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Fuel design in co-combustion of demolition wood chips and municipal sewage sludge

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ABSTRACT

Municipal sewage sludge (MSS) is a waste stream resource which contains both energy and elements such as phosphorus which could be recycled. If these two aspects of this waste stream resource are to be used to their full potential the sludge should not be used in landfills or road construction. There is some use of sludge in agriculture today but not all MSS produced is suitable for direct use on arable land due to its content of potentially harmful elements, pathogens or anthropogenic chemicals. By combusting sludge that is not used directly in agriculture the problematic organic content could be destroyed. The combustion process also produces an ash that possibly could be used either directly in agriculture or as a raw material for recovering phosphorus and energy could be recovered. Building mono-combustion plants for sewage sludge is not economically feasible in all parts of the world so it is of interest to investigate how MSS can be introduced together with other fuels in existing infrastructure which already have extensive cleaning systems for potentially harmful elements.

To investigate this possible path, demolition wood chips (DWC) were co-combusted with municipal sewage sludge (MSS) in a grate-fired combined heat and power plant running at 50% capacity producing 25 MW_{th} and 9 MW_{el}. The amount of MSS that was suitable to introduce in blends was determined using a "fuel fingerprint" based on the composition of the raw materials. Thermodynamic equilibrium calculations were made to evaluate potential problems with slagging based on the ash content prior to the combustion experiments. The fuels were introduced as a reference case with only demolition wood and pre-blended fuel mixtures in two ratios; 65 w/w-% DWC/35 w/w-% MSS and 55 w/w-% DWC/45 w/w-% MSS and were fired for 12 h. The high water content of the MSS affected how much MSS that could be introduced without compromising the heat and power production.

The fuel blends worked nicely for 12 h of continuous combustion with small adjustments where the primarily the air inlet configuration was changed. The main problems encountered related to cleaning of the flue gases and to some extent ash removal. The bed ash and fly ash produced was analysed both using ICP-AES (elemental) and XRD (speciation) and the bottom ash was subjected to ash melting tests. The major nutrient phosphorus was mainly found in bottom ash (80 w/w-%) as whitlockites with some hydroxyapatite whereas fly ash (20 w/w-%) contained larger amounts of hydroxyapatite, especially for the reference fuel. The amount of alkali chloride in the fly ash was reduced in favour of alkali sulphate formation.

1. Introduction

There is a global consensus that it is important to increase the share of renewable energy in the global energy system. This transition does however come with some considerable challenges, for instance where the source for this renewable energy should be found since energy production should not jeopardize food production. The use of waste streams from other sectors for energy purposes has become an important addition to the traditional woody-type biomasses and is likely to increase since deposition of material in landfills is decreasing due to legislation. Such waste streams may include logging residues but stretches over to demolition wood, agricultural residues such as wheat straw, municipal solid waste and also digested municipal sewage sludge. Changes in the fuel feedstock provide challenges with respect to ash-related operation problems [1,2], since existing facilities often have been built to handle traditional woody-type fuels with low ash content and inorganic compositions which do not cause large problems with fouling or corrosion.

Combustion facilities which are designed to admit more challenging fuels do exist [3,4]. These are often for mono-combustion of waste

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streams from society such as municipal solid waste, demolition wood, or municipal sewage sludge. The possibility of co-combustion of such streams may increase the available fuel feedstock for an existing facility and could reduce the need for investments in new infrastructure to meet changes in legislation for how such waste streams should be treated. They could also serve as good introduction points for assessing how potentially problematic fuels will behave in co-combustion situations since they often have good filtration capabilities for particulate matter, flue gas cleaning and generous ash removal systems. This could translate into an easier process when applying for permits to introduce fuels with more complex ash chemistry compared to the standard fuel into the fuel feedstock.

Municipal sewage sludge (MSS) is an interesting and well recognized [5–7] waste stream resource which contains both energy and elements such as phosphorus which could be recycled. If these two aspects of this waste stream resource are to be used to their full potential the sludge should not be used for purposes such as covering landfills or filler during road construction. Ideally, the sludge should be digested to produce biogas after which the MSS could be treated using various methods such as heat or storage after which it is referred to as biosolids. Biosolids are used in agriculture today as a fertilizing agent, but not all MSS produced lends itself to this direct use due to its content of potentially harmful elements [8–10], pathogens or anthropogenic chemicals [11] which may have a negative impact on the environment. From a European perspective there are indications that EU regulatory demands on MSS/biosolids used in agriculture may become stricter in a near future.

By combusting digested sludge that is not used directly in agriculture the problematic organic content could be destroyed. The combustion process also produces an ash that possibly could be used either directly in agriculture, or as a raw material for recovering macronutrients such as phosphorus [8,10,12–15]. Building mono-combustion plants for sewage sludge is not economically feasible in all parts of the world so it is of interest to investigate how large amounts of MSS may be co-combusted with other fuels in existing infrastructure which already have extensive cleaning systems for potentially harmful elements. The use of existing infrastructure can however limit the possibility of fuel design with the intent of producing an ash where phosphorus is readily available to plants and/or easy to extract in a following industrial process with the purpose of extracting phosphorus.

The aim of this work is to employ fuel design including thermodynamic equilibrium calculations to demonstrate co-combustion of municipal sewage sludge in an existing infrastructure which today mainly combusts woody-type fuels. This is conducted with minimal fuel preparation and small changes in operational parameters. Besides investigating what impact this has on the operation of the combined heat and power plant, the bottom and fly ash are analysed to determine where the macro-nutrient phosphorus can be found and in which form it is present.

2. Materials and method

2.1. Combustion facility and risk assessment

The combined heat and power plant used in this study is located in Enköping and is managed by ENA Energi AB. It is a Burmeister & Wain grate-fired boiler with a vibrating grate designed for firing chipped fuels with a moisture content of 40–45%. The standard fuel blend is logging residues, bark, wood chips, and DWC and the boiler provides 55 MW_{th}/24 MW_{el} at full load. In this study the plant was run at half load, producing 25 MW_{th} and 9–10 MW_{el}, for 12 h to ensure that the increased ash content and changed ash composition introduced with the fuel blends did not compromise power production where the system for bottom ash removal proved to have a limited capacity. Fine particulate matter is removed from the flue gas using an electrostatic filter. Ammonia is introduced in the flue gas for selective non-catalytic reduction of NO_x and SO_2/HCl is captured in a flue gas condensation step.

Prior to introducing the fuel blends, the risk involved with introducing the wet municipal sewage sludge in the combustion system was assessed using thermodynamic equilibrium calculations and preliminary fuel analysis. These calculations were primarily aimed at estimating melt and slag formation caused by the change in ash content. The high sulphur content in MSS has been shown to reduce the formation of alkali chlorides in fly ash and deposits, so the main concerns lay with the inorganic compounds forming on the grate. The same procedure was repeated once the final fuel blends were decided and the base materials DWC and MSS were analysed. Calculations were carried out in FactSage 6.2(preliminary)/6.4(actual fuel blends) using databases FactPS, FTOxide, FTPulp and the slag models FTOxid-SlagA/SlagB/SlagC. FT-OxidSlagB was finally chosen as the most suitable slag model for the present fuels and fuel blends due to its ability to handle both silicate and sulphate interactions with various positively charged ions whereas FTOxid-SlagC, which also contains thermodynamic data for phosphates, did not work well in the temperature range of interest.

2.2. Fuels, fuel blends and preparation

The base fuel for the combined heat and power plant is demolition wood chips (DWC) together with other woody-type fuels. The composition of DWC can vary greatly and the fuel analysis in Table 1 is based on fuel samples containing particles small enough to be suitable for analysis. Larger pieces of glass, rocks, metal strips and plastic material were removed during fuel sampling. This material comprised about 0.5–2% of the total weight. Table 1 presents average values from three separate analyses of demolition wood chips. Digested municipal sewage sludge may vary in composition depending on its origin, but typically has a LHV in the range of 11–13 MJ/kg of dry substance, 12.6 MJ/kg for the MSS used in this work. The high water content of MSS (76.20%) also falls within typical moisture content for the material, but it is quite high. The precipitation agent used in the MSS was $Fe(II)SO_4$. The fuel blends were prepared at Ragn-Sells, Högbytorp, Sweden, using an ALLU screening crusher two days prior to the combustion experiments using 130 tonnes DWC/70 tonnes MSS and 110 tonnes DWC/90 tonnes MSS.

2.3. Ash sampling and chemical characterisation

At least three different samples were collected from both bottom ash and fly ash from underneath the electrostatic filter during the 12 h combustion period. Elemental analysis of the fuels and ash fractions was

Table 1
Fuel composition for fuels and fuel blends used in this study.

	Demolition wood chips (DWC)	Municipal sewage sludge (MSS)	Fuel blend 1 65 w/w-% DWC 35 w/w-% MSS[a]	Fuel blend 2 55 w/w-% DWC 45 w/w-% MSS[a]
w/w-% of fuels and fuel blends, wet basis				
Moisture	16.13	76.20	37.16	43.16
Ash content	4.77	9.90	6.56	7.08
K	0.12	0.13	0.12	0.12
Na	0.11	0.06	0.09	0.09
Ca	0.40	0.70	0.50	0.53
Mg	0.09	0.12	0.10	0.10
Fe	0.23	1.35	0.62	0.73
Al	0.27	0.63	0.40	0.43
Si	0.99	1.28	1.09	1.12
P	<0.01	0.75	≤0.27	≤0.34
S	0.08	0.33	0.16	0.19
Cl	0.04	0.02	0.03	0.03
Energy content (MJ/kg)				
LHV (wet)[b]	14.84	1.13	10.04[a]	8.67[a]

[a] Calculated values based on DWC and MSS compositions.
[b] Determined under constant pressure.