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REDUCING FOSSIL ENERGY CONSUMPTION OF A BELT DRYER BY USING BIOGAS WASTE HEAT

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ABSTRACT Conventional multibelt dryers have a high energy consumption mainly supplied by fossil fuel energy resources. The goal was to harness the waste heat from a combined heat and power unit (CHP) of a biogas plant for drying curly parsley *(Petroselinum crispum)* on a belt dryer. After cutting the fresh material the stems and leaves were separated by air classifying. Both the stems and conventional substrates were used for the biogas fermentation. A standardised batch fermentation test (Hohenheimer biogas yield test) was carried out to measure the potential biogas yield of the parsley stems. The leaves were dried by hot air partially heated by the light fuel oil burners and waste heat from the CHP. The belt dryer consists of a single-belt predryer and a five-belt dryer including three temperature zones with a total drying area of 316 m². High temperatures were applied for drying parsley with a temperature profile of 90/80/75°C for the three zones. The energy consumption of light fuel oil and the energy from the biogas CHP was measured. The specific energy consumption for drying parsley was 7,158 kJ per kg of evaporated water, with a share of 47% thermal energy from the CHP. The throughput was 150 kg/h of dry material. The biogas test showed an output of 0.331 m³ of methane/kg of organic dry matter. The waste heat of the CHP was capable of heating the drying air to 75°C, but 90°C is recommended to achieve the best product colour. Therefore, a high amount of fossil energy must still be provided for parsley drying. Further research is required to reduce fossil energy consumption and CO_2 emissions.

Keywords: Multibelt dryers, energy consumption, biogas yield, spice plants, biogas CHP

INTRODUCTION Annual energy consumption of dryers in the german food processing industry is 20,000 GWh with 34% covered by natural gas (Jenlinek, 2001). Dryers for medicinal and spice plants have a high energy consumption between 5,000 and 12,500 kJ/kg of evaporated water, mainly delivered by fossil sources like natural and liquid gas or fuel oil (Mellmann et al., 2008)**.** To study the energy consumption of a dryer various parameters have been developed to evaluate drying and the applied technologies (Strumiłło et al.; 2006, Menshutina et al., 2004).

Great efforts have been taken to reduce fossil energy consumption by utilizing more efficient technologies and replacing fossil fuels by renewable ones. The application of combined heat and power (CHP) plants with an electrical efficiency of 30 to 40% and a global fuel efficiency of over 80% is increasing in the food industry (Fantozzi et al., 2000; Fritzson et al., 2005; Ruiz et al., 2009). One promising approach is biogas production and the cogeneration of heat and power in an internal combustion engine (ICE). The ICE recovers heat at low temperatures (90-120°C) from the jacket (25% of the heat available for recovery), lubricating oil (12%) and aftercooler (13%) cooling systems and at high temperatures (450-550°C) from the exhaust gases (50%) (Fantozzi et al., 2000)**.**

Cogeneration using ICE's can be applied in drying facilities with various fuels, such as diesel CHP's for tea drying (Riva et al., 1989), rapeseed oil CHP's for drying medicinal plants and herbs on flatbed dryers (Schröder, 1995), natural gas CHP's for drying vegetables and herbs on single belt dryers (Jelinek, 2001) and biogas CHP's for drying herbs on multibelt dryers (Schiele, 2008).

German legislation is promoting renewable energy with a law first published in the year 2000, by ensuring fixed electricity prices from renewable sources. In the year 2008 Germany was the largest biogas producing country with over 4,000 agricultural biogas plants (Weiland, 2009). This development is mainly focused on biogas CHP's for electricity production, utilizing heat as a "waste product". To utilize this produced thermal power many technologies are being applied like heat pipes for district heating, cooling devices and mobile latent heat storage systems (Gaderer et al., 2007; Schulz et al., 2007). This study focuses on the CHP heat use for drying processes.

MATERIAL AND METHODS

Drying technology The five belt dryer, shown in Figure 1, features a drying area of 300 m² with a belt width of three meters. The dryer is divided in three temperature zones (T 1 – T 3). The high temperature zone T 1 consists of the first one and half lengths of the second belt, the middle temperature zone T 2 spans the next one and a half belt lengths and the low temperature zone T 3 spans the last two belts at the bottom. The temperature levels of the three zones can be adjusted to suit the product. Each zone is supplied with hot air by a radial fan and an indirect air heater, with an installed thermal power of 990 kW, using light fuel oil. The air is partly recirculated to the heating room after passing through the bulk. The drying material is loaded via an oscillating conveyor belt and passes through the dryer from top to bottom and falls onto the upper surface of the end of the next lower belt. After leaving the dryer the product is weighed and packaged.

The drying system was modified after the harvesting season in 2008, with a predryer containing 18 m² of drying area. The predryer is heated with the heat dissipated from a biogas plant, which was constructed in the same year. Additionally a heat exchanger was installed in the heating room to raise the temperature level of the incoming make-up air.

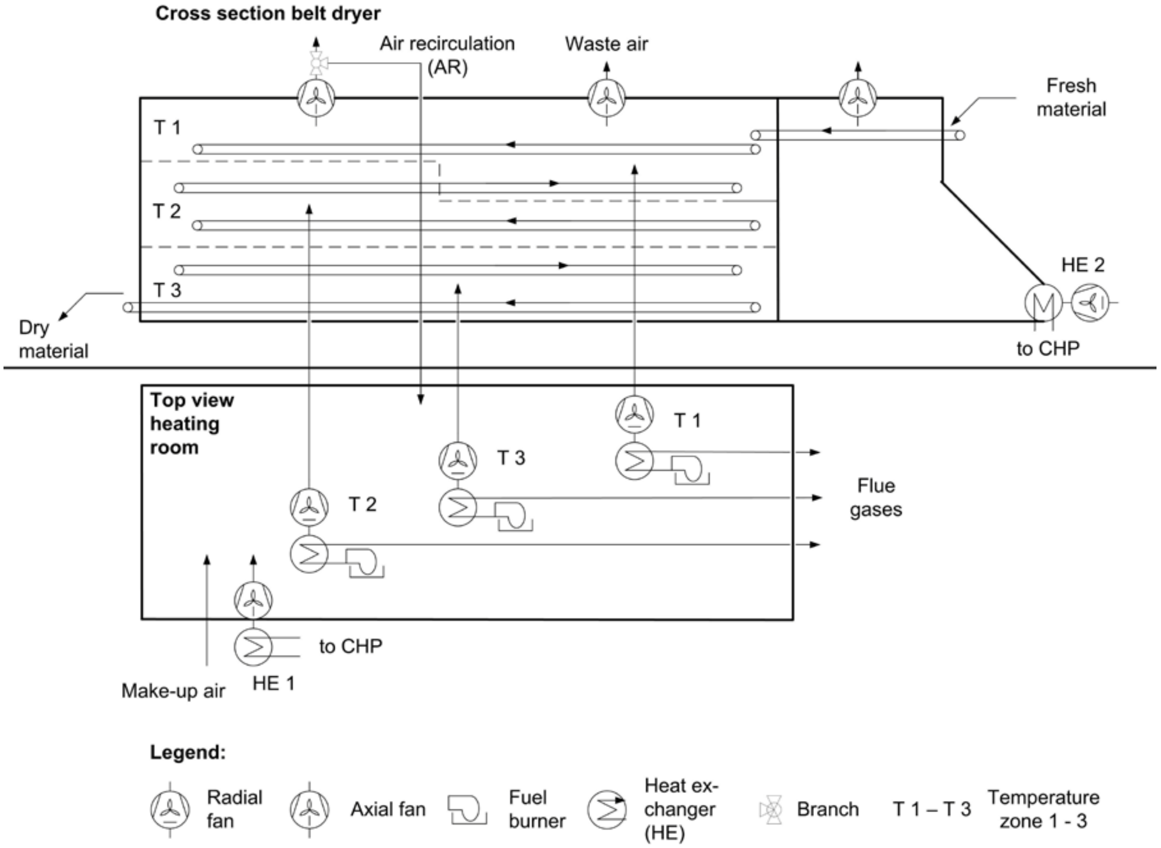

Figure 1. System schematic of the belt dryer, heating room and connected CHP

Drying material and handling Directly after harvesting, the spice plants are transported in a trailer to the dryer hall. A conveyor belt transports the plants from the trailer to a cutting machine where they are cut into pieces of 30 to 80 mm. Further on an air classifier separates the leaves from the stem fraction. The stems are then collected and transported to the biogas plant to feed the fermenter. The leaves are loaded via an oscillating conveyor belt and pass through the dryer from top to bottom and fall onto the next lower belt at the end of each belt. The drying usually lasts between 180 and 400 minutes depending on the type and the initial conditions (wet/dry) of the plants being dried.

The drying of two parsley varieties were studied, flat leaf parsley and curly leaf parsley. Parsley (*Petrosilium crispum*), belonging to the Apiaceae family is produced for the food industry. The bulk height for parsley is around 0.1 m. The drying temperatures in the season of 2008 was 105°C in temperature zone 1, 90°C in zone T 2 and 80°C in zone T 3. In the season of 2009 the temperature was reduced to T 1 =90°C; T 2 = 80°C; T 3 = 70°C, because of the additional heat from the predryer and a local limitation of fresh material supply.

Dryer performance and energy consumption To evaluate the performance of the dryer, samples of the fresh and dried product were analysed by the standard furnace method to determine the moisture content wet basis (MC) through mass loss (103±2°C, 18 h, triple determination, each sample 25 g). The dried product was weighed with scales during packaging (Reith, Typ 2000, Wolnzach, Germany) to determine the mass flow of the final dried product ($\dot{m}_{fin}$). To calculate the mass flow of evaporated water (evaporation rate, $\dot{m}_{\text{evaporation}}$) equation 1 was used, taking into account the mass flow of the final product**,** the initial moisture content wet basis (MC_{ini}) and the final moisture content wet basis (MC_{fin}):

$$\dot{m}_{evaporation} = \frac{\dot{m}_{fin} \cdot (MC_{ini} - MC_{fin})}{100 - MC_{ini}} \tag{1}$$

The fuel consumption ($\dot{m}_{fuel}$) was measured with a fuel meter (Aquametro VZO 8, Therwil, Switzerland) at each of the three burners. The heat input from the fuel oil burners ($\dot{Q}_1$**)** was calculated using equation 2 with the measured fuel consumption ($\dot{m}_{fuel}$), efficiency of the air heater (η_{heater} = 0.89), and the lower heating value of light fuel oil (LHV=36 MJ l^{-1}).

$$\dot{Q}_1 = LHV \cdot \dot{m}_{fuel} \cdot \eta_{heater} \tag{2}$$

The heat input $\dot{Q}_2$ from the CHP introduced into the two heat exchangers was calculated with equations 3 and 4. The air velocity was measure with a vane anemometer (Ahlborn FV A915 S220, Holzkirchen, Germany) and the air temperatures entering (T_{in}) and leaving (T_{out}) the heat exchanger were measured with type K thermocouples (Greisinger GTT 1150 OK, Regenstauf, Germany). Furthermore the specific heat capacity at constant pressure (c_p=1,005 kJ K^{-1} kg^{-1}) was used for equation 3. The mass flow of the air ($\dot{m}_{air}$) was calculated with the air pressure (p_0), recorded by the State Office for environment and geology of Hessen (Darmstadt, Germany), the measured air velocity (v_{air}), the area of the heat exchanger (A), the specific gas constant of the air (R_{air} = 287.058 J kg^{-1} K^{-1}) and the air temperature entering the heat exchanger (T_{in}).

$$\dot{Q}_2 = c_p \cdot \dot{m}_{air} \cdot (T_{out} - T_{in}) \tag{3}$$

with:

$$\dot{m}_{air} = \frac{p_0 \cdot v_{air} \cdot A}{R_{air} \cdot T_{in}} \tag{4}$$

The specific energy consumption for evaporation ($q_{evaporation}$) is expressed in equation 5 and is calculated by the sum of the heat input divided by the mass flow of evaporated water.

$$q_{evaporation} = \frac{\dot{Q}_1 + \dot{Q}_2}{\dot{m}_{evaporation}} \tag{5}$$

Biogas plant and CHP A biogas plant nearby the dryer was connected with a pipe network from the CHP to the dryer. The biogas plant has two fermenters, each with 2.218 m^3 fermenter volume. The digestate storage has a volume of 3.924 m^3. The main substrates are silage from maize, green rye, millet and sugar beets, cultivated by 50 farmers. The CHP consists of two Otto gas internal combustion engines (ICE). The technical data is given in table 1. The total thermal output of 1,031 kW is used for the drying process and the biogas plant itself, which requires about 20%.

Table 1. CHP technical data

	ICE 1	ICE 2
Engine type	Deutz TCG 2016 V16	MTU MB 3042 L5
Total combustive power	1,734 kW	955 kW
Electric power output	716 kW	370 kW
Electric efficiency	41.3%	38.7%
Thermal power output	605 kW	426 kW
Thermal efficiency	34.9%	44.6%
Total power	1,320 kW	796 kW
Cogeneration efficiency	76.2%	83.4%

Biogas yield test The total methane potential of the residues from the wind classifier was determined with the patented Hohenheim Biogas yield Test (HBT), according to the German VDI-guideline 4630. The samples, consisting mostly of stems, were taken from the processing line after cutting and air classifying. The studied samples were curly and flat parsley (*Petroselinum crispum*), dill (*Anethum graveolens*), red clover (*Trifolium pratense*) and artichoke (*Cynara cardunculus*). They were examined for the content of dry matter (DM), organic dry matter (ODM) and ashes.

In a 100 ml glass syringe , 500 mg of test substrate, which was dried (60°C over a period of 48 h), ground and sieved (<1 mm), and 30 ml inoculum (pre-digested liquid manure) were digested at 37°C in three replicates. The volume and methane content of the biogas produced were recorded periodically over a period of 35 days, until the gas yield reached a constant level. Additional inoculum without substrate was digested as zero variant with three replicates (Helffrich et al., 2003; Kusch et al., 2008).

RESULTS AND DISCUSSION

Dryer performance and energy consumption The dryer was evaluated in 2008, where only fuel oil was applied as an energy source for drying and in 2009 with additional biogas waste heat. The measurements were taken during normal processing. According to local limitations the material throughput changed during measurement as shown in table 2. In 2008 over-drying occurred, because of inhomogeneous air distribution across the belt. This was solved in 2009 by special air guiding plates.

For curly parsley the energy input was 1,827.8 to 1,878.0 kWh. Even with a lower evaporation rate in 2008 the specific energy consumption was lower in the season 2008, because of the higher throughput. The share of the energy from the biogas CHP introduced in the dryer with the two heat exchangers was 46.7%.

The energy input for flat parsley was lower, ranging between 1,615.2 and 1,678.6 kWh, with a higher evaporation rate and throughput the specific energy consumption was lower in 2009. The share of energy from the CHP was 38.6%.

Table 2. Parameters for the evaluation of the belt dryer for parsley without (2008) and with (2009) use of biogas waste heat.

Parameters	Curley parsley		Flat parsley	
	2008	2009	2008	2009
Initial Moisture content w.b. (MC_{ini}), %	82.6	87.0	84.05	83.0
Final Moisture Content w.b. (MC_{fin}), %	2.6	5.1	1.68	4.3
Mass flow final product ($\dot{m}_{fin}$), kg/h	217.6	150.0	154.00	186.0
Evaporation rate ($\dot{m}_{evaporation}$), kg/h	875.4	945.0	795.30	861.0
Total heat input from three oil burners ($\dot{Q}_1$), kWh	1,827.8	1,001.0	1,678.6	992.0
Total heat input from the two heat exchangers ($\dot{Q}_2$), kWh	-	878.0	-	623.2
Share of renewable energy input, %	-	46.7	-	38.6
Specific energy consumption ($q_{evaporation}$), kWh/kg evaporated water	1.83	1.99	2.11	1.88
Specific energy consumption ($q_{evaporation}$), kJ/kg evaporated water	6,577.2	7,157.9	7,610.0	6,753.4

The air conditions in the heating room are shown in figure 2. In general the temperature level for drying was lowered in 2009, because of the additional predryer and to prevent overdrying. The throughput could not be enlarged to apply the same temperatures as in 2008, because of limited material feed capacities. The heat exchanger 1 constructed in the heating room, raised the level of inlet temperatures for the air heaters, resulting in lower fuel oil consumption. The higher temperature of the air recirculation in 2009 was caused by less loading of the dryer.

A mass and heat flow balance of the air in the heating room was not performed, because the air flow of the make-up air from the environment could not be measured. This is a weak point of the open heating system, which can not be controlled and monitored. The additional make-up air is necessary, because of the under pressure in the heating room. The system can be improved by direct air guidance from the heat exchanger to the air heaters and an insulated heating room, resulting in smaller convective heat losses.

Another approach would be the use of thermo-oil instead of water as a heat transfer medium. Higher temperature can be archived without increased pressure in the tube system, but the heat transfer is lower. This would result in bigger heat exchangers at the engine for the same thermal power, moreover thermo-oil has higher requirements for safe handling in regard to leakage problems in the tube system.

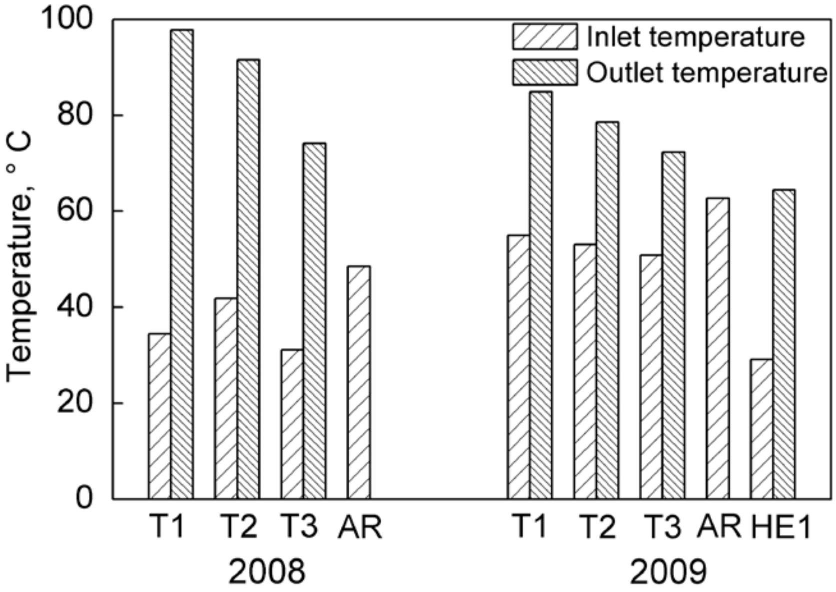

Figure 2. Air temperatures in the heating room of the air heaters (T1- T3), air recirculation (AR) and heat exchanger 1 (HE1) without (2008) and with (2009) biogas waste heat utilisation

The results for the Hohenheimer biogas yield test of the medicinal and spice plants are shown in table 3. For dill and flat parsley only two repetitions could be evaluated, due to substrate losses during gas measurement. The comparison to conventional substrate like maize or millet shows a rather high methane yield, so these substrates are suitable for fermentation.

Table 3. Hohenheimer biogas yield test for medicinal and spice plants and conventional substrate

Substrate	Norm methane yield, m³/kg ODM	Standard deviation
Red clover	0,262	0,008
Artichoke (n = 2)	0.274	0.008
Dill	0.306	0.008
Flat parsley (n = 2)	0.354	0.005
Curly parsley	0.331	0.004
Conventional substrate:		
Maize	0.40 (Oechsner et. al., 2003)	
Millet	0.31 (Oechsner et. al., 2003)	

The curve for the methane yield, figure 3, shows a rapid gas formation with the normal exponential shape, only artichoke is inhibited at the beginning resulting in a lower inclination.

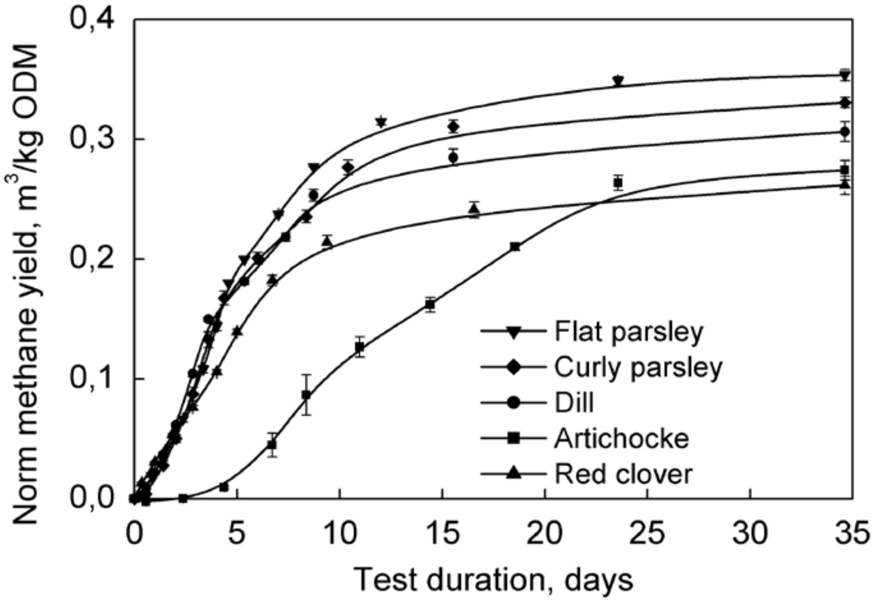

Figure 3. Biogas yield test for different medicinal and spice plants

CONCLUSION The combination of a biogas plant and belt dryer is a suitable combination, for energy efficiency with reduced emissions. The heat demand of the dryer can be covered by the CHP, the share is depending on the applied temperature level for drying. The studied dryer for medicinal and spice plants covers the base load of the heat demand with the CHP, while the additional load to adjusted the drying temperature is covered with light fuel oil burners. The seasonal heat demand according to the harvest time for medicinal and spice plants (April to October), has to be assisted by other heat users in spring and winter.

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