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Combustion of horse manure for heat production

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ABSTRACT

The main objectives of this paper have been to evaluate the use of horse manure and wood-shavings as a fuel for heat production and to provide sets of data on the chemical composition, ash characteristics and ash forming elements of the fuel. Another objective has been to investigate the possibility to use the ash as fertiliser by analysing the heavy metal and nutrient contents. The results showed that the fuel is well suited for combustion for heat production causing low emissions of products of incomplete combustion. The emissions of NO_x were however high due to the high content of fuel bound nitrogen. Emissions of CO and NO_x were typically in the range of 30–150 mg/Nm^3 and 280–350 mg/Nm^3 at 10 vol% O_2, respectively. The analysis of the ash showed on sufficiently low concentration of heavy metals to allow recycling.

1. Introduction

There are roughly five million horses living in stables in Europe today. The residues from the horses contain solid as well as liquid portions of waste, typically about 60% solids and 40% liquids (Wheeler and Smith Zajaczkowski, 2002). Bedding materials are used on the floor of the stall boxes to absorb the liquid part and are exchanged regularly in order to keep a hygienic environment for both, people working in the stables and for the horses. The residues from the stables consist therefore of a mixture of manure, urine and bedding material. There are several different types of bedding materials that are used. The most common are wood-shavings, sawdust, straw (silage or pellets), peat or paper pieces. The choice is strongly depending on which material that is available at low cost.

In northern Sweden, wood-shavings are generally used due to the great accessibility. From an inquiry made, it was found that the used annual volume varied from 9 to 29 m^3 per horse. The large variations are due to that the stables and riding schools often pay for the bedding material, and the share of the bedding material in the mixture depends strongly on how careful the keepers are when they clean the stall boxes (Pettersson and Lundgren, 2002). The options for handling the residues are recycling to agricultural land either through composting or via biogas production, deposition at landfills, combustion or other usage. In the study by Pettersson and Lundgren (2002), it was found that currently the largest part of the horse manure is recycled to agricultural land followed by deposition at landfills. Combustion and other usage such as soil production for lawns were of small importance. Wheeler and Smith Zajaczkowski (2002) have found that approximately 20 m^3 of bedding material is used per horse each year, which is close to the average value of the inquiry.

According to a law passed in the year 2001, landfill of organic material will be prohibited from 1st of January 2005 in Sweden (Swedish Codes of Statute, 2001). This law is based on a European Commission Directive (European Commission, 1999) which forces the member states to lower the landfill of biodegradable municipal waste to less than 35% of the amount produced in 1995. This means that the Swedish law is more stringent than the directive.

Currently, composting of the horse manure to be used as fertiliser on arable land is a viable alternative for many horse stable owners if the arable land is located in the vicinity of the stable. Otherwise costly transports of large waste volumes would be required, which many horse owners can not afford. Moreover, cereal farmers often hesitate to accept composted horse manure as fertiliser since it may contain oat weeds. This would force the farmer to weed the fields manually as no other weed control is available. Many do not recommend spreading of composted manure mixed with wood-shavings because of a rumour saying that lignin and terpene contents tend to restrain the growth. According to a study by Steineck and Svensson (2000), there are no valid theories confirming this rumour. Due to the above mentioned reasons, many horse owners have large problems to get rid of the residues.

For many stables, the energy content of the annual volume of bedding material used would easily cover the space heating demand and the demand for hot tap water over a year in a normal stable facility. There is a great interest in burning the manure for heat production amongst horse stable- and trotting course owners. By doing so, the stable and trotting course owners will on the one hand decrease the cost for heating of their facilities and on the other hand, decrease the waste volume. One important condition

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for motivating combustion of horse manure is that the emissions of harmful substances are kept at an environmentally benign level. The ash could potentially be used as fertiliser in forests, if the amount of heavy metals, like cadmium, is less than the prevailing regulations.

Very few studies have been found on thermochemical conversion of horse manure for energy generation. Schuster and Strömberg (1997) presented results from combustion experiments using horse manure mixed with straw as a fuel at the trotting course of Färjestad in Sweden. The results indicate a poor combustion process with very high emissions of CO. However, there are several studies made regarding thermochemical conversion of other types of animal manures. Zhu and Lee (2005) have presented experimental results from co-combustion of poultry wastes with natural gas in an advanced Swirling Fluidized Bed Combustor (SFBC). Sweeten et al. (2003) have thoroughly investigated the fuel properties of cattle manure, while Annamalai et al. (2003a,b) presents emission data and operational problems during co-firing of coal and cattle manure in two different burners. Priyadarsan et al. (2005) have experimentally investigated gasification of coal and animal waste-based fuels like feedlot biomass (cattle manure) and chicken litter biomass under batch mode operation. In a paper by Sánchez et al. (2007), experimental studies regarding pyrolysis of mixtures of sewage sludge and manure are presented. Möller et al. (2007) investigated co-combustion of treated pig manure.

In this paper, results from combustion experiments performed in a 250 kW_{th} furnace especially designed for wet and inhomogeneous biomass fuels is presented. The purpose has been to evaluate horse manure and wood-shavings as a fuel for co-firing for heat production in horse stable facilities. The results are compared with emission data from combustion of wood-chips with high moisture content. Furthermore, this paper provides sets of data on the chemical composition, ash characteristics and ash forming elements of the fuel. Another objective has been to investigate the possibility to use the ash as fertiliser by analysing the heavy metal and nutrient contents.

2. Test facility and experimental setup

The combustion experiments have been carried out in a 250 kW_{th} biomass-based district-heating plant located in the northern part of Sweden, around 70 km south of the Arctic Circle. The plant is connected to the local district-heating network of the town of Boden. The experimental facility includes, besides a furnace and a heat transfer unit, a water heat store to handle heat load variations as well as two cyclones that are used for flue gas cleaning.

2.1. The combustion chamber

The furnace is divided into a primary and a secondary zone. The primary combustion chamber is of a counter-current grate type, meaning that the flame direction is the opposite of the fuel flow. This type is appropriate for wet biomass fuels, due to the increased convective heat transfer contributing to an improved drying process of the fuel. After the final gas combustion in the secondary zone, the gases enter a convection boiler where the heat is transferred to the water. The cooled gases continue through a cyclone system.

Fig. 2 shows a sketch of the primary combustion chamber. Two fuel feeding screws (1) are used to transport the fuel from an intermediate fuel store into the furnace. The fuel enters the combustion chamber at a first horizontal plane (2) and moves slowly towards a slope. The purpose of the two planes is to dry the fuel before the combustion process starts, using heat transfer by radiation and convection from the combustible gases. Pyrolysis starts in the end of the slope and at the beginning of the fuel grate (4). The burning fuel bed is moved slowly forward towards the steps (5) and the ash bin (6) by short strokes from a rectangular piston (3). Final charcoal combustion takes place at the end of the second horizontal plane (4) and on the steps (5).

The largest difference compared to a conventional counter-current grate furnace is that the primary air is supplied from above the fuel bed and not through the grate. In this furnace, the combustion air is introduced partly through slotted steel pipes integrated in the sidewalls and partly through a pipe in the front of the furnace as illustrated in Fig. 2.

The secondary combustion chamber is cylindrically shaped in order to create a re-circulating flow and thereby enhance the large scale mixing and the combustion intensity. It is assumed that the most important factors for a good burnout rate are to create a good mixing between gases leaving the primary zone and secondary air and to maintain a high gas temperature. A proper method of achieving this is to supply pre-heated combustion air as high velocity air jets. To make the air jet penetration easier it is advantageous to have a low momentum of the primary gases and short distances for the secondary air jets to travel. Unfortunately, these two statements contradict each other since a low primary flow momentum requires a large cross sectional area, leading to larger penetration distances being required. The secondary air is pre-heated outside the cylinder to a few 100 °C depending on the thermal output. Also the gas residence time in the secondary combustion zone varies mainly with the thermal output, but is typically in the range of 0.6–1.6 s. The design was developed on the basis of CFD simulations and previous experiments. A thoroughly description of the design of the primary and secondary combustion chamber can be found in Lundgren et al. (2003, 2004a,b, 2005).

2.2. Measuring equipment

The analysis of the flue gas composition is carried out immediately after the heat transfer unit shown in Fig. 1. A multi-component gas analyser for online measurements of NO, CO, CO_2 and O_2 (Maihak) and a heated THC analyser (JUM) were used. A NO/NO_2 converter (JNOx) was used to measure total NO_x emissions.

The gases were extracted using a heated probe and gas sample line maintained at a constant temperature of 120 °C. Table 1 shows the measuring methods and ranges for the different gas components.

Gas temperatures have been measured before the secondary combustion chamber and after the heat transfer unit by using radiation-shielded thermocouples of type N. The location of the temperature gauges are shown in Fig. 1.

Fuel samples have been dried in an electrical oven for at least 24 h at approximately 105 °C to determine the moisture content of the fuel. Samples have been taken regularly during the experiments.

3. Experimental results

3.1. Fuel characteristics and analysis

The fuel consists of wood-shavings and horse manure (hereafter referred to as the fuel mixture), where the share of wood-shavings typically constitute 40–80 wt% depending on how careful the horse boxes are cleaned. The moisture content of the fuel mixture as received varies in the range of 45–65% (wet basis) mostly depending on if it is stored outdoors with cover or without.