The 20th International Conference on
Thermal Science and Engineering of Serbia
SimTerm2022
Niš, Serbia, Oct 18-21 2022

Apple Drying in Convective Belt Dryer

Filip Mojsovski[a], Vladimir Mijakovski[b]

[a] Faculty of Mechanical Engineering, Skopje, MK, filip.mojsovski@mf.edu.mk
[b] Faculty of Technical Sciences, Bitola, MK, vladimir.mijakovski@tfb.uklo.edu.mk

Abstract: Convective belt dryer was used for apple drying. Experimental research was conducted, for discovering the drying conditions which lead to quality dried product. Three-thermal zones convective drying was applied in intermittent process of heat supply. In the drying room, the apple slices were arranged in one level. The mutual influence of drying medium state, dried product state and dryer performances was observed and encouraged in correct direction. Air temperatures between 35 ºC and 85 ºC, air velocities between 2 m/s and 5m/s and drying intensity between 5 h/cycle and 8 h/cycle were used. The essential parameters were collected and applied in quality drying process realization.

Keywords: Food drying, Convective dryer, Apple.

1. Introduction

This paper expresses the results of apple processing in industrial type convective belt dryer. Various constructions of solar dryers for fruit drying are developed and are available on the market nowadays, but their drying conditions are rarely published.

The use of multi-zonal drying process was researched. A procedure for a comprehensive evaluation of drying conditions was defined. The principle of discontinuous heat supply was applied. In this intermittent drying process, during the pause of heat flow, moisture has enough time to diffuse within the dried material. As a result, the temperature and moisture content gradients in the product are sufficiently reduced, before further drying. This oscillatory drying process improves the quality of dried product, [1].

Intermittent food drying, in drying space organized as multi-thermal zone system [2], has wide application in practice, for example in high-capacity cereal drying systems [3].

In the conducted research, the inlet air temperature for every thermal zone was different. Fresh apple rings in the first zone were “attacked” with highest air temperature. In the second zone, lower temperature was applied. The temperature level in the third zone was regulated in accordance with the measured moisture content of dried product.

The influence of intermittent drying on quality of dried apple rings is determined by the number of pauses and duration of retention time.

Apple is juicy, nutritious and delicious fruit, usually consumed fresh, but is also used as dried product. Apple drying is preservation method. Drying process prolongs the availability of the apple, enlarges the list of its uses, enhances the product quality, eases its handling, transportation and further treatment. Before entering in the drying room, apple is prepared in the phases of washing, peeling, core removing and cutting in rings.

After the drying, the apple rings are packed in special bags for hygroscopic material. This processing requires space, machines, operators and energy. There are thousands of apple varieties. Apples of different varieties range in appearance, flavor and texture.

A distinction can be made between dessert apple (apple for eating fresh), commercial apple (industrial use for apple puree, apple jelly and obtaining pectin) and cider apple (juice, wine). Apples are categorized into summer, autumn and late varieties, depending on when they ripen [4].

The consumption of apple is enormous. The world apple production is at level of 80.000.000 tonnes [5]. In our country the apple production is at level of 100.000 tonnes [6].

For human consumption, the whole apple is suitable, except the seed skin and the core. The apple skin, nowadays is always eliminated of human nutrition, because during the apple tree protection, too much pesticides are applied. Apple consists of 86 % water and 14 % carbohydrates.

The apple is dried from initial moisture content, wet basis of up to 85 % to final moisture content which is four times lower. Dried apple quality depends on drying conditions. Applied combinations of drying medium state, dried product state and dryer performances, during the drying process, which provide a quality dried product, are suitable drying conditions.

The selection of these combinations was realized in the process of continuous valorization of the dried product behavior, based on: 1. measurements in the dryer, air state (temperature, humidity, velocity), dried product state (moisture content, thickness), dryer (drying time, energy consumption), 2. engineering experience (dryer construction, dryer location, product variety), 3 available data (climatic curves, weather forecast, published standards). The air temperature level has crucial influence on drying process. Higher temperature means shorter drying time, but for every product maximum permitted temperature exists, and it must not be surpassed [7]. Air flow intensity and direction have important influence on the process of heat and mass transfer from the apple rings surface to the surrounding air. They were determined according to the experience and conducted laboratory and field tests.

The quality of dried apple depends also on apple variety, maturity, harvesting and pre-treatment, but dominantly on applied drying process.

In general, attention was concentrated on determination of relevant parameters for drying process and identification of operational problems. The convective belt dryer, with three thermal zones intermittent drying, was successfully used for drying of other fruits and vegetables such as plum, fig, tomato, pepper and carrot, thus proving its universality in exploitation.

2. Equipment - Convective Belt Dryer

The actual research was carried out on industrial type dryer. Functional scheme of convective belt dryer is shown in Figure 1.

On one side, the dryer is loaded with apple rings from the transport belt, and at the other side the dried product is directly accepted by packing device.

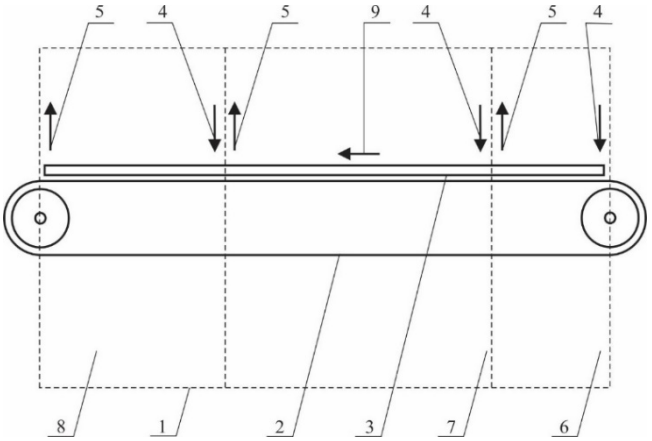
The thermal conditions were different along the drying room. Drying room space was divided in three thermal zones: zone 1 (length: 4 m), zone 2 (length: 8 m), and zone 3 (length: 6 m). Every zone was supplied with air from: one heat exchanger, one ventilator for inlet air and one ventilator for outlet air. The air flow corridor in the space over the dried apple rings was formed by tin deflectors. By using this construction, separate zonal and primary vertical air flow toward the dried surface and controlled air circulation, was achieved.

Apple washing, performed in the preparation room, was the first operation. The water spray system was used for high quality washing. Next operations were apple peeling, core removing and cutting in rings. They were done by machine, and losses up to 30 % were registered. For one cycle of the used dryer in the investigation, high quality machine can finish all phases of apple preparation, within one hour [8]. Finally, the apple pieces were transported to the conveyer in the drying room.

The conveyer, made of stainless steel wire, is 18 m long and 3 m wide. Velocity regulator is mounted on the conveyer, obtaining the opportunity to change the intensity of the drying process. Conveyer velocities of 4 m/h to 9 m/h were tested. An air knife, at the end of the conveyer belt, downloads the dried product from the belt. For cleaning and for sticking prevention, at the unloading side of the dryer, the top surface of the conveyer is equipped with dry and wet brushes.

Heat exchangers receive heat from the central hot water system. Atmospheric air is heated and distributed at the beginning of every thermal zone. Ventilator is installed for extraction of the used air in every zone. Drying room is carefully insulated. Side walls are built of insulated panels.

Electric command cabinet, for automatic guidance of the drying process, was connected with measuring instruments in the dryer and completed with specified data.



1-Drying room, 2- Conveyer, 3-Dried product, 4-Air inlet,
5- Air outlet, 6-Zone 1, 7-Zone 2, 8-Zone 3, 9- Conveyer direction
Figure 1. Convective belt dryer - functional scheme

3. Procedures, Results and Comments

The needed heat amount for atmospheric air heating, in the period from September until November, when the dried apple variety is harvested, was predicted with the use of climatic curve. The statistical data, for the mentioned period, showed air temperature range between 30 °C and 2 °C. Graphically, with the use of psychrometric chart, the air enthalpy range from 120 kJ/kg to 140 kJ/kg was calculated, for entrance air temperature of 80 °C in the Zone 1. The drying cycle with partial air recirculation was estimated as better and was applied. The values of 0,42 W/mK for apple rings thermal conductivity and 3,8 kJ/kgK for apple rings specific heat capacity were used [10].

The existing industrial convective belt dryer was constructively modified, to reach the drying conditions specified in the research plan. Three heat exchangers, three supply ventilators, three extraction ventilators and all the needed air ducts and air deflectors were mounted. Three thermal zones intermittent drying process, was selected as convenient. Correct location of tempering zones was determined in test procedure at industrial type dryer. Planed air zonal distribution and circulation was precisely realized with the effect of mounted ventilators and air deflectors. Duration of tempering period, which separates two adjoining drying steps, was investigated. Retention times from 30 to 80 minutes were used. Best results were reached with retention time of 60 minutes, after the apple rings have passed zone 1, and 60 minutes before their entrance in zone 3. Conveyer velocity of 6 m/h was selected as suitable. After the first and second zone the conveyer was immobile for 60 minutes. For one conveyer pass, five hours of time were required. Air velocities up to 5 m/s were practiced.

The apples were cut in rings, with a thickness of 3, 4 and 5 mm. The optimum ring thickness was determined by tests. In some experiments, apple rings were sulphuretted from 15 to 30 minutes. To avoid darkening, the apple rings were kept into water, with 1 - 2 % salt or lemon acid, until the start of drying operation. The fresh apple rings, have the maximum moisture content and therefore the inlet air temperature of 80 °C was used in the zone 1. At this point, the biggest amount of moisture was extracted from the product. The temperature was ten degrees lower in the zone 2. In the first two zones, the drying process was almost finished, and the use of third zone was for stabilization of the dried product state, at air temperature of 60 °C. Apple rings were dried from initial moisture content, wet basis of 80 - 85 %, to final moisture content, wet basis of 24 - 28 %.

Due to the lack of domestic standards for dried apples, foreign were taken into account. Final moisture content, wet basis of 24 %, is the lowest in the United States standard [10]. Two percent lower value, is specified as limit, in the standard for dried apples of the United Nations Economic Commission for Europe [11]. In the drying process, resulting in a quality dried product, apple rings were dried until the moisture content of 24 % (wet basis) was reached. The leading apple variety, in actual European apple cultivation practice, is Golden delicious [12]. Four apple varieties were part of the conducted research: Golden delicious, Red delicious, Jonagold and Granny Smith. An example of apple drying process, with well rated drying conditions for apple processing presented in Table1.

Table 1. Suitable drying conditions for apple

Parameter		Zone 1	Zone 2	Zone 3
Drying medium				
Temperature	°C	80	70	60
Velocity	m/s	4	4	2
Flow mode		Intermittent		
Dried product				
Variety		Golden delicious		
Diameter x Height	cm	6x7		
Weight	g	180		
Fresh ring thickness	mm	4		
Fresh apple/cycle	kg/cycle	140		
Moisture content, wet basis, initial	%	85	48	32
Moisture content, wet basis, final	%	48	32	24
Dryer				
Location		Kočani		
Type		Belt dryer		
Conveyer velocity	m/s	6	6	6
Drying time	min	40	140	120

4. Conclusion

Thermal solution, for quality dried apple slices obtaining, was recognized in the intermittent three thermal zone drying process applied in industrial type convective belt dryer. Both crucial problems for reaching suitable drying conditions: zoning of drying space and duration of tempering period, were solved in field test procedure, based on engineering experience and measurements.

Correct drying condition for apple processing are selected and proposed.

References

[1] A. Filippin, L. Filho, V. Fadel, M. Mauro: Thermal intermittent drying of apples and its effects on energy consumption, Drying Technology-An International Journal, 14 (2018), pp. 1662-1677
[2] ASHRAE (American Society of Heating, Refrigerating and Air - Conditioning Engineers), Handbook HVAC Applications, Chapter 25: Drying and Storing Selected Farm Crops, Atlanta, USA, 2011
[3] D. B. Brooker, F. W. Bakker-Arkema, C. W. Hall: Drying and storage of grains and oilseeds, Van Nostrand Reinhold, New York, 1992
[4] TIS (Transport Information Service) from the German Insurance Association: Fruit/vegetables/nuts/foods of vegetable origin-Apples, Berlin, 1998-2022
[5] FAO (Food and Agriculture Organization of the United Nations), FAOSTAT, Rome, Italy, 2021
[6] Statistical Yearbook of the Republic of N. Macedonia 2021, State Statistical Office, Skopje, Republic of N. Macedonia
[7] F. Mojsovski, P. Živković: Drying intensity influence on quality of dried food, Proceedings, 18th Symposium on Thermal Science and Engineering of Serbia, Sokobanja, Serbia, October 17-20, 2017, pp. 138-143
[8] ASETSM, Apple processing machine (peeling, coring, dividing, cutting), FEUMA Gastromaschinen GmbH, Gossnitz, Germany
[9] F. Mojsovski, D. Dimitrovski, Apple quality preservation with the use of intermittent drying process, Journal of Environmental Protection and Ecology, 4 (2018), pp. 1536-1543
[10] United States Department of Agriculture: United States Standards for Grades of Dried Apples, Washington, D. C., Published in the Federal Register (20 FR 7095), USA, 1955
[11] United Nations Economic Commission for Europe (UNECE): UNECE Standard DDP-16 concerning the marketing and commercial quality control of dried apples, New York and Geneva, 1998
[12] W. Guerra: Varieties-trends in the European Apple Cultivation, Schweizer Zeitschrift fur Obst-und Weinbau (SZOW), 5 (2016), pp. 8-12