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DEVELOPMENT OF SMALL-SCALE LOW-COST METHODS OF DRYING HERBS AND AGRICULTURAL PRODUCTS

Herbs are characterised by different contents of biologically active substances, hence they are widely used in various branches of industry. Herb cultivation in East-Central Europe focuses on small-sized areas requiring machines and equipment adapted to the scale of production. The processing of herb plants involves drying, which is one of the most important stages of herb preservation, conditioning the right quality of the raw material. This article presents a short description of the methods for herb preservation and a classification of drying systems using solar energy and hot air. Looking for ways to assure the drying of the crops in unfavourable atmospheric conditions, variants of solar collectors with the biomass-powered furnace for heating drying air in driers of herbs have been invented. The solutions developed by authors of this paper to provide small-scale low-cost technological devices for the drying of herbs and specialty crops are also presented. The installations presented use hot air from solar radiation and heat generated from the combustion of biomass in the form of wood chips. These installations and equipment do not require an electricity supply. The elimination of natural drying through the use of drying chambers eliminates the unfavourable effect of ultraviolet radiation on the loss of essential oils. The drying installations and devices presented in this article are under patenting procedure.

Keywords: drying, drying chamber, herbs, herbs cultivation, solar collector, spices, wood chip burner

1. Introduction

The preservation of food, herbal products and feed using drying processes is the oldest method commonly used in preservation. Climatic conditions – exposure to the sun, precipitation, and thermal conditions – are very important in

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drying processes, which are usually energy-consuming and therefore expensive to use in practice. In recent decades solar energy has been widely used as a heat source with wind acting as an important driver of drying kinetics. Natural environmental conditions are not favourable for carrying out drying processes in a continuous manner, because it is impossible in practice to ensure the stability of basic atmospheric parameters, such as the intensity of solar radiation, cloudiness, temperature and air humidity. About 130 species of herbal plants are cultivated on a large-lot production scale in Europe, and the area of cultivation of herbal plants in the European Union countries covers about 70,000 ha. About 20 thousand species are used for therapeutic purposes [1]. Specific species of herbs differ in biological features, require different types of cultivation and various protective treatments and cultivation.

The drying of herbs and agricultural products is a major operation in the pharmaceutical and food industry. A cultivated plants and herbs are harvested for food, livestock fodder, biofuel and medicine. Due to seasonal nature of agricultural crops, a need was felt to preserve crops over a period of time for use during off-seasons [2]. Crops need to be dried with low moisture content before long-term storage.

In the countries of East-Central Europe, the natural sun drying method is commonly used for drying herbs and spices. The products being dried in such conditions are usually contaminated with insects and dust [3]. Due to the rewetting of the products by rain during drying and the too slow drying rate in the rainy season, the use of natural sun drying is limited.

Herbs are characterised by different contents of biologically active substances, hence they are widely used in various branches of industry. Herb cultivation in East-Central Europe focuses on small-sized areas requiring machines and equipment adapted to the scale of production. The processing of herb plants involves drying, which is one of the most important stages of herb preservation, conditioning the right quality of raw material [4, 5]. This article presents a description of methods for herb preservation and a classification of drying systems using solar energy and hot air. Furthermore, the article also presents dryers and installations in small-scale and low-cost technological installations for the drying of herbs and specialty crops. The drying installations and devices presented in this article are under patenting procedure (Table 1). The installations presented use hot air from solar radiation and heat generated from the combustion of biomass in the form of wood chips. The drying installations and devices presented in the article fill the gap between high-performance commercial dryers and natural drying carried out by small producers of spices and herbal plants, especially in East-Central Europe.

Table 1. The drying installations and devices under patenting procedure

Name	Type	Number of application	Year
Photovoltaic solar collector	invention	P-426793	2018
Furnace-assisted solar drying installation	utility model	W-126579	2017
The air heater equipped with biomass furnace	invention	P-422748	2017
A wood-chip burner	utility model	W-126578	2017
Mobile drying chamber	invention	P 424894	2018

2. Methods of drying

The methods of drying herbs are presented in Fig. 1. Traditional methods have been used such as open-air sun and solar drying, with direct and indirect use of solar energy, respectively, and/or shade drying [6]. On a smaller scale, freeze drying, convection drying with hot air, and ultrasound assisted drying methods have also been used. Hot-air drying and shade drying are widely used due to their low cost [7].

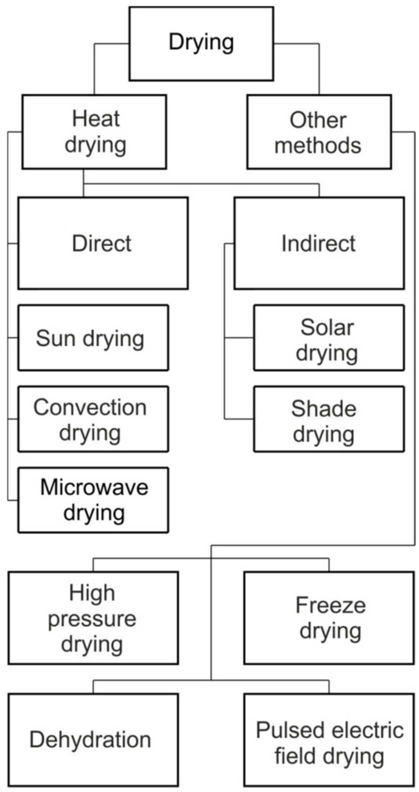

Fig. 1. Methods for drying herbs (prepared based on the [6])

Drying in the sun is one of the oldest methods of drying that utilise solar energy. It is widely used throughout the whole world to dry agricultural products, such as medicinal plants [8]. Solar drying systems can be categorised into indirect, direct and mixed [9]. Indirect solar drying is a very efficient method. In this method the atmospheric air is heated on a flat plate collector or concentrated-type solar collector. Hot air flows through the chamber where the raw material is stored. The heating process is either passive or active, and moisture from the product may lost by diffusion and convection [10]. In direct solar dryers, the heat is generated by absorbing solar radiation on the product itself and the internal surface of the drying chamber. Solar energy passes through a transparent cover and is absorbed by the product. The main advantage of the direct system is that the product quality obtained is higher than 'open to the sun' drying [10]. Mixed-mode solar dryers use the combined action of solar radiation incident directly on the material to be dried and air pre-heated in a solar air heater. The cost of installation for mixed mode drying is higher than for other drying installations, however, the time required for drying is less than with other drying techniques.

Hot-air drying using convection ovens is a fundamental technology for postharvest preservation of aromatic and medicinal plants [11]. The drying period with shade drying is longer than in the case of sun drying [12]. Moreover, rainy weather conditions lead to a susceptibility to rehydration of the dried product. To accelerate the mass transfer process and to shorten the drying time without over-heating the herbs, ultrasonic-assisted drying has been developed. Acoustic energy produces oscillating velocities and microstreaming at the interfaces which may break the bonding of water molecules [13]. Vacuum-microwave drying methods reduce the negative effects of excessive destruction of the herb structure. Microwave drying reduces both the drying time and the cost by rapid evaporation of water from the plant tissue [14].

Freeze-drying is a process in which the solvent and the suspension medium is crystallized at a low temperature and thereafter sublimated from the solid state into the vapor phase [15]. This process has become one of the most important processes for the preservation of herbs and agricultural products in the bio-industry sector. Although the freeze-drying is a most expensive process for manufacturing a dehydrated products this process is characterized by some advantages compared with other drying methods, i.e. high recovery of violates, high yield, lower processing temperature, reduced weight for storage and shipping, and minimal shrinkage and low alterations concerning both the chemical composition and color [16]. According to Rati et al. [17] freeze-drying allow the highest retention of bioactive compounds comparable with the raw material.

The high-pressure (HP) drying consists in removing spores of bacteria or microorganisms from the agricultural product. The high-pressure treatment is a preservation method that makes use of an interaction between three basic physical parameters: time, temperature and pressure [18]. HP drying of agricultural products is often accompanied by a reduction i volume. Moreover, application of high pressure to vegetables and fruit changes texture due to liquid infiltration. The effectiveness of HP drying depending on processing conditions, product form and intrinsic factor of food such as pH [18].

3. Proposals for small-scale drying methods

3.1. Modular solar collector

Commercially available solar driers are not adapted for, or are not fully adapted for, use in conditions of agricultural crop drying on a non-commercial scale. A solar collector has been developed which has a modular structure with a heating module and at least one photovoltaic solar collector, with the photovoltaic collector containing an air chamber inside which the solar cells are located. It is preferable that the solar collector is composed of tunnel-shaped modules.

The construction of the collector allows one to ensure appropriate kinetics of the process of drying large amounts of material with high humidity and independent of unfavourable weather conditions. By adding a larger number of photovoltaic modules, it is possible to easily increase the power of the collector, and in addition, the construction of the photovoltaic solar module allows its dismantling and convenient transport. Thanks to the use of a temperature sensor and controller, it is possible to control the temperature and prevent too high temperatures in the drying chamber of the dryer, which is particularly important when drying herbs. Most of the herbal raw materials require a so-called low or medium temperature convection drying process, with the temperature of the drying air not exceeding 40°C, thus creating very favourable conditions for the use of solar collectors. The use of a collector will be particularly beneficial in small and medium-sized farms. A modular solar collector is composed of a photovoltaic module and a heating module connected to each other by a channel (Fig. 2a). Inside the photovoltaic module there is an air chamber, with photovoltaic cells located on the bottom of this chamber (Fig. 2b).

The collector is equipped with an energy accumulator and a controller. Radiators, a temperature sensor, photovoltaic cells, a fan and an energy accumulator are connected to the controller and are supplied with electricity generated by the photovoltaic cells. The preheated air in the solar module passes to the inlet section of the heating module where it is preheated, and then goes to the outlet section where it is heated to the desired temperature. If the temperature obtained in the inlet section, as measured by the temperature sensor, is sufficient then the radiators in the outlet section are switched off. The heating power of the radiators and the air flow are controlled by a control system. In the input the controller is connected to a temperature sensor placed in the inlet section of the heating module. In the outlet the controller is connected with heaters located in the outlet section of the heating module and fan.

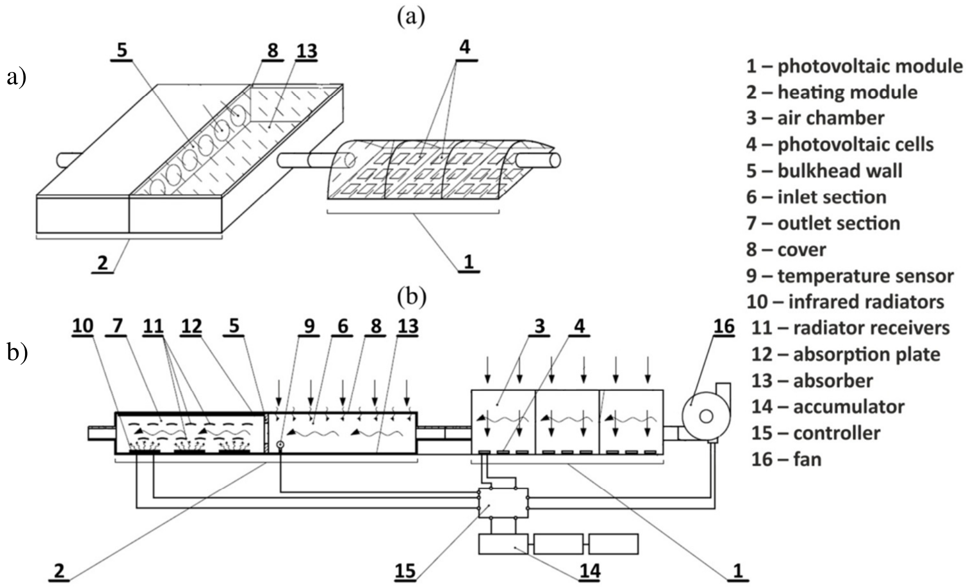

Fig. 2. Photovoltaic solar collector (a) and cross-section of the modular solar collector installation (b)

3.2.Furnace-assisted solar drying installation

Looking for ways to assure the drying of the crops in unfavourable atmospheric conditions, variants of solar collectors with the furnace (Fig. 3) for heating drying air in driers of herbs have been developed. The dryer is fed depending on the atmospheric conditions and the required drying parameters from the solar collector or furnace. The air after the flow through the collector is supplied to the combustion chamber in the furnace and to the heat exchange chamber located between the combustion chamber and the air inlet into drier. The device developed is currently under patent procedure. The combustion chamber is insulated from the walls of the heat exchange chamber by two insulating layers, one of which is a chamotte layer and the second is a vermiculite layer. When the furnace is fed with woodchips or pellets, the benefits of effective combustion of these heating materials are obtained if the burner is equipped with a fan.

The furnace for heating the air contains a combustion chamber, with a mounted burner, which is separated by a plate from the heat exchanger (Fig. 4). The flue consists of at least two sections connected to each other. The sections are made of a flexible metal tube coiled in conical spirals with at least two coils. The control of the heat exchange surface is possible by changing the number of mounted sections.

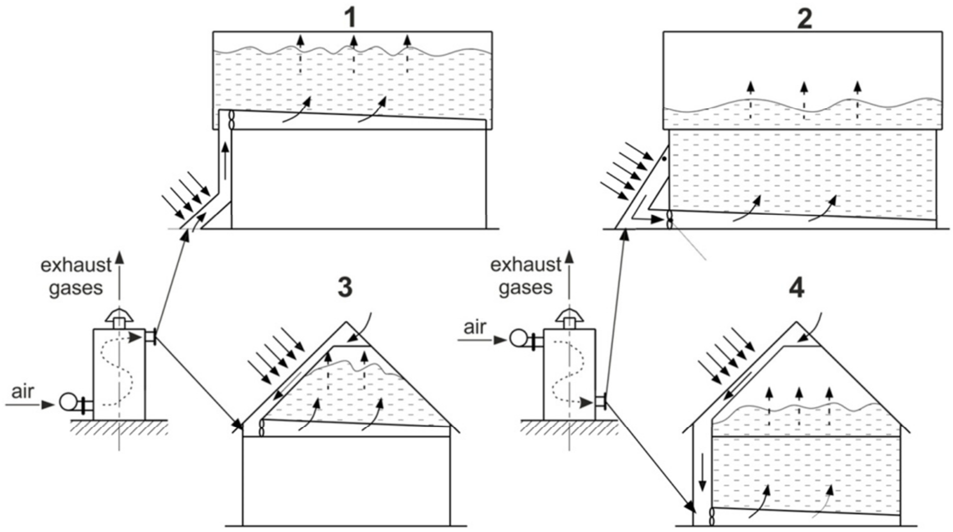

Fig. 3. The principle of cooperation of a furnace with the dryers equipped with solar collectors in the attic and in the barn: 1, 2 - a wall collector; 3, 4 – under roof collector

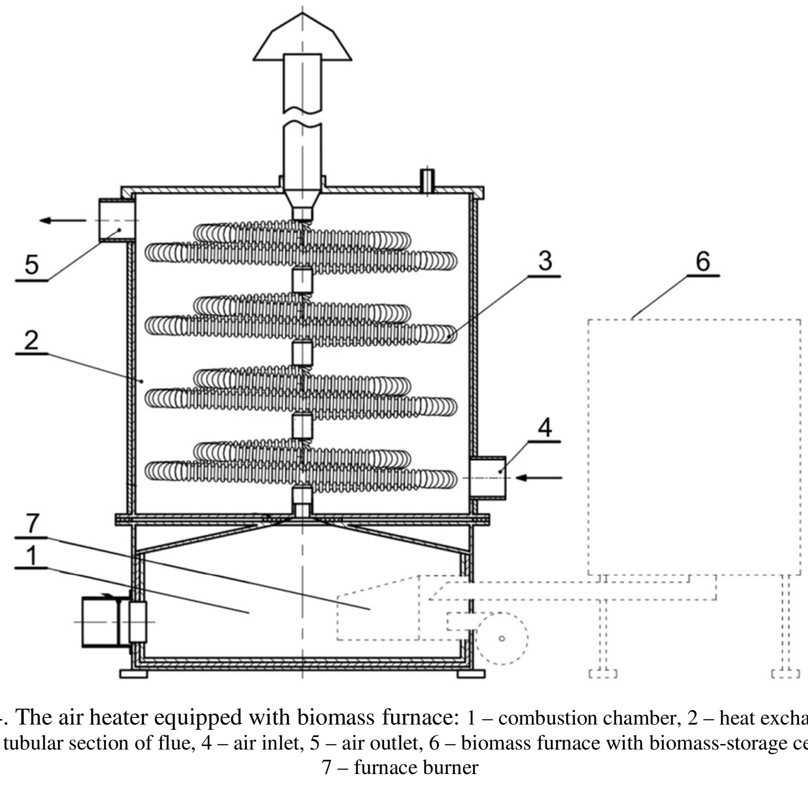

Fig. 4. The air heater equipped with biomass furnace: 1 – combustion chamber, 2 – heat exchanger, 3 – tubular section of flue, 4 – air inlet, 5 – air outlet, 6 – biomass furnace with biomass-storage cell, 7 – furnace burner

The biomass-powered furnace used in the heating system with variable heat exchange surface allows for easier maintaining the temperature of the heated air and, as a result, its adaptation to the weather conditions and the requirements of the dried material. The construction of the burner is original and is described in next section.

3.3. Wood chip burner

Commercially available furnace burners are effective in the combustion of pellets, whereas in the case of chips there may be difficulties in the transport and dosage of the fuel to the combustion chamber due to the varying geometrical characteristics of the shredded wood material. In addition, the solutions used are often of a complicated construction, and thus are expensive to purchase and operate.

Pipes are located inside a wood chip burner that has been developed for a furnace-assisted solar drying installation. These distribute the air in the combustion chamber which improves the effectiveness of combustion. The burner is mounted in a wood-fired furnace. The housing of the burner is a rectangular pipe, bevelled at the front. In the back part of the housing there is a connection to the fuel supply, and below there is an air inlet from the fan (Fig. 5). A channel is connected to the inlet, which divides into four tubes. Each of the tubes has nozzles directed towards the centre of the combustion chamber. In order to improve the air circulation and reheat the exhaust, the burner is equipped with an air guide which is curved downwards. A ceramic heater is mounted inside the combustion chamber at the bottom of the housing on the cast iron grate.

A layer of insulating material is provided on the bottom wall of the housing of the burner. At the exit from the burner, an exhaust temperature sensor is mounted, coupled to a fan. In the bottom part of the burner, between the grate and the insulating material, there is an inlet duct. Air is supplied to the inlet duct via a pipe which uses a fan to periodically blow ash from the combustion zone. The cleaning cycle of the combustion zone is controlled by the regulator.

The advantage of the burner idea is the possibility of regulating the burner combustion efficiency by controlling the delivery rate of a fan which supplies air to the combustion chamber through the pipes. The use of an air guide ensures better mixing of the air in the combustion chamber. Thanks to the complete combustion of fuel and small amounts of ash generated in the combustion process, the solution developed is also important for the protection of the atmosphere. Due to its compact, simple construction, the burner is characterised by failure-free operation and low cost of manufacture.

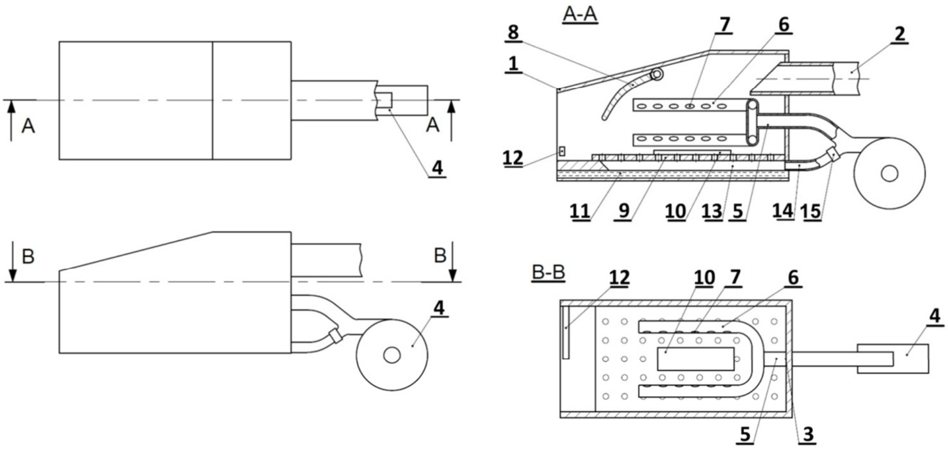

Fig. 5. A wood-chip burner: 1 – housing, 2 – connector, 3 – inlet, 4 – fan, 5 – channel, 6 – tube, 7 – nozzle, 8 – air guide, 9 – grate, 10 – ceramic heater, 11 – insulating material, 12 – temperature sensor, 13 – inlet duct, 14 – pipe, 15 – regulator

3.4. Mobile drying chamber

Mobile drying chambers consist of a drying chamber combined with a solar collector, fan, and fan control system. The solar collector contains an air flow chamber connected by a pipe to a drying chamber (Fig. 6). The fan is placed between the air chamber and the drying chamber. At the bottom of the air chamber there are photovoltaic cells.

The mobile drying chamber consists of a drying chamber, a solar air collector, a fan, a chassis and shelves arranged in a drying chamber. A photovoltaic cell is mounted at the bottom of the air chamber of the solar air collector. The control system and fan are supplied with electricity produced by this cell. In the upper part of the drying chamber there is a humid air outlet. Inside the drying chamber there are screen shelves with openings. On one wall of the drying chamber there are doors for loading. The dryer is equipped with a control system containing a set of sensors, including hygrometers and thermometers, to measure the parameters of the ambient air and dried material. On the inside of one of the walls of the drying chamber there is a battery for storing excess electricity generated by the solar cell of the collector.

The dryer should be placed in a favourable position in relation to the direction of incident solar radiation. The control system of the drying chamber allows automatic adjustment of the operating parameters, depending on the ambient air conditions. The dryer can also operate in tandem with a warm air furnace powered by biomass, liquid fuels or gas. By using a dryer, it is possible to reduce the costs of drying agricultural crops, especially herbs. The installation provides the possibility of drying using solar energy alone, which has a positive effect on the environment. Easy control of the drying parameters enables one to assure and control the optimal drying parameters.

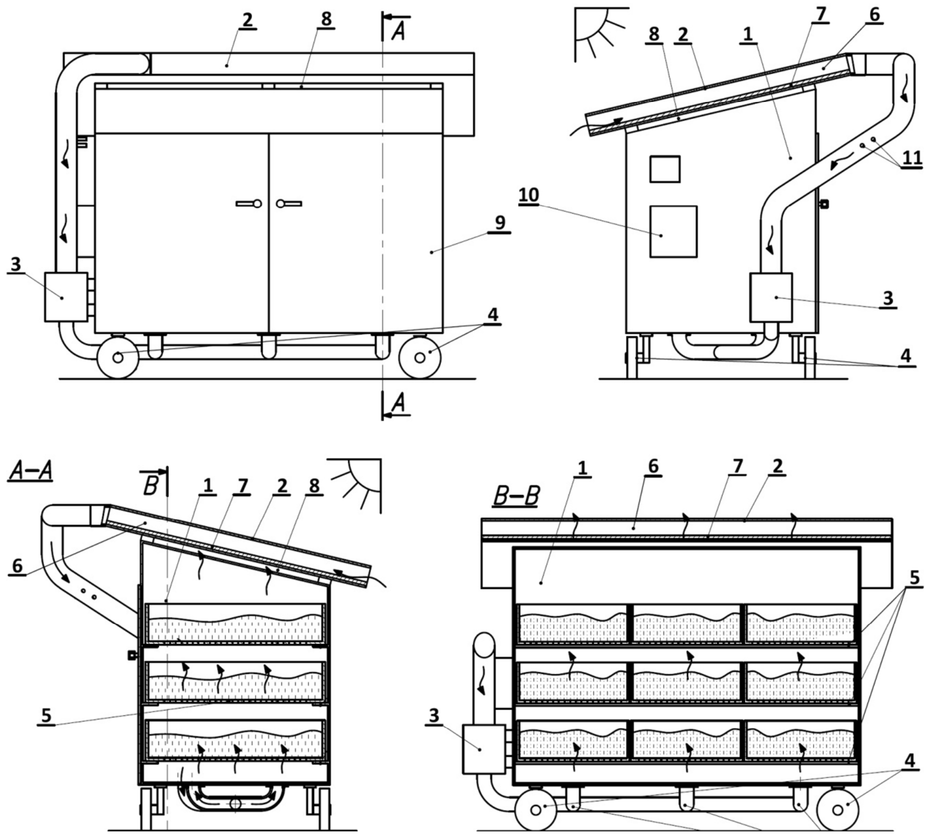

Fig. 6. Mobile drying chamber: 1 – drying chamber, 2 – solar collector, 3 – fan, 4 – chassis, 5 – shelf, 6 – air chamber, 7 – photovoltaic cell, 8 – humid air outlet, 9 – door, 10 – control system, 11 – sensors.

4. Summary

The structure of the raw material and the time of harvest, in addition to the climatic conditions, determine the opportunities for using solar energy for drying purposes in a given region. In the conditions in East-Central Europe, the most important agricultural products subjected to drying processes are herbs, spices and fruits. Most of the these raw materials require a low or medium temperature convection drying process, with a drying air temperature not exceeding 40ºC. This creates very favourable conditions for the use of solar collectors to heat the drying air. They fill the gap between high-performance commercial dryers and the natural drying carried out by small producers of spices and herbal plants, especially in East-Central Europe. The elimination of natural drying through the use of drying chambers eliminates the unfavourable effect of ultraviolet radiation on the loss of essential oils. The use of drying chambers also means that farmers are independent of weather conditions and thus can plan work on the farm in a rational manner.

References

[1] Olewnicki D., Jabłońska L., Orliński P., Gontar Ł.: Zmiany w krajowej produkcji zielarskiej i wybranych rodzajach przetwórstwa roślin zielarskich w kontekście globalnego wzrostu popytu na te produkty, Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie, vol. 15, no. 1, 2015, pp. 68–76.

[2] Gunathilake D.M.C.C., Senanayaka D.P., Adiletta G., Senadeera W.: Drying of agricultural crops [in:] Advances in Agricultural Machinery and Technologies, Chen G. (Ed.), CRC Press, Boca Raton, FL, USA, 2018, pp. 331–365.

[3] Janjai S., Tung P.: Performance of a solar dryer using hot air from roof-integrated solar collectors for drying herbs and spices, Renewable Energy, vol. 30, no. 14, 2005, pp. 2085–2095.

[4] Niemiec W., Trzepieciński T.: Drying of herbal plants as a method of management of waste land. Ekonomia i Środowisko, vol. 3, no. 66, 2018, pp. 55–63.

[5] Niemiec W., Trzepieciński T.: Machines and horticultural implements for the cultivation of small-scale herbs and spices, Journal of Ecological Engineering, vol. 19, no. 5, 2018, pp. 225–233.

[6] Orphanides A., Goulas V., Gekas V.: Drying technologies: vehicle to high-quality herbs, Food Engineering Reviews, no. 8, 2016, pp. 164–180.

[7] Soysal Y.: Microwave drying characteristics of parsley, Biosystems Engineering, vol. 89, no. 2, 2004, pp. 167–173.

[8] Janjai S., Bala B.K.: Solar drying technology. Food Engineering Reviews, vol. 4, no. 1, 2012, pp. 16–54.

[9] Sharma A., Chen C.R., Lan N.V.: Solar-energy drying systems: a review, Renewable and Sustainable Energy Reviews, vol. 13, no. 6–7, 2009, pp. 1185–1210.

[10] Sontakke M.S., Salve S.P.: Solar drying technologies: a review, International Refereed Journal of Engineering and Science, vol. 4, no. 4,2015, pp. 29–35.

[11] Antal T., Figiel A., Kerekes B., Sikolya L.: Effect of drying methods on the quality of the essential oil of spearmint leaves (Mentha spicata L.), Drying Technology, vol. 29, no. 15, 2011, pp. 1836–1844.

[12] Pirbalouti A.G., Mahdad E., Craker L.: Effects of drying methods on qualitative and quantitative properties of essential oil of two basil landraces, Food Chemistry, vol. 141, no. 3, 2013, pp. 2440–2449.

[13] Gallego-Juarez J.A., Rodriguez-Corral G., Galvez-Moraleda J.C., Yang T.S.: A new high intensity ultrasonic technology for food dehydration, Journal of Drying Technology, vol. 17, no. 3, 1999, pp. 597–608.

[14] Di Cesare L.F., Forni E., Viscardi D., Nani R.C.: Changes in the chemical composition of basil caused by different drying procedures, Journal of Agricultural and Food Chemistry, vol. 51, no. 12, 2003, pp. 3575–3581.

[15] Ciurzyńska A., Lenart A.: Freeze-drying – Application in food processing and biotechnology – A review. Polish Journal of Food and Nutrition Science, vol. 61, no. 3, 2011, pp. 165–171.

[16] Dinçer I., Kanoğlu M.: Refrigeration Systems and Applications. John Wiley & Sons, West Sussex 2010.

[17] Ratti C. Hot air and freeze-drying of high-value foods: A review. Journal of Food Engineering, vol. 49, 2001, pp. 311–319.

[18] Janowicz M., Lenart A.: The impact of high pressure and drying processing on internal structure and quality of fruit. European Food Research and Technology, vol. 244, 2018, pp. 1329–1340.

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