Baltic Forum for Innovative Technologies for Sustainable Manure Management

KNOWLEDGE REPORT

Combustion of Manure: Manure as Fuel in a Heating Plant

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PREFACE

This report offers an overview on manure combustion. It focuses mainly on combustion (incineration) of horse manure, but also includes experiences from other type of manures. General conclusions from combusting horse manure can also be applied when combusting other types of solid manures.

Most of the report was written by Mats Edström (Swedish Institute of Agricultural and Environmental Engineering, JTI) with valuable input from Ingmar Schüβler (Technical Research Institute of Sweden, SP). Sari Luostarinen (WP leader, MTT Agrifood Research Finland) took part in planning the report content and edited the report into its published form.

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the authors

CONTENT

1 Basic considerations for combusting horse manure

1.1 Composition of horse manure

Since combustion process in the furnace depends strongly on the fuel quality, the collection of reliable data is significant in order to consider the challenges in combustion of horse manure. The most important values are heating value and moisture content as well as ash content and composition. In order to avoid energy losses due to aerobic reactions, manure should be incinerated freshly, not after storage.

Importantly, manure itself is always inseparably mixed with bedding material. The amount and type of bedding material also differ depending mostly on geographical location (access to material) and horse stable operation. Typical bedding materials are straw, peat or wood shavings. The amount of manure and bedding material produced can vary between 9 and 29 m^3 per horse and per year [8].

All these variables contribute to the great variety in the fuel quality of horse manure found at various locations and dates. Some reported data is displayed in *Table 1.* The heating value for ash free dry matter in horse manure does not differ much even in comparison with the bedding material. Therefore the heating value will mainly be determined in practice by the moisture content.

Table 1. Chemical composition of horse manure. LHV = lower heating value (MJ/kg dry fuel, free of ash). HHV = higher heating value (MJ/kg dry fuel, free of ash).

Bedding material	Straw	Straw	Peat	Peat	Saw dust	Saw dust	nd	nd	nd
Dry matter (DM, kg/t)	300	329	270	312	315	301	272	310-330	300
Volatile solids (VS, kg/t)	252	-	-	257	-	292	-	240-260	240
Total-N (TKN, kg/t)	-	2.6	3.2	-	2.6	-	6.9	4-6	-
Ammonium, NH_4-N (kg/t)	-	0.7	2.0	-	1.0	-	0.7	-	-
Phosphorus (kg/t)	-	0.8	0.6	-	0.8	-	1.6	8-10	-
Potassium (kg/t)	-	8.5	4.3	-	3.7	-	9.9	3-5	-
Carbon	-	153	128	-	148	-	-	-	-
HHV	-	-	-	20.6	-	20.4	-	-	-
LHV	-	-	-	19.1	-	19.1	-	-	-
Specific methane production (m^3 CH_4/tVS)	180 *	-	-	-	-	-	-	-	170
Methane in biogas (%)	54	-	-	-	-	-	-	-	-
Reference	[3]	[2]	[2]	[10]	[2]	[10]	[6]	[5]	[1]

nd = not determined; - = not available
*batch digestion

1.2 Additional fuels for improving manure energy content

Horse manure has a high moisture content which makes its energy content too low for controlled and efficient combustion alone. One way to improve the fuel properties is to dry the horse manure to at least 50% dry matter content (estimation based on Pettersson et al. [4]) before using it as fuel in a heating plant. Another way is to mix the horse manure with a fuel of higher energy content, such as wood or peat (*Table 2*).

Table 2. Example of the chemical composition and properties for co-fuels for horse manure combustion. LHV = lower heating value (MJ/kg dry fuel, free of ash). HHV = higher heating value (MJ/kg dry fuel, free of ash).

Bedding material	Wood pellets	Wood chips	Saw dust	Peat	Straw
DM (% w.w.)	90.6	45-65	92.3	51.1	87.6
VS (% of DM)	99.4	-	99.5	94.8	95.1
HHV	20.4	19-21	20.1	22.4	18.86
LHV	19.05	18-20	18.6	21.2	17.57
Reference	[5]	[5]	[10]	[5]	[5]

2 Challenges in manure combustion

Since the composition of horse manure as presented in *Table 1* shows similarity in important figures to known fuels, experiences with these fuels can be used to determine the combustion challenges for manure. Some of these issues are discussed below.

When combusting biomass, the content of nitrogen oxides (NO_x) in the flue gas is determined mainly by the nitrogen content of the fuel. Therefore high nitrogen content in the manure fuel mix (when compared to wood) will lead to significant NO_x emissions. If these values do not match the emission limits, primary (as modifying the air supply) and/or secondary measures (as catalytic reduction of exhaust gas) have to be implemented.

One common problem of non-wood biomass is the high ash fusibility, meaning melting/sintering ash at lower temperatures. To avoid such behavior the temperature inside the combustion bed has to be limited. The actual figures are dependent on the amount of ash as well as on ash composition, especially potassium and silicon contents. Unfortunately a decrease in temperature will lead to an increase in carbon monoxide (CO) emissions if no adequate design adjustments are implemented. One possible design adjustment is the widely proven concept of staged combustion which will give the opportunity to fulfill the low temperature limit in the combustion bed (first stage) and the required higher temperature inside the second stage in order to achieve complete combustion.

Another problem that has been shown at combustion of fuels with high ash content is a high particle content in the flue gas. These high particle values will increase the fouling on heat exchanger surfaces. Additionally it could cause problems to fulfill the emission limits and therefore require additional measures, e.g. filters.

High chlorine content in the fuel generates corrosion risks inside the combustion chamber as well as on the heat exchanger surfaces. Moreover, high water content in the fuel will lead to an insufficient fuel heating value to maintain good quality combustion. In the worst case it will result in an incombustible fuel.

As mentioned before these issues are not unique for manure combustion. They have already been researched for different fuels and some adequate technologies to solve the challenges are available.

The biggest challenge in manure combustion is perhaps the mentioned variety in fuel quality, especially when the quality keeps changing at one location. The changes in the size of the fuel particles (for example through changes in the bedding material) could cause mechanical problems with the feeding system. A different ash composition or amount as well as different moisture content may require changes in operation which may not be possible with the actual plant design. In general there are two possibilities for solving these issues. The first is to design a facility that can be modified according to the fuel quality variation itself. The second is the precondition of the fuel to provide a standardized fuel at intake. Even if the latter would be easier for designing a combustion facility, it would require a much higher technical and economical effort on fuel preparation.

3 Legislation

In addition to the technical challenges, there is always the question of legislation. The important questions are whether manure combustion is permitted and which limits and regulations are required.

In the European Union member states, it is firstly important to determine whether manure is accounted as a waste according to the Waste Combustion Directive (WID 2000/76/EC) or as a renewable fuel for heat production. If heat production from manure follows WID it means that the plant owner has to fulfill regulations concerning:

- permit for a new plant
- operation conditions
- air emissions
- water discharges from the cleaning of exhaust gases
- handling of ashes
- system for control and monitoring
- measurement requirements
- access to information and public participation

It is complex and expensive to accomplish the WID measurements connected to air emissions and to water discharges.

If heat production from manure is considered to be a biofuel plant, there is no EU directive for the plant to fulfill.

The national interpretations of the EU legislation vary significantly and may also be dependent on the size of the combustion plant. Some countries do not have any actual requirements for small-scale biofuel plants, while some countries require exhaust gas emissions, thermal efficiency and supervision programs [13].

In Sweden manure combustion is included in WID, but despite the waste status of manure, it can be combusted without WID requirements based on regarding horse manure as a WID-free vegetable waste from agriculture and industry. The idea behind this is apparently that horse manure contains a lot of grass and bedding material as opposed to usual poultry, cow and pig manure.

In Finland, horse manure is accounted as waste and thus its combustion must be according to WID requirements. The national legislation prefers horse manure use as fertilizer or soil conditioner, even if horse manure e.g. with sawdust bedding is acknowledged to be slow to stabilise for field use.

Jansson [7] reports that there are great differences in the legislation on manure combustion in the Nordic countries. It is relative easy to get a permit for manure combustion plant in Sweden and in Norway, but more or less impossible in Finland and Denmark due to different interpretation of the EU-legislation.

4 Practical experiences and research results

In this chapter, a few commercial solutions for manure combustion are presented.

4.1 Reka boiler

Maskinfabriken Reka A/S (Denmark) offer biomass combustion plants for fuels up to 50% moisture content with a moving grate furnace in the range of 90-3500 kW thermal power (type HKRSV). Kristensen et al. [12] have reported the results of co-combustion tests using a 200 kW Reka boiler with a solid manure fiber fraction generated in a phase separation of liquid pig manure and straw. The separated manure had a moisture content of 76-77% (ash 15-16% of DM) and a lower heating value from 2.2 – 2.8 MJ/kg (wet based weight, while the straw had a moisture content of 14% (ash 3% of DM) and a lower heating value of 16 MJ/kg. The tested fuel mixture consisted of 27–55% solid manure (w.w.) the rest being straw. The thermal power achieved was 207–239 kW with the boiler thermal efficiency of 76.5-80.1%. The results showed that the high moisture content in the manure led to the maximum manure content of 50% (w.w.) in the fuel mixture. In the test combustion, the manure contribution was only 8-18% of the thermal power. It was also stated that if the plant had a condensation step for exhaust gas, the thermal efficiency would increase with 10% [12].

Reka A/S has sold several small boilers (60 kW) in Denmark, Germany and Austria for horse manure combustion using wood chips or wood pellets as co-fuel (Brusgaard, pers. com. [14]). Reka A/S also has smaller boilers (down to 20/30 kW) with moving grate in which horse manure is used as a co-fuel in Sweden (Skavhellen, pers. com. [11]).

4.1.1 Emissions from Reka boiler

Some emissions from co-combustion with a solid manure fiber fraction generated at a phase separation of liquid pig manure and straw has been reported. The emissions can be compared to combusting only straw [12].

Table 3. Emissions from test with 200 kW Reka biomass boiler with a 1) mixture of solid manure fiber fraction (from phase separation of liquid pig manure and straw) and 2) straw as fuel, based on Kristensen et al. [12]. The emissions are normalized to 10% O_2.

Fuel	Mixture: solid manure and straw	Straw	Unit
NO_x	345 – 462	432	ppm
CO	405 – 1279	280 – 473	ppm
Dust emission 1)	1496 – 2586	650 - 876	mg/Nm^3

1) The used plant for test combustion had no cyclone for reducing dust emissions from exhaust gases.

Kristensen et al. [12] conclude that the emissions of nitrogen oxides is on the same level both with fibre fractions from pig manure and straw and with straw alone. However, the carbon monoxide and dust emissions increase considerably in a plant using manure-straw fuel mixture compared to straw alone. Due to the high dust emissions when using manure-straw fuel mixture, a commercial plant would need a cyclone for reduction of dust emission.

It was also concluded that most of the phosphorus and potassium in the used fuel is found in the collected ashes after the combustion while most of the nitrogen is lost.

4.2 Swebo Bioenergy boiler

Swebo Bioenergy AB (Sweden) offers small-scale combustion plants for fuels with high moisture content. The development of the BioTherm plants started already in the 1990s and is in its 3rd generation at the time of writing (June 2011).

The smallest plants are working in the range of 80-200 kW thermal power with a capacity to combust manure from 15-25 horses. The biggest plant has a thermal power of 500-1000 kW and can combust manure from up to 200 horses (Jansson, pers. com. [7]).

The plants are designed as two-stage combustion with a grateless furnace. According to the manufacturer, it is possible to combust manure with a moisture content of up to 70% (w.w.), including the ability to react to fuel quality changes. This is achieved through a variable addition of wood pellets. The amount of pellet addition depends on the main fuel quality and is automatically determined by the operation system in order to achieve good quality combustion. Usually the share of pellets is about 5-10 volume percent, and does not exceed 15%.

A description of the plant in Skokloster, Sweden, featuring the latest generation of the BioTherm facilities is described more thoroughly in the separate Baltic MANURE report “Examples of existing good practices in manure energy use” (available at http://www.balticmanure.eu).

4.2.1 Emissions from Swebo Bioenergy boiler

Swebo Bioenergy AB reports the following emissions from combustion tests using their boiler and horse manure of 51% DM:

- NO_x: 320 mg/Nm^3
- CO: 40 mg/Nm^3

- O_2: 10 Vol.%

In the test, the bedding material was sawdust (wood chip). The thermal heat production was 150 kW and the temperature of the combustion gases was approx. 950 °C (www.swebo.com).

Pettersson et al. [4] also report results from tests with a mixture of horse manure and sawdust at a dry matter content of 43%. The emissions reported are in *Table 4*.

Table 4. Emissions from a test with Swebo Bioenergy boiler with horse manure or wood chips as fuel [4]. The emissions are normalized to 10% O_2.

Fuel	Horse manure	Wood chips	Unit
NO_x	362-438	120-150	mg/Nm^3
CO	78-258	50-150	mg/Nm^3
Dust emission	391-472	65-135	mg/Nm^3

Odor may occur in the plant surroundings if the combustion process is poor, but if the management of the plant is good, odor is not a problem (Jansson, [7]).

4.3 Säätötuli boiler

Puustinen et al. [10] report Finnish combustion tests on a mixture of saw dust and horse manure using a house-on-site 40 kW stoker feed furnace (manufacturer Säätötuli Oy). Two different horse manures were tested the difference being the bedding material, either saw dust or peat. The characteristics of the two different horse manures are shown in *Table 1* and of the additional fuel in *Table 2*.

A complete measurement of gaseous emissions from a fuel mixture of 40% horse manure and 60% saw dust or peat was carried out according to the WID. A short summary of reported emissions is in *Table 5*.

Table 5. Emissions from a test with Säätötuli boiler with 40% horse manure and 60% saw dust or peat [10]. The emissions are normalized to 11% O_2.

Fuel	Horse manure : saw dust	Horse manure : peat	Unit
NO_x	340	520	mg/Nm^3
CO	320	1700	mg/Nm^3
Dust emission	120	230	mg/Nm^3 (dry gas)

4.4 Experiences from a Swedish trotting track

The trotting track Solvalla, Sweden, had a plant for horse manure combustion. It was taken out of operation around year 2000 and later dismantled. It was a 1.5 MW plant using a screw conveyor to transport the manure into a grate furnace. The emissions (NO_x and CO/CO_2) were frequently measured and the levels met the legislation of year 1997. The manure was reported to have too high moisture content for combustion and needing addition of oil. Furthermore, there were problems with corrosion and fouling on heat exchanger surfaces [4].

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5 Some results on combustion of poultry manure

Poultry manure is reported to have a lower heating value of 17.5 MJ/kg dry and ash free fuel [5].It is also reported that solid poultry manure is commonly used as fuel in grate furnace combustion plants in the United Kingdom. As an example, one 13 MW plant uses 90% poultry manure the rest being wood chips. The moisture content in the fuel varies between 25 to 40%. The plant uses selective non-catalytic reduction to reduce the NO_x-emissions in the exhaust gases.

Strömberg [5] also reports of an investigation in Texas, USA, recommending the use a vortex cyclone combustion furnace with water-cooled stoker grate for combustion of poultry manure. The manure is pre-dried with the exhaust gases before the combustion. Co-combustion with coal was also recommended in orderto improve the plant performance.

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This report in brief

Manure combustion divides opinions. It may be seen as an effective way to utilize the manure energy content and to reduce the amount of manure regionally. On the other hand, possible emissions from the process require attention with varying requirements in different countries.

This report with focus on manure combustion in different boiler types summarizes the most important matters regarding combustion of especially horse manure, including factors such as manure composition, possible co-fuels, technical challenges, legislation and emissions. Some results are also given for combustion of poultry manure.

This report on manure combustion was prepared as part of Workpackage 6 on Manure Energy Potentials in the project Baltic Manure.

About the project

The Baltic Sea Region is an area of intensive agricultural production. Animal manure is often considered to be a waste product and an environmental problem.

The long-term strategic objective of the project Baltic Manure is to change the general perception of manure from a waste product to a resource. This is done through research and by identifying inherent business opportunities with the proper manure handling technologies and policy framework.

To achieve this objective, three interconnected manure forums has been established with the focus areas of Knowledge, Policy and Business.

Read more at www.balticmanure.eu.

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