

The Calculation of Fuel Consumption Reduction in the Drying Process of Camomile and Mint as a Function of Wasted Air Temperature

Bernarda ŠERUGA
D. MAGDIĆ

SUMMARY

The fuel saving calculated according to defined model for wasted air temperature from 40 and 50 °C with applying solar collector and recuperating heat exchanger. In function of burnt gas amount reduction in energy plant at dryer for camomile and mint, pollution of human environment reduction, and at the end environmental air the reduction of fuel consumption was analysed. Results showed that 41-53% fuel saving could be obtained for maximum air flow and 56-59% for minimum air flow.

KEY WORDS

camomile, drying, mint, reduction of fuel consumption

Bernarda.Seruga@ptfos.hr
Damir.Magdic@ptfos.hr
Faculty of Food Technology
POB 709, F. Kuhaća 18, 31000 Osijek, Croatia
Received: February 20, 1998



Izračunavanje smanjenja potrošnje energenta u procesu sušenja kamilice i mente kao funkcije temperature otpadnog zraka

Bernarda ŠERUGA
D. MAGDIĆ

SAŽETAK

Prema postavljenom modelu izračunata je ušteda energenta za temperature otpadnog zraka od 40 i 50 °C uz primjenu solarnog kolektora i rekuperativnog izmjenjivača topline. Smanjenje utroška energenta analizirano je u postrojenju za sušenje kamilice i mente radi smanjenja količine sagorjivnih plinova, smanjenja zagađenosti okoline i okolnog zraka.

Rezultati su pokazali da je moguća ušteda energenta 41-53% pri maksimalnom protoku zraka i 56-59% pri minimalnom protoku zraka.

KLJUČNE RIJEČI

kamilica, menta, smanjenje potrošnje goriva, sušenje

Bernarda.Seruga@ptfos.hr
Damir.Magdic@ptfos.hr
Prehrambeno tehnološki fakultet
POB 709, F. Kuhača 18, 31000 Osijek, Hrvatska
Primljeno: 20. veljače 1998.



INTRODUCTION

As big energy consumer industry takes a big role in environment pollution - especially in air pollution. The main pollution subjects are energy plants, thermal power stations, industry, traffic and homes. They bring in environmental air SO₂ and nitrogen oxides (No_x) through a wasted air became from oil or coal combustion. About 59 % SO₂ in environmental air comes from a thermal power stations, 30 % from an industry, 2 % from a traffic and 9 % from a homes, Šeruga (1994.).

Decrease of used classic fuel or its replacing should cause a decrease of burnt gas amount. Lower consumption of classic fuel can be obtained by optimisation of industry processes with using a wasted thermal energy combined with an alternate energy sources.

The drier work is seasonal and limited to the May-October period. In this period it is possible to use the solar radiation in the optimisation as one additional energy source.

MATERIALS AND METHODS-MODEL DESCRIPTION

Model for calculation of global irradiated energy and air solar collector energy

Extraterrestrial solar radiation was calculated for every day in a year on a horizontal plate on the top of the atmosphere, as follows:

$$Q_0 = \frac{24}{n} S_0 \cdot \left(1 + 0.034 \cdot \cos \frac{360 \cdot n}{365}\right) \cdot \left(\frac{\pi}{180} \cdot \omega_s \cdot \sin \varphi \cdot \sin \delta + \sin \omega_s \cdot \cos \varphi \cdot \cos \delta\right)$$

Hour angle was calculated:

$$\omega_s = \arccos(-\operatorname{tg} \varphi \cdot \operatorname{tg} \delta)$$

Declination angle was calculated as:

$$\delta = 23.5 \cdot \sin(2.2 + 1.012 \cdot n - 0.000227 \cdot n^2) - 82 \quad \text{for } 1 < n < 171$$

$$\delta = 23.5 \cdot \sin(299.209 - 0.79 \cdot n - 0.00031 \cdot n^2) - 264 \quad \text{for } 172 < n < 365$$

Loss of extraterrestrial solar radiation at the bottom of the atmosphere on the horizontal plate was calculated by an average cloudiness, Fančović, et.al, (1984.)

$$Q = Q_0 \cdot \left[f_1 + f_2 \cdot \left(1 - \frac{N}{10}\right) + f_3 \cdot \left(1 - \frac{N}{10}\right)^2 \right]$$

Coefficients of quadratic polinom (f_1, f_2, f_3) was obtained by the least square method.

Diffuse component of radiation was calculated by the Liu-Yordan expression, Liu-Yordan (1960.):

$$Q_d = Q \cdot \left(a - b \frac{Q}{Q_0} + c \frac{Q^2}{Q_0^2} - d \frac{Q^3}{Q_0^3} \right)$$

Ratio of direct energy on horizontal and tilted plate was calculated by:

$$R_b = \frac{\cos(\varphi - \varepsilon) \cdot \cos \delta \cdot \sin \omega_s^{\odot} + k \cdot \omega_s^* \cdot \sin(\varphi - \varepsilon) \cdot \sin \delta}{\cos \varphi \cdot \cos \delta \cdot \sin \omega_s^{\odot} + k \cdot \omega_s^{\odot} \cdot \sin \varphi \cdot \sin \delta}$$

Total radiated energy was calculated:

$$Q_\varepsilon = \left[\left(1 - \frac{Q_d}{Q}\right) \cdot R_b + \frac{Q_d}{Q} \cdot \frac{1 + \cos \varepsilon}{2} + r \cdot \frac{1 - \cos \varepsilon}{2} \right] \cdot Q$$

Useful energy of the air solar collector: $Q_c = 0.6 \times Q_\varepsilon$

Calculation is done by computer using MS Excel 5.0.

Model for calculation of the share of heat exchanger and solar collector in the consumption of drying energy

The calculation according to the proposed model requires the following data:

temperature and surroundings (t_0)
temperature of inlet air (t_{uz})
temperature of waste air (t_{oz}) and
area of collector (A).

Energy of solar collector (Q_c) was calculated by the model described in Chapter 1.1. Heat exchanger ratio was chosen for the heat exchanger with plastics tubes, $h=0.6$; Žakula (1989.).

This model enabled the calculation of the share of heat exchanger (U_1) by the equation:

$$U_1 = \frac{t_1 - t_0}{t_{uz} - t_0}$$

where

$$t_1 = t_0 - 0.6 \cdot (t_0 - t_{oz})$$

The share of solar collector and the heat exchanger (U_2) in the consumption of drying energy was calculated by:

$$U_2 = \frac{t_2 - t_0}{t_{uz} - t_0}$$

where

$$t_2 = t_c - 0.6 \cdot (t_c - t_{oz})$$

$$t_c = \frac{Q_c + D_{zr} \cdot cp \cdot t_0}{D_{zr} \cdot cp}$$

The calculation of the share of recuperative heat exchanger and solar collector energy as a function of wasted air

The two models are in using for the share calculation of each one element in drying process optimisation.

The first model is based on calculation of useful energy of a solar collector built in drying system. This model is founded and tested in Osijek, Croatia. All calculation details are given in the flow chart for calculating solar collector useful energy by Šeruga et al (1996.).

The total daily radiated energy on collector plate with declination angle from 0° to 30° south oriented was calculated by term:

$$Q_\epsilon = \left[\left(1 - \frac{Q_d}{Q} \right) \cdot R_b + \frac{Q_d}{Q} \cdot \frac{1 + \cos \epsilon}{2} + r \cdot \frac{1 - \cos \epsilon}{2} \right] \cdot Q$$

Useful energy of the air solar collector: $Q_c = 0.6 \times Q_e$

Using this mathematical model the calculation is made for the period of May to October and monthly values are given in Table 1.

The second model enables calculation of each element share in optimisation of energy consumption in drying process. Include of a recuperating heat exchanger and a solar collector provides continuing drying air pre-heating and causing a decrease the fuel share in total needed energy. When temperature of surroundings (t_0), waste air (t_{oz}), inlet air (t_{uz}) and radiation energy on collector plate (Q_c) are known this model enables calculation of a pre-heating energy in total drying energy.

Daily temperature course of pre-heating energy, heat exchanger and solar collector energy share for average day in August are presented on Figures 1 and 2.

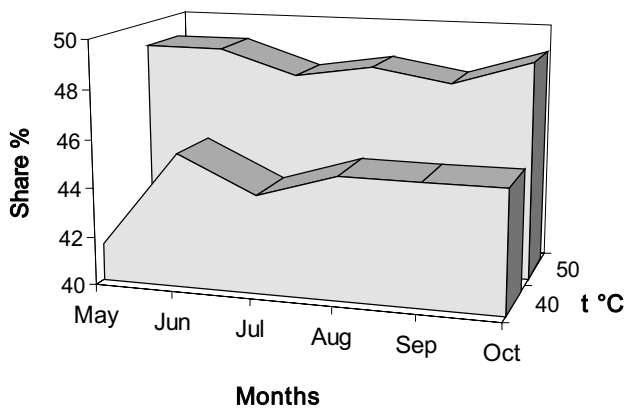


Figure 1. The daily course of temperatures for an average day in August

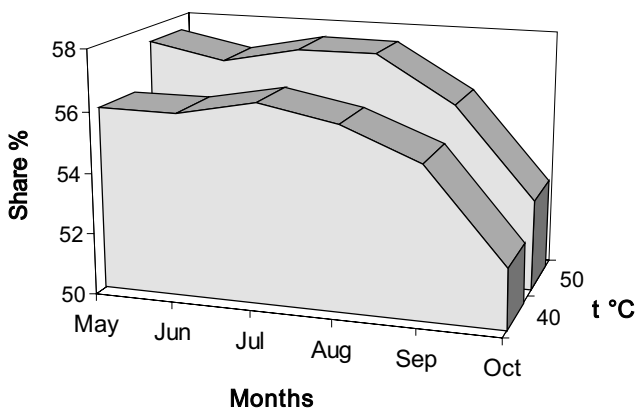


Figure 2. The share of heat exchanger and solar collector energy in the drying process energy, for an average day in August

Table 1. Collector energy at $\epsilon=20^\circ$

Month	The radiation energy Q_e kWh/m ² day	Energy of the collector Q_c kWh/m ² day
May	302.55	181.53
June	301.09	180.65
July	332.26	199.35
August	338.74	203.24
September	277.94	166.76
October	218.61	131.16

For experimental drying plant type ST66 the dependence of pre-heating energy on waste air temperature was calculated for temperature of 40 and 50 °C. This calculation was done for collector area of 360 m² and results are presented on Figures 3 and 4.

Thermodynamical calculation of air and thermal energy consumption in drying process

Warm air is mostly used as carrier of thermal energy in a drying process. It flows around or through a wet material. Because of that fact this air has to be with a

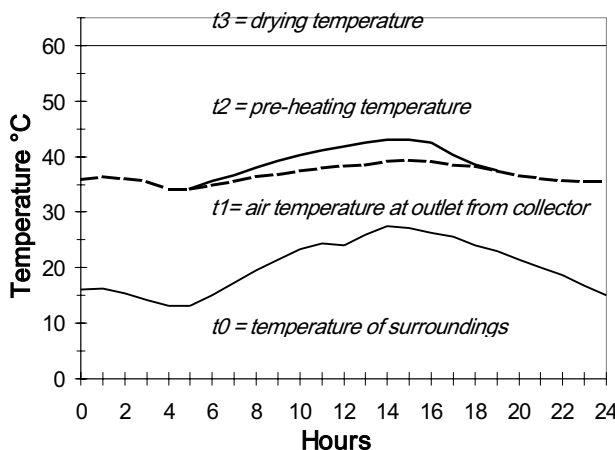


Figure 3. Dependence of preheating energy share in waste air temperature (maximum flow)

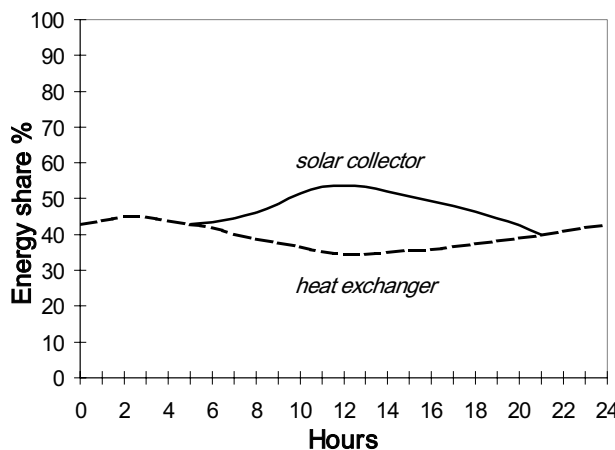


Figure 4. Dependence of preheating energy share in waste air temperature (minimum flow)

Table 2. Absolute humidity and air enthalpy in drying characteristic point

Month	H ₁ kg _{H2O} /kg _{air}	h ₁ kJ/kg	h ₂ kJ/kg	H ₂ kg _{H2O} /kg _{air}
May	0.009	39.75	75.35	0.0170
June	0.0110	49.00	80.00	0.0190
July	0.0120	52.00	82.00	0.0210
August	0.0112	50.00	80.00	0.0200
September	0.0100	41.86	75.35	0.0185
October	0.0080	30.56	71.16	0.0180

Table 3. Air and drying heat consumption

Month	l kg _{da} /kg _{H2O}	q kJ/kg	Q _h MJ/h	camomile			mint		
				Q _d MJ/day	Q kWh	Q _h MJ/h	Q _d MJ/day	Q kWh	
From May 25	125.0	4437.5	1369.40	32865.6	63905.1	1275.87	30620.88	59540.6	
June	125.0	3875.0	1195.83	28669.9	239166.0	1114.40	26745.60	222880.0	
July	111.0	3333.3	1028.66	24687.8	212588.7	958.39	23001.40	198067.6	
August	113.6	3409.1	1052.05	25249.2	217424.7	980.18	23524.30	202570.4	
September	117.6	3940.0	1215.88	29181.1	243177.0	1132.83	27187.90	226565.8	
to October 4	100.0	4060.0	1252.92	30070.1	33411.2	1167.33	28015.90	31128.8	
				Σ kWh: 1009672.7		Σ kWh: 940753.2			

Table 4. Fuel consumption on 1 kg vaporised water

Month	Consumption			
	l/day	l/h	l/kg _{vap. H2O}	kg _{fuel} /kg _{vap. H2O}
May	1700	70.83	0.236	0.2124
June	1400	58.33	0.194	0.1746
July	1000	41.66	0.138	0.1242
August	1050	43.75	0.145	0.1314
September	1500	62.50	0.208	0.1872
October	1600	66.66	0.222	0.1998

relatively high energy, low humidity contents and low relative humidity.

Steady state is usually established during a material drying and an air wetting. It is represent a main force in process of mass exchange between material and air, Mujumdar et al (1995.). Warming of wet air conducts in terms of a constant pressure where brought amount of thermal energy is determined from enthalpy differences:

$$Q = m_s (h_2 - h_1) ; \quad p = \text{cons.}$$

For ideal plant this process is brought at h=cons. and specific air consumption needed for drying is calculated:

$$l = \frac{1}{H_3 - H_2} = \frac{1}{\Delta H} \quad \frac{kg_{da}}{kg_{vap.H_2O}}$$

where H₂ and H₃ are absolute humidity. Specific energy consumption calculated from upper terms:

$$q = \frac{h_2 - h_1}{H_3 - H_2}$$

Calculation is done for camomile and mint drying at temperature of 50 °C, water vaporisation of 300 kg/h for period of May to October. Characteristic parameters of this process needed for calculating are presented in Table 2. Specific air consumption (l), specific (q), hourly (Q_h), daily (Q_d) and total thermal energy consumption are presented in Table 3.

The calculation of fuel consumption and saving in drying process

It is possible to calculate extra light oil consumption for air heating by using calculated values for thermal energy consumption in camomile and mint drying process. In this paper used data on fuel consumption on months for two drying seasons, which validated through calculation.

Daily and hourly average and fuel consumption on 1 kg vaporised water are presented in Table 4. These values are for classical drying plant without pre-heating elements.

Calculated average fuel consumption during drying season according to data from Table 4 is 0.2 kg on 1 l of vaporised water.

Table 5. Fuel consumption and saving in case of recuperating heat exchanger and solar collector plugging in drying system

Month	Energy consumption	Saving
	kg _{fuel} / kg _{svap. H2O}	kg _{fuel} / kg _{svap. H2O}
May	0.1677	0.0447
June	0.1349	0.0397
July	0.0968	0.0274
August	0.1018	0.0296
September	0.1446	0.0426
October	0.1548	0.0450

Decrease of fuel consumption is possible when air pre-heating is included in drying plant system by incorporating recuperative heat exchanger and solar collector. Pre-heating energy share obtained by these two elements calculated in Part 1. Results of this calculation are confirmed by experiment of Žakula (1989.) and determined the fuel saving of 21% because of ventilating losses.

Fuel consumption and saving in case of recuperative heat exchanger and solar collector plugging in drying system are presented in Table 5.

Calculated average daily fuel saving during drying season according to data from Table 5 is 482.4 kg/day.

Oxygen, dry air and wet atmosphere air minimal amount needed for 1 kg fuel combustion can be calculated from fuel content (Agst, 1993.).

Amount of dry air calculated:

$$L'_{\min_{da}} = 4.31 \cdot 10^{-2} (2.867 C \% + 8 H \% + S \% - O \%) \text{ kg}_{da}/\text{kg}$$

Amount of wet atmosphere air:

$$L'_{\min_{wa}} = L'_{\min_{da}} \cdot (1 - r) \text{ kg}_{wa}/\text{kg}$$

Relative humidity data presents average relative air humidity in Osijek for period of 1901 to 1955. year. Calculated values of air consumption are presented in Table 6.

The amounts of burnt gas in drying process with and without air pre-heating and results are presented in Table 7.

1508 kg is the average amount of burnt gas that every hour go in environment in drying season if air pre-heating is not plugged in. In case that air pre-heating is plugged in drying process that amount is 1175 kg/h.

RESULTS AND DISCUSSION

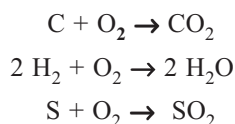
These calculations show an increasing of energy share of recuperating heat exchanger and solar collector for waste air temperature of 40 and 50 °C as surrounding

Table 6. Atmosphere air amounts needed for extra light oil combustion

Month	relative humidity	air consumption			
	\bar{r} %	$L'_{\min_{wa}}$	kg _{wa} /kg	$L'_{\min_{wa}}$	kg/kg
May	75	25.11		1777.78	
June	74	24.97		1456.58	
July	72	24.68		1028.33	
August	74	24.97		1092.43	
September	79	25.69		1605.62	
October	84	26.40		1760.00	

The calculation of burnt gas amount

Burnt gas amount and its contents strictly depends on fuel content. Combustion of extra light oil for air pre-heating in drying plant is shown by following reactions:

**Table 7.** Burned gas amount

Month	no pre-heating kg/h	with pre-heating kg/h
May	1848.61	1460.40
June	1514.90	1170.26
July	1069.99	834.59
August	1136.18	880.40
September	1668.12	1288.62
October	1826.66	1415.66

temperature increasing. It is 41-53 % of energy share for maximum air flow and 56-59 % for minimum air flow.

Measured and calculated fuel consumption for heat air needed for vaporisation of 1 kg of water in camomile and mint drying without air pre-heating is 0.2 kg and 0.133 kg in case air pre-heating is plugged in. Daily fuel saving during drying season is 482.4 kg/day.

The decrease fuel consumption causes the decrease of burnt gas amount. 333 kg/h is average calculated value.

CONCLUSION

These calculations show that energy saving could be obtained if air pre-heating is plugged in drying process from 41 to 53 % for maximum and from 56 to 59 % for minimum air flow. It causes the decreasing of energy consumption from 0.2 to 0.133 kg on 1 kg of vaporised water and that represents a decreasing of environmental air pollution.

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SIMBOLS

Simbol	Unit	Meaning
a	-	constant
A	m ²	area of solar collector
b	-	constant
c	-	constant
c _p	kJkg ⁻¹ K ⁻¹	specific heat at constant air pressure
d	-	constant
D _{zr}	kg s ⁻¹	mass flow of air
f ₁ , f ₂ , f ₃	-	coeff. of quadratic polinom got by least square method
h	J/kg	enthalpy
H	kg _{H2O} /kg _{air}	humidity
l	kg _{air} /kg _{H2O}	specific air consumption
n	-	order number of the day in the year starting from January 1st
N	-	average cloudness
Q	kWhm ⁻² dan ⁻¹	loose extraterrestrial solar radiation
Q _c	kWhm ⁻² dan ⁻¹	energy of the solar collector
Q _d	kWhm ⁻² dan ⁻¹	difuse component of radiation
Q ₀	kWhm ⁻² dan ⁻¹	extraterrestrial solar radiation
Q _e	kWhm ⁻² dan ⁻¹	total radiation energy
r	-	surfaces reflection coefficient
R _b	-	fraction of directly radiation energy on horizontal and tilted plate
S ₀	kWm ⁻¹	solar constant
t _c	°C	air temperature at outlet from collector
t _{oz}	°C	temperature of waste air
t _{uz}	°C	temperature of inlet air
t ₀	°C	temperature of surroundings
t ₁	°C	temperature of fresh air at inlet to the heat exchanger
U ₁	%	fraction of heat exchanger energy
U ₂	%	fraction of solar collector energy
b	°	correctivity angle (1°02'54")
d	°	declination angle
e	°	shope of collector plate
j	°N	geographic width
w _s	°	hour angle (sunrise - sunset)
w' _s	°	hour angle (sunrise - sunset) at the bottom of atmosphere
w* _s	°	hour angle (sunrise - sunset) on tilted plate in according to horizontal direction