ANALYSIS OF SYSTEM OF BIOMASS DRYING BY USE OF EXPERIMENTAL DRYER WITH SOLAR COLLECTOR

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Abstract. The paper describes the construction of an experimental dryer, which was built specially for biomass (bio-waste) drying. The dryer is equipped with the solar collector and the air being heated by the collector is used there as the drying medium. The principle diagram of the dryer including the main drying characteristics and parameters is presented. The paper focuses on description of the methodology of the main drying parameters calculation for assessment of the dryer efficiency. The experimental data are given and analyzed as well.

Keywords: drying chamber, solar collector, drying air, heat energy, biomass.

Introduction

Solid biofuels from biomass seem to be a perspective source of alternative energy. Utilization of biomass (bio-waste) for energy purposes carries the principle of sustainable development, it solves not only energy but also socio-economic and environmental problems as well as it contributes to effective and useful waste management policy. The production of solid biofuels such as briquettes and pellets depends on several factors – especially the moisture content in raw material which significantly influences the pressing process and the quality of the final product – solid biofuel. Hence, the method of drying and the selection of the drying equipment are very important. Drying should be effective and economical. The paper gives an example of an economic drying system.

The experimental biomass dryer was built as a part of laboratory in the area of the State Agrarian University of Moldova. The dryer was projected by a combined team of specialists and research workers from the Czech Republic and Moldova. The convection principle of drying is applied in the dryer; it is based on water evaporation being contained in the biomass into the air flow. The processes of thermo and mass (water) exchange between the air and drying material take place.

Materials and methods

Description of the experimental dryer

The experimental biomass dryer was built as an integral part of the main laboratory building, where a hot water boiler is placed. The main parts of the dryer are: a) drying chamber (tree sections), b) air mixing chamber – space between the main laboratory building and the drying chamber in which the fans are placed, c) solar collector.

The drying process in the experimental dryer can be provided with an air heated either by heat exchangers (heat from the boiler-heated water) or by a solar collector or by both of them combined.

The principle diagram of the drying chamber with the solar collector is given in Fig. 1. The diagram shows the behavior of drying air and includes the main drying parameters.

The combined dryer (its one section) consists of a part of three-section solar collector 1, which comprises channels K and the bottom of the cannels – absorber A; part of mixing chamber 2; one of three reversible fans 3 with heat exchanger 4; drying chamber 7; set of floor ventilation channels 5 covered with grids; cassettes with biomass 6.

Characteristics of the drying chamber and methodology of its parameter calculations

As it can be seen at the theoretic diagram of one section of the combined dryer (see Fig. 1) the outer air with the parameters (T_0, p_b, φ_0, d_0, i) comes to the channels K of the solar collector 1. The solar energy (direct, reflected or diffused) $I_{s.r}$ is absorbed by the absorbers A – $Q_{s.r.}$ and converted into the thermal energy – $Q_{s.r.}=Q_c$, which is then transferred to the transport medium – air. Heated air – $Q_{s.r.}=Q_c$ with parameters (Q_c, T_1, p_b, φ_1, d_0, i) coming out from the solar collector is conveyed into the mixing chamber 2 and then into reversible fans 3.

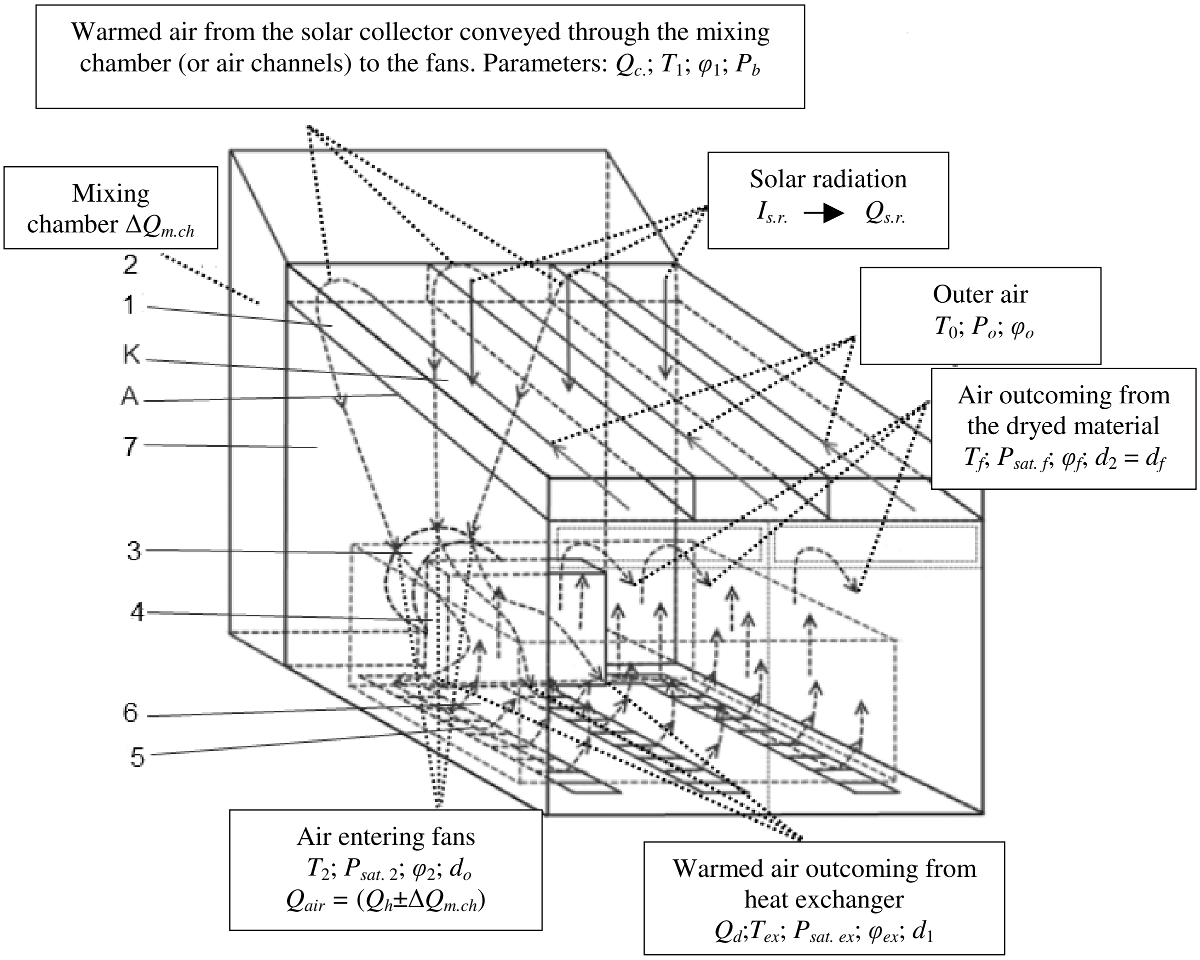

Fig. 1. **Theoretic diagram of one section of combined biomass dryer**

In the inlet to the reversible fan 3 the parameters of the mixed air are – $Q_{air}[Q_{air}=(Q_c \pm \Delta Q_{m.ch})$; T_2, $p_{sat.2}$, φ_2, d_0, $i_0]$. The air from the reversible fans is conveyed into the heat exchangers 4 (CIC H10 three-row with a general power of one section 57.9 kW and throughput 2.66 $m \cdot s^{-1}$), where if it is necessary the air can also be heated by the heat carrier (warm water) – Q_{ex}, which is brought through a system of distributors from the boiler (located in the main laboratory building). At the outlet from the heat exchangers the heated air parameters are $Q_d[Q_d=Q_{air}+Q_{ex}=(Q_c \pm \Delta Q_{m.ch})+Q_{ex}$; T_{ex}, $p_{sat.ex}$, φ_{ex}, d_1, $i_1]$.

Q_d – the heat energy needed for biomass drying. For this reason the heated air is conveyed from the air heaters 4 and distributed into the channels with grids 5 and then it passes through the cassettes 6 which contain biomass to be dried. At this process, under the influence of the heat energy – Q_d, the biomass moisture is taken by the air and is transported into the atmosphere. This can be possible thanks to the difference of the temperature values and water contents in the heated air on one side and in the biomass on the other. The used air has got the parameters (T_f, $p_{sat.f}$, φ_f, d_2, i_2).

The main parameters of the biomass which has to be dried (M_b, kg; W_b, %; T, ºC) and the time of the drying process t_d should be measured in order to conduct the necessary calculation.

If the mass of biomass used for drying M_b, its moisture content at the beginning W_b and its moisture must be reduced down to the moisture content $W_{b.d}$, it means that amount of water $M_{ev.w}$ (in kg) must be evaporated:

$$M_{ev.w} = M_{w.i} - M_{w.f}, \tag{1}$$

where $M_{w.i}=M_b \cdot W_b/100$, kg;
$M_{w.f}=M_{b.d} \cdot W_{b.d}/100$, kg.

Because the drying process occurs during t_d hours, the hourly amount of water evaporated in the drying process is:

$$M_{ev.w.h} = M_{ev.w}/t_d,\ \text{kg·h}^{-1}. \qquad (2)$$

The total amount of energy which must be used to evaporate the mass of water $M_{ev.w}$ during the drying process from the biomass with mass M_b can be expressed as $Q_{d.t}$, kWh. If the energy Q_c is from the solar collectors, the hourly energy consumption $Q_d=Q_{d.t}/t$ for evaporation of $M_{ev.w.h}$. In accordance with the principle diagram this energy is delivered by the heated air (per hour) at the outlet from the heat exchanger 4:

$$Q_d = Q_{air} + Q_{ex} = (Q_c \pm \Delta Q_{m.ch}) + Q_{ex},\ \text{kWh}. \qquad (3)$$

Determination of the heat energy in air flow necessary for biomass drying

To calculate the amounts of the air and energy required it is needed to know the input data of the fresh air, air before and after the heat exchanger as well as the data of used air outgoing from the dryer.

The relative air humidity and the air temperature can be measured by the electronic equipments. The pressure of water vapor in the point of saturation (in accordance with the air temperature) can be determined by means of information tables. So, the input parameters of the air at different locations could be expressed as following:

- for fresh air φ_0 %; T_0 ºC;
- for air outcoming from the solar collector φ_1 %; T_1 ºC;
- for air entering fans φ_2 %; T_2 ºC; $P_{sat.2}$ Pa;
- for air outcoming from heat exchangers φ_{ex} %; T_{ex} ºC; $P_{sat.ex}$ Pa;
- for the used air after its passage through the biomass φ_f %; T_f ºC; $P_{sat.f}$ Pa.

The reliable information about the above parameters allows determining the content (mass) of water in the humid air d (in different steps of its movement through the drying chamber):

$$d = 622 \cdot \varphi \cdot P_{sat} / (P_b - \varphi \cdot P_{sat}),\ \text{g·kg}^{-1}. \qquad (4)$$

Then we need to determine the specific enthalpy (in J·kg^{-1}) by use of formula 5:

$$i = i_{d.a} + i_v \text{ or } i = c_{d.a} \cdot T + d \cdot [(r_0 + c_v \cdot T)], \qquad (5)$$

where $c_{d.a}$ – specific heat capacity of dry air, equal to 1004.64 J·(kg·K)$^{-1}$;
c_v – specific heat capacity of water vapor, equal to 1841.84 J·(kg· K)$^{-1}$;
r_0 – specific heat of water evaporation at 0 ºC, equal to 2499.04 kJ·kg^{-1}.

Determination of full hourly air demand (mass and volume)

The full hourly air mass demand (in kg·h^{-1}) which is necessary to evaporate the water content $M_{ev.w.h}$ from the biomass is:

$$L = M_{ev.w.h} \cdot l, \qquad (6)$$

where l=1000/(d_2-d_0), kg·kg^{-1} – specific air consumption (kg of air on kg of evaporated moisture).

Then:

$$L = M_{ev.w.h} \cdot 1000/\ (d_2 - d_0), \qquad (7)$$

where d_2=d_f – water content in the used air coming out from the biomass, g·kg^{-1} dry air;
d_0 – water content in the air entering fans, g·kg^{-1} dry air.

Volume of the consumed air which is delivered by the fan through the heat exchanger (in m^3·h^{-1}) is:

$$V_{c.ex} = L/\rho, \qquad (8)$$

where ρ – air density at temperature T ºC, kg·m^{-3}.

The ρ values can be found in tables of physical magnitudes.

Determination of the Specific Heat Consumption for the Drying Process

$$q_d = l \cdot (i_2 - i_0), \tag{9}$$

where q_d – specific heat consumption, kJ·kg^{-1} evaporated humidity
i_2 – specific enthalpy of the humid air after passing through the biomass, kJ·kg^{-1} dry air;
i_0 – specific enthalpy of the humid air at the inlet into the fan, kJ·kg^{-1} dry air.

Determination of Hourly Heat Consumption

The amount of energy Q_d, which must be consumed for moisture evaporation $M_{ev.w.h}$ during the biomass drying per one hour:

$$Q_d = q_d \cdot M_{ev.w.h}, \text{ kJ·h}^{-1} \text{ (· } 2.78 \cdot 10^{-4} = \text{kWh)}. \tag{10}$$

The acquired value of Q_d should be compared with Q_c. If $Q_d \leq Q_c - \Delta Q_{m.ch}$, than the heat energy conveyed from the solar collector (with the account of heat losses in the mixing chamber $\Delta Q_{m.ch}$) is enough for the implementation of the process of biomass drying in the drying chamber. If the above condition is not met it is necessary to complement the missed energy by the Q_{ex} which is the energy contained in the heat carrying medium (hot water); the water is supplied through the system of distributors from the water boiler:

$$Q_{ex} = Q_d - (Q_h \pm \Delta Q_{m.ch}), \text{ kWh}. \tag{11}$$

Characteristics of the solar collector and methodology of its parameter calculations

The solar collector (SC) comprises the roof of the dryer and has the total area of three sections about 87.5 m^2. 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 – absorber. Both parts are separated by wooden beams which create the air channels (channel depth is around 15 cm). The roof inclination is about 9º and its orientation is to the north-east. The air speed in the channels can be 4 – 6 m·s^{-1} which ensures sufficient output of three reverse fans AVET 630/500E (maximum 3×8640 m^3·h^{-1}).

Initial input data for calculation of SC parameters

The total sum of the monthly solar radiation at cloudy sky is: $I_{s.r.m.c} \approx 569.7$ MJ·m^{-2} or $I_{s.r.m.c} \approx 153.04$ kWh·m^{-2}; the coefficient of the sunshine: $K_{s.sh} \approx 0.717$; average power of the solar radiation: $I_{s.r} \approx 527.8$ W·m^{-2}; average power of the solar radiation at direct (normal) sun illumination: $I_{s.r.n} \approx 570.3$ W·m^{-2}.

The solar radiation comes through the transparent surface of the solar collector; it is absorbed by the absorber and then transmitted to the passing air. The temperature growth of the heat accumulating element (absorber) which is due to the solar radiation absorption can be approximately calculated through the following formula:

$$\Delta T \approx Q_{a.e}/V \cdot c, \tag{12}$$

where ΔT – temperature growth of the heat accumulating element, ºC;
$Q_{a.e}$ – amount of the absorbed energy, J;
V – volume of the heat accumulating element, m^3;
c – specific volume heat capacity of the absorber material, J·(m^3·ºC)$^{-1}$.

Total hourly heat capacity

The amount of energy which is transmitted to the air flow by all the three sections can be determined through the following formula:

$$Q_c \approx F_h \cdot I_{s.r.d.c} \cdot \eta_0 \cdot \psi/t, \tag{13}$$

where Q_c – total hourly heat capacity, kWh;
F_h – total area of the helio-collector, m^2;
$I_{s.r.d.c}$ – total effective daily solar radiation, $I_{s.r.d.c} \approx I_{s.r.m.c}/30$, kWh·m^{-2};
$\eta_0 \approx 0.47$ – effective optical efficiency of the SC;
$\psi \approx 0.38$ – coefficient considering efficiency of the energy transfer from the absorber to the air flow which moves through the collector channels;
t = 9 hours – length of the daily solar radiation.

Results and discussion

The experimental drying by use of the above described dryer with the SC was held in August in Moldova, Chisinau. The chips of green cherry-trees were used as biomass to be dried. Their average diameter was 2.5 cm. The overall mass of the biomass M_b=2000 kg at the moisture contented of W_b=40 %. The drying process duration t_d=63 hours. The final dried biomass moisture was $W_{b.d}$=7.5 % at $M_{b.d}$=602 kg.

The amount of the water $M_{ev.w}$ which had to be evaporated from the biomass was:

$M_{ev.w} = (M_b \cdot W_b/100)-(M_{b.d} \cdot W_{b.d}/100)=800-45.15=754.85$ kg.

As the drying process duration is t_d=63 hours, the hourly amount of the evaporated moisture during the drying process in one hour was $M_{ev.w.h}=M_{ev.w}/t_d = 754.85/63=11.982$ kg·h^{-1}.

Determination of heat energy in the air flow spent on biomass drying

Calculation of the air parameters

The relative air humidity φ % and air temperature T ºC were measured by the electronic psychrometer Lutron LM-81HT (AC, 93573). The water saturation pressure (according to the air temperature) P_{sat} Pa was found from the tables. So the air parameters were:

For the fresh air: φ_0=27.9 %; T_0=31.1 ºC;

At the outlet from the solar collector: φ_1=19.1%; T_1=41.4 ºC;

At the inlet to the fan: φ_2= 26 %; T_2 = 37.4 ºC; $P_{sat.2}=6.4 \cdot 10^3$ Pa;

At the outlet from the heat exchanger (with the supply of complementary heat through water from the boiler): φ_{ex}=9.8 %; T_{ex}=52 ºC; $P_{sat.ex}=13.61 \cdot 10^3$ Pa;

The used air, after its passage through the biomass: φ_f 45 %; T_f =48 ºC; $P_{sat.f}=11.15 \cdot 10^3$ Pa.

The usual barometric pressure – P_b Pa was taken as yearly average value P_b=99 kPa.

Calculation of water content in the humid air in different steps of its movement through the drying chamber

At the entry to the fan:

$d_0=622 \cdot \varphi_2 \cdot P_{sat.2}/(P_b-\varphi_2 \cdot P_{sat.2})=622 \cdot 0.26 \cdot 6400/(99000-0.26 \cdot 6400)=10.63$ g·kg^{-1}.

At the exit from the heat exchanger:

$d_1 = 622 \cdot \varphi_{ex} \cdot P_{sat.ex}/(P_b-\varphi_{ex} \cdot P_{sat.ex}) = 622 \cdot 0.098 \cdot 13610/(99000-0.098 \cdot 13610)=8.494$ g·kg^{-1}.

The used air after its passage through the biomass:

$d_f=d_2=622 \cdot \varphi_f \, P_{sat.f}/(P_b-\varphi_f \, P_{sat.f})= 622 \cdot 0.45 \cdot 11150/(99000-0.45 \cdot 11150)=33.21$ g·kg^{-1}.

Calculation of specific enthalpy

At the entry to the fan:

$I_0=i_0=c_{d.a} \cdot T_2+d_0 \cdot [(r_0+c_v \cdot T_2)]=1004.64 \cdot 37.4+10.63/1000(2499040+1841.84 \cdot 37.4) \approx 37587$ J·kg^{-1} (37.6 kJ·kg^{-1}).

At the exit from the heat exchanger:

$I_1=i_1=c_{d.a} \cdot T_{ex}+d_1 \cdot [(r_0+c_v \cdot T_{ex})]=1004.64 \cdot 52+8.494/1000(2499040+1841.84 \cdot 52) \approx 52260$ J·kg^{-1} (52.26 kJ·kg^{-1}).

The used air after its passage through the biomass:

$I_f=I_2=i_2=c_{d.a} \cdot T_f+d_f \, [(r_0+c_v \cdot T_f)]=1004.64 \cdot 48+33.2/1000(2499040+1841.84 \cdot 48) \approx 48240$ J·kg^{-1} (48.24 kJ·kg^{-1}).

Calculation of the hourly air consumption (mass)

$L=M_{ev.w.h} \cdot l=M_{ev.w.h} \cdot 1000/(d_2-d_0)=11.982 \cdot 1000/(33.21-10.63)=530.65$ kg·h^{-1}.

Air consumption (volume)

Volume which is delivered by the fan through the heat exchanger:

$V_{ex}=L/\rho =530.65/1.128=470.43$ m^3·h^{-1}.

Specific heat energy consumption

The specific heat energy consumption was calculated as:

$q_d = l \cdot (i_2 - i_0) = 44.29 \cdot (48.24 - 37.6) = 471.25 \text{ kJ} \cdot \text{kg}^{-1}$.

Hourly heat consumption

$Q_d = q_d \cdot M_{ev.w.h} = 471.25 \cdot 11.982 = 5646.465 \text{ kJ} \cdot \text{h}^{-1} \cdot 2.78 \cdot 10^{-4} = 1.57 \text{ kWh}$

Total heat output

Total hourly heat output (see data at the legend to formula 13):

$Q_c \approx F_h \cdot I_{s.r.d.c} \cdot \eta_0 \cdot \psi / t \approx 87.5 \cdot (153.04/30) \cdot 0.47 \cdot 0.38/9 \approx 8.86 \text{ kWh}$.

Final speculations

Comparing Q_d (1.57 kWh) with the Q_c (8.86 kWh) is looks like that the heat energy supplied from the solar collector is enough for the biomass drying process implementation in the drying chamber, but the losses in the mixing chamber $\Delta Q_{m.ch}$ should be taken into account as well.

The energy $Q_{d.t}$, kWh, which was expended for drying of entire biomass M_b during t_d = 63 h was:

$Q_{d.t} = Q_d \cdot t_d = 1.57 \cdot 63 = 98.89$ kWh.

Conclusions

1. The paper demonstrates a detailed methodology for calculations of the main drying parameters on an example of the experimental biomass dryer equipped with passive solar system. The passive solar system is a quite simple solar collector which makes the roof of the dryer and essentially contributes to reduction of the costs of the drying process.
2. The measured data show that the dryer can be effectively used under the climatic conditions of Moldova during sunny periods of the year without additional energy from the water boiler. Significant heat losses were found in the mixing chamber. To avoid it the construction of the dryer should be improved.

References

1. Ivanova T., Havrland B., Kandakov A., Muntean A. Analysis of Constructional Parameters of the Combined Drying Plant with Helio-collector for the Biomass Drying. Strategii razvitija regionalnyx rinkov: infrastruktura, bezopasnost, kachestvo: materialy mezhdunarodnoj nauchno-prakticheskoj konferencii. Ch.1.- Voronezh: "Nauchnaja kniga", 2010, pp. 22-28. ISBN 978-5-98222-631-0.
2. Havrland B., Hutla P., Adamovský D. Experimental Biomass Dryer. Agricultura Tropica Et Subtropica. Volume 43-1. Prague, 2010, pp. 19-28. ISSN 0231-5742
3. Liashkov V., Kuzmin S. Netradicionnye i vozobnovjajemye istochniki energii (Non-traditional and Renewable Energy Sources). Textbook. Tambov: Publishing house: Tamb. gos. techn. university, 2003, 96 p.
4. Pobedinsky V., Havrland B., Muntean A., Vrancean V., Kandakov A., Ivanova T. Praktikum po discipline: zagotovka i pererabotka selskochozjajstvennoj produkci i bio-otchodov. Analiz i issledovanie processov proizvodstva granul i briketov iz fitomassi (Manual for the Subject: Preparation and Processing of Agricultural Production and Bio-wastes). Chisinau – Prague, 2009, 162 p., ISBN 978-80-213-2029-1
5. Sivoraksha V., Markov V., Petrov B., Zolotko K., Starenko I. Teplovye raschety gelio-sistem (Heat Calculations of Helio-systems). Publ. House Dnepropetrovsk Unievrsity, 2003.