Drying of cherry tree chips in the experimental biomass dryer with solar collector

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Abstract

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Drying significantly influences the process of a biomass conversion into the renewable energy source as well as quality of solid biofuels (briquettes, pellets). The research is focused on monitoring and evaluation of the drying process in the case of cherry tree chips drying in experimental biomass dryer with solar collector. The dryer has been conceived as a result of the project which was realized at the State Agrarian University of Moldova. Technological and construction specifics of the biomass dryer are described in the paper. The moisture content of the cherry tree chips was observed in dependence of the drying time and at different locations of the drying chamber. The drying process in the biomass layer was found as non-uniform. Further parameters such as relative air humidity and the air temperature were measured and analysed, as well. It was concluded that the experimental biomass dryer with solar collector can work well in the conditions of the Central Moldova during the sunny period of the year.

Keywords: bioenergy; drying process; material moisture content; relative air humidity, renewable energy; Republic of Moldova

Nowadays, the Republic of Moldova faces several serious problems, first of all ecological and energy supply. Ecological problem is caused by the accumulation of large quantities of waste from production and processing of agricultural products, and by using of non-renewable energy sources. The energy problem is characterized by deficit of energy carriers, the price of which has a tendency of constant rising, and it affects adversely all the other industries. It is obvious that for the stable development of economy of the Republic of Moldova is necessary to solve the above problems in the near future. The solution of these problems is possible through the widespread use of biomass as a cheep, ecological and locally unlimited source of alternative energy.

The development of bioenergetics gave rise to growing up of demand on new active research in this field. There is a huge lack of bioenergetics knowledge and experience as well as biomass processing technologies in the Republic of Moldova. The experimental biomass dryer with solar collector is a part of so called Laboratory of Bio-energetic which was built in the area of the State Agrarian University of Moldova in Chisinau for educational, demonstrating and research purposes in the framework of development project of Czech Republic in the Republic of Moldova.

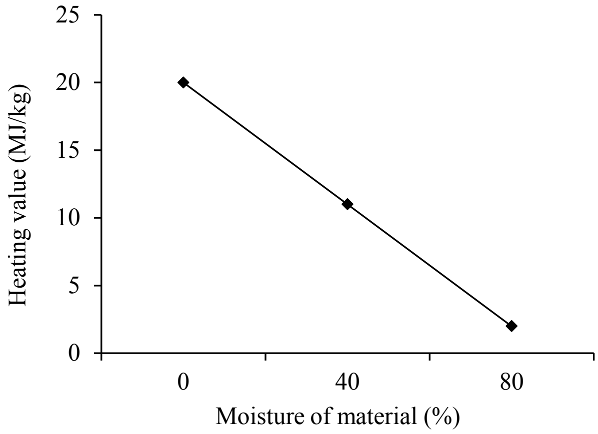

Fig. 1. The effect of moisture content on the heating value of wood biomass

According to the energy strategy of the Republic of Moldova in the year 2010 six percents of energy and in the year 2020 twenty percents of energy will be produced from renewable sources. Biomass will considerably contribute in this amount (Fomin 2009).

Very perspective form of alternative energy made from biomass is solid bio-fuels such as briquettes and pellets. To produce them, the biomass passes through the phased process: collection and preparation, preprocessing, drying, crushing, mixing and pressing. The paper is focused on biomass drying.

Reference analysis and theory

Drying is a process of evaporation of a liquid from the material that results an increase of its dry matter content. Drying is carried out for different purposes: to facilitate the transportations of the biomass and make the transportation cheaper, to increase the strength of the material and to make its further processing easier (Pobedinschi et al. 2009). Drying of plant materials is an important operation from technological point of view. Thanks to drying the material which would destruct in its natural state very quickly can be stored for a long (Souček, Kroulík 2010).

For these and some other reasons the low water (moisture) content in the biomass plays a significant role. The plants' organic life declines when the water content falls to 38%. The decomposing microbial processes cease to exist with water content in the material under 20% (Sladký, Hutla 2000).

The moisture content has a big effect to the heating value reached at the burning process as well. Vaporizing water requires energy from the burning process, thus reducing the heating value of the fuel (Fig. 1) (Huhtinen 2005). It is a very important fact that with the decrease of the moisture content the heating value of the fuel grows.

The speed of the drying process is influenced by the size, shape and type of material (Souček, Kroulík 2010). Beyond these factors, the moisture content in wood biomass depends on a combination of climatic conditions (relative air humidity, air temperature, etc.), time of year when harvesting takes place, and the duration and method of storage (Simpson, Tenwolde 1999). For example, during the drying process when the dried material loses water, the absolute air humidity of output air must be higher then that of the input air. This condition expressed mathematically is:

$$\varphi_o > \varphi_i + \Delta\varphi \ (\%) \qquad (1)$$

where:

φ_i – relative humidity of input air

φ_o – relative humidity of output air

$\Delta\varphi$ – difference of relative air humidity (Hutla, Sladký 2001)

Accordingly to Gottschalk and Scholz (2009) the drying process of the wood chips in the pile largely depends on particle size distribution. The authors developed thermodynamic model of the drying process which shows the development of temperatures and moisture content in piles of different heights.

Aerodynamic resistance of biomass layer is an important parameter, which influences the drying process as well. Hutla et al. (2005) determined theory about dependence of pressure decrease during air penetration through biomass layer on airflow velocity. Pressure decrease was measured by specially designed measuring device in the shape of cylinder.

Biomass moisture content is a basic input parameter for pressing process. If the moisture content exceeds the level of 20%, the wood biomass will not compress to required size in a pressing chamber and briquette will crumble (Plíštil et al. 2005).

Drying often involves high energy consumption, that is why it is very important to find an optimal design and use of drying equipment. Hutla and Sladký (2001) investigated the possibility of energetic wooden chips drying in the large-capacity hayloft. Two methods of controlling of fans' driving cycles were compared with the regime of time switching during the material drying. Both controlling methods were derived from the values of input

Fig. 2. Overall view of the experimental biomass dryer

and output relative air humidity. Four days were needed to reduce the water content from 50 to 20%. The same methodology was used by Hutla and Mazancová (2004) to study drying process of energy sorrel in the large-capacity hayloft. In this case the moisture content changed from 23.8% to an average value of 20.4% during 2 days, and only 8 hours were needed for the drop of moisture content from 20.4 to 14% under the conditions of low value of relative air humidity. Both researchers concluded that the method of fans controlling has no effect on moisture reduction in the material.

Oberhuber and Simader (1999) described drying system specially constructed for energy chips drying by solar roof which absorbs the sun radiation. Experimental biomass dryer built in Republic of Moldova has a similar design and principle of work.

Fig. 3. Mixing chamber with reversible fans

Objectives

The paper is focused on monitoring and analysis of drying process on example of cherry tree chips drying in the experimental biomass dryer using sun power (solar collector). The main purpose is to consider the efficiency of biomass drying in this constructional type of dryer.

MATERIAL AND METHODS

The dried material was fresh chips from small cherry trees plantation, which had to be liquidated. The harvest was carried out manually in the location of Central Chisinau, Republic of Moldova. After harvest the biomass was crushed by the wood crusher PIRBA (Bystroň Co., Valašské Meziříčí, Czech Republic). The trees age was 5 years; an average trunk diameter was 10 cm. The wood chips particles were about 10 cm long and 3 cm thick. The chips were mixed with a fresh leaves in the proportion 70:30. Starting moisture of the material was about 35%. Harvesting, crushing, transportation and deposition of the biomass in the experimental biomass dryer took place on August 21, 2009.

The drying was implemented in the combined biomass dryer (Fig. 2), which was built as an independent part of laboratory building in a campus of State Agrarian University of Moldova.

The combined dryer consists of three drying chambers (for the biomass deposition), solar collector, hot water boiler (located in the main laboratory building) with the system of distributors, air mixing chamber (Fig. 3), three reversible fans, heat exchangers, air dividers, system of floor cannels covered with grids over which the biomass is putt-

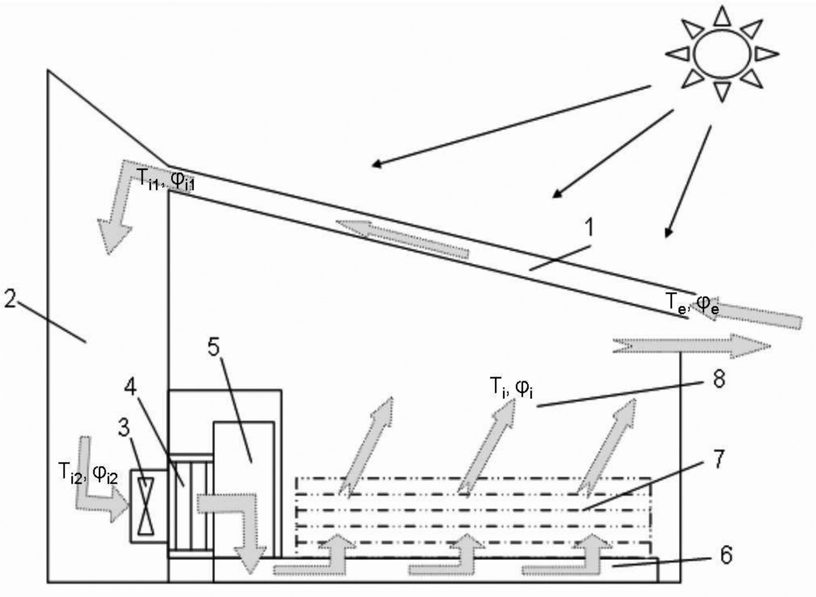

Fig. 4. Longitudinal section of experimental biomass dryer with demonstration of direction of air flow and illustration of main locations for air parameters' measurements

1 – solar collector, 2 – mixing chamber, 3 – fan, 4 – heat exchanger, 5 – air divider, 6 – floor channels covered with grids, 7 – layer of biomass, 8 – drying chamber; T_e, φ_e – air temperature (T) and relative air humidity (r.a.h.) on the entrance to the solar collector; T_{i1}, φ_{i1} – air T and r.a.h. on the exit from the solar collector; T_{i2}, φ_{i2} – air T and r.a.h. on the entrance to the reversible fan; $T_{i,}$ φ_i – air T and r.a.h. inside the drying chamber above the biomass layer

ed to be dried. The drying air in this construction of dryer can be heated by heat exchanger (heat from the water warmed up by boiler) or by sun (heat from warm air conditioned in the solar collector) or by both of them combined, and then forced by fans into the air channels (Ivanova et al. 2011).

The principal diagram of the experimental biomass dryer is shown in Fig. 4. The outside atmosphere air is drawn through the solar collector (1) by work of reversible fans and warmed up. It is then passed into the mixing chamber (2) where the fans (3) are located. Each fan pushes the warm air through the heat exchanger (4) into the air divider (5) and further into the channels (6) covered with grids and making the floor of the drying chambers. From the floor channels the air penetrates into the layer of biomass (7). After having passed through the biomass at drying chamber (8), the air returns out into the atmosphere (Havrland et al. 2010). The dryer is composed of three drying chambers; each of them has a ground-plan area of 24 m^2.

Fig. 5. Detail of solar roof

The solar collector comprises the roof of the dryer. It consists of an upper transparent part made of polycarbonate panels and a lower part made of galvanized sheet metal coated with matt black paint (Fig. 5). This part absorbs the solar radiation. Both parts are separated by wooden beams which create air cannels.

Every day of experiment the fans AVEN 630H/500E (Ventilátory Kadlec Co., Dašice, Czech Republic) (nominal flow capacity of each fan is 8,640 m^3/h) were switched on from 9 a.m until 6 p.m. Relative air humidity φ (%) and an air temperature T (°C) were measured in this period of time every single hour. These parameters were acquired by electronic psychrometer LM-81HT (Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) (Fig. 6) in eighth different places which situate inside and outside the dryer. Tree of these locations are inside the biomass layer.

Fig. 6. Electronic psychrometer Lutron LM-81HT

Data were measured there at the deep of 15 cm from biomass layer surface.

Moisture content of the cherry tree chips was observed at six chosen locations of the drying chamber differently remote from the reversible fan and placed over the floor channels and between them.

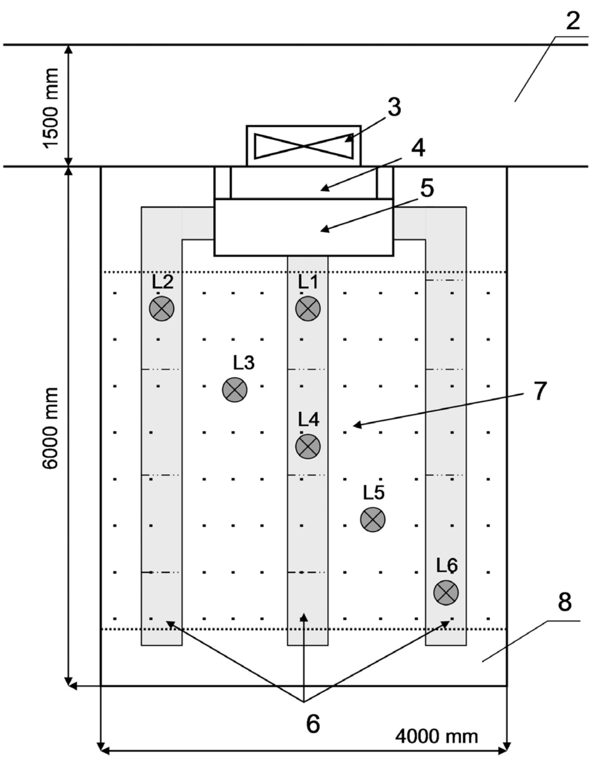

Fig. 7. Ground plan of the drying chamber and the locations used to measure the moisture content of dried material (L1, L2, L3, L4, L5, L6); 2–8 see Fig. 4

Samples of biomass for moisture content determination were collected from the middle height of biomass layer twice a day (in the morning before switching on the fans and at 6 p.m. after nine hour regime of the fans work). The ground plan of the drying chamber is presented in Fig. 7 and the places of samples' collection are mapped there.

The following simple equation was used to calculate the moisture content of biomass w_e (%):

$$w_e = [(m_v - m_s)/m_v] \times 100 \qquad (2)$$

where:

m_v – total mass of wet biomass (kg)

m_s – dry matter mass of the dried material (kg)

RESULTS AND DISCUSSION

The drying was performed from August 22, 2009 to August 28, 2009. Cherry tree chips biomass was placed in the middle drying chamber of the dryer (Fig. 8). The total weight of the material before drying was 2,000 kg and the material layer thickness was 0.5 m. An average speed of air in the fan which was measured by digital anemometer LM-81AM (Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) was 5.6 m/s.

Results of moisture content measurements are presented in Table 1. The experiment starts next day after harvesting, that is why the first data of moisture content given in the Table 1 are not the same and are different from the moisture content of freshly harvested cherry tree chips.

From Table 1 is evident that the morning water content in the material in all chosen (measured) spots was mostly higher than the water content found at 6 p.m. previous day. This phenomenon may have been evoked by the drop of temperature and growth of the air humidity during the night and in the early morning hours. At this time period the fans were switched off, so the air was not forced to circulate and the biomass was absorbing atmosphere humidity.

The Fig. 9 which was drawn according to the data in Table 1 shows the changes of the moisture content of cherry tree chips at different measurement points of the drying chamber during the drying time. The data were statistically processed by using polynomial mathematical models. The Fig. 9

Table 1. Changes of material moisture content in chosen locations inside the biomass layer

Date (August, 2009)	Moisture content (%)					
	L1	L2	L3	L4	L5	L6
22 M	32.41	29.83	37.22	39.38	35.41	31.72
22 A	24.77	18.22	38.04	21.38	34.2	19.26
23 M	20.91	20.42	39.25	24.13	38.08	21.12
23 A	8.82	11.29	34.68	19.69	39.88	9.15
24 M	20.63	10.35	37.67	11.75	34.14	13.43
24 A	13.02	7.00	30.08	10.52	36.87	10.10
25 M	10.66	9.88	27.96	12.18	33.2	12.59
25 A	6.13	7.94	31.83	9.20	28.17	8.53
26 M	8.07	8.27	31.52	9.81	28.39	9.11
26 A	6.07	5.63	27.79	5.09	25.79	5.84
27 M	7.36	7.71	27.34	7.36	29.07	7.40
27 A	5.35	4.85	21.92	4.47	20.85	5.39
28 M	6.32	6.46	12.55	6.02	29.53	6.27
28 A	3.95	5.29	11.33	3.60	16.84	4.23

M – morning, before the start of measuring; A – afternoon, at 6 p.m.

shows a certain non-uniformity of moisture content changes at different measuring points.

The data from the spots situated above the grids of the floor channels (L1, L2, L4, L6) are very similar as to their magnitude and course over the whole period of the experiment. In general, the speed of drying changed during the drying process course. The drying speed reaches its maximum after the initial period of warming up material and then monotonically decreases, i.e. material passes into the steady-state (dry state) under given external conditions. Significant water content reduction in the material was recorded during first two days of

Fig. 8. Layer of cherry tree chips in the drying chamber of biomass dryer

the drying in all these four locations. So the curves have very rapid decline. The last three days of drying the biomass moisture changes were very imperceptible, the drying was slow.

The moisture content reduction in the measuring points situated between the channels (L3, L5) was much slower during the whole drying time as compared with the situation at four other (already described) points. It can be well identified at Fig. 9. Both curves have slowly gradual decreasing character. Fig. 9 shows that the behaviour of moisture content changes in these two spots slightly differs from each other. The drying process speed at the point L5 is the slowest. It could be explained by its remoter location from the air current above the end of the channel, where the air speed is slower and its temperature is lower than those in the spots close to the fan.

Climatic conditions during seven days of measurements were very similar. Figs 10 and 11 depict changes of relative air humidity and air temperature in chosen spots during the day (nine hours interval of fans work) on example of sixth day of experiment (August 27, 2009). Main spots of air parameters' measurements are illustrated on Fig. 4.

Fig. 10 shows that in the period from 12 noon to 3 p.m. the temperature of heated air (in the solar collector) is becoming much higher then the temperature of incoming atmosphere air. So, this pe-

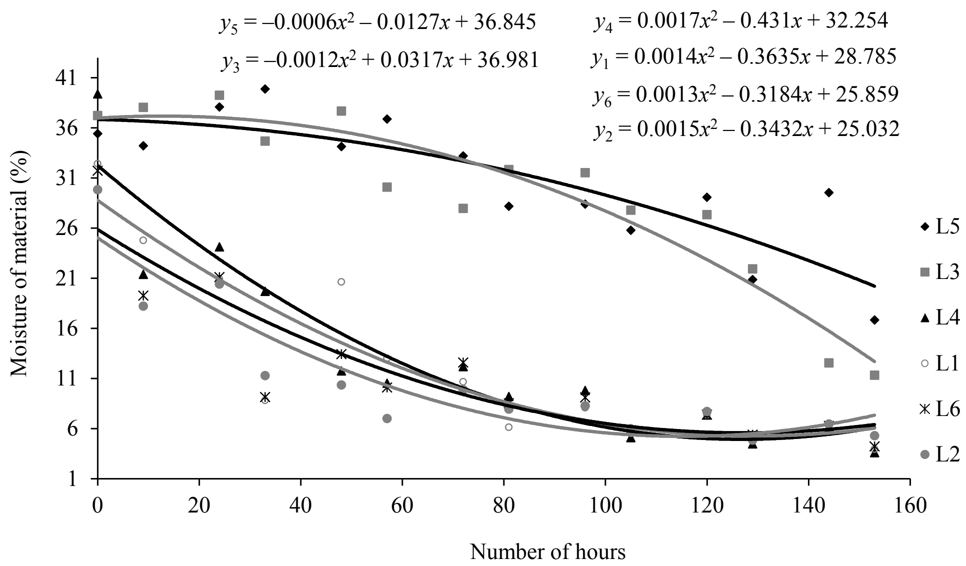

Fig. 9. Dependence of cherry tree chips moisture content on time

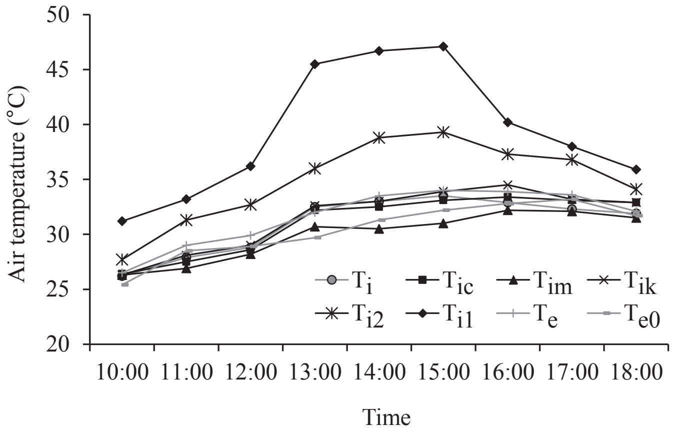

Fig. 10. Changes of air temperature at different locations during the selected day
T_i – air temperature (T) inside the drying chamber above the biomass layer; T_{ic} – air T inside the biomass layer above the middle channel; T_{im} – air T inside the biomass between the channels; T_{ik} – air T inside the biomass at the end of the left channel; T_{i1} – air T on the exit from the solar collector; T_{i2} – air T on the entrance to the reversible fan; T_e – air T on the entrance to the solar collector; T_{e0} – outside air T

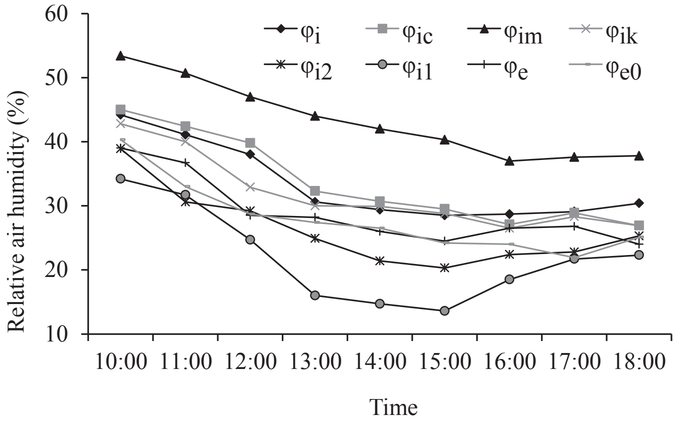

Fig. 11. Changes of relative air humidity at different locations during the selected day
φ_i – relative air humidity (r.a.h.) inside the drying chamber above the biomass layer; φ_{ic} – r.a.h. inside the biomass layer above the middle channel; φ_{im} – r.a.h. inside the biomass between the channels; φ_{ik} – r.a.h. inside the biomass at the end of the left channel; φ_{i1} – r.a.h. on the exit from the solar collector; φ_{i2} – r.a.h. on the entrance to the reversible fan; φ_e – r.a.h. on the entrance to the solar collector; φ_{e0} – outside r.a.h.

riod of time the solar collector riches the maximum of its efficiency.

It is evident (from Fig. 11) that the highest values of the relative air humidity (φ_{im}) were reached between the floor cannels (inside the biomass layer). This fact corresponds with the slower drying process in the locations between the channels (L3, L5).

CONCLUSIONS

On the basis of experiments with the drying of cherry tree chips by the dryer equipped with a solar collector the following can be concluded:

1. Under the climatic conditions of the Republic of Moldova at the period when the experiment was

implemented (end of August 2009), two days of drying was enough to rich an average moisture content in material about 12%. It was possible in the spots located above or close to the floor channels distributing the drying air.
2. On the other hand, seven days of drying were needed to dry up the cherry tree chips to the expected average value of moisture content (about 14%) in the spots between (or further from) the channels.
3. It is recommended that in order to make the drying process uniform the biomass must have regularly been mixed. Due to the construction of floor channels of the dryer, the flow of warm air cannot well penetrate through the down part of biomass layer in the places between the channels.
4. For more uniform air circulation the biomass should have to be placed on a platform (palettes) with grates located in some distance above the grids of floor channels.
5. Data characterizing changes of temperatures on the exit from solar collector (T_{i1}) and on the entrance to reversible fan (T_{i2}) show the imperfection of the dryer due to considerable heat losses in the mixing chamber. The increase of the dryer efficiency could be provided by installation of the intermediate air lines connecting solar collectors with fans.
6. It can be concluded that the combined biomass dryer with solar collector works very well in the conditions of the Republic of Moldova during the sunny months without any additional heat supply from the by-pass boiler. The drying process should be conducted continuously in order to increase its efficiency, to shorter the drying time and reduce energy supply.

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