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This issue is printed with financial support by Contract No. DNP 05-41/20.12.2017, financed from Fund ‘Scientific Research’ grant Bulgarian scientific periodicals.

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Theoretical analysis of the heat energy savings in wood pellets production

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(Manuscript received 4 June 2018; accepted for publication 6 August 2018)

Abstract. The report includes a theoretical analysis of the heat energy savings in the drying of wood biomass with desiccant fumes. With the current technological schemes for drying wood pellets most heat is lost with the exhaust fumes. To use the heat of exhaust fumes it is proposed to utilize these by a heat exchanger recuperator type, which transfers part of the heat of the exhaust gas to the fresh air entering the dryer installation. Thus, about 25% of the heat for drying biomass can be saved. The report examines the relationship between outdoor temperature and condensation of moisture from the exhaust gases on the relative share of energy saved using a heat exchanger.

Keywords: wood biomass, heat savings, desiccant fumes, exhaust fumes, heat exchanger recuperator

Introduction

Biomass and in particular wood is an enormous potential as a renewable energy source, which can be used successfully in heated livestock buildings. Pellets manufactured from wood are very suitable for this purpose because of the best heating quality (Uasuf and Becker, 2011; Selivanovs et al., 2012). In many cases they can replace natural gas, oil and coal as fuel. In the production of wood pellets significant energy costs are involved. The energy consumed to produce one tonne of pellets amounts at 400-600 kWh of energy on average (Di Giacomo and Taglieri, 2009; Pirraglia et al., 2010). About 70% of the total energy consumed goes for drying the source wood material (Pirraglia et al., 2010; Nikolov, 2013). Another feature of wood driers is the maintenance of a minimum temperature of 100°C at the outlet of dryers to prevent condensation from resins and acids from the exhaust gases (Amos, 1998). Of course, the proportion of energy for drying the wood depends on the moisture of the raw material (Peychev et al., 2006). It is different, but usually ranges from 30 to 55%. The use of waste and cheap heat to dry biomass is crucial for the efficient production of pellets (Li et al., 2011). To reduce energy costs in drying there are options for using the heat from waste gases. Karkania et al. (2012) reported 40-50% heat saving through the use of a heat exchanger recuperator-condenser. Dried technological wood waste (wood shavings and sawdust) are often used for production of pellets. Their wood is dried in advance to 10% and no further drying is needed. It has been found that the formation of the value of the pellets follows the following proportion - 50% for raw material, 40% manufacturing costs and 10% for transport of the pellets (The Wood Pellet Value Chain, 2013). The problem is also the drying of wood before its direct use, the requirement being its humidity to be not higher than 20-25% (Peychev et al., 2008; Prokkola et al., 2014; Laitila et al., 2017). Literature review showed that the most energy-intensive process in the production of pellets is the drying of the source material - wood.

The purpose of this paper was to made a theoretical analysis of the possibilities for heat energy savings in drying pelletwood by using flue gases.

Material and methods

The theoretical analysis of the possibilities for heat energy savings in drying pelletwood was made based on a pneumatic dryer for drying wood. A mixture of flue gases produced in a flue gas furnace and a preheated exhaust air in the heat exchanger (Figure 1) is used for the drying agent.

![Figure 1. Technological diagram of drying installation by suing a recuperator](image_url)

The drying installation consists of a flue gas furnace, a mixing chamber - lowering the temperature of the flue gases under the technological one by blending with external air and recuperator. The recuperator serves for utilizing the heat of the flue gases. It preheats the external air fed to the furnace and the mixing chamber. Such a heat exchanger or heat pipe heat exchanger is suitable because it only uses energy exchange and there is no mass transfer between streams, i.e. no moisture is transferred to the drying agent.
which is important in this case. The wood for drying is fed into the dryer cut, with dimensions less than 4 mm, allowing it to dry within a few seconds. The processes of air treatment and drying in the drying installation are described in the h-x Mollier diagram for humid air (Figure 2).

The technological points characterizing the beginning and end of the processes in the h-x diagram are as follows:

- p.0 - characterizes the external environment;
- p.A - characterizes the condition of air after heating in the recuperator;
- p.F - characterizes the condition of flue gases after the furnace;
- p.1 - characterizes the condition of the drying agent after mixing of flue gases and the external air heated by the recuperator;
- p.2 - characterizes the condition of the exhaust drying agent.

The process from p.0 to p.2 presents evaporative cooling of the drying agent in the dryer. It is caused by moisture evaporating from the drying wood. In well-insulated dryer it is assumed that the process is adiabatic, i.e. h=const. The exhaust drying agent leaves with the parameters in point p.2. Its cooling in the heat exchanger is represented by the process line p.2 - p.3. The point p.3 represents the highest condensing temperature of the spent drying agent with parameters in p.2.

The air parameters at p.0 are assumed on average for the region of central southern Bulgaria (average annual temperature and relative humidity). The temperature of the air after the recuperative T1 is determined by equation (8) and the temperature T2 by equation (9) at the recuperator efficiency assumed 0.65 (Stamov et al., 2001). At the mixing point p.1, the temperature T3 and the moisture content x3 are determined by mixing the inlet air after the heat exchanger and the flue gases in a ratio in which the temperature T4 does not exceed 220°C (as well as the point p.2). For the production of flue gas, it is accepted to use waste wood with about 25% humidity, as is common practice in the area. The temperature of the exit from the drier T5 is accepted at 100°C, as condensation of acids and resins in the dryer (Amos Wade, 1998) starts at a lower temperature.

The amount of moisture in the wood ▼ W with the initial weight and moisture content, respectively m, and W1 to moisture W2 is determined by (Kazakova-Sankeva, 2001, Selivanovs et al., 2012) with the following formula:

\[ ▼ W = m1 (W1 - W2) / (100 - W2), \text{kg} \]

where:

- ▼ W - moisture content of the air at the input and output of the dryer, g/kg;
- m1 - specific air consumption (at ▼ W=1kg), kg air/kg moisture.

The needed amount of heat to evaporate the moisture is:

\[ Q = L (h2 - h0), \text{kJ} \]

where:

- L - heat economy, kg; and the specific heat loss q (to evaporate 1 kg of moisture) is:

\[ q = (h2 - h0), \text{kJ/kg moisture} \]

The needed amount of heat to evaporate the moisture is:

\[ Q = L (h2 - h0), \text{kJ} \]

The heat economy qm for the specific flow rate l of the circulating air is determined using the h-x wet air diagram (Figure 2) and the equation:

\[ qm = (h_a - h_o), \text{kJ/kg moisture} \]

Where:

- Ce - specific heat capacity of air, kJ/kg°C;
- ha - air enthalpy after recuperator, kJ/kg.

The share of heat saved s1 is determined by the expression:

\[ s1 = qm/q \]

In a drying process with partial recirculation of the drying agent, the processes of preheating of the drying agent with heat exchangers do not change (Kazakova-Sankeva, 2001).

Under the conditions of the average annual temperature and humidity of the outside air, partial condensation of water vapor in the recuperator is achieved, which contributes to its relatively high efficiency. For temperature values Ta and T3 (Figure 1) according to (Stamov et al., 2001), the following is obtained:

\[ Ta = T0 + \eta (T2 - T0), \text{°C} \]

\[ T3 = T2 - \eta (T2 - T0), \text{°C} \]

Results and discussion

In the Mollier h-x chart (at 0.1 MPa), the individual points were determined under the conditions set forth above. One of the key technological points in the diagram of Figure 2 is p.1. It presents the parameters of the drying agent at the entrance to the dryer. The point p.1 (as well as the point p.F) lies to the right of the isotherm T1. As a result, the point p.2 also moves right to the isotherm T2, which can facilitate condensation in the heat exchanger as the condensate air temperature rises at point p.2. However, realistically, the...
consumption of wood for the production of flue gas is increasing to evaporate its own increased moisture.

The parameters of the drying agent (mixture of heated air and flue gases) at the technological points are presented in Table 1. The condensation temperature of the exhaust air $T_3$ (with parameters at point p.2) is reported at 44°C and the set temperature at the end of the heat exchanger $T_3 = 41.6°C$ (point p.3) is lower than the temperature of condensation (44°C), which favorably increases the energy exchange in the heat exchanger. It is found that at a temperature of the outside air $T_0$ above 15°C condensation of water vapor in the heat exchanger ceases, which reduces its efficiency.

The results for the energy-humidity flows when drying biomass with and without a heat exchanger are presented in Table 2. The presented results are for the energy and humidity flow when drying 1 t of wood with an initial moisture content $W_1 = 45\%$ to a final moisture content $W_2 = 10\%$, i.e. to the standard moisture content of the pellets.

From equations (2), (4) and (6) it follows that the different moisture of the drying wood changes the energy required for drying, but not the relative share of energy saved when using a heat exchanger. The results for the energy flows are illustrated in Figure 3.

### Table 1. Parameters of the technological points in the drying installation

<p>| Temperature, Moisture content, Enthalpy, h, |  |</p>
<table>
<thead>
<tr>
<th>Technological points</th>
<th>Temperature, °C</th>
<th>Moisture content, g/kg</th>
<th>Enthalpy, kJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>p.0</td>
<td>10.2</td>
<td>6.2</td>
<td>27</td>
</tr>
<tr>
<td>p.A</td>
<td>68.6</td>
<td>6.2</td>
<td>85</td>
</tr>
<tr>
<td>p.1</td>
<td>220.0</td>
<td>14.5</td>
<td>262</td>
</tr>
<tr>
<td>p.2</td>
<td>100.0</td>
<td>60.0</td>
<td>262</td>
</tr>
<tr>
<td>p.3</td>
<td>41.6</td>
<td>51.5</td>
<td>173</td>
</tr>
</tbody>
</table>

### Table 2. Energy and moisture flow when drying wood with an initial moisture content of 45% to a final moisture content of 10%

<table>
<thead>
<tr>
<th>Moisture content of the wood, W, %</th>
<th>Moisture withdrawn, W, kg</th>
<th>Required energy for drying without heat exchanger, $Q_1$, MJ/t</th>
<th>Saved heat with heat exchanger, $Q_s$, MJ/t</th>
<th>Share of saved energy, $S1$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1 45</td>
<td>10</td>
<td>388.9</td>
<td>2008.6</td>
<td>495.7</td>
</tr>
</tbody>
</table>

Therefore, the use of chemically stable heat exchanger material and its periodic cleaning is recommended.

### References


The Wood Pellet Value Chain, 2013. An economic analysis of the wood pellet supply chain from the Southeast United States to European Consumers. US Endowment for Forestry and Communities (edf.org/bioenergy), USA, p. 59.

<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>1 / 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genetics and Breeding</strong></td>
<td></td>
</tr>
<tr>
<td>Usability of metadata analysis of goat genetic resources among five</td>
<td>183</td>
</tr>
<tr>
<td>countries from Africa, Asia and Europe: Metadata analysis of goat</td>
<td></td>
</tr>
<tr>
<td>genetic</td>
<td></td>
</tr>
<tr>
<td>M.M. Musthafa, T. Hussain, M.E. Babar, R.S. Aljumaah, M.A. Alshaikh,</td>
<td></td>
</tr>
<tr>
<td>I. Muritala, V. Landi, A. Martinez, M. Amills, O. Dadi, J.V. Delgado,</td>
<td></td>
</tr>
<tr>
<td>A.B.J. Aina, A.A. Onasoga, O.A. Adebambo, C. Visser, E. Van Marle-Köster,</td>
<td></td>
</tr>
<tr>
<td>A.O. Adebambo, F.M.M.T. Marikar</td>
<td></td>
</tr>
<tr>
<td>Knezha 560 – a new mid-late maize hybrid</td>
<td>191</td>
</tr>
<tr>
<td>V. Valkova, N. Petrovska</td>
<td></td>
</tr>
<tr>
<td>Sources of resistance in chickpea (Cicer arietinum L.) to ascochyta</td>
<td>195</td>
</tr>
<tr>
<td>blight (Ascochyta rabiei)</td>
<td></td>
</tr>
<tr>
<td>M. Koleva, Y. Stanoeva, I. Kiryakov, A. Ivanova</td>
<td></td>
</tr>
<tr>
<td>Variability and grain yield potential of maize (Zea mays L.) genotypes</td>
<td>199</td>
</tr>
<tr>
<td>under irrigated condition in central Sudan</td>
<td></td>
</tr>
<tr>
<td>M.B. Alhussein, S.H. Suliman, A.A. Mohammed</td>
<td></td>
</tr>
<tr>
<td><strong>Nutrition and Physiology</strong></td>
<td></td>
</tr>
<tr>
<td>Effect of monosodium glutamate dietary supplementation on some</td>
<td>204</td>
</tr>
<tr>
<td>productive traits of common carp (Cyprinus carpio L.), cultivated</td>
<td></td>
</tr>
<tr>
<td>in net cages</td>
<td></td>
</tr>
<tr>
<td>G. Zhelyazkov</td>
<td></td>
</tr>
<tr>
<td>Effect of experimentally induced aflatoxicosis on haematological</td>
<td>208</td>
</tr>
<tr>
<td>parameters and bone marrow morphology in mulard ducks</td>
<td></td>
</tr>
<tr>
<td>I. Valchev, N. Groseva, D. Kanakov, Ts. Hristov, L. Lazarov, R. Biinev</td>
<td></td>
</tr>
<tr>
<td>Effect of dietary phytoextracts supplementation on the chemical</td>
<td>215</td>
</tr>
<tr>
<td>composition and fatty acid profile of rainbow trout                 (Oncorhynchus mykiss W.), cultivated in recirculation system</td>
<td></td>
</tr>
<tr>
<td>K. Georgieva, G. Zhelyazkov, Y. Staykov, D. Georgiev</td>
<td></td>
</tr>
<tr>
<td><strong>Production Systems</strong></td>
<td></td>
</tr>
<tr>
<td>Yield and seed quality of some soybean (Glycine max. L.) varieties,</td>
<td>222</td>
</tr>
<tr>
<td>cultivated in Osmaniye region, Turkey</td>
<td></td>
</tr>
<tr>
<td>F.F. Aşik, R. Yildiz</td>
<td></td>
</tr>
<tr>
<td>Productivity and yield stability at late treatment of durum wheat</td>
<td>227</td>
</tr>
<tr>
<td>(Triticum durum Desf.) with antiflodeled herbicides.</td>
<td></td>
</tr>
<tr>
<td>I. Influence at treatment during 1st stem node stage</td>
<td></td>
</tr>
<tr>
<td>Gr. Delchev, D. Delchev</td>
<td></td>
</tr>
<tr>
<td>The effects of inoculation and N fertilization on soybean [Glycine</td>
<td>232</td>
</tr>
<tr>
<td>max (L.) Merrill] seed yield and protein concentration under drought</td>
<td></td>
</tr>
<tr>
<td>stress</td>
<td></td>
</tr>
<tr>
<td>O. Basal, A. Szabó</td>
<td></td>
</tr>
<tr>
<td>Soil structure after treatment with different operation modes of</td>
<td>236</td>
</tr>
<tr>
<td>spading machine</td>
<td></td>
</tr>
<tr>
<td>Y. Stoyanov, K. Trendafilov, N. Delchev, G. Tihanov</td>
<td></td>
</tr>
</tbody>
</table>
Application of herbicides on common winter wheat (*Triticum aestivum* L.) at different doses and their reflection on the structural elements of spike
Z. Petrova, M. Nankova

**Agriculture and Environment**

Differences in carbon forms under two land use types in Abia State, South-east Nigeria
B.N. Ndukwu, D.N. Osujieke, C.M. Ahukaemere, P.E. Imadojemu

Theoretical analysis of the heat energy savings in wood pellets production
R. Georgiev, K. Peychev, V. Dimova, D. Georgiev

Agricultural characteristics of sugar factory waste products
B.B. Aşık, S. Dorak

**Product Quality and Safety**

Ontogenetic and diurnal variations of essential oil content of *Hypericum montbretii* Spach, cultivated in Kazdağlı (Edremit/Balıkesir), Turkey
C. Paşa, E. Esendal, T. Kiliç

Effect of *Artemisia annua* L. extract on growth performance, biochemical blood parameters and meat quality of rainbow trout (*Oncorhynchus mykiss* W.), cultivated in recirculating system
R. Koshinski
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