DEMI 2023

16th International Conference on Accomplishments in Mechanical and Industrial Engineering

Banja Luka
1–2 June 2023.

www.demi.mf.unibl.org

# Experimental research of thermal drying conditions in food dryer

F. Mojsovski[a], V. Mijakovski[b]

[a]*Faculty of Mechanical Engineering, Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia*
[b]*Faculty of Technical Sciences, Kliment Ohridski University, Bitola, Republic of North Macedonia*

***Abstract*** *Existing food drying theory cannot offer good enough prediction of the drying process. Therefore, the correct drying conditions were reached by fieldwork activity, conducted on a farm dryer. The dryer was designed with drying room in the form of horizontal one-level support for the dried product. In order to improve the forced convection effect, the dryer was equipped with solar collector, auxiliary heating system, axial ventilators and dumpers. The construction of the drying room is realized in modular concept. Locally grown vegetables and fruits were used in the process of drying, but only research results for tomatoes are here presented. In the drying room, tomatoes shaped into rings with thickness of 4-8 mm, were exposed to a complex process of simultaneous heat and mass transfer. During the drying process, the change of tomato rings moisture content depends on the intensity of air temperature, air humidity and air flow. The tomato rings, with initial moisture content wet basis of 80 to 90 %, were dried to final moisture content wet basis of 6 to 12 %, for three to five days of drying time.*

***Keywords*** *drying conditions, dryer construction, tomatoes*

## 1. AIMS AND BACKGROUND

The requirement for a more suitable tomato drying process was investigated. An attempt was made to improve the drying conditions with interventions executed on dryer construction. The objective was to create air states and air flows that lead to quality dried tomato slices. Test runs were carried out during the tomato harvest period. Every combination of air state, tomato state and dryer performance that provides quality dried product was used in the next drying process realization. Increase in hot air temperature or velocity, was considered as primary factor in reaching drying process that enables production of high quality final product.

Despite botanically being a fruit, it's generally eaten and prepared like a vegetable. Tomato is mostly eaten row, but it is also used as a dried product [1]. The increasing demand for dried food and the long time availability of the dried tomato, favor its use. Sun drying removes only water from the tomato, which concentrates the tomato flavor and nutrition. Fresh tomato consists of 95 % water, 4 % carbohydrates and 1 % fat and protein. Once dried, the tomato is packed in airtight bags or stored in sunflower or olive oil. Sun dried tomatoes are used in salads, pastas and cooked dishes when intensive tomato flavor is needed.

The global consumption of tomatoes is enormous. World production quantity of

***Corresponding author***

Prof. d-r Filip Mojsovski
filip.mojsovski@mf.edu.mk

*Ss. Cyril and Methodius University*
*Faculty of Mechanical Engineering*
*Skopje, Republic of North Macedonia*

tomato, in the last three years, was at the level of 180.000.000 tonnes [2]. The United Nations Economic Commission for Europe (UNECE) in effort to help international trade, encourage high-quality production and protect the consumer interests has issued standard concerning the marketing and commercial quality of dried tomatoes. According to this standard, the final moisture content of dried tomatoes is determined in four levels: high moisture content 25 % - 50 %, regular moisture content 18 % - 25 %, reduced moisture content 12 % - 18 % and low moisture content 6 % - 12 % [3].

Tomato is very popular food in our country. The production quantity of tomato, in the last three years, was at the level of 160.000 tonnes [4]. Only two agricultural products were produced in higher quantities, peppers and potatoes. Local climate and soil are ideal for tomato cultivation. Tomato is a summer season crop. Weather conditions with the maximum temperature between 25 $^{o}$C and 35 $^{o}$C are favorable for tomato growth. Minimum temperatures from 4 $^{o}$C to 8 $^{o}$C are undesirable, but not critical for some tomato varieties.

Drying of tomato is preservation method, used to prolong its consumption period, to enlarge the list of its popular uses, enhance the product quality and ease the product handling, storage and transport. When the tomato rings have been dried to their optimum moisture content, as any other hygroscopic material, they need to be immediately placed in special bags in order to stop the contact with the surrounding air. Fresh tomatoes can кeep satisfactory characteristics, no more than two weeks, while the dried tomatoes up to six months.

There are countless tomato varieties. The influence of the tomato variety on dried product is essential, but its quality depends also on local soil, local climate, maturity, harvesting method, pre-treatment, drying process and post-treatment. The best tomato for drying ought to be fresh, firm, ripe and meaty. When the tomato contains fewer seeds and more pulp, better quality of dried product is provided. The number and shape of liquid caverns in one tomato variety is also important and has great effect on ring thickness selection and also on the intensity of dried product sticking on the support in the drying room.

Various constructions of solar dryers are developed for fruits and vegetables processing, starting from the old-time simple dryer with only one element, horizontal flat support for dried product, to the nowadays models containing solar collector, auxiliary heating source, heat exchanger, ventilator, elements for control of air temperature and air flow intensity [5].

Forced convection dryer for tomatoes has already wide application in practice.

Location of the dryer ought to be carefully selected. Clean place, remote from any contamination source, possible shadow, usually in the middle of big grass area is considered as an appropriate location. Horizontal terrain, 5 m x 15 m, is sufficient for dryer accommodation. This area is fenced laterally and from the top, by plastic net. Only one door, 1 m x 2 m, is made for communication with the dryer space. Plastic ground cover, 2 m x 2 m, located at the collector entrance is needed to provide clean air inlet.

The air temperature level is crucial for the drying process. Higher temperature means shorter drying time, but the permitted drying temperature in the drying room cannot be surpassed. The maximum permissible temperature is determined by tests. The temperature profile in the drying room is mainly influenced by the collector, the heat transfer between the drying room and the environment and the air flow rate.

In the morning and late in the afternoon, the air temperature at the exit of the collector is close to the surrounding air temperature and for that reason help of auxiliary heating system is needed. At noon the air temperature at the exit of the collector is too high, and therefore atmospheric air is added in the mixing section.

## 2. EXPERIMENTAL

The research was realized with the use of farm dryer. Functional scheme of convective dryer is shown in Fig.1.

In our research, before drying, tomatoes were washed with water and then cutted at a test thickness of 3 mm, 5 mm and 7 mm. Than the tomatoes can be salted or sulfured. The tomato rings are treated with sulfur dioxide prior to drying. This procedure enables the tomato to keep its bright color, inhibits the microbiological growth and contributes to the unique flavor of the product. The sulfur dioxide, from the sun exposed tomato rings, evaporates slowly and creates barrier to the rodents, birds and insects. In our case, tomato rings were rather treated with salt then with sulfur dioxide. Tomato is dried from initial moisture content, wet basis, up to 95 % to final moisture content, wet basis, to at least 6 %.

Atmospheric air enters into the solar collector, passes through the heat exchanger and mixing section and dries the tomatoes in the drying room. The air velocity is intensified by axial ventilators. Protective cover is used, at the entrance of atmospheric air in the collector, to stop the elevation of dirt from the ground.

The basic elements of the dryer are: solar collector, heat exchanger, auxiliary heating device, mixing section, drying room, ventilators and dumpers. The solar collector intensifies the thermal energy flow at the entrance of the drying room. Heat exchanger is used to reheat the inlet air in the drying room. Additional heating is realized with the use of auxiliary heating device which uses liquefied petroleum gas as fuel. In the mixing section, high temperature of the air is lowered by adding atmospheric air. Drying room is covered by plastic foil which can be raised for loading or unloading the dryer.

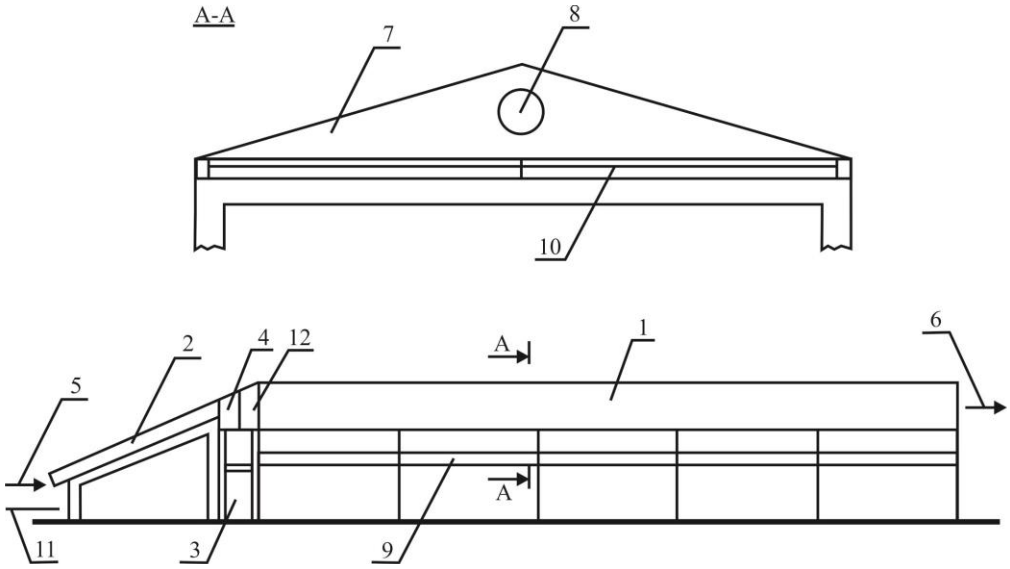


**Fig. 1.** Functional scheme of convective dryer

1-Drying room, 2-Solar collector, 3-Auxiliary heating source, 4-Heat exchanger, 5-Air inlet, 6-Air outlet, 7-Plastic cover, 8-Axial ventilator, 9-Dryer support, 10-Dried product support, 11-Protective cover, 12- Mixing section

A tent model of dryer was developed, to protect the dried product from direct solar radiation, to reduce the heat losses, to eliminate the influence of wind, dust, rain, birds and insects. The inlet of the solar collector and the air outlet from the drying room are closed by plastic net. The collector entrance and the drying room exit have dumpers to stop the air flow in occasion of bad weather conditions. Dumper is positioned at the drying room entrance in order to regulate the air temperature. Between the solar collector and the drying room, heat exchanger is installed to enable heating of the drying air with the use of auxiliary heating device, and mixing section for regulation of the entrance air temperature. During the period of extreme solar radiation the air temperature, at the solar collector exit, exceeds 60 $^{o}$C and ought to be reduced.

To increase the thermal inertia of the drying system, two tests were conducted. Under the supports of the drying room, rocks were placed or metal tanks filled with water. This accumulation of thermal energy, partially reduced the lack of energy during sunless periods.

Five dryers of the same construction were located across the country.

The basic drying room module is the horizontal support, 1.5 m x 1 m. Two trays, with dimensions 0.7 m x 0.9 m, are used. They are made of stainless wire net and covered by plastic net. The hot air has the possibility to flow under the trays.

Two factors are crucial for drying tomatoes successfully: the control of temperature level and air circulation. At temperatures lower than 30 °C, the product will dry slowly, giving bacteria or mold chance to grow. On the other hand, at temperatures higher than 75 °C the tomato cooks or hardens on the outside, while in the inside remains moist. The optimal drying temperature range is between 45 °C and 60 °C.
Properly harvested tomatoes were visually inspected, washed with water and then cutted in rings of 3 mm, 5 mm and 7 mm thickness. The initial moisture content, wet basis of 80 % - 90 %, was reduced in the drying process to final moisture content, wet basis of 6 % - 12 %.
In the next step, the dried product was accepted by vacuum packing device.
For every drying process, tomatoes were arranged at the flat support of the drying room. Those tomato rings that had peel on one side, were placed on the support with the peel-side. In order to retain the tomato juice and seeds in the rings, baking paper is placed under all the tomato rings. The use of this method also reduces the intensive sticking at the flat support.
The moisture content of the samples was controlled by weight measurement at fixed time intervals. Air flow in the drying room was continuously measured, and estimated based on experience and tests conducted in laboratory conditions.
Drying process was inspected by measurements, visual evaluations and tests. The measurements were applied to dried product state, drying medium state and drying room characteristics: 1. initial, modular and final dried material state (moisture content, temperature), 2. initial, modular and final drying medium state (temperature, relative humidity, flow), and 3. dryer (drying time, fuel consumption for additional energy). Digital thermometers, hygrometers and anemometers were applied.
Weather conditions at dryer location (cloudiness, wind intensity and wind direction), were also recorded. Ventilated hygrometers and psychrometric diagram, were used for determining the state of the atmospheric air [6]. The expected weather conditions were planned in accordance to the climatic curve for the dryer location [7].
Three tomato varieties were tested: Hamson, Heinz and Roma.

## 3. RESULTS AND DISCUSSION

Fresh tomatoes, after washing and cutting, were arranged in one row at the flat support of the drying room.
Tomato rings with thickness of 5 mm were evaluated as the best. This drying product reached 4.5 kg/m$^2$ product load.
To keep the drying space in the desired state, needed air flow rate was provided by ventilators. Required supply air flow rate was reached by axial ventilators. Velocities up to 4 m/s were used in accordance to previous gained experience and laboratory conducted tests.
The decrease of moisture content, in the dried tomato rings, was inspected every hour. Selected samples were controlled in the laboratory. When the specified final moisture content was achieved, the drying process was completed. Drying curves were obtained for every drying cycle.
Correct air flows were in the range up to 1 m$^3$/s. Tomato rings were dried until final moisture content, wet basis of 6 % - 12 % was reached. In order to achieve the specified moisture content, tomato rings needed three to five days drying time. Thirty kilograms fresh tomatoes were dried per cycle.
An example of correct operational drying conditions for tomatoes is presented in Table 1.

**Table 1.** Operational drying conditions for tomatoes

| Drying medium | Dried product | Dryer |
|---|---|---|
| Period of drying: 1.06 - 30.09 | Variety: Hamson | Type: Convective |
| Air state in atmosphere | Diameter x Height: 7 x 5 cm | Modules: 5 |
| temperature: 20 - 40 °C | Weight : 230 g | Module capacity: 6 kg |
| relative humidity: 20 - 60 % | Moisture content | Ventilators: 2 |
| Air state in drying room | initial, wet basis, 80-90 % | Orientation: South |
| temperature: 40 - 60 °C | final, wet basis, 6-12 % | Area: 15 x 5 m |
| air flow: 0.25 - 1 m$^3$/s | Inlet temperature, 25 - 35 °C | Location: Skopje |
| air velocity: 1 - 4 m/s | Final temperature, 45 - 50 °C | Accumulator: Rocks |
| | Thickness: 5 mm | Drying time: 3-5 days |

## 4. CONCLUSIONS

Farm dryer for tomato drying is made functionally more advanced with creating conditions for obtaining higher temperatures at the entrance of the drying room and by intensifying the air flow around the dried product.

The proposed dryer construction solution has contributed significantly in the improvement of the drying process for producing quality dried tomatoes. Results from this research showed that the actual drying system has maintained functional stability even in the sunless periods. The stronger heat source and the increased air flow, additionally provide the possibility to dry other vegetables, at higher temperatures and with more intense air flow.

Well rated drying conditions, for locally grown tomato variety, are reached and published.

## REFERENCES

[1] Parnell, T., Suslow, T., Harris, L. (2004). Tomatoes: Safe methods to store, preserve and enjoy. *ANR Publications*, Publication 8116. DOI: 10.3733/ucanr.8116

[2] FAO (Food and Agriculture Organization of the United Nations). (2020). *FAOSTAT*. Rome, Italy.

[3] UNECE STANDARD DDP-19. (2007). *Concerning the marketing and commercial quality control of DRIED TOMATOES 2007 Edition*. United Nations. New York, Geneva.

[4] State Statistical Office: Statistical Yearbook of the Republic of North Macedonia for 2021. (2021). Skopje.

[5] Mojsovski, F. (2014). Drying conditions for rice and tomato. *International Journal of Mechanical Engineering and Technology*, vol. 5, no. 10, p. 78 - 85.

[6] (2011). *Handbook HVAC Applications*. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), Atlanta.

[7] Mojsovski, F. (2010). Prediction of moist air specific enthalpy. *Mechanical Engineering-Scientific Journal*, vol. 29, no. 1, p. 19 - 23.