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New types of air heating solar collectors and their use in drying agricultural products

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Abstract. The aim of this research was to make new types of air heating solar collection for agricultural production drying and check their operation. In 2011 and 2012 were obtained two Latvian Republic Patents for air heating solar collectors. One for an autonomous, compact air-heating solar collector, the other one for a cylindrical crop production drying device with solar collector that can be used for drying products. So there are two different types of drying facilities with solar collectors using sun-warmed air: cylindrical crop production drying device, and autonomous, compact crop production drying facility. Cylindrical facility is tested for drying 19.5% wet wheat. Autonomous, compact crop production drying facility is tested for fresh carrots and apples 5–10 mm slices drying, using ambient air, heated with the solar collector. For experimental results on carrot and apple slices the layers of humidity and temperature changes in the drying process are given. Grain temperature distribution in wet wheat layers during drying with heated ambient air depending from sun radiation is given.

Key words: drying, solar collector, air heating.

INTRODUCTION

Over the past century, fossil fuels have provided most of our energy, because it was much cheaper and more convenient than the energy from alternative energy sources. The limited reserves of fossil fuels causes a situation in which the price of fuels will accelerate as the reserves decrease. Sun, that alternative energy source, is increasingly more widely used in national economics. The sun is the most powerful heat generator, which none of the heat sources created by mankind can compete with. Yearly the earth is reached by solar energy 15,000 times more than the power industry of the whole world can produce. The greatest advantage of solar energy as compared with other forms of energy is that it is clean and can be supplied without environmental pollution. So if more people used solar energy to heat the air and water in their homes, our environment would be cleaner.

The solar energy collectors are a special kind of heat exchangers that transform solar radiation energy into transportable energy. This is a device that absorbs the incoming solar radiation, converts it into heat, and transfers the heat to a fluid (usually water, air or heat transfer oil) flowing through the collector.

In general, solar air heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature and wind speed), design parameters (type of collector, collector materials) and flow parameters (air flow rate, mode of flow). The principal requirements of these designs are a large contact area between the absorbing surface and the air (Kalogirou, 2009).

The efficiency of an air heating solar collector varies depending on collector covering materials (polyvinylchloride film, cell polycarbonate PC, translucent roofing slate), absorber (black colored wood, steel-thin plate etc.) and insulation of collector body with different air velocities in the collector (Palabinskis et al., 2008; Aboltins, et al., 2009; Aboltiņs[a] et al., 2010; Aboltiņs[b], et al., 2010; Aboltins et al., 2011, 2012; Ruskis et al., 2011).

The air heating collectors can be used in two main directions- for production drying and room heating (ventilation). Production issues through drying in the sun-warmed air are discussed a lot in works (Mulet et al., 1993; Ratti & Mujumdar 1997; Andoh et al.; 2010; Aboltins & Upitis, 2011, 2012).

1. The aim of this research was to make new types of air heating solar collectors for agricultural production drying and to check their operation. In 2011 and 2012 we got a Latvian Republic Patent for an autonomous, compact air-heating solar collector (Patent LV-14486, 2011), that can be used for product drying and a cylindrical crop production drying device with solar collector (Patent LV- 14528, 2012).

MATERIALS AND METHODS

We made two different types of drying facilities using sun-warmed air (Figs. 1, 2).

Figure 1. Cylindrical crop production drying device with solar collector.

Figure 2. Autonomous, compact crop production drying facility.

Cylindrical crop production drying device with solar collector (Fig. 1) is based on two cylinders. Outer cylinder is transparent and serves as a protective surface of the absorber in the second cylinder. The internal cylinder painted black, working as a solar collector absorber, functioned as an equipment dryer. The internal cylinder lower part is built on a perforated floor where there is placed the material that needs to dry. The fan positioned at the bottom of the internal cylinder, takes atmospheric air, heated moving from top to bottom between the two cylinders. This drying equipment is a construction that combines the drying facility with a cylindrical solar collector in one integrated system: drying device with solar collector. Cylindrical shape of drying device and solar collector is much of the day situated facing the sun and thus ensures efficient operation of the equipment.

Autonomous, compact crop production drying facility (Fig. 2) equipped with air heating solar collectors and its aim is to use compact light drying devices of various types of crop production using solar energy. Equation essence is the production drying with solar heated atmospheric air, which is transported with the fan, which is powered by photovoltaic panel. The proposed drying system operates completely independently, it is easily and quickly transportable and oriented to the sun, the easily installed and demounted solar collector transformed part. It is possible to use only stationary part of the solar collector at high ambient air temperature. Drying products are placed on easily removable trays with perforated bottom.

We tested cylindrical facility (Fig. 1) for drying 19.5% wet wheat. The funnel of the dryer takes ambient air coming from top to bottom and heating between two cylinders. The funnel, placed at the bottom of the internal cylinder, capacity was 300 m^3 h^{-1} and grain layer thickness was 40 cm.

Experiments were prepared in the drying facility (Fig. 2) equipped with five trays, two 12V DC fans with a total maximum capacity of 360 m^3 h^{-1}, which is placed at the bottom of the side wall of the equipment, where are located air intake vents. The air velocity in the dryer was 0.95 m s^{-1}. Carrots were used in the experiments, cut into 5–10 mm slices and apples cut into 8–10 slices so the slices should be about the same thickness (Fig. 3). Cut products were laid in one layer over the tray area.

Air heating collector covered material – polystyrol plate and absorber – black coloured steel-tinplate in middle. Collector length in the open position was 1.8 m.

a) b) c)

Figure 3. Fresh (a), dry (b) apples slices and dry carrot slices during experiments.

RESULTS AND DISCUSSIONS

The data of drying experiments with autonomous, compact crop production drying facility shown in Fig. 4 and Fig. 5. Drying curve of the linear phase of the apple slices are much more than the carrot slices with similar drying temperatures. Inlet air temperature changes smooth out in drying process, during heating air flows through the trays.

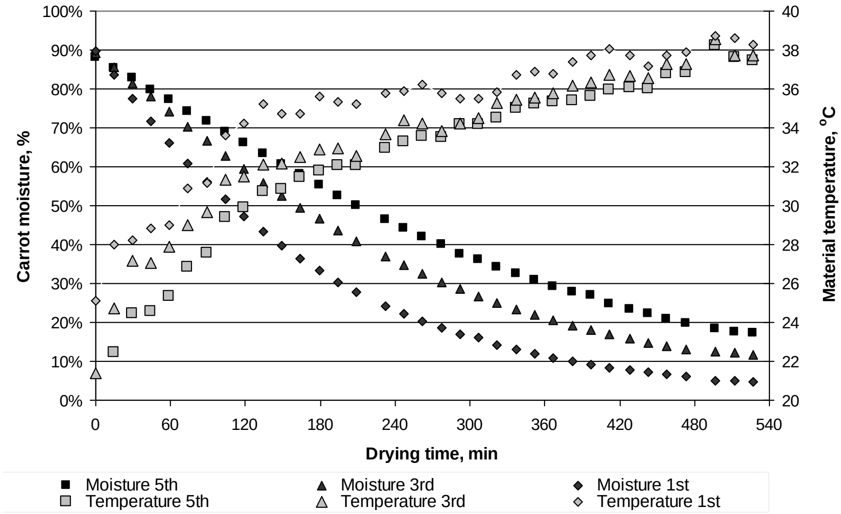

Figure 4. Moisture and temperature changes of carrot slices layers /trays (1st, 3rd, 5th) during drying.

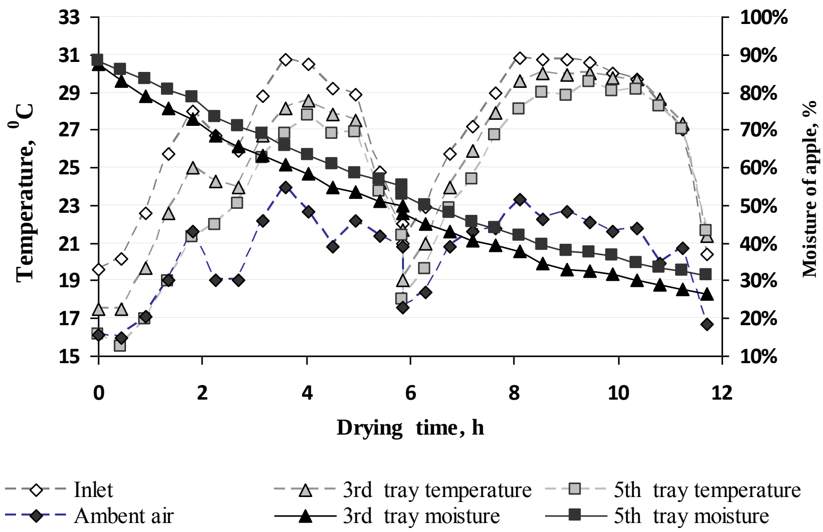

Figure 5. Moisture and temperature changes of apples slices layers /trays during drying with crop production drying facility Fig. 2.

Moisture removal of carrots is much faster than the apple samples. After 9 hours of drying, moisture content of carrot slices is less than 2 times compared with the apple slices. In addition, the first layer carrot humidity is less than 5%, but the apple slices humidity reaches 24% in the first layer /tray. Low-temperature at the beginning of drying process can be explained by increased evaporation of moisture from the apples and carrots, which consumes additional heat. Internal moisture diffusion of samples plays a vital role in the end-stage of the drying process.

Ambient air heating degree in collector during 12 hours of apple slice drying (30.04 and 01.05. 2012) 30.04 9:30–15:30 with average radiatiom 630 W $(m^2)^{-1}$ and 01.05. 10:30–16:30 with average radiation 760 W $(m^2)^{-1}$. Average temperature increase during drying process 6.7 °C Fig. 5.

Smaller temperature difference between the third and fifth layer compared with the first and 3rd layer can be explained by the fact that an increase of the passing air humidity in the drying process and less air, absorbs moisture from the product. Consequently, the energy consumption is lower.

A similar situation is observed in grain drying experiments using a device with 80 cm long cylindrical air heating solar collector Fig. 1. The experiments 21.05.2012 from 10:30 to 13:30 shows good correlation between ambient air heating degree and sun radiation Fig. 6.

Using this type of solar collector the observed temperature difference between sun and shade sides Fig. 7. The ambient average air temperature increase during the experiment was 1.7 degrees with average radiation 340 W $(m^2)^{-1}$. The average temperature difference between sun and shade sides was 1 °C. The obtained average heat for one drying hour was approximately 600 kJ.

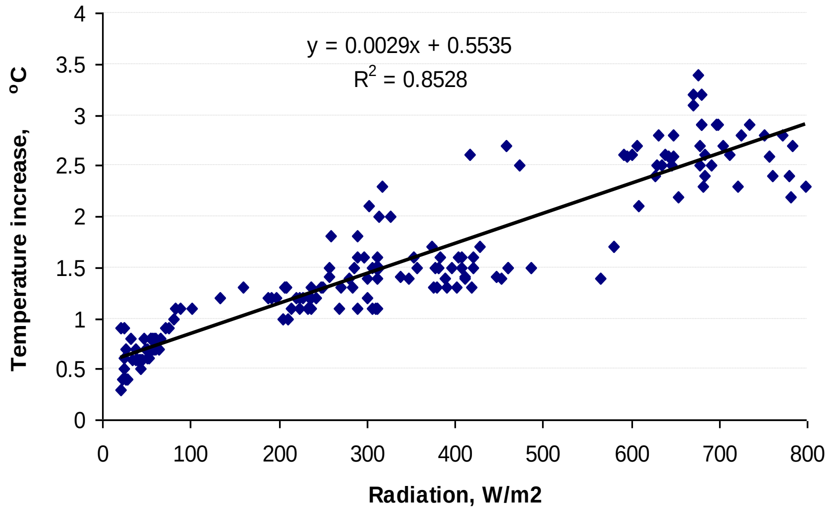

Figure 6. Atmospheric air heating degree dependence from sun radiation.

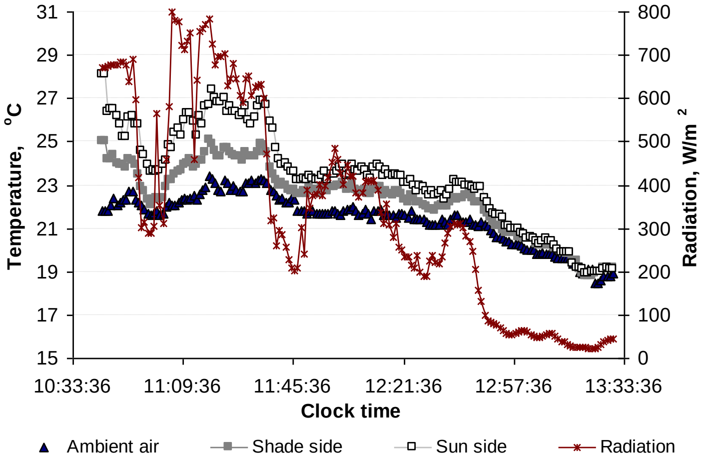

Figure 7. Inlet air temperature changes dependeding on the side of collector and sun radiation (21.05.2012).

A similar situation is observed in the grain drying experiment 07.09.2011 (Fig. 8). Here a clearly visible layer of the grain temperature distribution and moisture evaporation heat was consumed, causing a drop in temperature. As we can see the given system (Fig. 1) warmed atmospheric air an average of 3 degrees during the experiment. Warm-up depends on the degree of solar radiation. Ambient air is warmed by more than 4 degrees with radiation more that 600 W $(m^2)^{-1}$, it's all just off the equipment length of 80 cm. Temperature of the layer can be reduced to the grain equilibrium moisture content temperature during drying process.

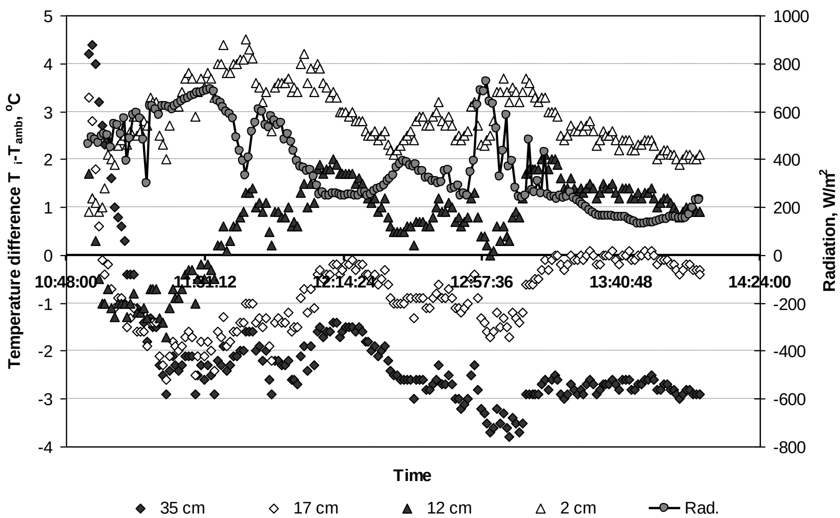

Figure 8. Grain temperature distribution from bottom (T–grain temperature, T_{amb} – ambient air temperature) during drying with heated ambient air depending on radiation.

CONCLUSIONS

1. Autonomous, compact crop production drying facility can be used for a variety porous product gentle drying regime at low temperatures. The use of a solar panel installation does not require a constant electrical connection point and is a facility easy to use in meadows, forests, marshes, etc.

2. Cylindrical crop production drying device with solar collector is applicable to Latvia's climatic conditions. 80 cm long facility raised ventilated ambient air temperature by 4 degrees with radiation 700 W $(m^2)^{-1}$.

3. Air-heating solar collectors for use in drying agricultural production are simple, cheap and save energy resources.

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