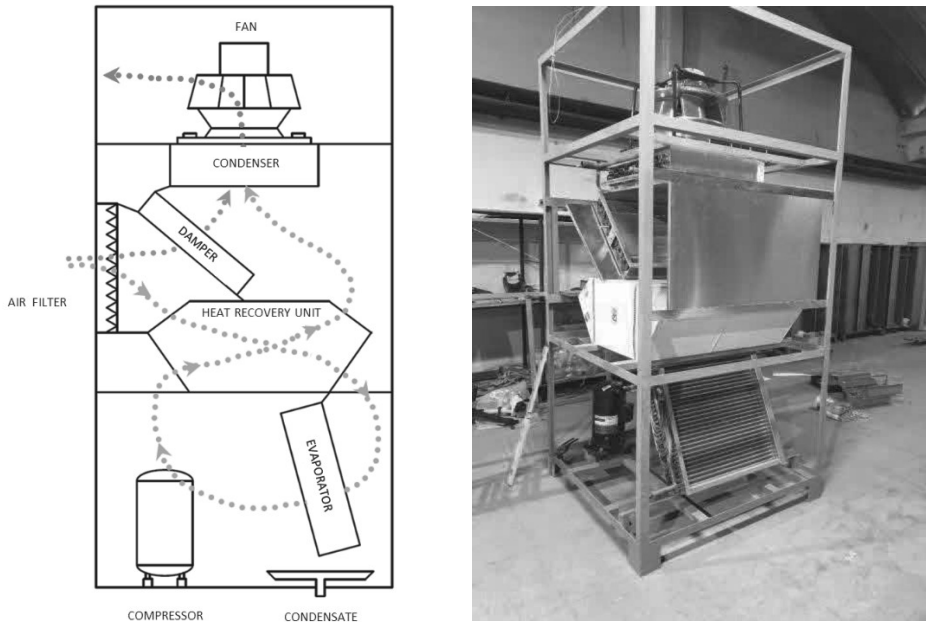


Figure 1 Schematic presentation of a low-energy air dryer

Figure 1 shows a low-energy dryer for the drying air preparation that consists of an evaporator, compressor, condenser, ventilator and a heat recovery unit. The humid and warm air coming from the drying chamber in the low-energy dryer unit is dewatered and reheated to a drying temperature that depends on the material that needs to be dried (food or non-food). The integration of the low-energy dryer for air preparation with the drying chamber is shown in **Figure 2**.

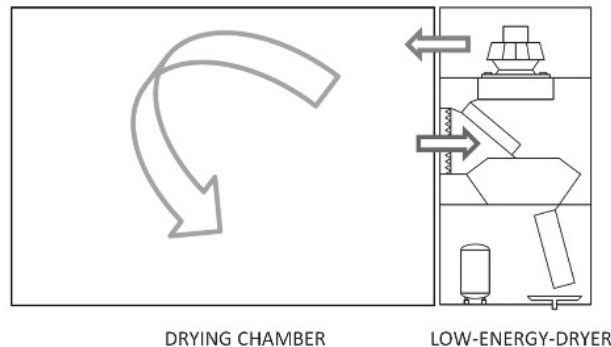


Figure 2 Schematic presentation of a low-energy air dryer with a drying chamber

The equipment is designed for drying a variety of materials including clothes and foods (fruits, vegetables and herbs). The use in two sectors, hotel and agro-food industry, is the result of the introduction of a dual name for dryer. The name *THAR* indicates the use in the hotel industry for drying laundry, while the name *SINAI* is a designation for drying agricultural products. The unit is freestanding and consists of two parts, a drying chamber and a condensing unit, which are connected by ducts for supply and exhaust air. Unlike conventional dryers, the *SINAI* and *THAR* condensing dryers use the flow of the same amount of air in a closed system. During the process, there is no mixing of air inside the dryer with fresh air from the outside. This innovative low-energy air dryer can save up to 59-70% of the energy required for conventional hot air drying (Lee and Kim, 2009; Taseri et al., 2018). After designing commercial equipment, tests need to be carried out in an appropriate laboratory scale that simulates commercial operating conditions. In cases where laboratory testing cannot be performed, commercial drying may be based on the experience of the equipment manufacturer as an important source of data. Based on scientific research related to the drying of different materials, a prototype of the dryer was made; the validation was tested in the food drying systems as well as on textile materials. On the prototype model, manufactured by Cras Ltd., the following tests were performed: the modelling of the drying system; moisture transfer testing; air quality testing; checking the content of dry matter particles in and out of the chamber; thermal dissipation of energy from the chamber; testing of primary measuring devices and testing the condensing unit drive group. The fan aspirates the heated and dry air, directing it to flow through the top opening on the left side of the dryer and blow into the dryer chamber where the material for drying was placed. At the inlet to the dryer chambers, the air temperature was measured with a PT1000 probe. The drying chamber contains partitions that take the air flow in the desired direction. By recirculation in the chamber, the air becomes saturated with the moisture it receives from the drying materials. During the drying process, the indoor air does not come in contact with the fresh air outside. The whole process takes place by flowing an equal amount of air in a closed system. Since it is a closed dryer system, the excess heat generated during operation can be used for heating up the sanitation water and/or for unburdening the heating system (such as plant halls), via a fan-convector/heat exchanger unit that requires a circulation pump. The control is designed so that the dew point of the return air is continuously monitored and the control is held for optimum evaporation of the system, taking into account the compressor characteristic for the most efficient separation of moisture from the air. From temperature and humidity, the absolute humidity (kg/m^3) can be calculated as the indication of the amount of moisture before the evaporator and the amount of moisture after the evaporator. The efficiency of individual modes of operation by collecting condensate and measuring the efficiency of moisture separation by changing the operating parameters were tested.

Experimental measurements and data collection

Prior to commissioning, an electrical control circuit for the automatic control of the system was created. When designing the wiring diagram, a Freon circuit diagram was used to select the number and type of sensor to be monitored in the operation of the device. In the frame of automatic control, there are executive parts: low pressure switch (LP) - low pressure switch on suction in the compressor; high pressure switch (HP) - high pressure switch at the outlet of the compressor; compressor thermal protection (COMPRESSOR_TP) - compressor motor protection switch; fan alarm (FAN_AL) - air circulation fan error. In case that one of the conditions is not fulfilled, the compressor does not have the signal to start operation. Thermocouples mounted inside the dryer, 10 points measure the air temperature (inlet and return flow from the drying chamber, inlet and outlet of the evaporator - after the recuperator, in the outlet tube of the evaporator and condenser, the inlet and return temperature of the Freon-water exchanger and the outlet temperature from the compressor).

Operations of the dryer are simply regulated via automatic control. The regulation of operation in the drying program is designed in such a way that the user selects the foods, and at the same time chooses the recommended mode of operation for the specified material, all based on an experimental tests conducted on the prototype. **Figure 3** shows the interface for automatic control of the dryer operation.

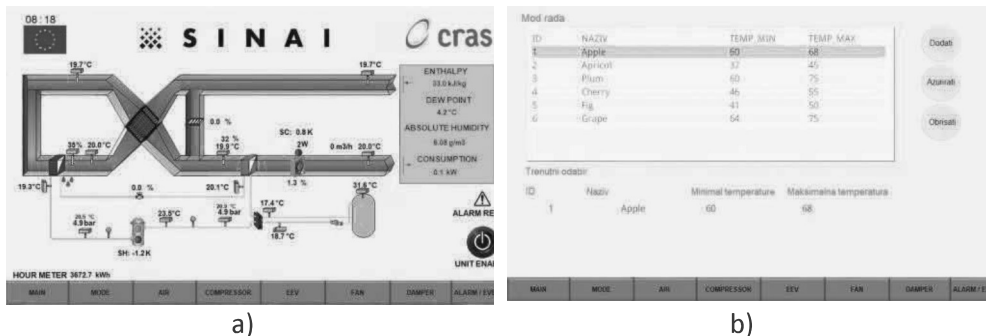


Figure 3 Interface for automatic control of the dryer operation: display of process diagram (a) and drying process menu (b)

Drying is carried out from an initial humidity to a final humidity, which is lower than 10%. In condensers, the drying air temperature should be about 50 °C and the inlet temperature 5-10 ° lower at air flow rates of about 3 m/s. The process lasts until the humidity is reduced to the desired level (when it evaporates about 80% of the balance from the initial one). A prototype low-energy dryer designed for drying materials and raw materials is intended for two areas, the hotel industry (laundry) and the agro-food industry (fruits, vegetables and herbs). Considering the two applications, the prototype of the low-energy dryer was tested during two drying cycles in the period 9/2018 to 6/2019. The evaluation of the functionality of the low-energy dryer in the first test cycle was performed on the drying of linen and sheets, provided by Hotel Osijek from Osijek. In the second test cycle, the functionality of

the prototype low-energy dryer was evaluated during the drying of agro-food products: plums (with and without pits), pumpkin seeds (ordinary and hull-less), red spice pepper, pomegranate and aronia (berry and cake left over after juice production from aronia). Agro-food materials were supplied by the producers from Osijek-Baranja County. The data collected during drying, in both cycles, were used to create programs that, as the part of the developed and constructed prototype of the low-energy dryer, enable potential customers to select the appropriate drying program for the material they wish to dry when commissioning the dryer, with the option of entering drying parameters independently. The testing was conducted by the Cras Ltd.'s R&D team, in cooperation with the Faculty of Food Technology Osijek. By collecting data during textile and food drying the results showed that the amount of energy consumption ranged from 44.38 to 59.17 kWh/t evaporated water. Compared to the consumption of a conventional hot air dryer (900 - 1400 kWh/t evaporated water) and/or superheated steam dryer (170 to 400 kWh/ evaporated water), the constructed dryer shows significantly lower energy consumption, up to 3.17%.

CONCLUSIONS

The prototype of the *SINAI* and *THAR* low-energy dryer has been successfully designed, constructed, tested and automatized. In addition, within the framework of the implemented project, the final goal was achieved, i.e. the commercialization of a low-energy dryer that can be used for the drying of textile and agro-food materials.

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