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DRYING PROPERTIES OF HOPS LAYER

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A b s t r a c t. The investigation was aimed at defining the characteristics of the hops drying process under the real condition in a solar dryer.

The 25, 55, 85, and 115 cm thick hops layer were solar dried in 2x2 m boxes.This paper presents the results of changes in moisture content depending on each layer thickness at the unchanged fan power (0.5 kW, 3 900 m^3/h). The paper also describes the changes in moisture content at different heights within the 85 cm layer. The energy consumption and the quantity of dried material were used as the criteria for defining the optimal thickness of a layer to be dried, which for the described type of equipment is about 55 cm. When the layers over 90 cm are dried in this type of a dryer, if the climatic condition are unfavourable and only solar energy is used, the hops may lose in quality. The height of the dried hops layer containing 9 % of moisture is around 70 % at the beginning of drying, when the moisture content was 73 %. No statistically significant differences in eteric oil, alfa-acid and humulen content have been found between the samples consisting of solar dried hops layer up to 85 cm, and the samples consisting of hops dried in dark drafty places.

K e y w o r d s: hops, drying properties, hop quality

INTRODUCTION

The solar plastic house - the bath-in-bin dryer developed due to the cooperation between the Stuttgart-Hohenheim Institute for Agricultural Engineering and the Institute for Mechanization and Institute for Plant Production, from Novi Sad can successfully be used for drying the medicinal plants. There are both will and need for this plant to be used for hops drying. If realized, this idea would not only widen the use of this solar plastic house, but as well cut the fixed costs per dried commodity unit. On the other hand, it is well known that hops drying requires significant quantities of mineral fuel. Since the hops harvesting season covers the end of August and the beginning of September, the climatic conditions in the areas where hops is grown usually provide sufficient solar energy to be used for hops drying. Besides, there is an indisputable need for reconsidering the justifiability of the usual method of bath-in-bin hops drying. Therefore the ultimate aim of this paper is to optimize the mutual influence of the factors affecting the efficiency of hops drying.

This should be achieved by investigating the influence of particular factors on the efficiency of drying the hops layers of various thickness. On that base the optimal height of a layer should be defined for a given plant, as well as the limit height of a layer, beyond which no guaranty can be given for solar drying to be successful-both in the sense of economic effects and the quality of hops dried.

MATERIAL AND METHOD

Experimental solar dryer-plastic house is presented in Fig. 1.

The investigation was aimed at analysing the process of drying the hops layers of different height, in practical conditions of a solar dryer already described in

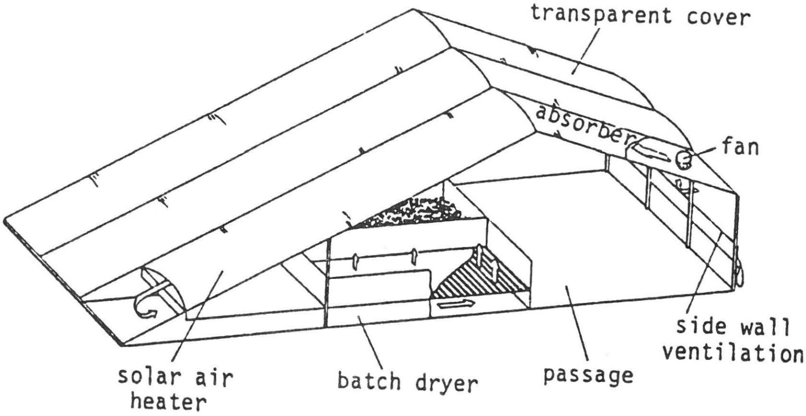

Fig. 1. Experimental solar dryer-plastic house.

earlier papers [1,2]. For such a purpose the drying boxes were reconstructed. Each of the 4 boxes of 2x2 m was, almost simultaneously, filled with the Backa sort of hops, so as to form the 25, 55, 85 and the 115 cm layer, respectively. The boxes were placed on the electric balances which quasi-continually measured the changes of the mass in boxes [3]. In each of the 4 boxes the mass was exposed to the airflow produced by a 0.5 kW fan, quantity passing being nominal 3 900 m^3/h. In all boxes only the solar-heated air was used. During the first night of drying the material was fanned with the outside air, and during other nights the fans were switched off. The measured airflow was different in each particular box depending on the height of particular layer. The average quantity of air passing during one batch drying was as follows: 3 173 m^3/h in the box containing the 25 cm thick hops layer; 2 498 m^3/h in the box containing the 55 cm thick hops layer; 2 093 m^3/h in the box containing the 85 cm thick layer, and 1 850 m^3/h in the box with the 115 cm thick layer of hops. The quantity of air passing was changing in dependence on the resistance during the process of drying. At the beginning, when the moisture content in the material in each of the four boxes was $w=73$ %, the quantity of air passing was found to be as follows: 3 138 m^3/h in the box with the 25 cm layer, 2 464 m^3/h in the box with the 55 cm layer, 1 923 m^3/h in the box with the 85 cm layer, and 1 575 m^3/h in the box containing the 115 cm layer of hops. The plan of measuring points is given in Fig. 2. Detailed description of measuring equipment and procedure is given in earlier paper [2].

The data on solar radiation intensity, air temperature, relative air humidity and dried material mass were measured and recorded with the use of Hewlett Packard computer system, in 10 min intervals. Measurements of airflow, air pressure, and electric energy consumption were discontinual. The HP Vectra 286 and Data Acquisition HP 75000 Series B, model 1 300 A were used. The Labtech Notebook software was used and the data tables were recorded in the ASCII code. For converting the tabular data into diagrams the Grapher programme was used. The drying curves as well as the curves expressing other interesting parameters were displayed and monitored on 12 diagrams simultaneously.

RESULTS

Drying process in the layers of different height

Figure 3 presents the process of hops drying, for the layers of 25, 55 and 85 cm. The experiment was performed in identical technical

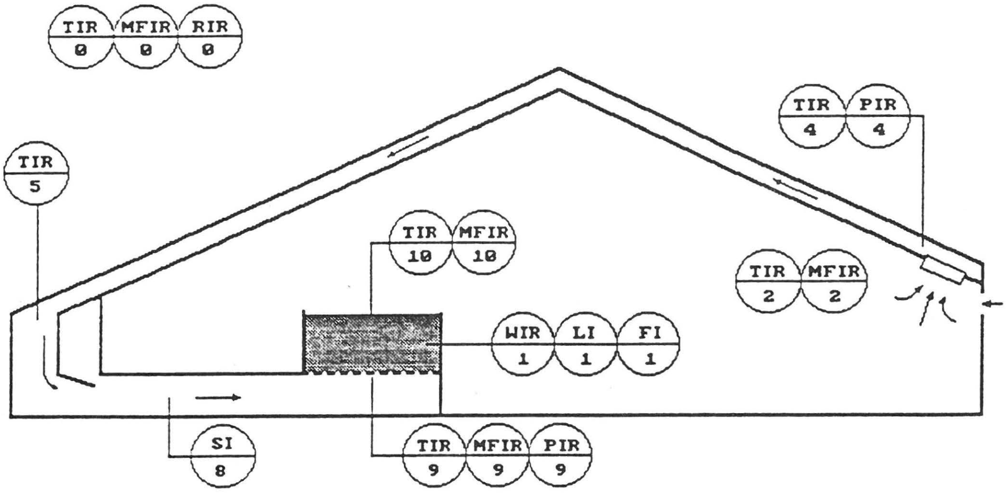

Fig. 2. Plan of measuring points.

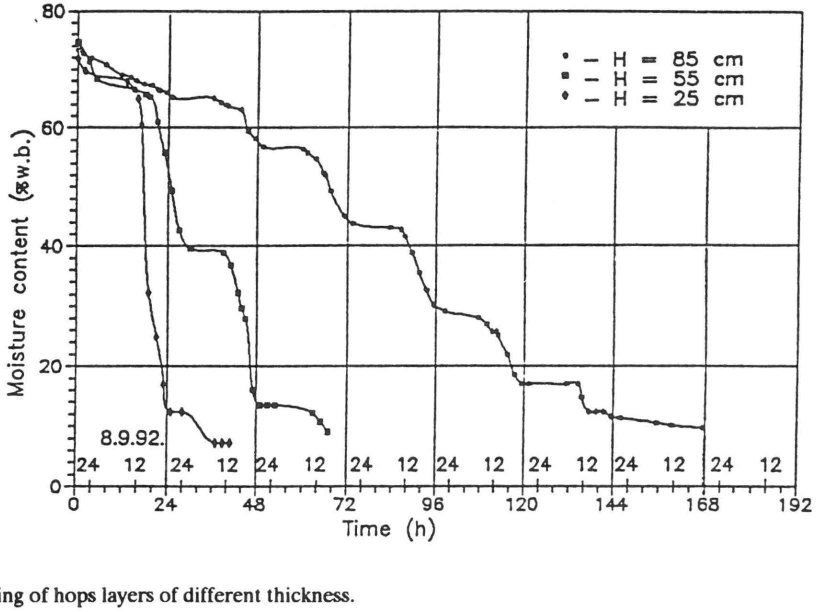

Fig. 3. Drying of hops layers of different thickness.

conditions (fan construction) and simultaneously, so that climatic conditions were identical as well. As expected, it took more time for the thicker layers to get dried. It was noticed that it took disproportionately more time than had been expected for the 85 cm thick layer to get dried. The drying lasted 140 h, while the 55 cm layer was dried in 70 h and the 25 cm layer in 40 h. The mass of dried hops was 105 kg (H=85; w=10 %), 62 kg (H=55 cm; w=9.87 %), and 17 kg (H=25 cm; w=7.24 %).

If compared to identical moisture content (w=10 %), the mass in the observed boxes was 104.4, 62.1 and 17.5 kg, respectively. This means that effect of drying was

0.6525 kg/h (H=85 cm), 0.8871 kg/h (H=55 cm) and 0.4375 kg/h (H=25 cm). In regard of the effect of drying and the energy consumption, these data show that the layer of H=55 cm is the optimal variant for drying the hops in this type of dryer. As for the layer of H=25 cm the drying process was not finished in the first day, since the moisture content only fell to 12 % so the drying had to be continued during the night and the next day. Therefore the drying effect is relatively minor; 0.4375 kg/h. The specific consumption of electric energy for the fan, i.e., for drying at whole was found to be: 0.214 kWh/kg of evaporated water for the 25 cm layer; 0.136 kWh/kg of evaporated water for the 55 cm layer, and 0.210 kWh/kg of evaporated water for the 85 cm layer.

At the very same time an experiment was performed with a layer of H=115 cm. It took over 140 h for this layer to be dried. The quality of hops from this layer was tested and the results have shown the degradation of hops in higher segments of the layer (H=90-115 cm). Therefore this particular case is not presented in the diagram of drying.

Figure 4 presents the drying curves for boxes containing the 25, 55, 85 and 115 cm layers of hops, during the period 1-8 September, 1992. The 115 cm layer was dried in 135 h, and in that period of time the following quantities of hops were dried:

- 3 batches in 25 cm layers, in sum 191 kg of wet, or 57 kg of dried hops;
- 3 batches in 55 cm layers, in sum 523 kg of wet, or 159 kg of dried hops;
- 1.5 batch in the 85 cm layer, in sum 470 kg of wet, or 139 kg of dried hops;
- 1 batch in the 115 cm layer, in sum 452 kg of wet, or 128 kg of dried hops.

These data suggest that the 55 cm layer is optimal one for this type of bath-in-bin dryer design. The average drying effect for one batch in the 55 cm layer is 1.205 kg/h, measured in dry material, while for the layers of 85, 115 and 25 cm it is 1.003, 1.023 and 0.5797 kg/h, respectively. The unsatisfying drying effect for the 25 cm layer indicates the insufficient use of the solar-heated air potential.

Also the data on the quantity of evaporated water per hour of drying, during the process of hops drying, prove the advantage and justifiability of the 55 cm layer as the optimal solution for this experimental plant. The quantity of water evaporated from the layers of 25, 55, 85 and 115 cm was found to

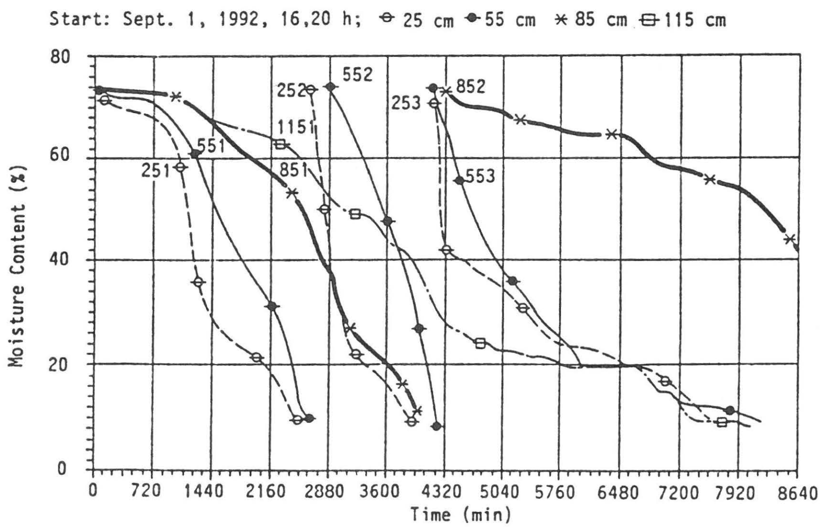

Fig. 4. Drying curves of hops layers of different thickness in the period 1-8 September 1992.

be 1.362 kg/h, 3.516 kg/h, and 2.535 kg/h, respectively.

The same tendency is found with the data on electric energy consumption per 1 kg of dried material. For the 25, 55, 85 and 115 cm layers it was 0.944, 0.371, 0.422 and 0.435 kWh/kg, respectively.

Drying process on different heights within a layer

The gradual change in moisture content on different heights within a thicker layer of hops (H=85 cm) is presented in Fig. 5. In certain intervals of time the samples were taken from the box containing the 85 cm layer of hops: the first sample from the height of 25 cm, the second from the 55 cm and the third one from the 85 cm above floor. In the thin segment within the big batch the dominant change is a relatively quick one - which is indicated by a significant angle the drying curve makes in particular points. This significant change in moisture content happens in fact within a single day (during the sun radiation), which means that only a narrow segment of layer is bring intensively dried. Due to the high percentage of moisture in the material dried, the air gets saturated very soon - while passing through the relatively thin segment of the layer; therefore on this way through the higher segments no exchange of moisture between the material dried and the drying fluid is possible. In practice, this phenomenon is usually called 'the drying front movement'. This movement of the zone of intensive drying is indicated by the shifted steep lines in Fig. 5.

The moisture content to layer thickness ratio

During the process of drying the layer gets thinner, in certain proportion to the moisture content. The simultaneous measuring of (a) changes in the initial height of layer and (b) the content of moisture in the material dried, during the solar drying with the air flow of around 0.3 m/s, the data given in Fig. 6 were recorded. The relative reduction of the initial height of the layer observed, with the initial moisture content of 73 %, is proportional to the loss of moisture, and is changing as the curve in Fig. 6 shows. Its expression is:

$$(h/h_0)\,100 = 62.12 \exp(0.005684\,w)$$

As shown in Fig. 6, the height of the layer of hops dried to 9 % of moisture content

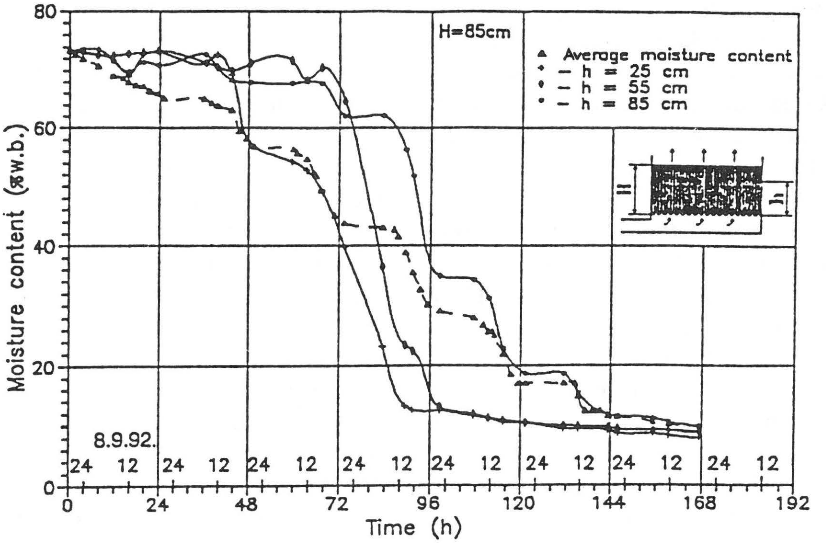

Fig. 5. Drying of hops in different segments within the 85 cm layer.

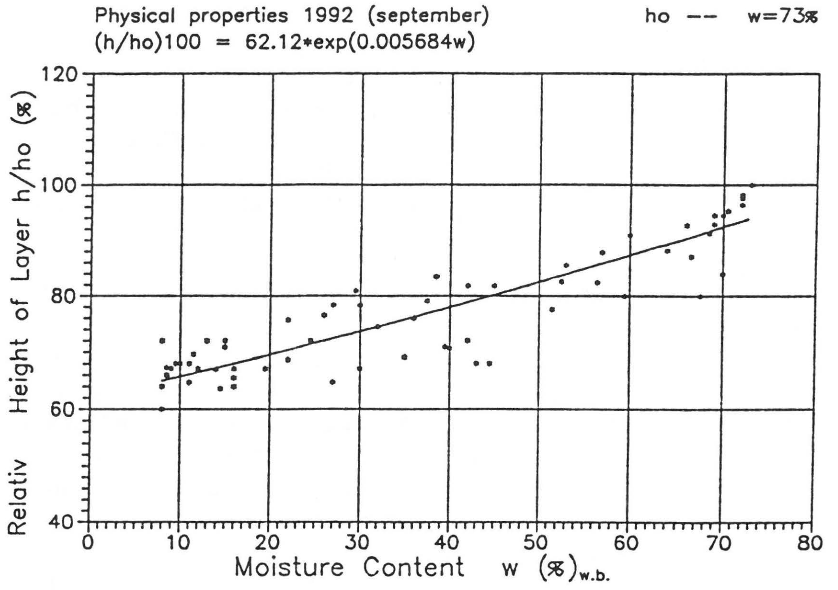

Fig. 6. The relative reduction of the hops layer's initial height during drying.

makes 70 % of the height at the beginning of drying - when the moisture content was 73 %.

Evaluation of the quality of solar-dried hops

Evaluated on the base of visual impression, the colour and the consistency of the hops cones remained unchanged after the solar drying in the layers under 90 cm. The colour of solar-dried hops cones in the 25, 55 and 85 cm layers remained closer to the natural one than the colour of the cones that had been, for the purpose of comparison, dried in the shadow of the storehouse.

The analyses of the content of etheric oil, alpha-acid and humulen in the solar-dried hops from the 25, 55, 85 and 115 cm layers have shown no significant difference in comparison to the control sample. However, the colour of the hops in the 115 cm layer was significantly more different from the natural colour than it was the case with the hops in the 25, 55 and 85 cm layers. Degradation of both colour and quality of hops cones was found in the 115 cm layer, in its segments over 90 cm, during the 140 h long process of drying. The reason is, in the first place, the insufficient fan power. The fact that the chemical analysis did not prove the obvious degradation of colour and quality indicates the inadequacy of the method used for evaluation of dried hops quality.

CONCLUSIONS

In the period 1-15 September, 1992, in the experimental plant of the solar plastic house the hops was dried in four boxes (each being 2x2 m), with the use of 4 identical fans (0.5 kW, airflow 3 900 m^3/h). In the layers measuring the heights of 25, 55, 85 and 115 cm the total amount of 17 batches of hops was successfully dried. As the balances have shown, the 55 cm is the optimal height for the layer to be dried in this dryer. The average drying effect for one batch of the 55 cm layer, expressed in dry material, is 1.205 kg/h, and for the layer heights of 85, 115 and 25 cm it is 1.003, 1.023 and 0.5797 kg/h, respectively. The minor effects of drying the 25 cm layers indicate that the potential of the solar-heated air was insufficiently used. The analogous tendency is noticed in regard of energy consumption per 1 kg of dried material. For the 25, 55, 85 and 115 cm layers the energy consumption per 1 kg of dry drug is 0.944, 0.371, 0.422 and 0.435 kWh/kg, respectively.

The analyses of the drying process at different heights within the same, thicker layer have shown that only a narrow segment of the whole layer is intensively dried. The drying process in this type of dryer should be carefully conducted if the layer thickness exceed 90 cm, since the degradation of the upper segments of the layer are possible. When the layers over 90 cm are dried in this type of a dryer, the climatic conditions are unfavourable and only solar energy is used, the hops may lose in quality.

In proportion to the loss of moisture, the hops layer gets thinner during the process of drying. The height of the dried hops layer, containing 9 % of moisture, is around 70 % of the height at the beginning of drying, when the moisture content was 73 %.

REFERENCES

1. **Müller J.:** Troccknung von Arzeipflanzen mit Solarenergie. Diss. Universität Hohenheim, 1991.
2. **Müller J., Mühlbauer W., Martinov M., Tesić M.:** Verbesserung der solaren Trocknungslange für die Trocknung von Heil- und aromatischen Pflanzen. (in Serbo-Croat). II Tagung 'Prozesstechnik und Energetik in der Landwirtschaft', Landtechnische Geselschaft von Vojvodina, Novi Sad - Lepenski Vir, Tagungsfsreferatenbuch, 80-86, 1989.
3. **Tesic M. et al.:** Solare Trocknung von Hopfen in Foliengewachschaus - Optimierung der Schutthohe. Institut für Mechanisierung, Novi Sad, 1993.