

POSSIBILITY OF USING A SOLAR AIR COLLECTOR FOR DRYING PARSLEY

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Abstract: Fresh parsley leaves used for culinary and curative purposes are highly perishable in nature. Losses after harvest are quite often observed and significant deterioration in quality is noted. In order to keep the leaves longer and to ensure their easy accessibility for off-season use without significant deterioration in nutrient levels, they has to be dried. The low moisture content of products made from dried leaves helps to improve their shelf life and reduce weight for transportation. Applying an optimized drying process is necessary not only to preserve the leaves, to achieve concentrated nutrients but also to minimize energy consumption for the process. The parameters for selecting the technique of drying individual leaves are based on local climatic conditions, drying agent temperature, relative humidity, drying time, size, shape and age of the leaves, etc. This article shows the possibility of replacing a conventional energy source with a renewable one. This study highlights the need to look for alternative renewable energy sources when drying food for energy saving and reducing greenhouse gas emissions.

INTRODUCTION

Increasing the energy efficiency of different facilities as well as reducing CO₂ emissions generated by different technological processes is a problem of constant relevance. The main directions in the development of the global energy strategy are as follows:

- use of renewable energy sources;
- creating new, less energy-using technologies using these alternative sources;[1-3]
- increasing the efficiency of the used conventional energy sources.[4]

The safe and long-term storage of fresh agricultural products is particularly difficult, as the high water content affects the physical, chemical and nutritional quality of the products during the storage period. In a relation with this, a drying process is used to reduce the moisture content of the products to a certain value, to improve the expiration date, to preserve the quality of the appearance and nutritional value during life after harvest. The drying process is a typical high-energy process, leading to the consumption of large amounts of energy and increasing of environmental problems [5]. This way, like other energy-intensive

industries, the drying industry is looking for energy-saving strategies to achieve the most effective and economical methods. [6], [7]. The effect of lowering energy consumption would lead to significant global results because the annual global cost for drying amounts to approximately 10-15% of the total energy costs of the industry. [8].

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Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

The aim of the study is to demonstrate the potential for energy savings and the achievement of saving CO₂ emissions in the process of parsley leaves drying using solar energy compared to conventional electricity drying. A chamber dryer with a classical design is explored [9] with an electric energy source subsequently replaced with a solar collector [10].

In the kinetics of the drying process, the average moisture content and temperature of the material within the process are considered. Heat drying is a complex heat and mass exchange process, driven by the interconnectedness of the heat and moisture transfer processes. The drying curve represents the dependence of the moisture content of the product as a function of the drying time. The drying curve is obtained experimentally, but its essential parts can be defined - initial heating period, I and II drying periods [11].

The objective of this study is to design, construct and evaluate the performance of a prototype solar drying for parsley leaves drying. The features of the designed device are presented as well as performance testing by parameters such as temperature, relative humidity, flow rate and air efficiency and drying kinetics. An analysis of the possible reduction of CO₂ emissions is done. It is important to note that the developed system allows the study of many different solar drying configurations for a wide variety of food products and drying regimes.

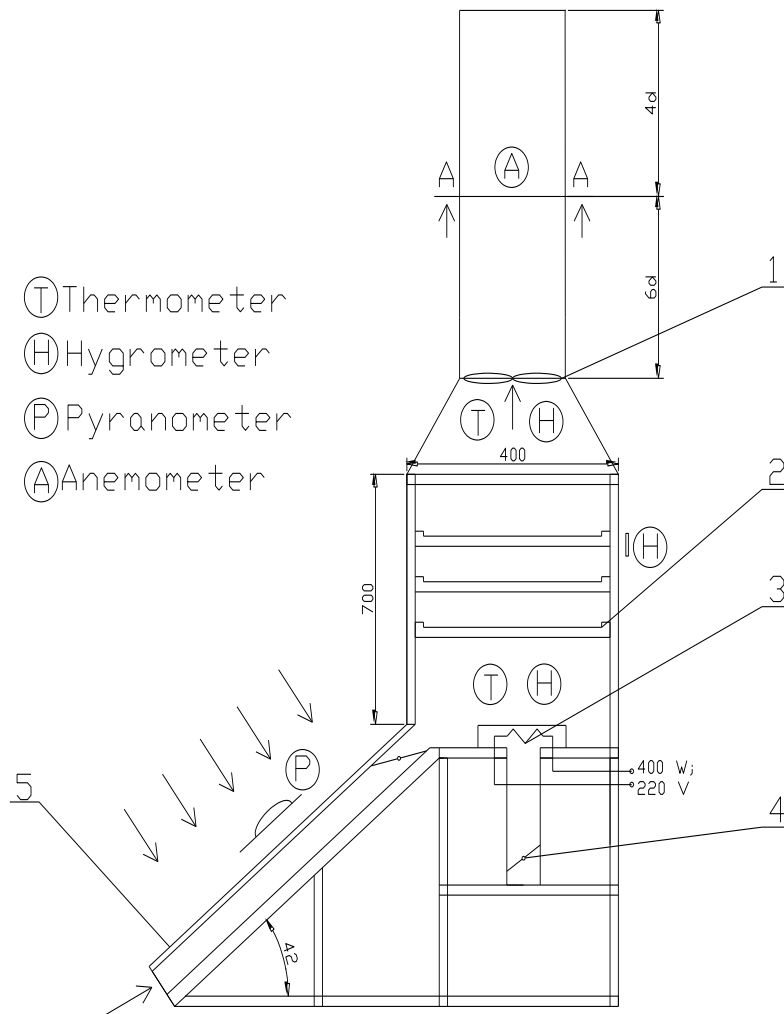
DESCRIPTION OF THE EXPERIMENTAL LAYOUT

All experimental studies underlying this development are made on a laboratory physical model of a continuous convection dryer. The drying chamber – figure 1 is in the form of parallelepiped and geometric dimensions length 400mm, width 700mm and height 700mm. 3 frames made of wire mesh are installed in height in the drying chamber, onto which the material is set to be dried. The distance between the individual frames is 100mm, the bottom is 200mm from the base of the drying chamber. The drying agent enters the drying chamber through the valve (4), passes through the electric heater (3), sweeps the trays (2) and through the fan (1) is thrown into the atmosphere. The flow rate of the drying agent passing through the dryer can be changed by hand valve (4) and hence its speed of movement. The drying agent is heated inside the drying chamber, where is installed a 400W electric heater. The heater has a continuous power supply. The temperature and relative humidity of the air in the drying chamber at its inlet and outlet are measured. To determine the flow rate of the drying agent passed through the dryer a circular air duct with $d = 100mm$ is mounted in the top of the

drying chamber. At a distance of $6d$ after the fan and $4d$ before the exit to the atmosphere are drilled holes, through which the airflow rate is measured by anemometer TESTO 405 according to the scheme shown in figure 1.

For the measurement of the inlet and outlet temperature of the drying agent as well as the temperature inside the drying chamber are mounted Pt100 thermal resistors, whose resistance is converted by three transmitters into a unified signal $4 \div 20$ mA. For measuring inlet and outlet relative humidity as well as the under pressure are selected sensors with built-in transmitters, which have a direct output of $4 \div 20$ mA.

A solar collector is connected to the dryer chamber in the bottom part [12]. The sizes of the solar collector are $700 \times 1000 \times 100$ mm. A double glazing is used for transparent coating over the absorbent plate, with a glass thickness of 4 mm, tightly fitting to the absorber. The flat absorbent plate is "MIROTHERM MT 1300". To determine the falling down solar radiation on the air collector in its plane a solar meter KIMO SL 100 is installed.



1. Figure 1. Scheme of the drying chamber
1- Fan; 2- trays; 3- electric heater; 4- valve; 5- an air solar collector.

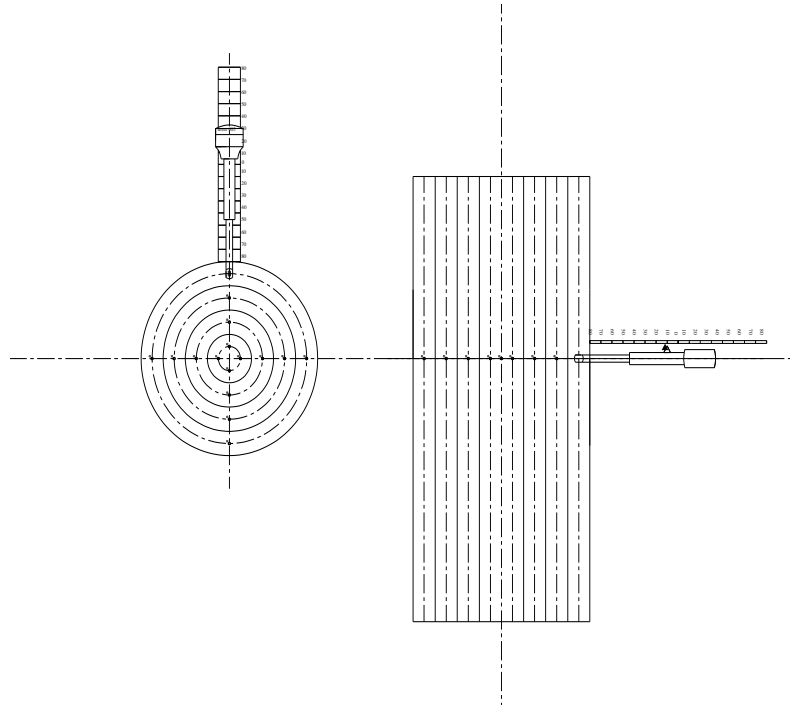


Figure 2. Scheme of measuring the speed of the drying agent

RESULTS AND DISCUSSION

Developed physical model of the continuous-action solar dryer was considered as a management object. An algorithm for drying was used in the experimental study in determining criteria - the final moisture content of the dried product. A method for static optimization of the parameters of the drying process has been developed with guaranteed accuracy and energy efficiency of drying. The method is suitable for this product due to the relatively shorter time it takes to dry it because of the large heat exchange surface compared to other drying products.

Most management methods do not count the energy aspects related to energy savings under the existing quality limits for dried material. Estimation and comparison of the energy efficiency of the drying installations are carried out on the basis of their thermal efficiency indicators, which takes into account besides the energy consumed by the installation, also its load. The requirements for energy economy in the management of such objects are related to the achievement of a certain drying accuracy by indirectly measuring the moisture of the dried product.

The problem of energy-saving management of the drying process, with the achievement of a specified accuracy of the final moisture content of the leaves of parsley has been achieved using balance equations for substance and energy storage.

The initial moisture content of the leaves of parsley which is the ratio of the mass of moisture to the absolutely dry mass is:

$$u_h = \frac{m_B}{m_0} = \frac{W_H}{1 - W_H}, g / kg \quad (1)$$

Where W_H is the moisture of parsley.

The final moisture content of parsley, which is the ratio of the mass of moisture to the absolutely dry mass is:

$$u_k = \frac{m_B}{m_0} = \frac{W_K}{1 - W_K}, g / kg \quad (2)$$

Where W_k is the final moisture content of parsley after drying.

Dryer productivity by evaporated moisture expressed by the initial and final moisture content of the product is:

$$\Delta U = m_1 \frac{u_H - u_k}{1 + u_H}, kg \quad (3)$$

Where $m_1 = 1,8$ [kg] is the mass of the parsley leaves before the drying process.

The mass of parsley leaves m_2 after drying shall be equal to:

$$m_2 = \frac{\Delta U}{\frac{u_H - u_k}{1 + u_k}}, kg \quad (4)$$

As the drying is carried out with an air drying agent with initial and final moisture content - d_H and d_k respectively, and consumption of drying agent $\dot{m}_{ca} = 0,03$ [kg/s], the water that evaporates and passes into the drying agent for a time period τ is determined by the dependence:

$$\Delta U_{B-X} = \dot{m}_{ca} \int_0^\tau (d_H - d_k) dt \quad (5)$$

Subject to the condition:

$$\Delta U_{B-X} = \Delta U \quad (6)$$

It follows that the desired final moisture content of the dried material has been reached.

The duration of drying in (5) in the experimental studies is in accordance with the recommendations of [9].

The implementation of (6) guarantees high drying accuracy, provided that the air inlet flow is equal to the inlet. Since sensors for measuring the relative humidity of the drying agent are installed at the inlet and outlet of the dryer φ_H and φ_k for the calculation of d_H and d_k the following relationship is used:

$$ud = 623 \frac{\varphi P_{HH}}{P_6 - \varphi P_{HH}}, g / kg \quad (7)$$

where: $P_6 = 96800$ [Pa], is the average barometric pressure for the city of Sliven;

P_{HH} - partial pressure of saturated water vapor, [Pa].

Partial pressure of saturated water vapor P_{HH} depends on the temperature t . This dependence on the temperature range $t = 0 \div 300^\circ\text{C}$, with accuracy which is sufficient for the practice is expressed:

$$P_{HH} = 1,40974 \cdot 10^{10} \cdot e^{\frac{-3928,5}{t+231,667}} \quad (8)$$

So with a well-sealed dryer and known drying agent flow rates m_{ca} , initial φ_H and final φ_k relative humidity of the drying agent, initial t_H and final t_k temperature of the drying agent, using (5), (7) and (8) a high accuracy of drying can be achieved in the embodiment of (6). Using the above-described dependencies and obtaining in real time information about the initial and final relative humidity of the drying agent and obtaining in real time information about the initial and final relative humidity of the drying agent, as well as its initial and final temperature the desirable final moisture content of the dried material can be achieved.

After processing the experimental results are presented below in tabular form.

Table 1		
1.Parameter	1.Drying using a conventional heat source	1.Drying using a renewable heat source
2.initial moisture of the leaves of parsley	2.W=75%	2.W=75%
3.final moisture of the leaves of parsley	3.W=10%	3.W=10%
4.initial moisture content in the product	4.u _H =3 g/kg	4.u _k =3 g/kg
5.final moisture content in the product	5.u _k =0,11 g/kg	5.u _k =0,11 g/kg
6.weight of parsley leaves before drying	6.m ₁ = 1,8 kg	6.m ₁ = 1,8 kg
7.weight of leaves of parsley after drying	7.m ₂ = 0,5 kg	7.m ₂ = 0,5 kg
8.dryer performance by evaporated moisture	8.ΔU=1,3	8.ΔU=1,3
9.weight of leaves parsley after drying	9.m ₂ =0,5 kg	9.m ₂ =0,5 kg
10.consumption of drying agent	10.m _{ca} = 0,03 kg/s	10.m _{ca} = 0,03 kg/s
11.average temperature in the drying chamber	11.t _m = 50 °C	11.t _m = 40 °C
12.duration of the drying process	12.120 min	12.150 min
13.amount of heat needed to heat the drying agent	13.400W	13.580W
14.fan power	14.P=100W	14.P=100W
15.total electricity consumed for carrying out the drying process	15.P _e =1,0 kWh	15.P _e =0,25 kWh
16.Ecological equivalent coefficient [12]	16.F _i =819 gCO ₂ /kWh	16.F _i =819 gCO ₂ /kWh
17.Amount of CO ₂ emissions generated per cycle of the drying installation	17.819 gCO ₂ /kWh	17.204,75 gCO ₂ /kWh
18.Amount of CO ₂ saved as a consequence of replacing a conventional dryer with solar	18.614,25 gCO ₂ /kWh	

CONCLUSIONS

The drying of parsley leaves has been carried out through the use of renewable solar energy. The performance characteristics of the prototype of a solar dryer are determined. An analysis of the possible reduction of CO₂ emissions has been carried out. The proposed and developed system allows the study of many different solar drying configurations for a wide variety of food products and drying regimes.

Based on the experiments conducted, it can be concluded that in order to minimize the energy costs of drying other leaf spices and herbs such mode parameters should be sought in which drying temperature is within the lower limit of the permissible variation range, while the flow rate of the drying agent is within the upper range of allowable variations. The optimum values of drying agent parameters that are found so ensure low energy consumption.

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REFERENCES:

- [1] Rositsa Velichkova, Detelin Markov, Iskra Simova, Peter Stankov, Zahari Ketipov, Tsvetelina Petrova, Iliyana Naydenova, Radostina Angelova, August Wierling, Utilization of hydrogen sulfide from biogas installation, EFEA'2018, Rome , Italy, Category numberCFP1876T-ART; Code 144483, **ISBN:** 978-153865517-7, **DOI:** 10.1109/EFEA.2018.8617104
- [2] Rositsa Velichkova, Iskra Simova, Detelin Markov, Venelin Makakov, Milka Uzunova, Valeria Schwanitz, Utilization of wave energy by hybrid system, EFEA'2018, Rome , Italy, Category numberCFP1876T-ART; Code 144483, **ISBN:** 978-153865517-7, **DOI:** 10.1109/EFEA.2018.8617056
- [3] Ivaylo Ganey,I.Naydenova, Evaluation of potential opportunities for electric power generation from landfill gas in "Tsalapitsa, Serbian journal of electrical engineering, vol.11, № 3, ISSN 1451-4869, e-ISSN 2217 – 7183Iliev I., A. Terziev, V. Kamburova, Combined Heat and Power Production trough Biomass Gasification with „Heat Pipe-Reformer”, 5th International Conference Thermal Systems and Environmental Engineering", 1-2 November 2013, Galati, Journal TERMOTEHNICA/THERMODYNAMICS, p.p. 128-131, ISSN ISSN-L 1222-4057.
- [4] Syahrul S., F. Hamdullahpur, I. DincerExergy analysis of fluidized bed drying of moist particles, Int J Exergy, 2 (2002), pp. 87-98
- [5] Aghbashlo M., H. Mobli, S. Rafiee, A.MadadlouA review on exergy analysis of drying processes and systems, Renew Sustain Energy Rev, 22 (2013), pp. 1-22
- [6] Hristov H., Penov N., Dichev S., Process kinetics investigation in low temperature drying of apples in heat pump drier, Proceedings of the Symposium EUDrying 03, Heraklion, Crete, September 4-5, 207-215 pp, 2003
- [7] K.J. Chua, A.S. Mujumdar, S.K. Chou, M.N.A. Hawlader, J.C. HoConvective drying of banana, guava and potato pieces: effect of cyclical variations of air temperature on drying kinetics and color change, Dry Technol, 18 (2000), pp. 907-936
- [8] Chagin O.B., N.R. KOKina,V.V. Pastin, Equipment for drying food, University of Chemical Technology Ivanovo, 2007, UDC 631.362: 633.1
- [9] Kostov K., P. Tsankov, T. Tanev, I. Ivanov, Experimental test-rig for air solar collector, Toplotehnika #3, book 1 , 2012 pp, 82-85, ISSN 1314-2550
- [10] Langrish T.A.G., Characteristic drying curves for cellulosic fibres, Chemical Engineering Journal 137 (2008) 677–680
- [11] Babu A., G.Kumaresan, V. Antony Aroul Raj, R.Velraj, Review of leaf drying: Mechanism and influencing parameters, drying methods, nutrient preservation, and

mathematical models, Renewable and Sustainable Energy Reviews, Volume 90, July 2018, Pages 536-556
[12] ORDER № E-РД-04-2 from 22.01.2016 on the energy consumption and energy performance indicators for buildings

ВЪЗМОЖНОСТ ЗА ИЗПОЛЗВАНЕ НА СЛЪНЧЕВИЯ ВЪЗДУШЕН КОЛЕКТОР ЗА СУШЕНЕ ПАРСЛЕЙ

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Ключови думи: процес на сушене, възобновяеми енергийни източници, намаляване на CO₂, енергийна ефективност

Резюме: Пресните листа от магданоз, използвани за кулинарни и лечебни цели, са силно нетрайни по природа. Често се наблюдават загуби след прибиране на реколтата и се забелязва значително влошаване на качеството. За да се запазят листата по-дълго и да се осигури лесната им достъпност за употреба извън сезона без значително влошаване на нивата на хранителните вещества, те трябва да бъдат изсушени. Ниското съдържание на влага в продуктите, изработени от сушени листа, спомага за подобряване на техния срок на годност и намаляване на теглото при транспортиране. Прилагането на оптимизиран процес на сушене е необходимо не само за запазване на листата, за постигане на концентрирани хранителни вещества, но и за минимизиране на консумацията на енергия за процеса. Параметрите за избор на техниката на сушене на отделните листа се основават на местните климатични условия, температурата на сушилният агент, относителната влажност, времето на сушене, размера, формата и възрастта на листата и т.н. Тази статия показва възможността за замяна на конвенционален енергиен източник с подновен. Това проучване подчертава необходимостта от търсене на алтернативни възобновяеми енергийни източници при сушене на храни за енергоспестяване и намаляване на емисиите на парникови газове.