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

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## 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% energy saving could be obtained for maximum air flow and 56-59% for minimum air flow.

## KEY WORDS

**camomile, drying, mint, reduction of fuel consumption**

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

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**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 sagorjevnih plinova, smanjenja zagađenosti okoline i okolnog zraka.

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

**KLJUČNE RIJEČI**

**kamilica, menta, smanjenje potrošnje goriva, sušenje**

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## 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 $SO_2$ and nitrogen oxides ($No_x$) through a wasted air became from oil or coal combustion. About 59 % $SO_2$ 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.

## MATHERIALS 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:

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

Declination angle was calculated as:

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

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

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:

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

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: $Q_c = 0.6 \times Q_e$

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:

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

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

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.

**Table 1.** Collector energy at **ε**=20°

| Month | The radiation energy $Q_\varepsilon$ kWh/m²day | Energy of the collector $Q_c$ kWh/m²day |
|---|---|---|
| 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

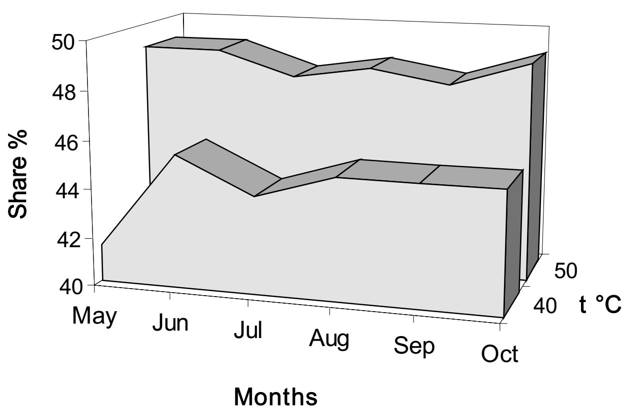


**Figure 1.** The daily course of temperatures for an average day in August

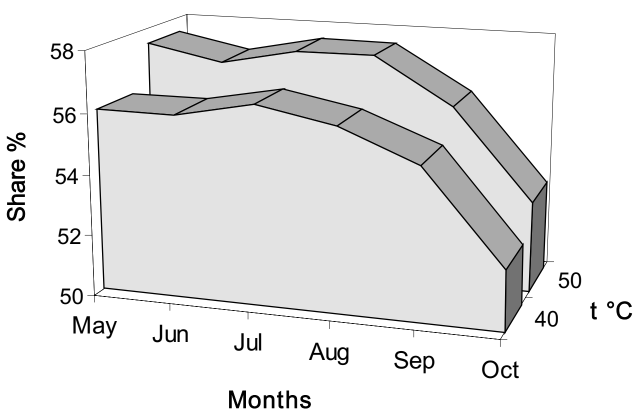


**Figure 2.** The share of heat exchanger and solar collector energy in the drying process energy, for an average day in August

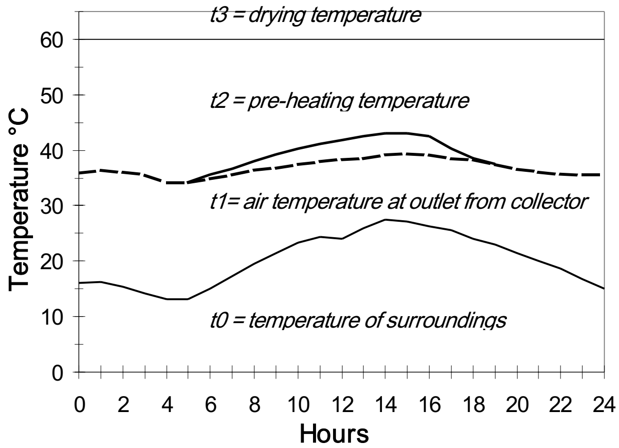


**Figure 3.** Dependence of preheating energy share in waste air temperature (maximum flow)

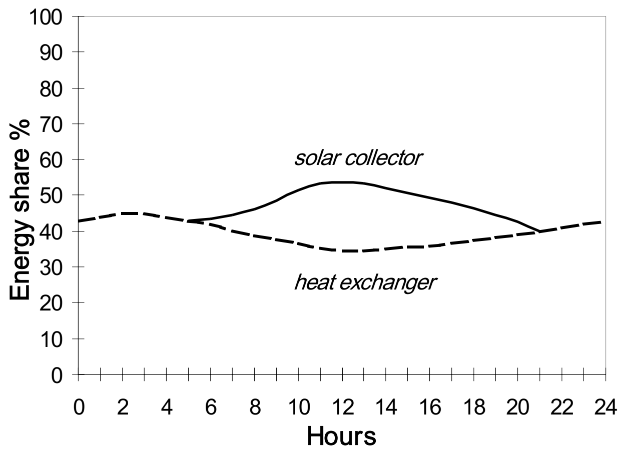


**Figure 4.** Dependence of preheating energy share in waste air temperature (minimum flow)

**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 | q | camomile | | | mint | | |
|---|---|---|---|---|---|---|---|---|
| | | | $Q_h$ | $Q_d$ | Q | $Q_h$ | $Q_d$ | Q |
| | $kg_{da}/kg_{H2O}$ | kJ/kg | MJ/h | MJ/day | kWh | MJ/h | MJ/day | 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:

$$Q = m_s\,(h_2 - h_1)\,; \qquad p = cons.$$

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

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

where $H_2$ and $H_3$ 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. Charasteristic parameters of this process needed for calculating are presented in Table 2. Specific air consumption (l), specific (q), hourly (Qh), 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 $kg_{fuel}/kg_{vap.H20}$ | Saving $kg_{fuel}/kg_{vap.H20}$ |
|---|---|---|
| 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:

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

Amount of wet atmosphere air:

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

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 Table7.

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 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.

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

| Month | relative humidity $\bar{r}$ % | air consumption $L'min_{wa}$ $kg_{wa}/kg$ | $L'min_{wa}$ 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:

$$C + O_2 \rightarrow CO_2$$

$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

$$S + O_2 \rightarrow SO_2$$

**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 |

## 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 |
| $D_{zr}$ | $kgs^{-1}$ | 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 |