Available online at www.rajournals.in

RA JOURNAL OF APPLIED RESEARCH

ISSN: 2394-6709

DOI:10.47191/rajar/v8i5.02

Volume: 08 Issue: 05 May-2022

International Open Access

Impact Factor- 7.036

Page no.- 346-350

Intensification of the Process of Drying Fruits and Vegetables in a Recirculating Solar Dryer

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ARTICLE INFO

Published Online: 06 May 2022

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ABSTRACT

To intensify the drying process and refine the modes of drying fruits and vegetables, the authors have developed a recirculating solar dryer with a recuperative heat exchanger for drying fruit and vegetable products with a loading capacity of 30 kg for fresh fruit.

The solar drying plant contains a drying chamber equipped with a ventilation system, an autonomous power supply unit (solar panel), a control panel and automatic control systems. The recirculating solar dryer works only with solar energy.

In this solar dryer, the kinetics of fruit drying was studied in the drying agent recirculation mode with and without a heat exchanger. It has been established that in the recirculation mode, the drying time of fruits is reduced by 1.5-2 times compared to that in a conventional solar dryer.

KEYWORDS: drying, solar dryer, solar energy, automatic control system, recuperation, recirculation, ventilation.

INTRODUCTION

Sun drying is a popular and economical method of drying fruits and vegetables in developing countries. But the main disadvantage of this method is the long duration of the drying process, as well as dependence on climatic conditions and environmental friendliness (the surface of the products is exposed to the interaction of dust and precipitation; insects and rodents also spoil the products). These disadvantages can be eliminated by using dryers with traditional energy sources. However, the use of such dryers is associated with a high consumption of organic fuel or electricity. Due to the high fuel consumption and their unprofitability, drying plants with an artificial heat source have not found wide application in the production of dried fruits [1,3,5].

Along with the indicated methods, in Central Asia, drying of fruits and berries is carried out using solar drying plants based on the use of solar energy [1,2,3,5,12].

Solar dryers, both abroad and in domestic practice, are most widely used in agriculture for drying agricultural products.

Currently, in a market economy, despite numerous research and development of solar installation designs, there are no operating industrial installations with high efficiency. Therefore, the development of highly efficient solar installations for drying fruits and berries, which makes it possible to ensure the production of high quality dried fruits, is of great economic importance [1,5,6,7].

Combined solar-drying installations of radiation-on-convective type are known, consisting of a drying chamber, a solar-air heater, a heater and a ventilation system [1,3,5,12,13,15].

The advantage of combined solar-drying plants is that the products dried in these installations are of high quality compared to air-solar drying.

Combined solar drying plants have a number of disadvantages: in the dryer chambers, the air temperature changes during the day, the drying process is interrupted in the evening (the drying process slows down a lot, sometimes it stops completely), the lack of the ability to control technological modes, convective heat loss, etc.

In these dryers, along with solar energy, thermal energy is additionally used to intensify the drying process.

In recent years, there has been a growing interest in the international market for high-quality dried apricots, apples, and other medicinal fruits. To get high-quality dried fruits, it is necessary to dry them on special solar dryers and work out the drying mode.

In the work [15] developed a hybrid solar dryer for drying tomato. It consists of a flat concentrating collector, a heat exchanger with an additional heat accumulator and a drying unit. The dryer has a load capacity of 20 kg of fresh chopped apples. The dryer has been tested in various weather and operating conditions. The performance of the dryer was compared with drying (in an open area) in the sun.

In the work [8], the authors developed and manufactured a solar dryer for drying bananas. The dryer consists of a solar flat air heater and a drying chamber equipped with a chimney. The solar air heater consists of a corrugated plate, painted in selective black, and has a glass cover. Drying chamber with dimensions 1m×0.4m×1m is made of aluminum sheet.

Experiments were carried out to study the kinetics of banana drying. Fresh ripe banana slices were used for drying. During the drying process, the decrease in moisture in the banana was determined by weighing the sample every hour. During the experiment, the air temperature inside the chamber, solar radiation and the change in banana moisture were measured.

The data presented show the urgent need to improve the energy efficiency of drying plants by using the best achievements of modern technology and technological methods, the possibility of recycling and recovering the heat of the spent drying agent and optimizing drying modes [12,13,14].

To solve this problem, it is necessary to investigate methods for increasing the energy (thermal) efficiency of solar dryers and develop optimal designs for solar dryers. This can be achieved by utilization and recycling of the spent drying agent in drying units with a significant enthalpy, which makes it expedient to use it as a secondary energy source [5,12,13].

OBJECTS AND METHODS OF RESEARCH

To intensify and improve the efficiency of the drying process, the authors [3,16,9] developed a solar dryer with a recuperative heat exchanger for fruit and vegetable products with a load volume of 30 kg for fresh fruit, with a transparent surface of 6.5 m^2. The schematic diagram of the proposed solar dryer is shown in Figure 1.

The solar drying plant contains a drying chamber equipped with a ventilation system 2,3,17 and an automatic control unit 8 with autonomous power supply. The drying chamber is a rectangular shape 2.0 × 0.80 × 1.30 m in size with an arched, transparent top cover 4, mesh trays 5 for the product to be dried. The dryer and air heater are combined in one chamber. Mesh trays are arranged in tiers in the drying chamber, and the distance between them was chosen considering the creation of a uniform heat carrier flow. The trays with a metal mesh bottom are rectangular in shape with dimensions of 0.80 × 0.80 × 0.05 m. The dryer accommodates six trays with a total area of 1.80 m^2.

Solar-drying installations are covered with transparent sheets of cellular polycarbonate and tightly sealed, as this material reduces heat loss by 2-3 times compared to window glass. For refilling with fresh portions of fruits, there are tight-closing doors in the front of the drying chamber. The side parts of the solar dryer are made of 15 mm thick chipboard, which ensures the mechanical strength of the unit and reduces heat loss.

To eject the spent drying agent outside, an exhaust pipe 16 is installed in the upper part of the dryer. The exhaust pipe is made so that it is also used as a recuperative heat exchanger-utilizer19 (RHU). RHU consists of an inner and outer pipe (pipe in pipe) and an exhaust fan. The height of the inner pipe is 2 m; a screw device 18 is installed inside it. The diameter of the inner and outer tubes of the RTU are 20 cm and 16 cm, respectively. The outer tube of the recuperative heat exchanger is painted black and is heated during the day by solar radiation (Fig. 1).

The principle of operation of the RTU is as follows. In the process of drying the fruits with the help of an exhaust fan - 17, the spent drying agent is discharged into the atmosphere through the exhaust pipe (through the screw channel). During its movement, the spent drying agent through the walls of the screw pipe gives off part of its heat to the atmospheric air entering the heat exchanger from the outside. The outer tube of the recuperative heat exchanger is heated by absorption of solar radiation and transfers part of its heat to the air flow entering the dryer (Fig. 1).

The flow of flows in the inner and outer channels can be assumed to be countercurrent, since countercurrent recuperative heat transfer is the most efficient. Thus, this measure with the use of RHU makes it possible to provide additional heating of the internal air of the chamber in the process of drying products by utilizing the heat of the waste coolant.

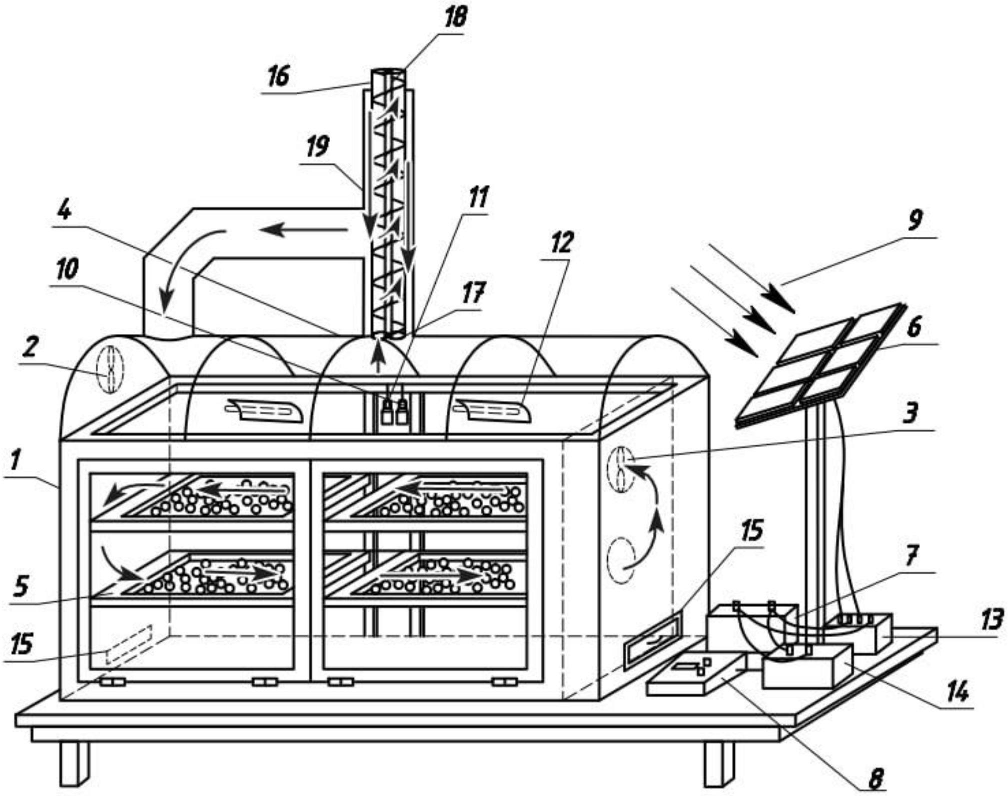

Figure 1. Circuit diagram recirculating solar drying installation (RSDI):: 1 - drying chamber; 2 - fan 1 (for ejection of moist air); 3 – fan 2 (for active ventilation); 4 - transparent insulation; 5 - pallets for dried products; 6 - solar battery (SB); 7 - battery; 8 - CP (control panel); 9 - sun rays; 10 – temperature sensor; 11 – air humidity sensor; 12 - IR lamps; 13 - controller; 14 - inverter; 15 - entrance window; 16 - exhaust pipe; 17 - exhaust fan; 18 - screw device; 19 - recuperative heat exchanger.

The proposed solar drying plant can operate in the following modes: 1). Forced circulation; 2). Recirculation mode using RHU.

The dryer is in forced circulation mode, after loading the dryer with products, fans 2 and 3 turn on, and drying of the products begins.

In recirculation mode (using RTU) it works as follows. The air heated to a temperature of 60-65°C is driven by the blower 3 through the dried fruits. In the recirculation mode, drying of fruits is carried out with a closed drying chamber (in this case, the lower windows and exhaust openings are closed). Fan 2 (exhaust) serves to remove the vapor-air mixture from the drying chamber and maintains the required temperature and humidity conditions inside the dryer. In the first period of fruit drying, the moisture content of the air in the chamber gradually increases. Upon reaching the set value of relative humidity inside the chamber, the humidity sensor (type DHT-21) 11 automatically turns on 17 the intake fan. Further, with a decrease in air humidity in the chamber to a predetermined value, the fan 17 is turned off by a signal from the humidity sensor, and the process is repeated.

EXPERIMENTAL RESULTS OF THE RESEARCH

In the solar dryer, the temperature and humidity conditions of the drying process were investigated and experiments were carried out to test the mode of drying fruits and vegetables.

To measure the temperature and humidity of the drying agent, copper-constantan thermocouples connected to a potentiometer, as well as an electronic thermometer and a humidity sensor are mounted inside chamber 1. The air velocity in the working section of the chamber was measured with an AP-1 anemometer. During the experiments, the air velocity on the upper shelf was 1.5-2 m/s, and on the lower shelf 0.5-0.8 m/s.

The temperature distribution along the height of the dryer chamber is uneven. At noon, when the average temperature at the top of the dryer was about 70°C, and at the bottom of the dryer it was about 60°C (without product loading). After loading the dryer with products, the air temperature inside the dryer drops by approximately 10^0C. But when the blower 3 is running (forced air circulation), the air temperature is almost the same in height and the temperature difference is only $1\text{-}2^0$C.

In a solar drying plant, experiments were carried out to study the kinetics of drying fruits and vegetables. Apples were chosen as the object of drying. So, apples as a valuable food product are rich in vitamins and microelements necessary for human life. Before the start of the experiment, fresh apples were cut in the form of a disk with a thickness of 3-4 mm. with a sharp knife and then laid out in a single layer on the mesh shelves without pre-treatment. Each shelf can hold 5-6 kg of product. The trays loaded with products were placed in the drying chamber. Drying began after the completion of loading, usually at 9 am.

To compare the productivity and quality of drying, samples (sliced apples) of the same weight (100 g each) were placed in the middle of the dryer and in an open area (in the sun).

During the experiments, the weight loss of the samples every hour was measured by electronic balance. Based on the weight of the samples, the relative moisture content of the product was calculated and a fruit drying curve was plotted. The studies were carried out in the recirculation mode. In this mode, after loading the camera with the product, fans 2 and 3 are turned on.

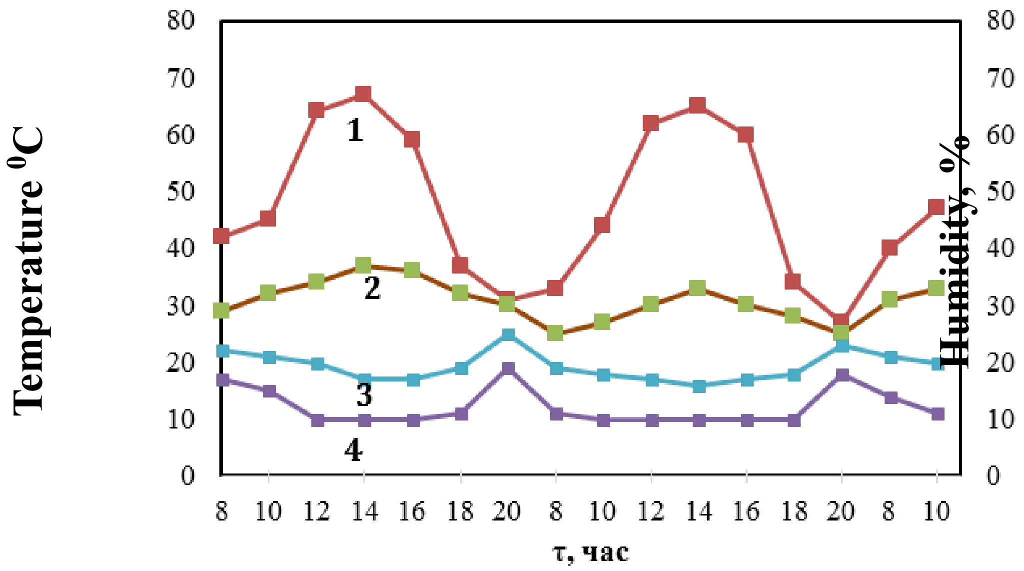

Fig.2. Temperature and humidity regime in the RSDI. 1 - air temperature in the chamber, 2 - ambient temperature, 3 - ambient air humidity, 4 - air humidity in the chamber.

In Fig.2. the temperature - humidity conditions of the RSSU during the drying of apples are shown . From fig. 2. it can be seen that the daytime temperature was about 25-30 C higher than the ambient air temperature.

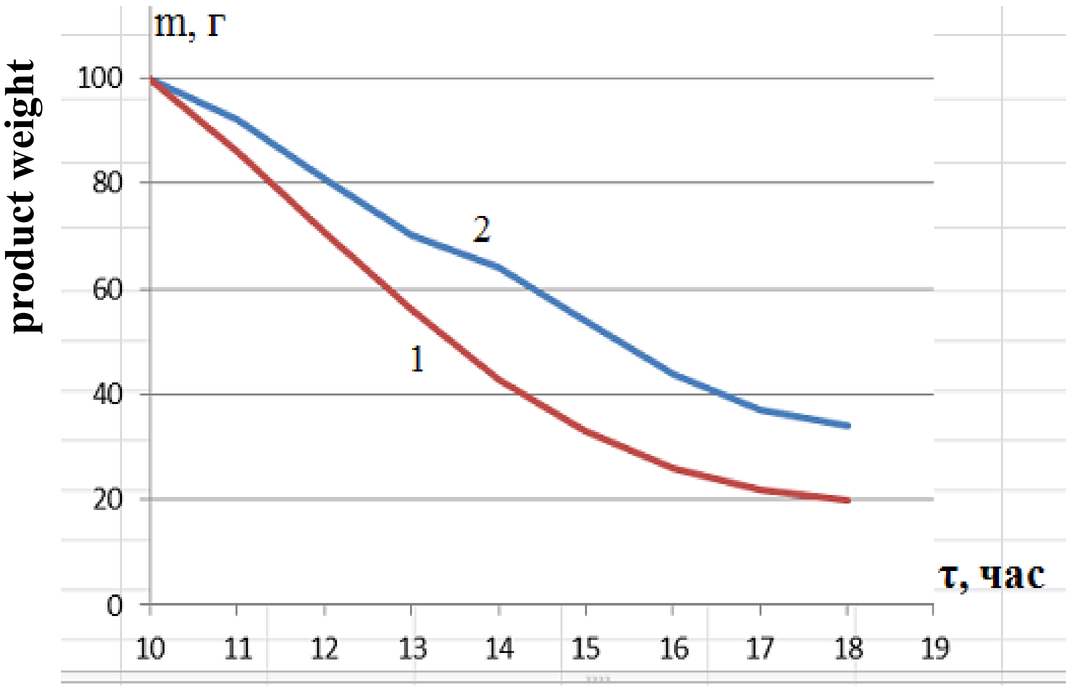

Fig.3. Curve of the kinetics of drying apples in the RSDI. 1-change in the mass of the product in a heli-dryer with a heat exchanger, 2-change in the mass of the product in a heli-dryer without a heat exchanger.

From 09:00 to 15:00, the temperature in the drying chamber gradually increases, most intensively from 13:00 to 15:00, the maximum temperature is 60-650 C. With increasing temperature, the relative humidity of the air inside the dryer decreases.

In the RSDI with a recuperative heat exchanger, the kinetics of drying apples in the drying agent recirculation mode was studied. On fig. 3. shows the curve of the kinetics of drying apples in the RSDI.

It has been established that, in this mode, the drying time is reduced by 1.5-2 times compared to that in a conventional solar dryer. At the end of drying, the moisture content of apples was 7-10%. From fig. 3. it can be seen that the use of the proposed drying modes provides an increase in the drying rate of the product by 2-2.5 times (depending on the type of product) compared to the air-solar method. Dried apples have a natural color, good taste and appearance, in all respects they meet the requirements of GOST a. The output of the finished product compared to air-solar drying increased by 2.5-3% and amounted to 8-10%.

CONCLUSION

On the basis of the carried out design and constructive and experimental work, the following conclusions can be drawn:
1. A recirculating solar drying plant with a recuperative heat exchanger has been developed, manufactured and tested.
2. The temperature and humidity regimes of the solar dryer in the process of drying apples and other fruits have been studied. It was found that the highest air temperature inside the dryer without product loading was about 70°C at mid-afternoon (13^{00}-14^{00} hours) in the month of July.
3. In the RSDI with a recuperative heat exchanger, the kinetics of drying apples in the drying agent recirculation mode was studied. It has been established that, in this mode, the drying time is reduced by 1.5-2 times compared to that in a conventional solar dryer.

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