Propensity for the Formation of Dioxins during the Cool-Down of Plumes from Medical Waste Incinerators in South Africa

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BACKGROUND

The most toxic group of substances associated with waste incineration emission controls are the 210 dioxin compounds. Concentrations at which it is required to be measured range are 0.1 ng/m^3 in the EU where large 100 000 tonne per annum plants are operated and to 0.2 ng/m^3 in SA where the largest plants are less than 5000 tonne per annum. EU target daily intakes are 1 pg/kg/day and this is determined by measurements and fate and transport models of emission.

Dioxin compounds are formed as by products of all combustion processes in the gas phase. With the introduction of emission controls in USA, the main source of dioxin has changed from industrial activities (12 kg/annum)[1] to forest fires (1.3 kg/annum) and open burning of general waste (0.62 kg/annum)[2]. In SA, as in most developing countries, less than 1% of the 137 medical waste incinerators registered in SA[3] are fitted with gas clean up systems, and the exhaust gases are vented at temperatures above the onset of dioxin formation (450 °C to 150 °C). It is not possible to measure in a plume, and the existing stack dispersion models do not address the conditions occurring at the exit of the stack, so it is also not possible to make estimates of the human health impacts of these emissions using international standard methodologies.

PROBLEM STATEMENT

Does direct venting of incinerator exhausts adequately quench the formation of dioxin during cool down in an incinerator plume in South Africa?

TASKS

1. Prepare a model of plume formation in zone of flow establishment (ZFE) and zone of established flow (ZEF) a two stage plume model.
2. Validate the reaction zone model
3. Use empirical models of published data that correlate dioxin formation with exhaust gas parameters.

TASK 1: MODELLING THE REACTION ZONE

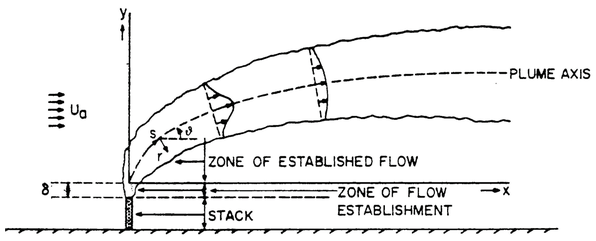

Figure 1: Modelling the reacton zone

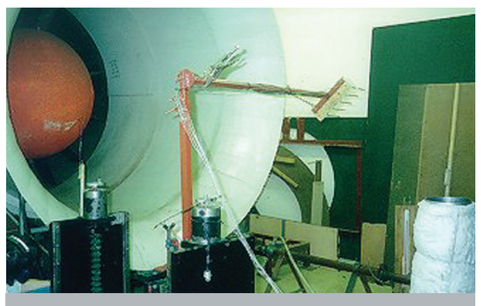

Figure 2.

Property	Units	Experiment	Industrial Process
Temperature	°C	286	900
Velocity	m/s	1.49	5
Diameter	m	0.2	0.2
Density	kg/m3	0.56	0.27
Viscosity	kg/m.s	0.29	0.47
Wind velocity	m/s	1.42	5
Reynolds number		5740.21	5731.42
Velocity ratio		1.05	1.00

Table 1: Validation of the scale model in the CSIR wind tunnel experiment

For an accurate simulation the Reynolds number of the exiting plume and the velocity ratio (Ua/Uo) should be similar[4].

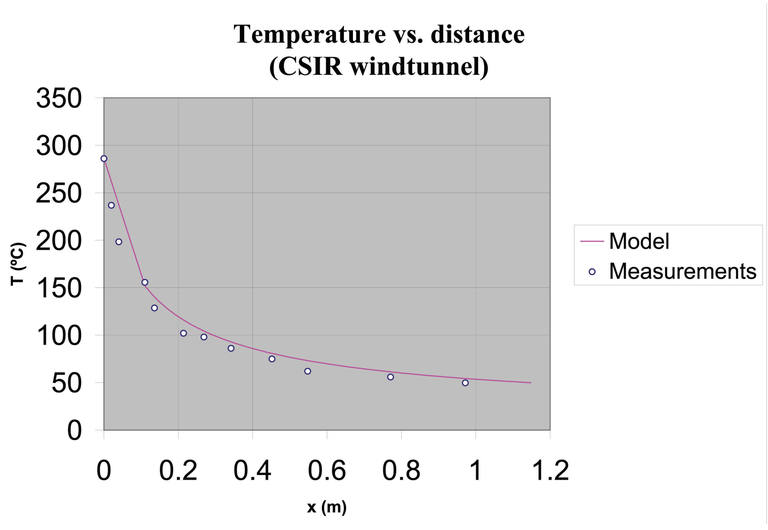

Figure 3: Validation of the reacton zone

[1]"US Environmental Protection Agency Inventory of Sources of Dioxin-Like Compounds in the United States-1987 and 1995" http://cfpub.epa.gov/ncea/cfm/dioxindb.cfm?ActType=default.
[2]U.S. Environmental Protection Agency, The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update (External Review Draft). On-line. Available: http://www.epa.gov/ncea/pdfs/dioxin/2k-update/, March, 2005.
[3]DEC Rogers, SA National Waste Management Implementation Strategy: Survey of treatment facilities. DEAT, NDoH, In preparation D Rogers, February 2006
[4]Emori, RI;Schuring,DJ; Scale models in engineering, Fundamentals and applications;Pergamon Press;Elmsford NY 1977

Parameter		Value	
Mean wind velocity	U_a	0.5	**m/s**
Ambient temperature	T_a	19.7	**°C**
Ambient density	ρa	1.002	**kg/m^3**
Emission exit velocity	U0	4.62	**m/s**
Emission exit temperature	T0	460	**°C**
Emission exit density	ρ0	0.402	**kg/m^3**
Initial plume angle	φ0	1.5708	**rad**
Stack diameter	D	0.915	**m**

Table 2: Initial conditions at stack tip for a SA incinerator

Parameter		Value	
Target temperature	T_{target}	150	**°C**
Reference density	ρ_{target}	0.694	**kg/m3**
Density difference	ρ^*_{target}	-0.308	**kg/m3**
Plume width	b_{target}	2.075	**m**
Height above the stack	y_{target}	6.277	**m**
Distance from the stack	x_{target}	0.428	**m**
Distance along trajectory	s_{target}	6.325	**m**
Plume velocity	$u_{*(starget)}$	5.7	**m/s**
Residence time	t_{target}	1.252	**s**

Table 3: Reaction zone of formation reactions

Reaction zones in ducts with these residence times are correlated with dioxin formation. Therefore dioxin formation in plumes can be expected.

TASK 3: MODELLING OF PLUME REACTION ZONE CONDITIONS
Four possible pathways[5, 6] for the formation of dioxin

Empirical data indicates that dioxins are formed during cooling of high temperature

- Condensation reactions, eg, chlorophenols, catalysed on fly ash
- De-novo synthesis, eg, C-H and Cl, catalysed on fly ash
- Pyrosynthesis from high temperature gas phase reaction

Condensation reaction model and empirical data

Gaseous precursors (g) eg, poly chlorinated phenol, are adsorbed as gs to a site (s) on fly ash, and condense to form dioxin on the site (ds), which is then desorbed (dg) and allows the process to be repeated at the site.

- g + s → gs
- gs + gs → ds
- ds → dg

De Novo synthesis reaction model and empirical data

The De Novo synthesis reaction model proposes that dioxin compounds are formed by reactions between the carbon in fly ash (C H)with and chlorine in the gas phase. The reaction is catalysed by the presence of metals chlorides such as Cu, Fe and Zn in the fly ash. Empirical data are correlated with HCl measurements, but not metal concentrations.

The chemical reaction scheme is envisaged to follow

- (C H) + Cl_2 → (C Cl) + HCl
- (C Cl) + Cl_2 → Dioxin + HCl
- HCl + ½ O_2 → Cl_2 + H_2O

Parameters		Precursor Condensation Model	De Novo Synthesis Experiments
Applicable temperature range	°C	450 – 150	450 – 225
Residence time in range	s	1.252	0.977
Total predicted dioxins and furans	ng/Nm^3	7.0	110.1
Toxic equivalent (TEQ) estimated as 1/15th of the total concentration	ng/Nm^3	0.46	7.34

Table 4: Estimates of dioxin formation using empirical data on and the modelled plume parameters have been made (see publication for more details[7])

DISCUSSION AND CONCLUSIONS

Residence times, particulate concentrations, and temperature profiles typical for stack emission plumes in SA have been calculated for average ambient conditions using stack measurements and a scale model in a wind tunnel.

Estimates of the quantities of dioxin that can be produced in these plume conditions have been made using published data on dioxin precursor concentrations and two published models that have been prepared to account for the observed correlations of dioxin formation rates with temperature, time, and gaseous concentrations of fly ash, HCl and polychlorinated phenols in the cool down zones in ducts.

The data indicate that concentrations in the plume may exceed current SA emission concentration limits of 0.2 TEQ ng/Nm3, and that the direct ejection of emissions cannot be assumed to be an adequate quench for dioxin formation in exhaust gases.

[5]Harrison, RM; Hester, RE; Waste Incineration and the Environment Royal Society of Chemistry, Cambridge 1994
[6]Tuppurainen, KA; RuokoJaervi, PH; Asikainen, AH; Aatamila M; Ruuskanen, J; Chlorophenols as precursors of PCDD/Fs in incineration processes: Correlations, PLS Modelling, and reaction mechanisms; Environ.Sci. Technol. 2000, 34, 4958-4962
[7]Brent AC;Rogers DEC; Establishing the propensity for Dioxin formation using a plume temperature model for medical waste incinerator emissions in developing countries. 2002, J. Air &Waste Management Assoc. 52:811-821