Pilot-Scale Simulation of PCDD and PCDF Emissions from Hog Fuel Boilers

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1. Introduction

Combustion of chlorine containing materials is an air emission source of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF). This may occur in waste incinerators and hog fuel boilers. The chlorine in the feed material can be present as organic or inorganic compounds. The effect of the form of chlorine on the formation of dioxins and furans is not very well understood[1].

In the pulp and paper industry, it is a usual practice to burn waste wood for energy recovery. The wood wastes collectively are called "hogged fuel" and consists of saw dust and bark from debarking operation. Recent field studies[2,3,4] on wood fired or hog fuel boilers showed that PCDD and PCDF are formed from sodium chloride (NaCl) contaminated hog fuel combustion. The salt contamination generally occurs during the sea transportation of logs to the coastal pulp mills. The concentration of salt in the hog fuel is up to 1% dry weight and the typical moisture level is 50%. The auxiliary natural gas fuel ranges, for maintaining a combustion temperature of 850°C, from 10% to 15% of the total heat input [5].

Field investigation of the trace organic emissions from combustion processes is very expensive, difficult to perform and cumbersome. Thus, well controlled laboratory or pilot-scale simulation experiments are preferred. It is however vital to ensure that the experimental conditions mimic the field operation. A pilot-scale incinerator was used to simulate the generation of PCDD and PCDF emissions from hog fuel boilers burning NaCl contaminated bark. The aim of the present study was to confirm the first important step of ensuring that the pilot-scale combustion simulation corresponds to the field observations.

2. Pilot-Scale Facility

Since a more detailed description has been given elsewhere[6], only a brief summary is provided here. A schematic diagram of the pilot-scale process equipment is shown in Figure 1. Either solid or liquid waste can be incinerated, but not simultaneously. Solid waste incineration is carried out batch-wise and takes place in three chambers (Chambers 2,3, and 4). During solid waste incineration, the liquid combustion chamber (Chamber 1) is isolated using a guillotine door. The solid waste is fed into chamber 2 using a ram feeder. Chambers 3 and 4 serve as afterburners. Each chamber has provision for independent supplies of auxiliary fuel and combustion air. During the present tests the fuel and air supplies were limited to only chamber 2 thus simulating the combustion furnace of the boiler.

The flue gas is normally directed to a wet scrubber, consisting of a venturi and a packed column, to remove particulates and acid gases. An emergency stack, which is connected to the incinerator, is used in case of scrubber failure and during start-up and cool down periods.

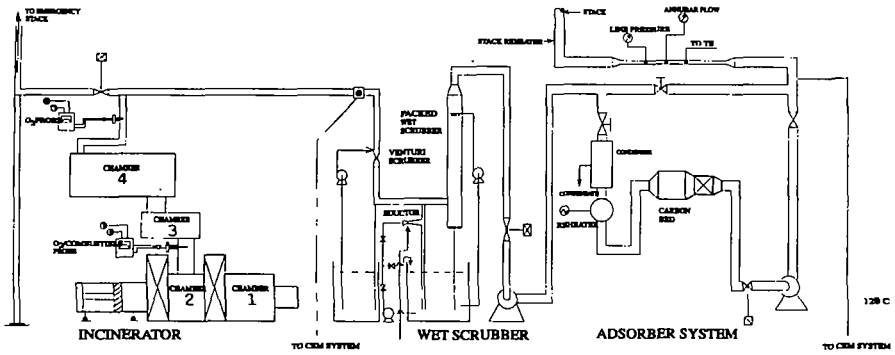


Figure 1. Pilot-Scale Incinerator

The gas from the wet scrubber passes through a condensing heat exchanger to reduce temperature and moisture content, followed by an electric heater to reduce relative humidity. An activated carbon adsorber and a high efficiency particulate air (HEPA) filter are used to remove remaining organic compounds and particulates. These systems ensure emission compliance at all times and thus provide the opportunity for short term, deliberate non-optimum operation of the incinerator or the scrubber, which is required for research purposes. Prior to being discharged to the atmosphere through a stack, the flue gas is reheated to improve dispersion. The system is equipped with an integrated process control, data logger and continuous emission monitors.

3. Experimental Approach

The feed material, level of salt contamination and moisture in the feed, primary combustion chamber temperature, flue gas cooling zone temperature and flue gas oxygen levels were considered as relevant variables. Wood bark was chosen as the feed material with salt added and moisture controlled to the typical levels. Unsalted bark test was conducted as a "control" experiment.

Before conducting the control bark test, the pilot plant was "cleaned" by operating the incinerator facility with natural gas as fuel and operating the combustion chambers at 1000°C for a few hours. The next day the pilot plant was operated again using natural gas as fuel but with the incinerator chambers maintained at the same temperatures that were used for the test. Less than 2 ppm of HCl in the flue gas was used as the criterion of cleanliness of the pilot plant.

4. Feed Material Preparation

Aspen bark was collected from a local pulp mill debarking facility, which contained considerable size variation. It was hammer milled and the fine fraction (less than 1mm) was removed. The salt contamination was simulated by soaking the bark in salt solution of 15 grams of NaCl per liter and decanting the solution after half an hour. The moisture level was brought down to about 50% by air drying. Two separate batches of feed material were prepared, one without salt and the other with salt

contamination. The salt contamination and moisture were determined on the composite samples of the bark feed collected during the experiments.

5. Pilot Plant Operating Conditions

A summary of the operating conditions of the test runs is given in Table 1. The typical mean furnace temperature of the hog fuel boilers during the reported field tests was approximately 850°C. The incinerator primary combustion chamber was thus preheated to about 850°C before starting the wood bark feed. Figure 2 shows typical temperature readings along the incinerator flow path. "Venturi " is the gas temperature just before the wet scrubber. The flue gas sampling for semi-volatile organic compounds including PCDD and PCDF using the reference method for source testing[7] was conducted at this location.

Table 1. Summary of Operating Conditions During Sampling

Operating Variables	Control	Salted Bark
Feed Rate kg/hour - Wood Bark	51	59
Natural Gas % Total Heat Input	23	26
Moisture in feed - Wt.%	48	54
Primary Chamber (Chamber 2) Temperature °C	833	830
Secondary Chamber (Chamber 3) Temperature °C	734	718
Secondary Chamber (Chamber 4) Temperature °C	584	591
Oxygen % dry	13	15
CO ppm dry*	11	22
CO_2 % dry*	5	10
NO_X ppm dry*	69	136
Chloride in Feed - Wt.% dry	**0.007**	**0.760**
HCl (grab sampling) ppm dry*	**1.4**	**55.3**

* Corrected to 11% Oxygen

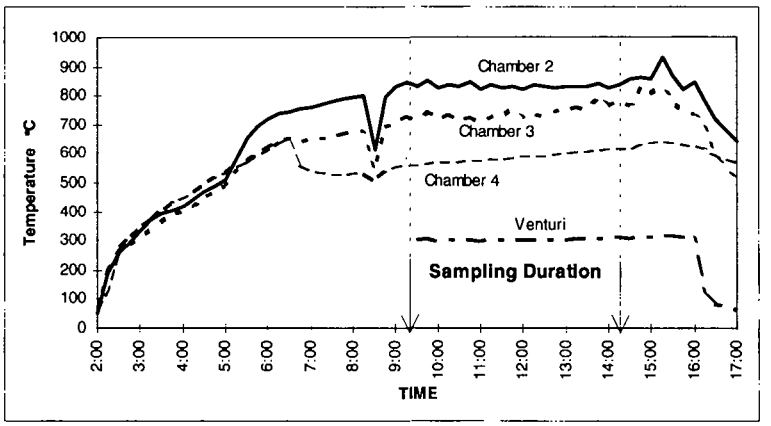


Figure 2. Typical Temperature Profiles During the Test

6. Sampling and Analysis

Two sampling trains were used simultaneously. The XAD-2 resin in the test train was spiked before sampling with a set of surrogate compounds to determine their recoveries after sampling. An internal standard was also added prior to instrumental analysis. The sampling and analytical details including the quality assurance and surrogate recovery data are discussed elsewhere[8]. A blank train was spiked and kept at the sampling location in the pilot plant during the sampling to determine background contamination (field blank).

7. Results and Discussion

Effect of NaCl on Total PCDD and PCDF: The total PCDD and PCDF in the flue gas from the control and salt contaminated bark combustion are given in Table 2. This confirms that the PCDD and PCDF are generated from the inorganic chlorine (NaCl) present in the feed material. It is also significant to note that the control test met the Canadian toxicity equivalent (TEQ) guidelines of 0.5 ng/dsm^3 for PCDD and PCDF[9], whereas the salted bark test did not.

Table 2. Total PCDD, PCDF and TEQ Comparison of Salt-Contaminated to Control Tests

TEST	Total PCDD*	Total PCDF*	TEQ*
Salted Bark**	54 ± 11	106 ± 12	3.2 ± 0.6
Control	0.3	0.3	0.02

* ng/dsm^3 Corrected to 11% Oxygen TEQ : Toxicity Equivalent;
** Average ± Standard Deviation

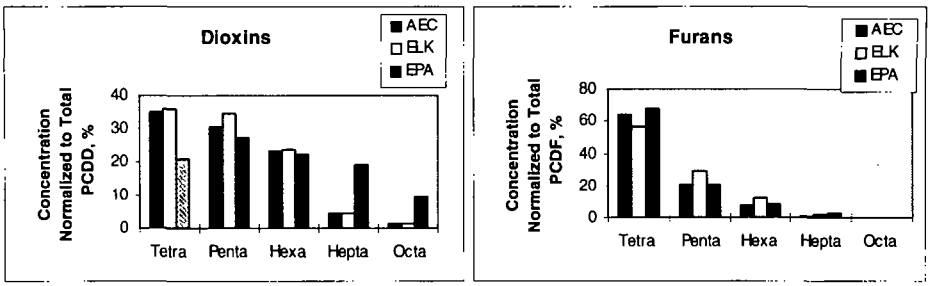
A comparison of the present results with the field data as reported by EPA and Elk Falls Studies[2,3] is presented in Table 3. It can be noted that the amount of total PCDF in the flue gas is higher than the total PCDD in each of the three data sets. Additionally the values of total PCDD and PCDF are comparable in the case of EPA and the Alberta Environmental Centre (AEC) results. In the case of Elk Falls, the corresponding values are less than half of either the AEC or EPA value. This can be attributed to the different sampling location, namely after the scrubber in case of Elk Falls.

Table 3. Comparison of AEC Pilot Plant results with Available Field Data

Items	AEC	ELK FALLS[1]	EPA[2]
Chloride in Feed Wt.% dry	0.76	0.21	0.30
Average Carbon Monoxide in Flue gas ppm	22	424	272
Average Total PCDD ng/dsm^3 @ 11% O_2	54	34	56
Average Total PCDF ng/dsm^3 @ 11% O_2	106	38	86
TEQ ng/dsm^3 @ 11% O_2	3.2	1.4	N/A

NA : Not Available

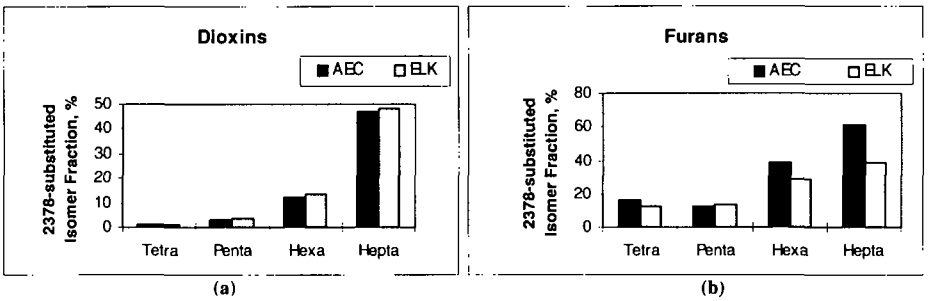
Validity of Simulation: Comparison in PCDD and PCDF "fingerprints" with field data. The distribution of the homologues relative to the total has been used as a basis of comparison. The results, given in Figures 3(a) and 3 (b), show excellent agreement between the field and pilot-scale results.



(a) (b)

Figure 3. Relative Homologue Distributions: Comparison of Pilot Plant Results with Field Data

As the 2378-substituted isomer is the most toxic in each homologue series, its fractions in each homologue has also been used as a basis for comparison. The results are presented in Figures 4(a) and 4(b). Data from EPA tests are unavailable and therefore not included in this comparison. The agreement between the field and pilot-scale results is also very good.



(a) (b)

Figure 4. Fraction of 2378-substituted isomers of each Homologue Group: Comparison of Pilot Plant Results with Field Data

8. Conclusions

The results of the salted wood combustion and control tests confirm that PCDD and PCDF are generated from the inorganic chlorine (NaCl) present in the feed material. The pilot scale incinerator has been successfully used to simulate PCDD and PCDF emissions from hog fuel boilers. Homologue distributions and the fractions of 2378-substituted isomers in each homologue group are in good agreement with the field data. The pilot plant can thus be used for PCDD and PCDF monitoring and control studies.

9. Acknowledgments

Excellent technical support from J. Dach, D. Uchman, R. Milner, and B. Soldan, during the project is gratefully appreciated. The authors extend their gratitude to C. Luthe, V. Uloth and I. Karidio of the Pulp and Paper Research Institute in providing valuable field information and timely discussions.

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