Installation of a Feed-and-Turn Dryer: An Option to improve Heat Utilization and Economy of an existing Biogas Plant

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ABSTRACT

In Germany there were approximately 6,000 biogas plants in operation in 2010. Most of these biogas plants were situated in agricultural enterprises and most of them in rural areas with low utilization opportunities of the excess heat from combined heat and power units (CHPUs). Drying agricultural goods may be an option to utilize this excess heat. Among the available technologies feed-and-turn dryers can be used for drying a manifold of agricultural produce. In this study the drying of draff, maize silage and saw dust were investigated with an already installed feed-and-turn dryer. The focus was on drying effectiveness, economic benefits and probable changes in chemical composition of the materials investigated. Results demonstrate that the installation of the feed-and-turn dryer is a substantial efficiency improvement of the biogas plant, since it increased heat utilization from 24.5 % to 73.2 % in average from the available excess heat. It provides, in addition, the agricultural enterprise with valuable equipment for producing high quality and high valuable feed and other products. The products in this study were dried to 85 % dry matter content in the case of maize silage, 97 % for draff , and 98 % for saw dust. In addition to the water loss there were slight changes in the chemical composition. Draff showed an apparent conversion of crude fiber to sugars. Furthermore draff showed a shift from NDF to ADF, maize silage a general increase in NDF and ADF and saw dust a general decrease of NDF and ADF. On-farm drying generated an additional income of 20 to 50 € per ton of dried good.

Keywords: Biogas, CHPU excess heat, drying, agricultural produce, efficiency improvement

1. INTRODUCTION

The German biogas sector is dominated by biogas plants situated in agricultural enterprises and most of them in rural areas. The produced biogas is mainly used for the generation of electricity (Büsgen & Dürrschmidt, 2009). This implies firstly that the biogas is combusted in combined heat and power units (CHPUs) with generation of electricity and heat in parallel and secondly that there is only limited use of the excess heat due to the lack of consumers in the vicinity of most farms. Hence, energy efficiency would certainly improve if there is an appropriate way of using the excess heat.

A promising and well-fitted practical solution for the use of heat energy within the operating schedule on farms is the drying of agricultural goods and by-products. Drying is an important post-harvest technology and preserves quality and storability of many kinds of agricultural products (Rahman, 2005; Lewicki, 2006).

However, drying as a technically efficient process is typically not integrated in internal farming procedures. If required, it is mostly organized with centralized drying capacities close to major storage locations. Therefore, drying is often limited to high quality produce (Sokhansanj & Aaghavan, 1996; Piacentini & Mujumdar, 2009).

The availability of excess heat from biogas CHPU could be a way of extending drying on produce and by-products usually not valuable enough for drying. But improving the quality of these produce or improving the applicability of these by-products would benefit the farm operation (Yiridoe *et al.*, 2009).

In order to analyze suitability and effectiveness of farm-integrated drying processes on-site experiments were carried out at Rhinmilch farm in Fehrbellin, Germany. Here a complete drying system was built downstream to the biogas plant based on the feed-and-turn dryer by the company RIELA® Karl-Heinz Knoop e.K. (www.riela.de).

Main goal of the monitoring and evaluation of the on-site drying experiment was the assessment of the practical approach in drying three different products: maize silage, draff and saw dust. The focus was on drying effectiveness (*i.e.* to decrease water content to less than 15 %), economic benefits for the farmer and biogas plant owner, and probable changes in chemical composition of the materials investigated. The objective of selecting these products was first their availability as well as to obtain valuable products. These additional values of the products is given by increasing storability of feed and providing special feed for dietary purposes and the option to exchange litter material for cattle houses. This investigation did not focus on the technical efficiency of the dryer in comparison to state-of-the-art drying and did not evaluate the general suitability of drying goods.

The study was conducted in the framework of the EUAgrobiogas (http://eu-agrobiogas.net) project which aimed to improve the efficiency of existing agricultural biogas plants by optimizing internal processes, energy utilization and feedstock provision.

2. GENERAL REMARKS ON DRYING

Assessing a drying process independently from dryer types and configurations, a complete mass and energy balance has to take into account energy input, mass and energy flows of the drying material as well as the mass and energy flows of the air let through the system for drying (Vauck & Müller, 2000).

Mass balance:

$$M_F \cdot X_{F,I} + M_A \cdot Y_{A,1} = M_F \cdot X_{F,O} + M_A \cdot Y_{A,3} \tag{1}$$

Energy balance:

$$M_A \cdot h_{A,1} + M_F \cdot h_{F,I} + Q_{inp} = M_A \cdot h_{A,3} + M_F \cdot h_{F,I} + Q_{loss} \tag{2}$$

where M_F = mass feedstock
M_A = mass air

$X_{F,I}$ = water content of feedstock inflow
$X_{F,O}$ = water content of feedstock outflow
$Y_{A,1}$ = water content of air at condition 1
$Y_{A,3}$ = water content of air at condition 3
$h_{A,1}$ = evaporation enthalpy of water in air at condition 1
$h_{A,3}$ = evaporation enthalpy of water in air at condition 3
$h_{F,I}$ = evaporation enthalpy of water in feedstock at inlet
$h_{F,O}$ = evaporation enthalpy of water in feedstock at outlet
Q_{inp} = heat input
Q_{loss} = heat loss

In order to assess the on-site experiments the calculation will be simplified by the following assumptions:

- Drying is modeled as pure water evaporation neglecting material specific forces;
- Heat losses are assumed to be small in comparison to the heat that is necessary for drying;
- Stationary drying parameters set during the experiment are assumed to be optimal without extra heat losses with higher air outlet temperatures and air fluxes than necessary.

Hence, the energy input into the drying system can be calculated considering the heat Q_{HE} (kJ) from the heat exchanger. One phase heat flow in general is characterized by:

$$Q_{HE} = c_{p,H2O} \cdot m \cdot (T_{outlet} - T_{inlet}) \tag{3}$$

where $c_{p,\,H20}$ = heat capacity of water (kJ·kg^{-1}·K^{-1})
m_{H20} = water mass (kg)
T_{inlet} = temperature of water inlet (°C)
T_{outlet} = temperature of water outlet (°C)

Heat transfer within the water-air heat exchanger is assumed with 95% efficiency. Dry matter content data from the samples being taken together with the daily drying material flow allows calculating a specific heat input $Q_{input,\,H2O}$ in comparison with evaporated water and dried material.

$$Q_{input,H2O} = 0.95 \cdot Q_{HE} \tag{4}$$

The drying process is evaluated by an output-input factor (O/I-factor) comparing the specific heat input related to the evaporated water amount multiplied by the specific evaporation enthalpy of water.

$$O/I - factor = \frac{\Delta h_{V,H2O,T} \cdot m_{H2O}}{Q_{input,H2O}} \tag{5}$$

$\Delta h_{V,\,H2O,\,T}$ = specific enthalpy of water at 333 K according to general table (2,358 kJ·kg^{-1})
The enthalpy difference of the entire drying process is ΔH, composed of the heat transfer into the dry matter content of the moist material (ΔQ_{dm}) plus the heat transfer into the water content of the moist material (ΔQ_{H2O}) plus the necessary enthalpy at 333 K for the evaporation of that water (ΔH_V) during the drying process:

$$\Delta H = \Delta Q_{dm} + \Delta Q_{H2O} + \Delta H_V \tag{6}$$
$$\Delta Q_{dm} = c_{p\,dm} \cdot m_{dm} \cdot \Delta T \tag{6a}$$
$$\Delta Q_{H2O} = c_{p,H2O} \cdot m_{H2O} \cdot \Delta T \tag{6b}$$
$$\Delta H_V = \Delta h_V \cdot m_V \tag{6c}$$

where $c_{p,dm}$ = specific heat capacity of dried drying good on dry matter basis ($kJ \cdot kg^{-1} \cdot K^{-1}$)
m_{dm} = mass of completely dried drying material (kg)
m_{H2O} = mass of remaining moisture in the drying material (kg)
m_v = mass of vaporized moisture in drying material (kg)
Δh_v = specific evaporation enthalpy of water at 60 °C ($kJ \cdot kg^{-1}$)
ΔT = temperature difference of moist and dried drying good (°C)

Heat capacity of all examined completely dry drying materials is generally assumed with 1.75 $kJ \cdot kg^{-1} \cdot K^{-1}$ which is equal to 0.49 $Wh \cdot kg^{-1} \cdot K^{-1}$. The measured medium temperature for all drying materials of the air flow for drying was around 60 °C, the related specific evaporation enthalpy h_v of water is about 2,358 $kJ \cdot kg^{-1}$ water.

3. MATERIAL AND METHODS

3.1 Feed and Turn Dryer

The drying is conducted with a feed-and-turn dryer from RIELA. Excess heat is delivered by the nearby (less than 3 meters) combined heat and power unit (CHPU) of the biogas plant with a thermal power of approx. 1.1 MW (Figure 1).

The feed-and-turn dryer is composed of the following elements:

- Filling unit with automatic transportation;
- Cross-flow drying channel with sieves and turn-over and transport installations;
- Heat exchanger-system with exhaust-gas heat exchanger and downstream water-air heat exchanger;
- Switch-panel with control unit.

Figure 1. Feed-and-turn dryer at investigation site: in front the feeding device (a), in the green container the CHPU (b) is situated, right to the CHPU is the feed-and-turn dryer (c) with inlet (d) on the left site and outlet (e) on the right side (inside the shelter)

Drying material is delivered by a wheel loader to the filling unit. A system of band conveyors feeds the moist material into the feed-and-turn dryer. A pushing floor transports the material into the drying channel where turning-tools push the material through the drying channel. A water-air based heat exchanger designed as damper register supplies two installed fans with heat that is let through sieve and drying material as across flow. A stable air flow at constant turn-over and an extended channel surface secure a constant and stable drying process.

The system is operable for any free flowing material and can be operated in batch and continuous mode. The automatic feeding system allows a 24 hour operation. The heating scheme of the feed-and-turn dryer examined at Rhinmilch farm is configured as follows:

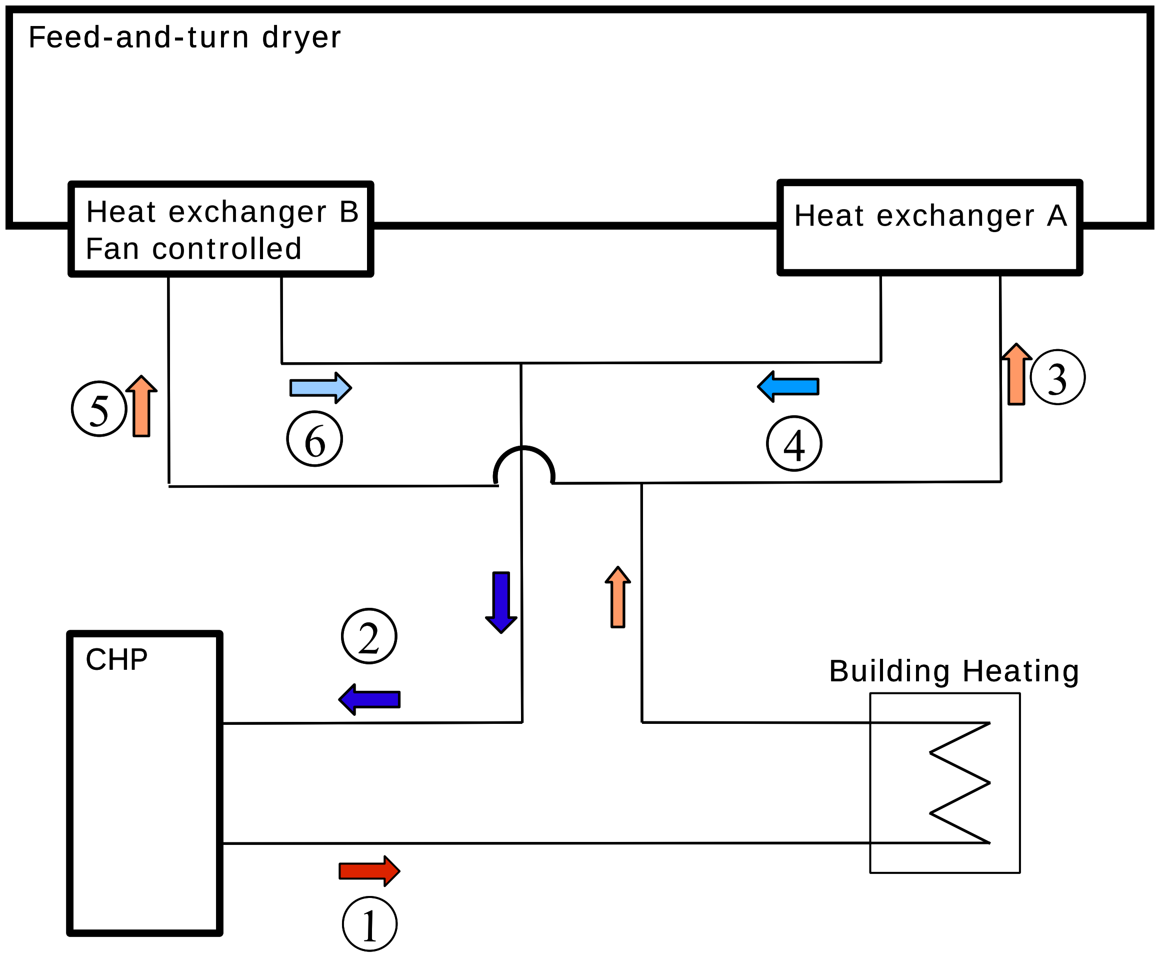

Figure 2. Schematic of heat flow. Heat flows first from CHPU (1) to building heating and splits then into two parallel circuits with inlets at (3) and (5), integrated water-to-air heat exchangers (A and B) and outlets at (4) and (6) linked together to backflow to CHPU (2).

Excess heat from the CHPU is taken from the return line for the building heating and is split in two parallel circuits with integrated water-to-air heat exchangers. Both air circuits are equipped with fans, one situated at the beginning (A) the other at the end (B) of the drying channel. In the experimental configuration the dryer circuit B is switched off. Inlet and outlet temperatures of the water circuits are measured with attached standard thermometers. Volume flow of the water circuit is given by HYDROMETER Scylar Heat 762 (Hydrometer GmbH - www.hydrometer.de) with integrated sensors. These parameters configure the total heat input flow into the drying system. Air flow and air temperature instrumentation was not available.

3.2 Feedstock

The experiments were conducted with maize silage from farm own production, draff from an ordinary beer brewery and saw dust form nearby sawmill. Input and output materials were carefully sampled and analyzed according to proximate analysis (Table 1). The analysis was executed as a triple replicate. The lab analysis included pH, electric conductivity (EC), dry matter (DM), organic dry matter (ODM), total nitrogen (N_{tot}) and ammonium nitrogen (NH_4-N), volatile fatty acids (VFA), The maize silage analysis was extended to crude fat, crude fiber, neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin content (ADL), and sugar contents.

Table 1. Analytical methods

Parameter	Method	Reference	Literature
pH	VDLUFA	VDLUFA MB. BD. 3, Kap. 18.1	[11]
EC	DIN	DIN EN 27888	[12]
DM	ATB	VDLUFA MB. BD. 3, Kap. 3.1	[11]
		Weissbach and Kuhla	[13]
ODM	VDLUFA	VDLUFA MB. BD. 3, Kap. 8.1	[11]
VFA	DIN	DIN 38409 H21	[12]
NH_4-N	VDLUFA	VDLUFA MB. BD. 3, Kap. 4.8.1	[11]
N_{tot}	ATB	DIN EN ISO 16634	[14]
		VDLUFA MB. BD. 3, Kap. 4.1.1	[11]
Crude fat	ATB	VDLUFA MB. BD. 3, Kap. 5.1.1	[11]
		Legerken and Zimmermann	[15]
Crude fiber	ATB	Anakom Technology	[16]
		VDLUFA MB. BD. 3, Kap. 6.1.2	[11]
NDF	VDLUFA	Anakom Technology	[16]
		VDLUFA MB. BD. 3, Kap. 6.5.1	[11]
ADF	VDLUFA	Anakom Technology	[16]
		VDLUFA MB. BD. 3, Kap. 6.5.2	[11]
ADL	VDLUFA	VDLUFA MB. BD. 3, Kap. 6.5.3	[11]

EC = electric conductivity; DM = dry matter; ODM = organic dry matter; VFA = volatile fatty acids; NH_4-N = ammonium nitrogen; N_{tot} = total nitrogen; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin

3.3 The drying experiment

After completion of the start-up procedure one working day per drying produce for on-site investigation was scheduled. A constant drying material input flow is ensured by a system of constantly charged band conveyors.
The drying process is controlled manually. During the start-up procedure moisture content of the drying material is periodically checked both by sensing it manually as well as by a hand-held moisture meter. Heat fluxes and the feed and turn carriage velocity are regulated until satisfactory output quality, i.e. 15 to 5 % moisture content dependent on drying good, is reached. Carriage velocity or better its runtime frequency is simply set by breaks at the end of each cycle. As soon as the operating personnel found a deceptive optimum the drying process for the relevant drying material is constantly run with parameters fixed to this optimum.

Briefly resumed, inside the drying channel water is vaporized out of the drying materials into the hot air flow resulting in dried material and damp air outputs.
The experimental parameters focused on are the moisture and energy related difference between input and output of drying material in relation to the respectively provided drying heat.
The daily input weight was calculated with a vehicle scale of company NAGEMA (GDR production) by weighing the wheel loaders unloaded and loaded weight. The daily drying material weight is calculated by the difference in weight multiplied by the numbers of shovels put into the filling unit during the experiment.

3.4 Experimental Setup

In order to assess the drying process within certain period each experiment is composed of various measuring cycles. Table 2 documents the number of measuring cycles conducted.

Table 2. Conducted drying experiments

Date of experiment	Drying material	Measurement cycles
18-03-2009	Draff	17
02-04-2009	Maize silage	15
15-04-2009	Saw dust	13

Each experiment is characterized by defined data collection during each measuring cycle. A complete measuring cycle comprises the following:

- Timestamp of measuring cycle start;
- Sample drawing for input and output;
- Reading inlet and outlet temperatures;
- Reading water side mass flow of heat exchanger.

For the particular material a period of 3.5 to 6.5 hours was scheduled for the experiment. As soon as steady state conditions within the drying process were reached, input and output samples were regularly taken. The input and output samples were mixed separately and from the well-mixed probe of the investigation period an analysis sample for the input and output, respectively, was handed to the laboratory.
Average values of all experimental data, including every measuring cycle, are calculated to assess the drying process during a complete experiment. This gives the average heat flow necessary for reaching the strived moisture content of 15 to 5 %.

4. RESULTS AND DISCUSSION

4.1 Analysis of drying materials

Table 3 summarizes the results from chemical analyses of the fresh and the dried material. The fresh material, draff, maize silage, and saw dust, showed average composition regarding dry matter and organic fraction of dry matter as well as the other components. Comparing the three selected feedstock to each other maize silage had the lowest content of NDF, which was the main fraction of saw dust. Draff had comparable high contents of crude fat. Saw dust and draff had also considerable fractions of ADL. Fresh maize silage showed the highest content of volatile fatty acids. Dry matter content after drying showed in the case of maize silage the intended value of approx. 85 % whereas draff was dried to 97 % and saw dust even to 98 %. With drying the content of organic material, related to dry matter, did not change in all three cases, but the composition of organic fraction was modified.

Table 3. Results of proximate analyses of fresh and dried materials (draff, maize silage, and saw dust). Average (AVG) and standard deviation (SDEV) are of three samples of each portion

		1. experiment				2. experiment				3. experiment			
		Draff fresh		Draff dried		Maize silage fresh		Maize silage dried		Saw dust fresh		Saw dust dried	
		AVG	SDEV	AVG	SDEV	AVG	SDEV	AVG	SDEV	AVG	SDEV	AVG	SDEV
pH-value	-	4.5	0.09	4.3	0.04	3.8	0.03	3.8	0.01	5.3	0.06	4.9	0.05
EC	$mS \cdot cm^{-1}$	0.49	0.02	1.15	0.04	1.21	0.04	2.78	0.03	0.04	0.002	0.10	0.005
DM 105°	$g \cdot kg_{FM}^{-1}$	269.6	0.68	971.0	0.64	348.9	3.05	854.5	28.57	519.3	1.95	983.5	1.18
ODM	$g \cdot kg_{DM}^{-1}$	952.0	0.82	951.4	0.47	968.1	0.72	968.8	1.41	997.1	0.42	998.2	1.20
crude ash	$g \cdot kg_{DM}^{-1}$	48.0	0.82	48.6	0.47	31.9	0.72	31.2	1.41	2.9	0.42	1.8	1.20
VFA	$mg \cdot kg_{DM}^{-1}$	5.5	0.42	3.2	0.28	25.9	0.63	7.8	0.12	1.3	0.06	1.3	0.07
NH_4-N	$mg \cdot kg_{DM}^{-1}$	0.1	0.03	0.1	0.01	0.7	0.04	0.8	0.05	b.d.l.	b.d.l.	b.d.l.	b.d.l.
N_{total}	$mg \cdot kg_{DM}^{-1}$	41.6	1.34	39.9	1.90	10.7	0.81	10.1	0.34	b.d.l.	b.d.l.	0.8	0.36
crude fat	$g \cdot kg_{DM}^{-1}$	107.9	0.18	104.7	2.92	36.6	2.09	33.5	4.13	13.0	0.97	11.0	1.78
crude fiber	$g \cdot kg_{DM}^{-1}$	197.9	0.72	174.8	8.85	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
NDF	$g \cdot kg_{DM}^{-1}$	754.4	41.83	793.3	40.52	421.2	11.52	496.3	35.74	915.5	7.55	889.7	2.90
ADF	$g \cdot kg_{DM}^{-1}$	302.6	16.11	272.0	52.51	253.7	8.79	305.0	11.65	785.1	5.16	762.8	3.72
ADL	$g \cdot kg_{DM}^{-1}$	102.6	8.20	83.6	34.55	22.4	1.38	68.2	43.27	267.4	4.40	320.6	106.61
sugar	$g \cdot kg_{DM}^{-1}$	81.1	3.92	96.7	0.68	81.5	0.41	81.5	0.80	n.d.	n.d.	n.d.	n.d.

VFA = Volatile fatty acids; FM = Fresh matter; DM = Dry matter; ODM = Organic dry matter; b.d.l. = below detection limit; n.d. = not detected

4.2 Drying experiments

Table 4. Daily input of drying materials, dry matter content of fresh and dried material, water evaporated during drying and energy for drying

	Daily input	DM content fresh material	Water evaporated	Energy consumed	DM content dried material
	$t_{FM}\cdot d^{-1}$	$g\cdot kg_{FM}^{-1}$	$t\cdot d^{-1}$	$kWh\cdot d^{-1}$	$g\cdot kg_{FM}^{-1}$
Draff	10.8	269.6	7.6	11,158	971.0
Maize silage	7.0	348.9	3.5	9,311	854.5
Saw dust	10.0	519.3	4.6	8,580	983.5

4.2.1 Draff

In the first experiment the drying process was tested with draff. The amount dried was equivalent to 10.8 tons fresh matter per day (24 h). Material temperature was 4 °C before and 15 °C after the drying process.

Average dry matter content of fresh material was 269.6 $g\cdot kg_{FM}^{-1}$. Drying increased the average dry matter content to 971.0 $g\cdot kg_{FM}^{-1}$. The water amount evaporated was 7.6 $t\cdot d^{-1}$. The average heat flow used for the drying process was calculated to 11,158 $kWh\cdot d^{-1}$ (Table 4).

There are two remarkable changes in the composition of the organic matter: a general decrease in crude fiber (197.9 g kg_{DM}^{-1} to 174.8 g kg_{DM}^{-1}) and increase in sugars (81.1 g kg_{DM}^{-1} to 96.7 g kg_{DM}^{-1}), and a shift from ADF (302.6 g kg_{DM}^{-1} to 272.0 g kg_{DM}^{-1}) to NDF (754.4 g kg_{DM}^{-1} to 793.3 g kg_{DM}^{-1}).

4.2.2 Maize silage

In the second experiment maize silage was dried with a turn over equivalent to 7.0 tons fresh matter per day. Material temperature was 21 °C before and 30 °C after the drying process. This experiment was executed with an average input fresh matter content of 348.9 $g\cdot kg_{FM}^{-1}$ and reached a dried average value of 854.5 $g\cdot kg_{FM}^{-1}$. The process evaporated 3.5 $t\cdot d^{-1}$. The medium heat flow used for this result was 9,311 $kWh\cdot d^{-1}$ (Table 4).

VFA decreased to a third of the original value by drying (25.9 mg kg_{DM}^{-1} to 7.8 g kg_{DM}^{-1}), crude fat also showed a considerable decrease of 10 % (36.6 g kg_{DM}^{-1} to 33.5 g kg_{DM}^{-1}). NDF and ADF increased both (421.2 g kg_{DM}^{-1} to 496.3 g kg_{DM}^{-1} and 253.7 g kg_{DM}^{-1} to 305.0 g kg_{DM}^{-1}) which can be regarded as a general increase in crude fiber, which unfortunately was not investigated.

4.2.3 Saw dust

The third experiment was conducted with saw dust equivalent to 10.0 tons fresh material per day. Material input temperature was 21 °C and output temperature 30 °C after the drying process. The saw dust experiment was conducted with an input dry matter content of 519.3 $g \cdot kg_{FM}^{-1}$ and reached a dried average of 983.5 $g \cdot kg_{FM}^{-1}$ on average. The process evaporated a water amount of 4.6 $t \cdot d^{-1}$. The average heat flow for this result was 8,580 $kWh \cdot d^{-1}$ (Table 4).
Differences in organic dry matter content between fresh and dried material lie in the range of measurement variation, i.e. it can be considered constant. The only alteration that can be regarded as significant was the reduction in fiber content, i.e. decrease in NDF (915.5 g kg_{DM}^{-1} to 889.7 g kg_{DM}^{-1}) and ADF (785.1 g kg_{DM}^{-1} to 762.8 g kg_{DM}^{-1}).

4.3 Specific heat requirements

Specific heat input (Table 5) for the drying material ranged from 3,089 kJ kg^{-1} (saw dust) to 4,789 kJ kg^{-1} (maize silage) for the water evaporated it ranged from 5,303 kJ kg^{-1} (draff) to 9,471 kJ kg^{-1} (maize silage). These values reflect the fact that the density of the materials, the size of particles and the structure of the surfaces, has considerable effect on the ability to fix the water. The denser maize silage requires more heat input than the lighter draff. While the saw dust itself is heated easily the vaporization of the bound water needs medium heat input.

Table 5. Specific heat input and output-input factor (O/I factor) of drying material, specific heat input for evaporated water

	Specific heat input dried material	Specific heat input evaporated water	O/I factor
	$kJ \cdot kg_{FM}^{-1}$	$kJ \cdot kg^{-1}$	-
Draff	3,719	5,303	0.468
Maize silage	4,789	9,471	0.262
Saw dust	3,089	6,654	0.373

In comparison to unbound water (2,358 kJ kg^{-1}) the values are two to four times higher (Figure 3) which is also reflected in the O/I-factors of 0.262 to 0.468 (Table 5). The values determined here are in the case of draff comparable to optimal operated band dryers. These have usual heat requirements of 4,000 to 6,000 kJ kg^{-1} of water evaporated (Mujumdar, 2007). Altogether the experimentally defined heat inputs seem to have been sub-optimally fixed and offer further optimization. In conclusion higher O/I-factors are definitely possible.

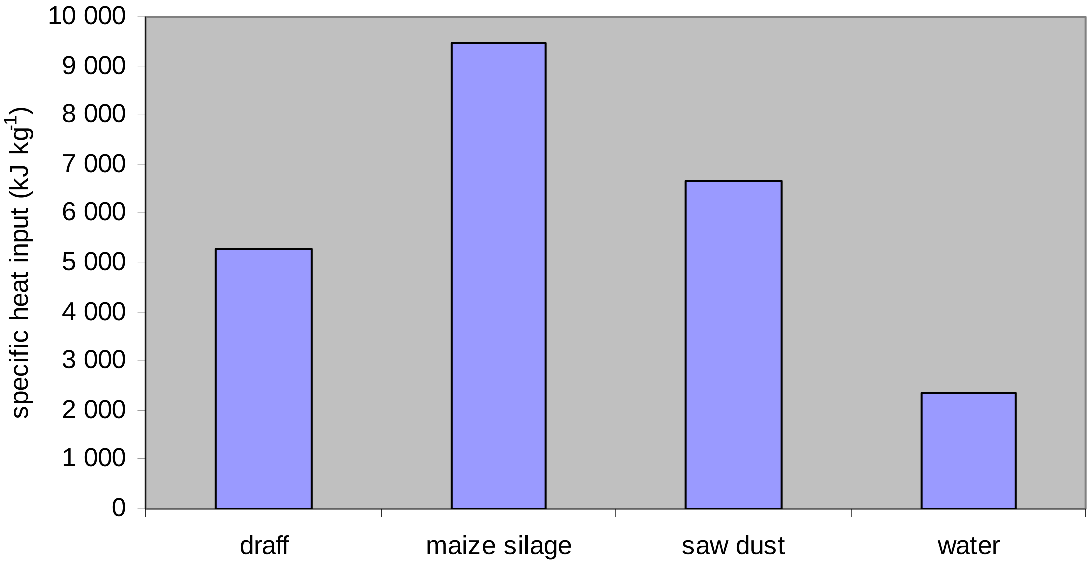

Figure 3. Specific heat requirements for vaporizing water measured for the selected feedstock compared to the theoretical value for vaporizing unbound water.

4.4 Economic considerations

The entire installation of a feed-and-turn dryer needs a total investment of approximately 125,000 €. Average life time is assumed with 10 years which compares to the time span of paying the credit. For the credit it is assumed that it covers the total sum and that the interest rate is 6% p.a. This leads to annual payment of 16,983 € or 46.53 € per day.
With an average price for electricity of 0.11 €·kWh^{-1} a 24 h operation per day, 614.4 kWh (for fans, conveyor, electronics) would cost 67.58 € for the electricity consumed. Costs for maintenance of installation as well as for labor and wheel loader sum up to 146.80 € per day.

Under German conditions the heat utilization would produce an additional income of 186 to 242 € for the same time span from additional KWK-bonus (bonus of 0.02 € per kWh for combined heat and power generation) paid with the feed-in tariff for the biogas electricity (EEG, 2009). This additional income is not used for the further assessment.
The value of the drying is very difficult to assess as there is no fixed value of the dried goods.

Draff is recognized as a valuable substitute of other protein rich feed like soy bean. But fresh draff can be stored for one or two days only without molding hence, the drying improves the availability of the draff (Weber & Kaiser, 2009). The draff can be purchased for 28 € per ton. The costs for drying add up to 24.16 € per ton from investment and operating costs. Such that 52.16 € per ton compare to 75.84 € per 159 kg soy bean which has a comparable protein amount of 70 kg per one ton of fresh draff.

The dried maize silage is regarded as a dietary feed for calves and dairy cows in precarious situations and obtains its value from the improvement of animal health. It can be compared to other feed given in such cases as e.g. hay. The price of hay is currently between 85 and 115 € per ton if purchased as large rectangular bales. One ton of hay can be compared to the dried equivalent of one ton of fresh maize worth 28 € for the fresh material plus the costs of drying of 37.27 € per ton from investment and operating costs.

Providing a ton of straw causes costs of 70 to 100 € per ton. Hence, using dry saw dust is expected to decrease costs for litter in cattle houses. Dry saw dust is assumed to take up more water than straw thus one ton of un-dried saw dust is supposed to be equivalent to one ton of straw. Straw dust could be purchased for 15.50 € per ton fresh matter. The drying adds up to 26.09 € per ton considering the costs for investment and operating costs. Hence, providing one ton of fresh saw dust, equivalent to 528 kg dried saw dust, costs 41.59 €, which is approximately half of the costs for straw.

5. CONCLUSIONS

Drying with a feed-and-turn dryer does not lead to considerable losses of organic material excepted volatile organic acids. There are also only minor changes in the particular composition. In the case of draff there is an apparent conversion of crude fiber to sugars. In all cases an alteration in NDF and ADF can be observed. Whereas draff shows a shift from NDF to ADF, maize silage shows a general increase in NDF and ADF and saw dust a general decrease of NDF and ADF.

Drying has only little effect on the major composition of the draff. Storability and taste of draff seem to improve due to drying. The dried draff can be stored for weeks without problems whereas fresh draff has an aerobic stability of only two days. Although draff can be stored for months by ensiling, its aerobic stability does not differ from the fresh material (Weber & Kaiser, 2009). Like maize silage draff is an easy to handle material before and after drying.

Drying of maize silage increases the relative fiber content as can be seen from the increase in NDF and ADF and of course a considerable decrease in volatile fatty acids. The increase in fiber by constant protein content may be one of the reasons why dried maize silage is used as a dietary feed for calves and cattle.
The aim of drying saw dust was to find a substitute for straw as litter in cattle houses. Compared to 70 to 100 € per ton straw the costs for saw dust and drying of it are much lower but there are several reasons which make the application of saw dust less practicable. During drying saw dust emits in large quantity from the process and produces considerable immissions close to the working place. This may cause serious health problems to workers and certainly leads to reasonable loss of material and there is a considerable risk of self-ignition of the material during storage.

Drying agro-products in practice is undertaken with a variety of drying systems. The RIELA® feed-and-turn dryer is principally comparable with so called band dryers. Although the feed-and-turn dryer has no band and matter transport within the dryer is realized by a carriage equipped with adequate turning tools and the air flows upwards whereas in the band dryer the air flows downwards.

The specific heat requirement is not only typical for the kind of installation but also of course on the kind of drying material. The latter has also effect on the temperature which can be used for drying and thus on the time span necessary to dry a given unit weight and volume.

As a further application of the described technology the drying of cereals also may be advantageous. One dries the own grain of known quality and does not obtain a mixed charge as it can be possible if drying with an external service provider.

The feed and turn dryer seems to be easily manageable. The operation personnel is able to adjust drying conditions appropriate for different goods without deep knowledge of thermodynamics but good quality results as can be seen from the results shown here.

The installation of the feed-and-turn dryer is a substantial improvement of the biogas plant. It significantly increases the energy utilization of the CHPU. In 2007 heat was used for heating offices, buildings, and processes in animal houses. From accounting with the electric grid owner the heat balance summed up to 6,669 GJ in 2007. This is an annual average of 24.5 % of the available heat used with a range from 12.2 % to 40.5 %. In the year 2009, after installing the feed-and-turn-dryer the heat utilization was more than four times higher: the balance reached 27,542 GJ with an annual average of 73.2 % (ranging from 63.8 % to 88.7 %) of the available heat used.

It further provides the agricultural enterprise with valuable equipment for producing high quality and high valuable feed and other products. It produces additional income from saving expenses for high value feed (20 to 50 € per ton) and straw (approx. 40 € per ton). Another way of calculating the advantage is to compare the costs of drying with the excess heat to heat provided by natural gas. This comparison gives saving values of 42.90 € to 66.50 € per ton.

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