INTENSIFICATION OF CROP PRODUCTION DRYING USING SOLAR RADIATION POWER

Algirdas Raila, Egidijus Zvicevicius, Arvydas Bocys, Ausra Cipliene
Aleksandras Stulginskis University, Lithuania
algirdas.raila@asu.lt, egidijus.zvicevicius@asu.lt, arvydas.bocys@gmail.com, janausra@yahoo.com

Abstract. When fossil fuel is used for energy production, various pollutants are discharged into the air, including CO_2, the increase in concentration of which promotes climate changes. The article analyses the capabilities of use of the solar energy radiation for crop production drying. The distribution intensity of the perennial solar energy radiation in the territory of Lithuania is analysed. It is established that the Western regions of the country have greatest prospects in solar energy application; its intensity in the central part of the country is approximately less than 5 % and it is the least in the Eastern region. The researches were conducted in the chemist's herbal raw material drying room using the solar collector of 131 m^2 net usable space. It is found that the degree of heating of air flowing through the solar collector depends on the air stream and the solar radiation intensity. With the short-term variations in the solar radiation intensity, the heating of injection air (drier) in the collector changes insignificantly; these variations are compensated by the accumulated heat of the solar collector structural units and the absorber. The goal of the paper is to determine the efficiency of use of solar radiation for crop production drying.

Keywords: solar energy, crop production, drying, collector, drier.

Introduction

The present-day civilization uses mainly non-renewable sources of energy, known as fossil fuels (coal, oil and natural gas). During the latest centuries huge amounts of fossil fuel were used by energy production industry and transport, therefore, these resources are rapidly running out [1].

Renewably energy sources are natural resources, originated and renewed by natural processes and by the purposeful human activity - energy crops growing. Usage of the resources is environment-friendly and positively contributes to the stabilizing of climate changes [1].

A solar collector transforms energy of solar radiation into thermal energy. The collector consists of a transparent cover, absorber, housing and thermal insulation. Sunlight radiates through a transparent cover and falls on a black absorber plate and as a result heats it up. A heating agent removes heat from the absorber. The transparent cover keeps long-wave radiation emitted from the absorber and warms up air inside the collector [2].

Medicinal plants are described as valuable healthful herbs, with better taste and aromatic characteristics. It is very important for herbs that are grown in clean natural environment to be timely harvested, nevertheless proper drying and user readiness are important as well. Drying of medicinal plants is one of the most important post-harvest processes, reducing enzymes activity and activity of microorganisms [3; 4].

The drying process should preserve medicinal properties of herbs and facilitate their long-term storage. The optimal drying parameters depend on the variety of medical plants, on a part of the plants and on stored active substances [5; 6].

The test results have shown that enzymatic activity in plants inhibits and ceases at temperature 50 to 60 ºC. Raw materials accumulating alkaloids, glycosides, saponins and vitamins are dried at the mentioned above and at higher temperature. For some active substances as volatile compounds, i.e., essential oils in herbs, the recommended temperature of drying should not exceed 35 to 45 ºC [7; 8]. The aim of the research was to determine the efficiency of solar radiation utilisation for drying of crop products.

Analysis of solar radiation characteristics in Lithuania

The annual solar energy resources in any area of the country are estimated by average annual solar exposure on conventional planes of solar energy space. After estimation of solar energy resources in all areas, tables and maps of the country yearly (or of the other period) solar energy resources are created [9].

Differences of exposures in particular Weather stations are not significant. Viability of different regions in Lithuania from the solar resources point of view is shown in Table 1.

Table 1

Viability of different regions of Lithuania from the solar resources point of view [9]

Lithuanian Weather station	Complete radiation energy over the		Viability
	E_h, kWh·m^{-2} *(to the horizontal plane)*	E_n, kWh·m^{-2} *(to optimally inclined plane)*	
Klaipėda, Kybartai, Telšiai, Lazdijai, Šilutė, Nida. (The country's western region)	1015 – 1042	1405 – 1439	Maximum
Utena, Kaunas, Vėžaičiai, Dotnuva, Šiauliai. (Central part of the country)	946 – 996	1316 – 1380	Middle
Biržai, Varėna, Dūkštas, Vilnius. (Eastern regions)	926 – 939	1290 – 1306	Minimal

In Lithuania solar energy accessing the ground, spreads out over a much wider area than in those geographic latitudes, where the sun is at zenith at noon. Solar radiation has also a longer way in the atmosphere here and thus experiences higher absorption and diffusion losses. Yearly energy of solar radiation in the territory of Lithuania is presented in Table 2 [10].

Table 2

Yearly energy of solar radiation in the territory of Lithuania [10]

	Horizontal plane, kWh·m^{-2}	Vertical plane, kWh·m^{-2}	Optimally (37°) inclined plane, kWh·m^{-2}	Total horizontal surface of the country (64878 km^2), GWh
Minimum	983	798	1131	$73.38 \cdot 10^6$
Average	1003	823	1160	$75.26 \cdot 10^6$
Maximum	1034	858	1205	$78.18 \cdot 10^6$

Nearly 1000 kWh·m^{-2} of solar energy falls on the ground in Lithuanian conditions. More than 80 % of the amount corresponds to a 6 months period (April to September) [9].

Another characteristic of solar radiation energy is solar radiation time, i.e., the period when the level of solar illumination exceeds 0.21 kWh·m^{-2}. Solar radiation time at the Lithuanian coast is nearly 1900 h, whilst in the eastern part it counts to 1700 h. Solar radiation time in Kaunas is shown in Table 3 [2].

Table 3

Solar radiation time in Kaunas [2]

Values	Months												Yearly
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Solar radiation time, h	41	59	133	178	255	177	267	234	166	96	37	30	1773
Days “without the sun”	18	13	8	4	2	1	1	2	3	9	19	21	101

Materials and methods

The study was conducted in July, 2011 on a raw medicinal plant dryer with the solar collector. The dryer with the solar collector (Fig. 1) consists of two shelf-type chamber dryers and four bins with active ventilation; two bins were used for peppermint drying.

In the solar collector with air flow, the absorbed solar radiation energy is converted into heat energy and is transferred to an air flow inside the collector. The solar collector consists of a transparent cover (2), absorber (3) and two air chambers. The transparent cover is made of a polycarbonate duct, its thickness is 6 mm and optical conductivity rate τ = 0.82 to 0.89. The absorber is made of a black-painted 0.8 mm steel sheet, with the absorption capacity α = 0.94 to 0.98. The total effective solar collector area is 131 m^2.

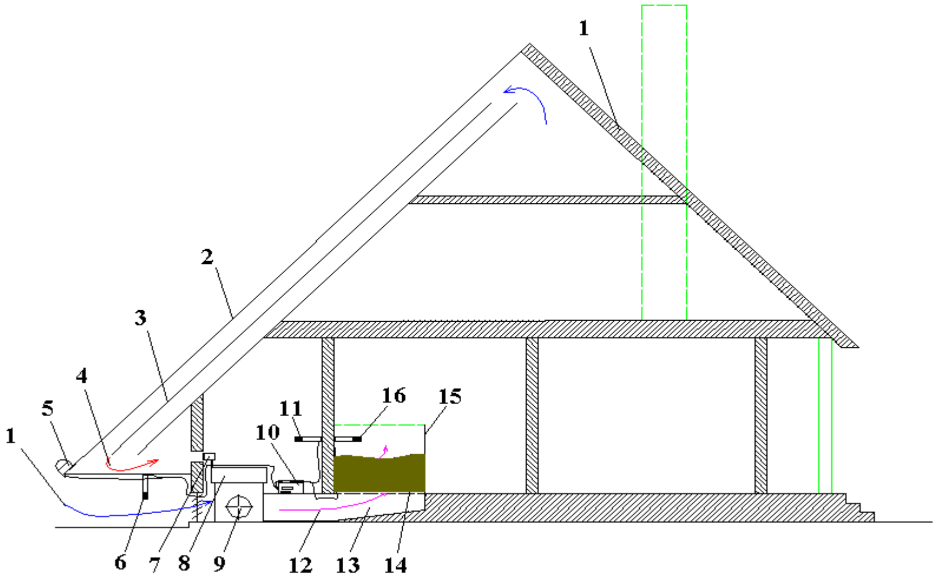

Fig. 1. **The scheme of a dryer with solar collector:** 1 – ambient air flow; 2 – transparent cover; 3 – absorber; 4 – heated air flow; 5 – pyranometer; 6 – a sensor for outside air parameters; 7 – vane anemometer; 8 – heat exchanger; 9 – fan; 10 – data logger; 11 – dryer parameters sensor; 12 – prepared drying agent; 13 – under–sieve chamber 14 – sieve; 15 – bin; 16 – the outgoing air parameter sensor

Warm air flow enters a block of fans through 21 0,195 x 0,245 m holes in a wall of the air-type solar collector. The air flow is created by four high pressure and powerful air flow fans; they allow setting the required air supply to each bin, depending on the dried raw material. Ambient air is supplied through the holes at the bottom of the dryer, when the raw material needs ventilation with ambient air. When the drying agent is ready, it is supplied through the heat exchanger (8) to the under-sieve chamber (13), where air is evenly distributed and enters the bins with stowed medicinal plants for drying.

The obtained solar radiation falling onto the transparent cover of the air-type collector was measured with a pyranometer AHLBORN FLA 613 GS (5) during our studies. A vane anemometer (7) was used for air velocity measurements at the openings of the ambient air intake manifold and at warm air aspiration openings. The air parameters (temperature and relative humidity) were measured with Almemo sensors and recorded with a digital logger ALMEMO 3290 (10). The ambient air parameters were measured with the sensor (6) in a block of fans (11) and the parameters of the outgoing air flow were measured at a layer of dried herbs (16).

The research was carried out at different weather conditions and at different air flows: 0.40; 0.70; 0.92; 1.03; 1.10; 1.20; 1.34; 1.83; 2.02; 2.41; 2.90 $m^3 \cdot s^{-1}$. Solar radiation was measured every hour during the tests, the measurements had three repetitions.

Results and discussion

The data obtained during the tests showed that the degree of air heating in a solar collector depended on the air flow and solar radiation intensity. At an average solar radiation level 560±50 $W \cdot m^{-2}$, the air flow through the collector varied from 0.40 $m^3 \cdot s^{-1}$ to 2.9 $m^3 \cdot s^{-1}$ (Fig. 2).

The resulting output from the air solar collector is calculated with formula:

$$Q_k = m \cdot c \cdot \Delta t \,, \tag{1}$$

where m – air weight, kg·s^{-1};
c – specific heat of air, J·kg^{-1}·K^{-1};
Δt – temperature difference.

The efficiency rate of the air-type solar collector is calculated:

$$\eta = \frac{Q_k}{Q_s}, \tag{2}$$

where Q_k – output power of the air solar collector, W;
Q_s – total solar radiation falling on the collector surface, W.

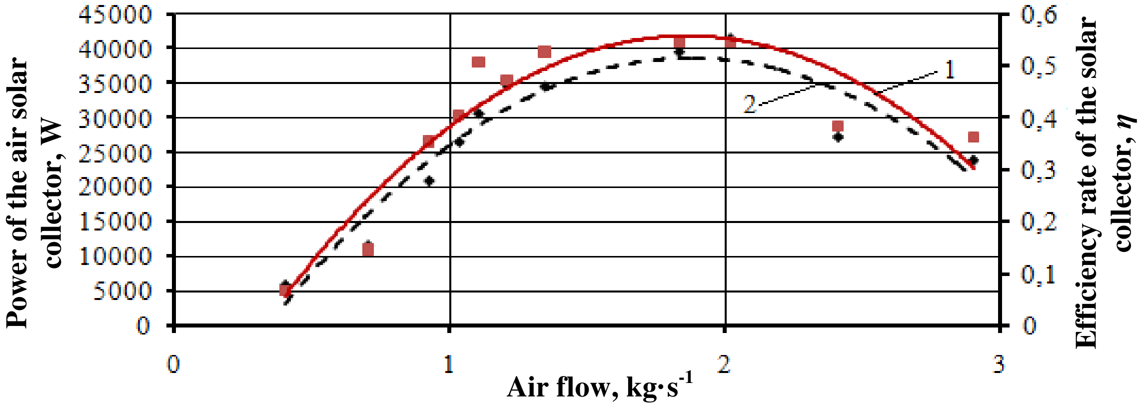

Fig. 2. **Efficiency of the air-type solar collector:** solar radiation intensity was 560±50 W·m^{-2}; 1 – efficiency rate of the solar collector; 2 – output power of the solar collector

The highest efficiency rate was obtained when the average solar radiation intensity was 560 W·m^{-2} and the air flow through collector was 1.83 kg·s^{-1}.

We have calculated instantaneous efficiency rate of the collector at a constant air flow and at different solar radiation levels (Fig. 3). Solar radiation increases at 12 o'clock, while the efficiency rate increases with some delay and the interval of increasing efficiency is equal to three hours. Heating of air flow (drying agent) in the collector varies slightly and is offset by the accumulated heat of the solar collector structure and absorber at short-term changes in the solar radiation intensity.

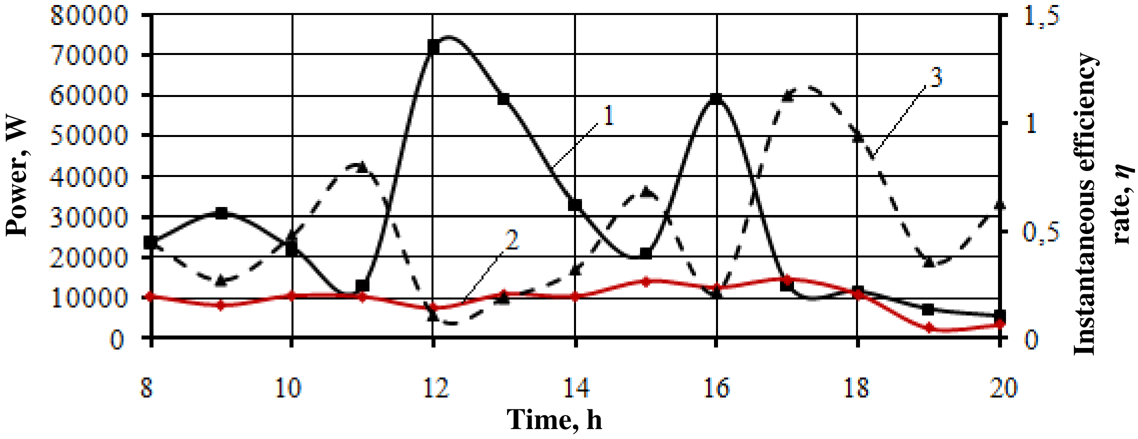

Fig. 3. **Changes of instantaneous efficiency rate of air solar collector:** 1 – total solar radiation falling on the collector surface; 2 – output power of the solar collector; 3 – instantaneous efficiency rates

The accumulated heat partially compensates irregularities of solar radiation and provides continuity of medicinal plants drying.

In the medicinal plants dryer with the solar collector it is provided that under unfavourable weather conditions heat for drying is produced by solid biofuel burning. This option ensures continuity of the medicinal plants drying process and quality preservation.

Energetic assessment

Due to the periodical pattern of medicinal plant raw material drying, the dryer is used frequently or at partial capacity.

Table 4

Changes of emissions rate depending on electric energy consumption [11]

Indices	The dryer operates 50 % of time per month	The dryer operates 70 % of time per month
Electric energy consumption	4209 kWh	5934 kWh
Emissions from electric energy production (indirect effect)	CO: 4,067 kg NO_X: 2,023 kg CO_2: 926,105 kg	CO: 5,884 kg NO_X: 2,928 kg CO_2: 1339,896 kg

When we use the air-type solar collector in the medicinal plants dryer for air heating in May to August, at the operation rate 70 % of the time, we should save about 23536 kWh of electric energy per season, while reducing annual emissions to the atmosphere: CO – 23,536 kg; NO_X – 11,712 kg; CO_2 – 5359,584 kg.

Conclusions

1. The analysis of annual solar radiation flux distribution in the country shows that the highest solar radiation energy flux is in the western region of the country, the average total annual sun exposure is 1015 to 1042 $kWh \cdot m^{-2}$; the intensity is nearly 5 % lower in the central part of the country and the lowest in the eastern region.
2. The degree of air heating in the solar collector depends on the air flow and solar radiation intensity. The highest efficiency rate of the solar collector was at relative air flow 0.0122 $m^3 \cdot s^{-1} \cdot m^{-2}$. With an average solar radiation level of 560 $W \cdot m^{-2}$, the 131 m^2 solar collector produced 34.5 kW heat flux.
3. When the air-type solar collector is used for air heating and operates 70 % of the time, the energy consumption is reduced by 5,934 kWh per month and emissions, due to reduction of the electric energy consumption, are reduced respectively: CO by 5.884 kg, NO_X by 2.928 kg and CO_2 by 1339.896 kg.

References

1. Atsinaujinanti energetika Lietuvoje. Saulės energijos panaudojimas, 2009. [online] [20-09-2011]. Available at: http://saule.lms.lt/main/solarl.html.
2. Genutis A., et al. Atsinaujinančiosios ir alternatyviosios energijos naudojimas šilumos gamybai. Kaunas: Technologija, 2003. 112 p.
3. Janjai S., Tung P. Performance of a solar dryer using hot air from roof-integrated solar collectors for drying herbs and spices. Journal of Renewable energy, 30 (2005) pp. 2085-2095.
4. Fargali H. M., Nafen A. E. A., Fahmy H. F., Hassan M. A. Medicinal herb drying using a photovoltaic array and a solar thermal system. Journal of Solar Energy, 82 (2008) pp. 1154-1160.
5. Asekun O. T., Grierson D. S., Afolayan A. J. Influence of drying methods on the chemical composition and yield of the essential oil of leonotis leonurus. Department of chemistry, University of Lagos, Akoka – Yaba, Lagos, Nigeria. Journal Sci. Res. Dev., 2005/2006, Vol. 10, pp.61-64.
6. Topić R. M. Small Capacity Mobile Dryers for Drying Biological Materials. Journal of Drying Technology, 2003, vol. 21, no. 6, pp. 1137-1150.
7. Jakubonienė R., et al. Vaistažolės. Ekologija. Saulės energija. Panara, 2007. ISBN 978-9955-822-00-4.
8. Akpinar E. K. Drying of mint leaves in a solar dryer and under open sun: Modeling, performance analyses. Journal of Energy Conversion and Management, 51 (2010) pp. 2407-2418.
9. Adomavičius A., Balčiūnas P. Atsinaujinantys ir alternatyviosios energijos šaltiniai. Kaunas: Technologija, 2003, 112 p.
10. Kytra S. Atsinaujinantys energijos šaltiniai. Kaunas: Technologija, 2006, 301 p.
11. Staniškis J. K., Stasiškienė Ž., Kliopova I., Varžinskas V. Darnios inovacijos Lietuvos pramonėje; kūrimas ir diegimas. Kaunas: Technologija, 2010, 376 p.