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Usage of hybrid solar collector system in drying technologies of medical plants

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ABSTRACT

In the temperate climate zone under natural conditions, medicinal plants drying up to 8–12% moisture content and preparation of the quality medicinal plant's raw material are complicated tasks. In many cases drying process of medicinal plants raw material, particularly rich in volatile compounds, needs the optimal drying temperatures of 30–45 °C and relative humidity not higher than 50–60%. In Lithuania, located in the northern part of the temperate climate zone, in summer the average temperature of ambient air is 16.1 ± 0.5 °C, and relative humidity is 77.3 ± 1.8%. In order to improve the sorption properties of ambient air, it is heated up to the admissible drying temperature. The experimental dryer was developed comprising two different solar collectors: the air type solar collector with area 12 m^2 for direct heating of the drying agent and the flat-plate type solar collector (8 m^2) for accumulation of converted heat energy. The research of motherwort (*Leonurus cardiaca* L.) drying was carried out in the dryer. It was determined that by combining operation of two different solar collectors, the solar radiation energy for drying agent's heating could be used continuously around the clock by employing the accumulated energy, in order to compensate the solar irradiance variability and to ensure stability of the drying process. In the daytime the air-type solar collector at an airflow equal to 367 $m^3\,h^{-1}$, i.e. at comparative flow of the drying agent per ton of dried medicinal plant raw material – 2450 $m^3\,h^{-1}$, heats the air up to 30 °C when the solar irradiance is not lower than 380–400 W m^{-2}. In order to maintain such drying agent parameters in the dark time, it requires 99.9 MJ of energy stored in the accumulation water tanks.

1. Introduction

Drying is one the oldest methods of preserving agricultural products. This is the complicated, energy-demanding process, inhibiting undesirable quality changes taking place in products [1]. Strict requirements are particularly applied for medicinal plants drying.

Medicinal spice plants accumulate biologically active substances. The substances can be accumulated in a whole plant or in the specific aboveground and underground parts [2,3]. Partial losses of biologically active substances occur during drying of medicinal plant material.

Temperature has the strongest impact on losses of biologically active substances. The higher, the temperature of drying agent, the faster the medicinal plant raw materials dries up to the recommended 8–12% moisture content [4–8]. However, if the temperature is too high, the losses of biologically active substances are higher. Test results have shown that enzymatic activity in plants slows down or completely ceases at temperatures 50–60 °C [9]. This temperature range is recommended for drying medicinal plant raw materials, which specifically accumulates alkaloids, glycosides, saponins and some vitamins. When medicinal or flavour value of medicinal plant raw material depends on the volatile compounds, i.e. essential oils, it should be dried at 35–45 °C or at lower temperature [5,10,11].

Another important factor is the time of drying. Scientists recommend duration of medicinal plant material drying up to 4 days [12]. It is stated that longer drying time increases the losses of essential oils and other biologically active substances. What is more, colour of medical plants changes from green to greyish-brown as a result of chlorophyll degradation, and mycotoxins may appear in a product, due to intense activity of micro-organisms [13–16].

Lithuania is located in the northern part of a temperate climate zone with prevailing western wet air mass transfer and changeable weather conditions. Summers expose more than 50% of the average annual rainfall. The analysis of multi-annual ambient air

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Nomenclature

G	solar irradiance, W m^{-2}
R	solar radiation energy, J m^{-2} or kW h m^{-2} per unit of time
δ	optical permeability factor
σ	absorbing capacity
A	variation amplitude of irradiance in the daytime W m^{-2}
τ_d	duration of the daytime h
τ	time h
I	east longitude of a place where the solar collector was location, in degrees
k_s	mixing rate
L_{ap}	not pre-wormed ambient air flow entering to the mixing chamber kg$_{d.a.}$ s^{-1}
L_k	an air flow through the collector kg$_{d.a.}$ s^{-1}
d_{ap}	absolute humidity of ambient air entering into a mixing chamber kg (kg$_{d.a.}$)$^{-1}$
d_k	absolute humidity of air flow through the solar collector kg (kg$_{d.a.}$)$^{-1}$
d_s	absolute humidity of air at set temperature of a drying agent kg (kg$_{d.a.}$)$^{-1}$
H_{ap}	enthalpy of ambient air entering into the mixing chamber kJ (kg$_{d.a.}$)$^{-1}$
H_k	enthalpy of air flow inside solar collector kJ (kg$_{d.a.}$)$^{-1}$
H_s	enthalpy of drying agent at set temperature with d_s humidity, kJ (kg$_{d.a.}$)$^{-1}$
H	enthalpy of moist air kJ (kg$_{d.a.}$)$^{-1}$
c_p	specific heat of dry air kJ (kg K)$^{-1}$
c_{pg}	specific heat of air steam kJ (kg K)$^{-1}$
r_0	latent heat of evaporation kJ kg^{-1}
t	air temperature °C
d	absolute humidity of airflow kg (kg$_{d.a.}$)$^{-1}$
t_s	set temperature of a drying agent °C
t_k	temperature of air outflow which passed through the solar collector °C
t_{ap}	temperature of ambient air entering into the mixing chamber °C
τ_n	calculated time of the accumulated heat usage for a day, 1800 s
Q_s	amount of consumed heat J
m_2	air flow supplied (through the dried material layer) kg s^{-1}
$\bar{t}_{a,i}$	average temperature of ambient air in a period i in °C
L_0	comparative intensity of ventilation m^3 (t h)$^{-1}$
m_1	weight of dried medicinal plant raw material t
ρ_2	air density kg m^{-3}

parameters has shown that in Lithuania-ambient temperature in summer is 16.1 ± 0.5 °C and relative humidity is 77.3 ± 1.8% [17]. Thus, such air demonstrates poor sorption characteristics. In order to dry out medicinal plant raw material to 12% its moisture content, you will need air with relative humidity 50–60% [12]. One of the ways to step up the drying process could be air pre-warming and higher sorption characteristics of ambient air. It is known that warming up ambient air by one degree decreases its relative humidity by 4–5% [12], it improves sorption characteristics of drying agent, whilst moisture from the treated products is absorbed easier and much faster. Therefore, development of sustainable medicinal plant raw material drying technologies, in order to ensuring preservation of stored biologically active substances, is complicated without the usage of external energy sources.

The main yield of medicinal plants is harvested in summer. Harvesting and drying periods coincide with the period when the most sunshine hours are measured and solar radiation is the most intensive. It is appropriate to utilize it for reducing the concentrated energy consumption in drying agent's conditioning process.

The usage of solar radiation in drying technologies is widely studied: starting from efficiency range of different design and types of solar collector, and ending with different drying technologies [13,18–24]. However, this inexhaustible and environment friendly energy has fairly large shortage – i.e. its variations in time and high changeability [25–27]. Early in the morning, at night and late in the evening solar radiation is insufficient, and at noon, on a hot summer day solar energy surplus is estimated. Storage of this surplus amount is reasonable and the accumulated heat should be used in case of deficiency to maintain stability of the drying process.

Scientists have studied in their works various surplus solar radiation energy storage systems, employing specific heat of materials or latent heat, i.e., physical changes in a state of materials [25]. There are attempts to deal with the solar energy periodicity problem by creating hybrid, photovoltaic and thermal element systems, as well as the combination of solar energy conversion systems with heat pumps, biogas production and other installations [28–31].

In cool temperate climate zone, conditions favourable for natural medicinal plant drying are not predominant and for the most part appear in short periods of time. Usage of the concentrated energy for the drying agent's conditioning is inevitable. Development of sustainable, cleaner technologies of medicinal plant raw materials drying requires new technical solutions in order to reduce the concentrated energy costs. Most of the solar radiation energy utilizing drying systems and technologies have been developed and tested in tropical and subtropical climate zones, where average solar radiation energy at the ground reaches to approx. 1900 kW h m^{-2} per year [19,31]. In cool temperate climate zone the average solar radiation energy is approx. 1.46–1.9 times lesser, i.e. reaches up to nearly 1000–1300 kW h m^{-2} per year [27–32]. It is important to investigate and evaluate possibilities of solar energy usage in medicinal plant raw materials drying technologies in temperate climate zone due to different solar radiation energy values.

The objective of research is to determine the possibilities of solar energy utilization in cool temperate climate zone conditions for motherwort (*Leonurus cardiaca* L.) drying in a dryer with combined solar collector system and solar energy storage facility.

2. Materials and methods

2.1. Equipment, site and layout

Experimental dryer was designed and constructed for the research purposes with two types of solar collectors: an air-type collector for direct heating of drying agent and a flat-plate type collector for water heating in heat storage tanks. Both solar collectors were oriented southwards. The inclination angle of the collector panels was 45°. The coordinates of the dryer's location were: north latitude 55° 7′ 4.95″ and east longitude 22° 7′ 37.83″.

Two rack-type drying chambers (8) (Fig. 1) were installed in the dryer. The first drying chamber was used for crude raw material drying with ambient air flow, while the second drying chamber was arranged for medicinal plant raw material drying in preheated airflow. Drying agent is preheated by applying direct and accumulated heat, obtained from the solar radiation energy converted in the collectors.