



Full Length Article

Measurements of the NO_x precursors and major species concentrations above the grate at a waste-to-energy plant

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ABSTRACT

Satisfactory results from modelling of NO_x formation in CFD during combustion of Municipal Solid Waste (MSW) in grate-fired waste-to-energy plants is highly depended on accurate descriptions of the temperature field in the free-board above the waste bed. Accurate modelling of the temperature field relies on an accurate determination of the boundary conditions; the species concentration, gas temperature and gas velocity from the waste bed into the computational domain. In this study the gas temperature and the gas concentration profiles of O₂, H₂O, CO, CO₂, CH₄, C₂H₂, C₂H₄, NH₃ and HCN along the waste bed were measured. The measurements were performed on a 9 ton/h grate-fired waste-to-energy plant, Affald + unit 4 in Denmark. The species concentration profiles were determined by gas extraction using a 6 m water cooled probe and FTIR spectroscopy, while the gas temperatures were determined by suction pyrometer. The major combustible gasses were determined to be CO, CH₄ and C₂H₄, which are only found above the first half of the grate. Furthermore, it was determined that during grate-fired MSW combustion the majority of the NO_x precursors are released as NH₃; more than 80%. The influence of NO_x precursor composition on the NO_x formation was examined through CHEMKIN simulations. It was shown that for reliable modelling of the NO formation at high excess air ratios, $\lambda > 1.1$, it is important to determine the correct ratio between NH₃ and HCN. The importance of an accurate precursor determination increases considerably with decreasing temperatures.

1. Introduction

According to the European Landfill Directive the use of landfills has to be avoided whenever possible [1]. This has generated a shift in municipal solid waste handling, from disposal at landfills to extraction of energy through combustion. One of the main combustion technologies for solid waste is grate-firing [2]. By grate-firing of waste heat and power is produced and the volume of waste is greatly reduced. This technology enables the use of a wide range of fuels; both biomass and solid waste, with varying moisture content, and the fuel preparation and handling requirements are limited.

Combustion of solid waste, similar to combustion of other solid fuels, emits nitrogen oxides (NO_x). The emission of NO_x continues to be a major environmental concern [3] as it is an acid rain precursor and participates in formation of photochemical smog, which is problematic in urban areas [3,4]. Nitrogen oxides are formed either from oxidation of the N₂ in the combustion air (thermal NO_x formation), prompt NO

formation, which is initiated by attack of CH radicals on the N₂ triple bond, the N₂O mechanism or from oxidation of organically bound nitrogen in the fuel (fuel-NO_x formation) [3]. For solid fuels such as waste, which has a significant content of organic nitrogen, the fuel-NO_x mechanism is the dominating source of NO_x [3] due to low combustion temperatures. The NO_x precursors, released during devolatilisation of the fuel in the fuel-bed, mostly consist of ammonia (NH₃) and hydrogen cyanide (HCN) [3]. It has been shown that the formation and partitioning of these NO_x precursors depend strongly on fuel characteristics (i.e., biomass type, fuel nitrogen content, particle size, and moisture content [3,5,6]) and on process conditions (devolatilisation temperature and stoichiometric air ratio [3,7]). The reactive nitrogen species released from the fuel-bed are subsequently oxidized to either NO or N₂ in the freeboard. The selectivity for forming NO, rather than N₂, depends strongly on the reaction conditions in the freeboard, mainly temperature and stoichiometry [3].

In order to achieve a satisfactory result from CFD modelling of NO_x

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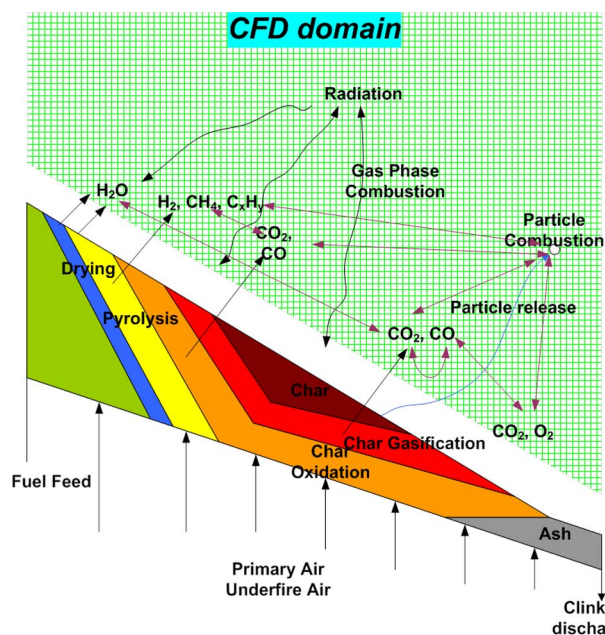


Fig. 1. Schematic overview of the procedure for CFD modelling of solid fuel combustion in grate-firing units. (Needs to be in Color). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

formation during combustion of waste in grate-fired waste-to-energy plants an accurate description of the temperature field in the free-board is essential, due to the dependency of the temperature on the low temperature fuel NO_x chemistry [3,8]. Modelling of the temperature field in the free-board relies on an accurate determination of the boundary conditions, e.g., species concentrations, gas temperature and gas velocity from the bed into the computational domain. Most CFD models of grate-fired waste-to-energy (W-t-E) plants use a stand-alone model of the bed, describing the waste devolatilisation and the partial oxidation of volatiles. The volatile oxidation is strongly coupled to the combustion of gaseous species in the free-board due to the radiation onto the bed as indicated in Fig. 1.

Coupling the devolatilisation of the fuel and partial oxidation of the volatiles in the bed with the combustion of gaseous species in the free-board has been applied with success in previous studies [9,10].

Recently the NO precursor concentrations were measured at a full-scale waste-to-energy plant [12]. However, the measurements were limited to two fixed positions above the grate.

The objective of this study is to measure the gas temperature and species concentrations just above the fuel bed in a full-scale W-t-E plant. The gas species concentrations are measured by gas extraction and use of FTIR spectroscopy in four fixed positions above the bed. By suction pyrometer the gas temperatures were measured concurrently to the species concentrations. The results are useful for evaluation of bed models and will provide a more accurate description of the temperature field in the free-board. The species measurements include the NO_x precursors released from the bed. Based on the results, the importance of the partitioning of NO_x precursors on the formation of fuel NO_x in grate-fired W-t-E plants is discussed.

2. Plant and grate characteristics

Over a span of three days the gas composition and temperatures above the bed from combustion of municipal solid waste (MSW) were measured. All measurements were performed at Affald+, a W-t-E plant located in Næstved, Denmark. The W-t-E plant has a nominal waste

Table 1
Specifications of Affald+ line 4 during the three days of measurements.

	Air dist. 1	Air dist. 2
Waste feed (tons/h)	7.2 ± 1.6	7.3 ± 0.9
Avg. heating value (MJ/kg)	13.5 ± 1.2	13.8 ± 0.5
Avg. primary air (Nm^3/h)	$17,454 \pm 1808$	$20,215 \pm 2017$
Fraction on grate section 1	0.20	0.20
Fraction on grate section 2	0.35	0.27
Fraction on grate section 3	0.35	0.43
Fraction on grate section 4	0.10	0.10
Avg. secondary air (Nm^3/h)	$10,851 \pm 326$	$10,847 \pm 300$
Temp. primary air ($^\circ\text{C}$)	45.5 ± 3.2	45.9 ± 3.6
Temp. secondary air ($^\circ\text{C}$)	41.9 ± 0.6	40.6 ± 0.6
Avg. O_2 (% wet)	6.3	6.2
Steam production (kg/s)	9.5	
Steam temperature ($^\circ\text{C}$)	400	
Steam pressure (bar)	55.6	
Grate dimension	10 m long, 6 m wide	

capacity of 8.2 t/h. During the days of measurements the plant was operated slightly below nominal capacity as seen in Table 1. The plant uses the Dynagrate® grate technology. The grate is a single-lane grate, with dimensions 10.6x4m. The grate has been split into four zones with lengths of 2.8, 2.7, 2.7 and 1.8 m, respectively. Predefined fractions of the primary air can be distributed to each zone.

2.1. Plant operation

During the three days of measurements, the waste-to-energy plant was running stable without any malfunctions or shut-downs. The plant was operated with an oxygen set point of 6 vol% (wet) and a steam production of 9.5 kg/s as shown in Table 1. The steam pressure was kept at a constant value of 55.6 ± 0.1 bar with a steam production of 9.5 ± 0.1 kg/s corresponding to full capacity.

During the measurement campaign the plant was operated under two different settings, as seen in Table 1 and Fig. 2, to evaluate the effect of primary air distribution on the concentration profile of combustibles, water, CO_2 and NO_x precursors. The tonnage was changed between the two plant settings to accommodate the changes in heating value of the fuel. The tonnage is lower than the yearly average of 9 ton/h [13] due to the high heating value of the waste, which in the period of measurements contained large quantities of dry waste wood.

The average waste feed and heating value of the fuel for the period of measurements provide data for an estimation of the waste composition. The waste composition was estimated based on correlations between waste feed and heating value established over a long period of time by B&W Vølund. In Table 2 the estimated waste composition has been shown.

The primary and secondary air flows were obtained from the plant control system. The changes in primary air distribution involved only Sections 2 and 3 on the grate. The fractions of air on grate 1 and 4 were unchanged as grate 1 acts to dry the waste and grate 4 mainly serves as ash transport; full conversion of the waste has occurred on the previous 3 sections.

2.2. Gas phase composition and temperature measuring system

The flue gas composition was measured with a 6 m water cooled probe. The temperature in the center of the probe and from end of the probe to the cooler was kept at 150°C to avoid water condensation. Prior to the O_2 analyzer the gas is cooled to 5°C to remove any water and aerosols. The system allows simultaneous IR, UV and O_2 measurements. Attached on the probe was a non-cooled suction pyrometer

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