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Drying Kinetics of Biological Materials in a Combined Solar Dryer

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Abstract* - The paper presents the investigative findings of the drying process in a combined solar dryer. Combined solar dryer has collector of solar energy (1m x 2m), drying are consists from dryers the chambers with pans (eight pan measuring 0.3m x 0.5m) and recirculating channel, flow regulators, fans, drain channel and support structure. In kiln drying is performed carrots. Drying has been carried 14 and 15 10.2014.Years. We measured the following values: the temperature of the outside air, the temperature of the drying agent at four positions, the mass of moist material, intensity of solar radiation. Based on the measured values were determined for each pan in particular: absolute moisture content of materials, isolated moist on each of the pans, the relative moisture content of materials, absolute humidity of the drying agent, the drying rate, the critical moisture, characteristic moisture.

***Key words* or phrase; Moisture content (d.b), The characteristic moisture content, solar driers,**

I. INTRODUCTION

Drying is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development [4]. Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from biological produce so as to provide a product that can be safely stored for longer period of time."Sun drying" is the earliest method of drying farm produce ever known to man and it involves simply laying the agricultural products in the sun on mats, roofs or drying floors. This has several disadvantages since the farm produce are laid in the open sky and there is greater risk of spoilage due to adverse climatic conditions like rain, wind, dust and moist, to produce loss of birds, rodents and insects (pests); totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large area of land, takes time and highly lab our intensive [5]. With cultural and industrial development, artificial mechanical drying came into practice, but this process is highly energy intensive and expensive which ultimately increases product cost [5]. Recently, efforts to improve "sun drying" have led to "solar drying“. In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect pests, dust and rain. In comparison to natural "sun drying", solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying [5].The solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying, most biological produce can be preserved and this can be achieved more efficiently through the use of solar dryers. It is worth noting that until around the end of the 18^{th} century when canning was developed, drying was virtually the only method of food preservation). Studies showed that food items dried in a solar dryer were superior to those which are sun dried when evaluated in terms of taste, colour and mould counts, [7]. Solar dried food are quality products that can be stored for extended periods, easily transported at less cost while still providing excellent nutritive value. This paper therefore presents the design and construction of a domestic passive solar food dryer. For centuries, people of various nations have been preserving fruits, other crops, meat and fish by drying. Drying is also beneficial for hay, copra, tea and other income producing non-food crops [6]. With solar drying being available everywhere, the availability of all these farm produce can be greatly increased. Solar dryers [8] can be generally classified as solar radiation (direct), whose characteristic is direct exposure of the drying material to solar radiation and solar indirect dryers, which use corresponding collectors of solar energy for the preparation of drying agents. The main characteristic of solar indirect dryers is the use of solar energy for the preparation of drying agents. Compared to drying directly in the Sun, the drying Material in these dryers does not get dirty and it is protected from insects, dew, rainfall and the other possible outside influences. Also, these dryers enable better preservation and keep the nutritious and biological value of drying material which is the most important for the high quality of the final product. Compared to the direct dryers the indirect dryers are capable to concentrate solar energy. Also it is possible to increase the collector surface and air flow through the collector which enables indirect dryers to attain almost optimal working parameters in different climate and weather conditions.

II. MATERIALS AND METHODS

During the drying process of defining a specific starting point is the theoretical basis of the description given in the form of process in mind the necessary mathematical apparatus. This is followed by the collection and analysis of

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Existing data from a given field. The next step is to define the parameters to be measured in concrete the example, combined solar dryer Fig. 1, [2]. Followed by performance measurement predefined parameters for specific (our) case. Based on the results form the necessary tables, diagrams and mathematical models (formulation) changes measured and derived quantities in particular drying process. With these data obtained clearly defined values for the specific drying process and concrete kiln.

Fig.1. Active combined solar driers

In further work, which is not showing now will be used for sorption isotherm data carrots. Sorption isotherm is obtained on the basis of existing data based on Henderson's expressions for sorption isotherm.

A. *Preparation materials*

Biological material (carrot) was prepared as follows,[1]:

- was mechanically cleaned (dirty and peeling damaged parts)
- washing,
- Longitudinal or transverse cutting.
- Setting up of material in one or two layers on the surface of the pan.

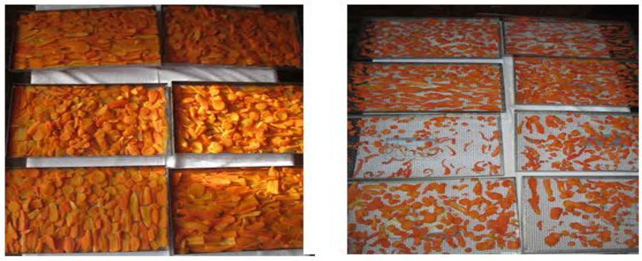
Pans are numbered and during the drying process and measurement, position them in the dryer is not changed. Schedule and set the pan starting from the lowest to the highest in the chamber, before and during the drying process, fig. 2, is as follows:

- Verticals 1 - 2.2 skillet, frying pan 2, 1.2 skillet, frying pan 1,
- Vertical 2: - 4.2 skillet, frying pan 4, 3.2 skillet, griddle third.

B. *Measured values and performance of the experiment*

Measurements included the following values:

- Temperature of the outside air
- Intensity solar radiation on the surface of the hair collector
- Temperature of the drying agent in the four characteristic points of the dryer
- Weight wet material during the drying process
- mass absolutely dry material.



a) b)

Fig.2. the appearance and layout of the pan before the drying process a) and in the process of drying b)

III. EXPERIMENTAL RESULTS

After the measurements experimental data are presented in tables graphically. In Fig. 3., and 4., are shown temperature fluctuations outside air for the first and second day. The temperature of the outside air during the first day of the changing in the range of from 12.6 ° C to 21.5 ° C. The second day of the outside air temperature is varied in the range from 12 ° C to 26 ° C. On fig. 5., and 6.. Shows changes in the value of irradiated for the first and second day. The intensity of the solar radiation on the first day changed in the range of 480 to 880 W / m^2, and the second day is in the range of 470 to 1,060 W / m^2. On fig.7.. And 8. indicating changes of temperature differences of the drying

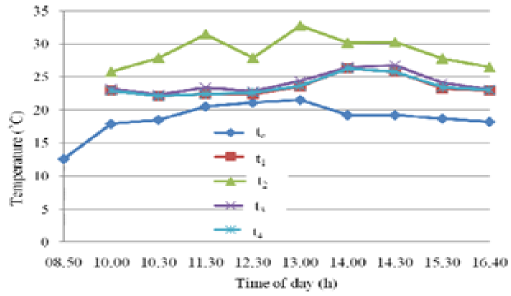


Fig. 3. Changes to the external temperature for the first day

Agent and the outside air. The temperature difference of the drying agent and the outside air ranged from 8.3 to 11.3.° C on the first day of drying and from 8 to 17.1 ° C. The markings on the diagrams are: t_{oca}, t_{ica} - temperature at the outlet from the chamber and the door of the chamber; t_{ico}, t_{oco}

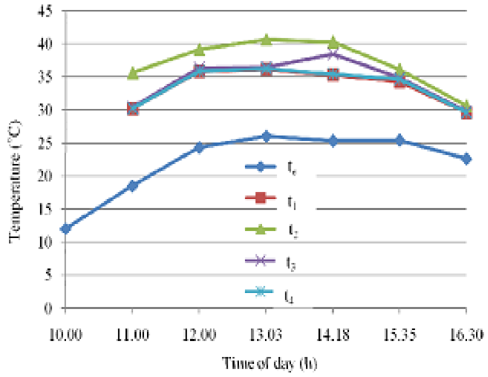


Fig.4. Changes to the external temperature for the other day

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- Temperature at the outlet from the collector and at the entrance to the collector; t_{se} - the temperature of the outside air.

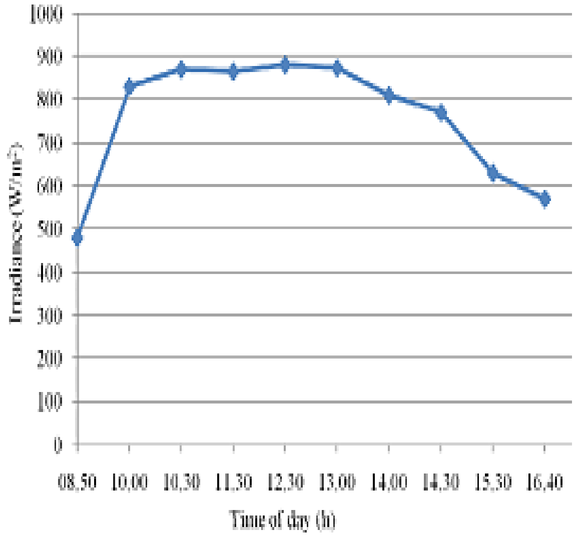

Fig.5. Changes in the value of irradiated in the course of the day for the first day

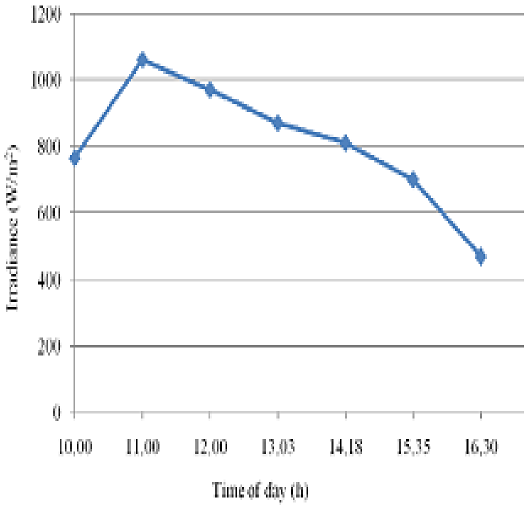

Fig.6. Changes in the value of irradiated in the course of the day for the first day) and on the second day b)

The temperature difference of the drying agent before and after the absorber ranged from 2.9 to 9.3 on the first day of drying and from 1 to 5.4 ° C on the second day of drying. The temperature difference of the drying agent before and after the chamber ranged from 2.6 to 8.4 on the first day of drying and from 0.8 to 5.2 °C on the second day of drying. The diagrams of the solar radiation are observed on the first day decline in the intensity of solar radiation in point, the measuring time of 11.30 h. Similarly fluctuation occurs in the diagram outside air temperature and drying agents with a certain delay. This situation is reflected in other temperature differences. On fig.7.and 8. Indicating changes of absolute moisture content (dry basis) of material with time, drying curves, for the first and second day.

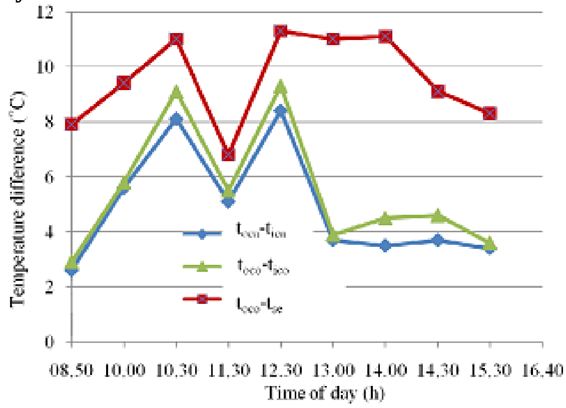

Fig.7. the changes of temperature differences of the drying agent and the outside air, and for the first day

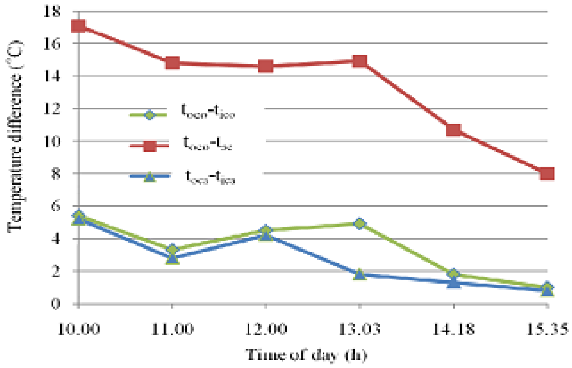

Fig.8. the changes of temperature differences of the drying agent and the outside air, and the next day

IV. ANALYSIS OF THE RESULTS

The diagrams changes the absolute moisture content of moist material is observed changes in absolute moisture content in the range:

- 11.089 to 0.005, kg_m / kg_{adm}, pans for 1 to 2.2
- 11.089 to 0.016, kg_m / kg_{adm}, for pans 3 and 4.2

There is an absolute difference in changing the moisture content of the height of the chamber. The highest pans absolute moisture content is high and declines to lower pans.

The difference between the relative moisture content Wet bases). Of the top three pans there but not great. However, the relative moisture content for the lowest pan is obviously different, is significantly lower than the relative moisture content in the upper pans. The reason for this phenomenon is the very position the pan in the chamber. Drying agent when exiting the solar collector heats the first material in the lowest pan, dried material and moves to the next pan. In this way, the temperature of the drying agent decreases through the chamber, and the absolute humidity of the drying agent increases.

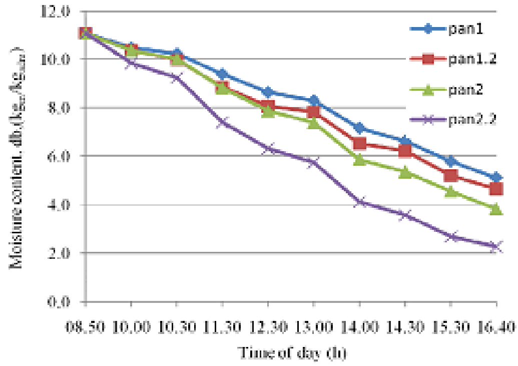

Fig.7. The curves for the drying of the media and on the first day

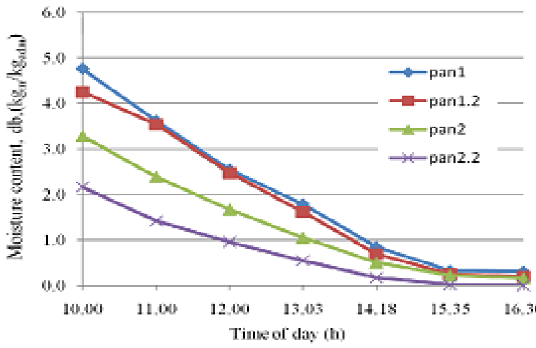

Fig.8. The curves for the drying of the media and on the next day

In the course of the drying process due to the more rapid reduction in values of moist material in the pans to the riser 2, increases, the surface of inner dimensions on the vertical side 2. In this way, has been intensified in the flow of the drying agent, and thus accelerates the drying of the material in the vertical direction second. After termination of the drying material on the first day, the material is standing for the next day when the drying continued. In the charts for changing the absolute humidity can clearly see the continuation of the drying process during the night. It is noticeable change in the amount of moisture decreases, night - time "aging". By observing the diagram to change the speed of drying, which are not presented in the paper, are observed one or two peaks. By observing the diagram for changing the amount of moisture evaporated from the material, study it seems that these phenomena coincide. The reason for this behavior and the situation in the drying process is probably clouds that affected the external conditions, temperature, intensity of radiation, and above all the intensity of radiation. This disorder is observed in the results of measurements of the intensity of solar radiation. The values of characteristic moisture content are defined according to the equation:

$$u_{ca} = \frac{u - u_e}{u_{crI} - u_e} \qquad (1)$$

where in the first u_{crI} critical moisture content and the u_e equilibrium moisture content.

On fig. 9., shows the characteristic curve of drying for all pans in the dryer.

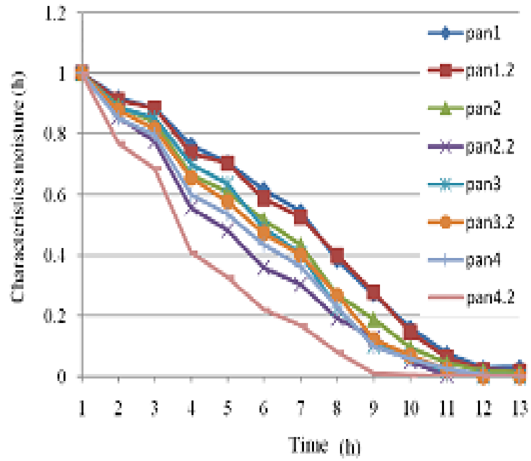

Fig. 8. The characteristic curves for the drying

V. CONCLUSION

On the basis of the results of measurements and processing functions can conclude the following:

- Confirmation of the mathematical model. Starting from the Mathematically model defined the starting characteristics and dimensions of the kilns,
- identifying and defining further the necessary correction models and assumptions. Analyzing the results of a mathematical model of drying is checked, comparing the models investigative findings with the results obtained by the measurement and performs the necessary correction in the model with the aim of making these two results,
- The identification and definition of potential aggravating factors that affect the drying process, as follows: on subjective (thickness, size piece of material, the material on schedule pans, gaps in the construction of kilns affecting the surface of inner dimensions, air velocity). Subjective circumstances and impacts can be reduced and corrected during the preparation of the dryer, by adjusting the dimensions of certain parts of the dryer, changing the dimensions of the pieces of material, even arrangement and an even amount of material in each pan, changing the speed of air flow depending on the timing (time).of the objective (external temperature and intensity of solar radiation).
- Recognition of the impact the process of "aging" of the material on the process of drying. The obtained results it was established that after the physical completion of the drying process in a dryer material continues to dry. In this way, part of the moisture from the material discharged into the surroundings, and the absolute and relative moisture of the material are reduced. The material practically continued to dry under the influence of temperature to which it is heated and due to still not reached the equilibrium moisture content.

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Radivoj M. Topić is a full professor Faculty of Mechanical Engineering University of Belgrade Serbia,, Was born 05. February 1948. Education**:**1983. Degree PhD, Faculty of Mechanical Engineering University of Belgrade Serbian; 1977.M.Sc. Faculty of Mechanical Engineering University of Belgrade Serbian; 1971.B.Sc. Faculty of Mechanical Engineering University of Belgrade Serbian; **1**996.Full Professor, Faculty of Mechanical Engineering University of Belgrade Serbian; 1991. Associate Professor, Faculty of Mechanical Engineering University of Belgrade Serbian; 1986. Assistant Professor, Faculty of Mechanical Engineering University of Belgrade Serbian; 1973. Assistant, Faculty of Mechanical Engineering University of Belgrade Serbian. Research interests**:** Drying; Heat and mass transfer und plants; Alternative and restorable energy sources. Publikacion: More then 160 scientific and engineering papers; 17 books, monographs and brochures; More papers in International Journal Drying Technology**,** Marcel Dekker, New York.; More tens projects and technical solutions (mini dryers for houm: infrared and convective; combine for grass; dryers for individual farms: infrared and solars; trailer for drying; dryers for wood; cleaner for biogas; wind plants; different medicinal device and equipment).; More tens expert opinions and reviews of Sciences projects and boocks; More Patent registrations**.** Professional Experience: Delegat Yugoslavien, SCG in European Federation of Chemical Engineering (EFCE), Member and expert European Federation Chemical Engineering, EFCE - Working Party on Drying, Expert of The Federal Minisrtry for Science, Development and the Environment since.

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