STUDY OF A MSW INCINERATOR: OVERALL OPERATION AND ON-SITE MEASUREMENTS OVER THE GRATE

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ABSTRACT

A measurement program of a municipal solid waste incinerator was carried out. The aim was to characterize the grate's distributed off-gas temperature and composition. Simultaneously, all operating conditions were recorded. Two complete passes over the bed were achieved with the measurements of the concentrations of CO_2, CO, O_2, H_2, C_1–C_3, NO and SO_2 taken. The most significant combustible species were found to be CO, H_2, and CH_4. The concentration of O_2 in the off-gas was low, indicating low air by-passing. The bottom ash was analysed in the laboratory and found to contain 4.8% unburned carbon, showing good burnout. The waste composition was estimated from the plant data to be $C_6H_{9.1}O_{3.75}$, with a moisture content of 27%. The LHV as-delivered was found to be 9279 kJ/kg. The average grate energy release amounted to 772 kW/m^2, and the overall energy recovery efficiency to 89%, at 56% excess air.

Nomenclature

A_b = by-passing air, %
A_g = grate area, m^2
E_g = grate Energy Release, kJ/s-m^2
EA = excess air
F = mass fraction, kg/kg
F_u = unburned carbon in bottom ash, kg C/kg ash
h_i = enthalpy of ith gas, h_i(273K) = 0.0 kJ/kg
LHV = waste lower heating value, as-delivered, kJ/kg
m = mass flowrate, kg/s
$m_{u,O_2}(z)$ = undergrate oxygen input into zone z, kg/s
Q = energy, kJ/s
Q_c = energy absorbed in convective section, kJ/s
Q_h = heat delivered to water, kJ/s
Q_m = heat loss to environment
Q_r = energy absorbed in radiative section, kJ/s
Q_u = useful energy to net, kJ/s
T = temperature, °C
η = energy recovery efficiency, %

Subscripts

a = ash
e = exhaust (flue gas)
p = primary (undergrate) air
s = secondary (overfire) air
ta = total air
w = waste

INTRODUCTION

The aim of the measurement program was to collect vital information on waste bed processes occurring in a

reciprocating grate-type MSW incinerator, by carrying out in-situ measurements of temperature and gas concentrations as close to the surface of the waste bed as possible. This data, together with the measured plant's operating conditions, can furnish input to a computer program to model the incinerator's radiative section (waterwall or firebox section). Improved performance of incinerators creates the need for predicative tools to model the thermal-chemical-flow processes occurring in the bed. The need for these measurements is imperative because of the complexity of the fuel and its combustor environment.

A review of the published literature over the past 20 years reveals a noticeable lack of in-situ incinerator data. Most measurements carried out in the laboratory, like those of Rogers et al. (1974), have only a limited value for realistically correlating bed off-gas composition with operating variables for computer modeling.

The single, most used source of data for many researchers in this field is perhaps that for the Oceanside incinerator published by Arthur D. Little, Inc. (1972). To the authors' knowledge, no other work of this kind has been published since then. The current work, then, becomes important for several reasons:

(a) Extension and checking of Oceanside data.

(b) Testing of a more modern incinerator type.

(c) Supply data for testing of equations, models, etc.

The measurement procedure and raw data are found in Viberg (1990). The measurements were taken on April 4 and 5 of 1990. Two complete sets of measurements were taken over the waste bed. Measurements were also taken at the outlet of the furnace section, i.e., right before the convection section. The data supplied by the Unit's on-line instruments were also recorded. Measurements carried out in 1991 in the firebox will be published in a subsequent paper.

DESCRIPTION OF UNIT

The plant chosen is located outside the town of Linköping (Gärstadverk) in Sweden, and is comprised of three incinerating units. These units deliver saturated water for district heating purposes. The measurements were done on Unit 1, which accepts municipal and some industrial waste from the Linköping area. Technical information on the Unit is given in Table 1.

A diagram of Unit 1 is shown in Fig. 1. The plant runs without odors except for a very slight smell of sulphur inside the building. Its emissions, as will be discussed later, are quite low. The plant can be seen as a paradigm of waste processing via incineration.

TABLE 1 GÄRSTADVERK UNIT 1, LINKÖPING, SWEDEN

Operator: Tekniskaverk Linköping (TVL)
Manufacturer: Von Roll (Switzerland)
Installation: Svenska von Roll AB
Start-up date: February 1982
Fuel: MSW and industrial forest residuals from the Linköping area
Capacity: 7 ton/h
Output: 18 MW saturated, water at 10 atm (180°C)
Cleaning system: Svenska Fläkt's Dry-Pack System
Division of undergrate air: inlet --> outlet 10 - 40 - 40 - 10%
Division of overfire air: front/back 70 - 30%
Clinker cooling air: 20% of total

OVERALL MEASUREMENTS

To assess the overall behavior of the Unit, both a mass and an energy flow balance of the same are necessary. This was done by combining the Unit's on-line instrument readings with our own measurements. These measurements were done continuously over the 2-day period in which the over-the-bed measurements were taken.

Measurement Errors

The combustion air flowrates, except for the clinker air, are measured on-line by the Unit's instruments. These flowrates were also measured manually during the measurement program. Further, the division between the four undergrate, primary air zones and the overfire air, front and back rows of jets, were also taken manually. A comparison between the Unit's instruments and the manual readings revealed a difference of 10% on the total air, which we take to be the uncertainty on these measurements. All manual readings were taken with instruments calibrated on the spot.

For the overall energy balance, this uncertainty affects the energy calculations very slightly as the amount of heat in the preheated air, Q_p, is on the order of 2% of the total energy liberated by the burning garbage, Q_w. On the other hand, uncertainties in these mass flows cause a substantial uncertainty in the overall mass balance and resulting ash fraction calculation.

This evaluation of plant performance is not to be taken by the reader as a formal performance test. Even though the measurement crew's equipment was calibrated on site, the plant's instruments, e.g., temperature of boiler feedwater, were not. So the uncertainty on these readings is much higher than the better than 1% called for by, for example, ASME's PTC 33.

For the funds available and for the projects's goals, it was decided to live with a 5–10% uncertainty on plant performance. The point was to make an energy balance at low cost while obtaining useful results which can be used in further work on numerical simulation of the plant. The results proved to be consistent with the work of others as shown ahead in Tables 4 and 5.

Mass Balance and Waste Composition

The waste mass flowrate was not measured directly, but is derived from the plant's daily weighing of incoming waste-carrying trucks. The waste composition is unknown, but based on the amount of combustion air and on the exhaust gas composition, we are able to estimate what this composition is.

The solid waste is burned in the as-delivered state. The amount of ash remaining after incineration is not weighed, but is estimated from the data. The analysis of ash composition revealed about 4.8% of unburned carbon, F_u, kg C/kg ash, which is in the low end for this type of incinerator. This shows that the bed combustion efficiency is quite good.

For mass and energy balance purposes we will assume:

(a) Exhaust mixture is composed solely of CO_2, H_2O, O_2, and N_2, each with uncertainty = value ± 2%.

(b) Total water vapor content is the sum of the product of combustion with the moisture contained originally in the waste. Moisture in the combustion air is neglected.

(c) Gases and vapor are treated as ideal.

(d) Average of gas temperature and composition at the measuring plane at the outlet of the furnace section.

(e) Conservation of N_2 is used to compute exhaust mass flow. Neglect fuel-derived N_2.

The water vapor content in the exhaust was measured by condensation to be 14.8% volume. Given our assumptions, we calculate at the exhaust, on a dry basis, the nitrogen's mass and volume flowrates. And from there the volume and mass flowrates of the other species. These results are summarized in Table 2.

To determine the inert's (ash) content of the waste we draw an overall mass balance on the incinerator:

$$m_a = m_{ta} - m_e + m_w, \text{ kg/s}$$

Where m_a, m_{ta}, m_e, and m_w are the mass flowrates of ash, total inlet air, exhaust gas, and waste, respectively. The waste ash fraction is then $F_a = m_a/m_w$, kg ash/kg waste and the mass of unburned carbon, $m_u = m_w \times F_a \times F_u$, kg/s. An analysis of error propagation of the above mass balance reveals a very high uncertainty on m_a, making the ash fraction obtained by this method not very convincing. Still, despite the uncertainty on F_a, the calculation on carbon balance is affected very little as the amount of unburnt carbon is small.

TABLE 2 EXHAUST GAS COMPOSITION FOR MASS AND ENERGY BALANCE CALCULATIONS; UNCERTAINTY ON MEASUREMENTS OF VOL. %, DRY = VALUE ± 2%

Gas	Vol.% dry	Vol.%	kg/s	Nm^3/s
CO_2	12.75	10.86	2.17	1.10
H_2O	-	14.8	1.21	1.50
O_2	7.57	6.45	0.94	0.65
N_2	79.68	67.89	8.62	6.89
Total	100.0	100.0	12.92	10.15

Given the gas compositions and the flowrates of the combustion air and the exhaust gas, we can arrive at the waste composition. This method has been proposed in the literature as a way of estimating MSW element composition. For example, the amount of carbon in the waste is given by

$$m_C = m_{CO_2}\,(12/44) + m_u$$

The overall substance equation, on a kmol/s basis, under excess air conditions, and assuming complete combustion, is given as

$$C_{n_1}H_{n_2}O_{n_3} + n_4H_2O + n_5O_2 + n_5\,3.76N_2 \rightarrow$$

$$(n_1 - n_u)CO_2 + n_4H_2O + n_2/2H_2O + n_6O_2 + n_5\,3.76N_2 + n_uC$$

where

$$n_6 = n_5 + n_3/2 - (n_1 - n_u) - n_2/4$$

As we don't know what n_2, n_3, and n_4 are, and we only know the sum (measured) of $(n_4 + n_2/2)$, we modify the equation by combining the combustible fraction with the moisture:

TABLE 3 WASTE FORMULAS DERIVED FROM THE MEASUREMENTS FOR COMBINED COMBUSTIBLE MOISTURE: n_1, n'_2, n'_3; ASH-FREE BASIS

$C_{0.050}\ H_{0.13}\ O_{0.06}$
$C_1\ H_{2.67}\ O_{1.20}$
$C_6\ H_{16.0}\ O_{7.23}$

TABLE 4 WASTE FORMULAS FOR DIFFERENT MSW (Combustible Fraction) AND MOISTURE CONTENT

	C_6 basis	moisture (%)	Ash (%)
Linköping	$C_6\ H_{9.1}\ O_{3.75}$	27.	12.37
			15-20[1]
Högdalen:			
70.12.10	$C_6\ H_{8.9}\ O_{3.5}$	24.8	15.7
70.12.11	$C_6\ H_{8.6}\ O_{3.5}$	31.3	16.5
USA	$C_6\ H_{9.51}\ O_{3.75}$[2]		20-30
Cellulose	$C_6\ H_{10}\ O_5$		-

[1] Plant manager in Linköping [2] Niessen (1978)

$$C_{n_1}H_{n'_2}\ O_{n'_3} + n_5O_2 + n_5\ 3.76N_2 \rightarrow$$

$$(n_1 - n_u)CO_2 + n'_2/2H_2O + n_6O_2 + n_5\ 3.76N_2 + n_uC$$

where

$$n'_3 = 2n_6 - 2n_5 + 2(n_1 - n_u) + n'_2/2$$

The combined combustible-moisture formula for the waste (ash-free basis), is calculated and given in Table 3. We can further estimate both the combustible fraction and the moisture content as follows. By assuming different values for n_3 based in the literature (see Table 4) we can compute the moisture content, then n_4 and n_2. The moisture content of the waste is given by

$$F_m = n_4\ (18)/m_w$$

Based on these equations we include in Table 4 the estimated composition of the waste for the Linköping area. We have assumed a value of $n_3 = 3.75$ as this brings the formula closer to cellulose reflecting the increased percentage of paper in Swedish MSW. Still, we have to take these values with some reservation given the uncertainties involved in these types of measurements.

Once we have the waste composition, we can calculate the stoichiometric air requirements and the excess air. At stoichiometric conditions $n_6 = 0$, then

$$n_{5,s} = (n_1 - n_u) + n_2/4 - n_3/2$$

In our case the excess air is

$$EA = 100(n_5 - n_{5,s})/n_{5,s} = 55.6\%$$

Energy Balance

With the mass balance obtained in the previous section and given the temperatures at the system boundaries, an energy balance on the system can be drawn. Estimates of both the waste heating value and the Unit's energy recovery efficiency can be determined. Figure 2 shows a furnace diagram with the most significant energy flows calculated as shown next.

The overall energy balance is given by

rate of energy input = rate of energy output, or

$$Q_w + Q_p + Q_s = Q_a + Q_h + Q_e + Q_m$$

where the net waste heating value (as-delivered) is

$$Q_w = m_w\ \text{LHV, kW}$$

The heat required to breakdown the waste, i.e., heat of pyrolysis and the moisture's latent heat of evaporation, are implicitly included. The heat contained in the preheated primary air is taken from the hot water heated by the Unit, Q_h.

Q_h includes the energy recuperated in the economizer, as recorded on-line by the Unit's instruments. The useful heat delivered to the net is then

$$Q_u = Q_h - Q_p\ (2 - \eta_p)$$

where η_p is the heat exchanger efficiency. The energy in the ash (all lumped as bottom ash) is

$$Q_a = m_w\ F_a\ C_{p,a} T_a$$

where F_a is the ash fraction, $T_a = 350°C$ is the approximate ash temperature, and $C_{p,a} = 0.84$ kJ/kg−°C, Niessen (1978). The energy in the exhaust gas mixture (including water vapor) is

TABLE 5 SUMMARY OF ENERGY BALANCE

	Measurements	Other
Energy recovery efficiency	89%	87% [1]
Ave. grate energy release	772 kW/m^2	<1000 kW/m^2 [2]
Waste LHV, as-delivered	9279 kJ/kg	10000 kJ/kg [3]

[1] Plant operator from a previous test.

[2] Common for mass-burn grates.

[3] Typical LHV for Swedish waste.

$$Q_e = \sum_{i=0}^{4} m_i \, h_i \, (T_e)$$

where T_e is the temperature after the economizer section (139°C), and i corresponds to CO_2, H_2O, O_2, and N_2. The energy loss from the furnace walls and ducts to the environment is estimated as $Q_m = 0.3$ MW, Brunner (1984).

Summing these quantities, we can calculate the waste's lower heating value, LHV. The waste's higher heating value, HHV, is obtained by adding to LHV the heat that would be released if all the water vapor in the flue gas was condensed. The energy efficiency is given by

$$\eta = 100 \, Q_u / Q_w$$

and the average grate energy release is

$$E_g = Q_w / A_g, \text{ kW/m}^2$$

where $A_g = 4 \times 2 \times 2.9 = 23.2$ m^2 is the grate area, zones 1 through 4.

Table 5 summarizes the result of the energy balance on the Unit and compares these with other sources. Figure 2 shows the major energy flows in the unit.

OVER-THE-BED MEASUREMENTS

Over-the-bed measurements were not done without difficulties due to the harsh environment near the burning-bed surface. A 10-m long, water-cooled, suction probe was inserted into the bottom section of the furnace as shown in Fig. 1. Probe and filter clogging, as well as a host of other problems, did not permit readings to be taken in the drying zone, zone 1, and allowed only two passes over the bed—each pass taking about 6 hr.

The probe was placed at the desired measurement location, and kept there for approximately 30 min. During this period, gas was suctioned through the probe and filtered; water was condensed out of the gas, which was then filtered again; and the dry gas composition was then recorded by on-line instruments. Temperature was also recorded continuously with a sheathed, protected type-K thermocouple. The instruments were calibrated before and after each measurement set or when deemed necessary.

At several measurement locations, gas was collected into small bags (also after filtering, cooling, and condensation) and subsequently analysed in the laboratory for H_2 and C_1 to C_3 hydrocarbons. The uncertainty on these gas compositions is estimated as value ± 10%. The choice of the gases monitored follows that found in the literature: we sampled for those gases which we would expect to appear in significant quantities.

Limitations Of Data

Care must be taken in interpreting the data as several hard-to-avoid problems are present:

(a) An over-the-bed measurement point is located somewhere 0–0.5 m above the bed "surface."

(b) In-probe deposition and condensation, followed by filtering, removed tars and condensable material from the analysis.

(c) The data plotted are not simultaneous, but are sequential in time, which does not appear in the plots.

(d) The temperature measured is not corrected for radiative interaction with the surrounding environment.

Results

Plots of the results are shown in Figs. 3 to 9. An inspection of Figs. 3 and 4 reveals that the location of the fire-intensive zone in the bed was shifted towards the exit side of the grate on the fourth figure. This was visually witnessed as the fire could be seen occurring in the burnout zone. This is, in part, due to the fact that it is within the operator's power, for this plant, to strongly affect combustion on the grate from the control room.

Combustion on the fifth figure was apparently much more unstable, as can be seen by the spread on the temperature measurements in Fig. 3, and perhaps ex-

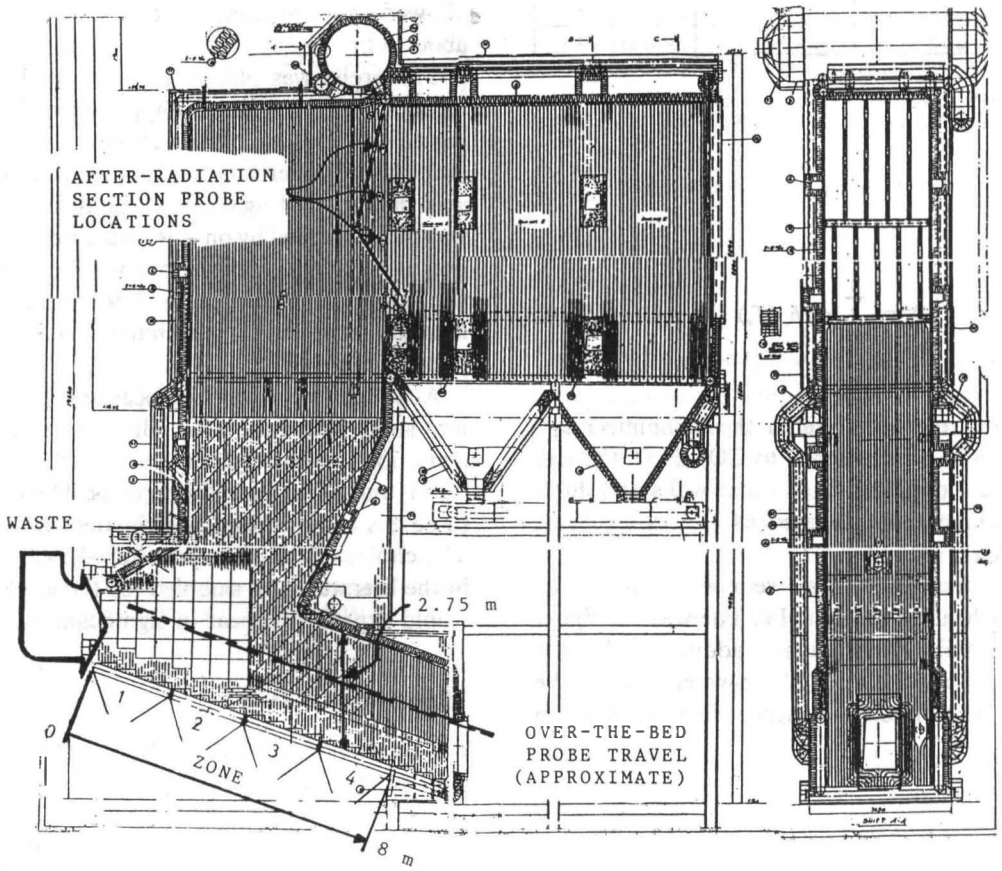


FIG. 1 CROSS-SECTION OF UNIT 1 SHOWING: MEASUREMENT LOCATIONS; COMBUSTION AIR INLETS; AVERAGE FIRE-BOX TEMPERATURES

plains the large swings in (H_2) in Fig. 6 for this day. When the temperature data are superimposed for both days, shown in Fig. 3, a curve is produced giving a more clear trend for the 2-day period. This combined distribution will be used as input to the numerical three-dimensional model of the firebox.

Despite the somewhat limited amount of data, several important trends and conclusions can be drawn from these figures which seem valid for both test periods. To wit:

(a) Large [CO_2] and correspondingly low [O_2] show that the bed is under high oxidative conditions and that significant combustion is taking place within, and very close to, the bed.

(b) The gas composition reveals the difference between this mass-burn process and that of plain pyrolysis. For the latter, we would expect a higher [CH_4] and lower [H_2] than that measured.

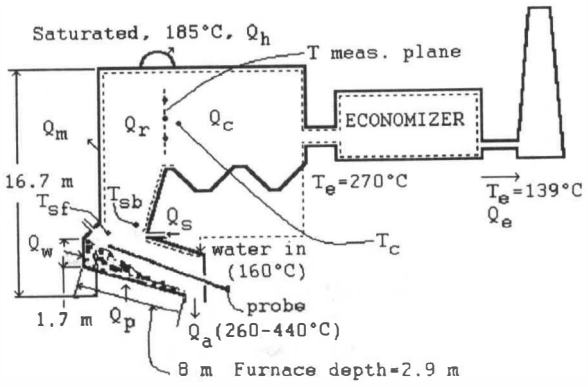
(c) The high concentration of [H_2] throughout the bed (or at least in the sections measured) points to the water–gas shift reaction at work:

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

(d) The hydrocarbon concentrations are higher for the lower molecular weight species. The most important fuel gases in decreasing order of concentration are: CO, H_2, CH_4, and C_2H_4.

(e) Composition of the off-gas confirms results from other workers; see, for example, Arthur D. Little, Inc. (1972). Unfortunately, no measurements of H_2 and C_1–C_3 were made in zone 4. But we would expect no H-containing compounds to appear in this zone to any significant level.

(f) The fact that CO_2 decreases sharply at the beginning of zone 3 and becomes close to zero, and that [CO]



Q_h = 16300 kW
Q_p = 315
Q_s = 55
Q_e = 1608
Q_a = 71
Q_r = 6062
Q_c = 8339
Q_m = 300

	DATE 900404	900405
T_c	948°C	918°C
T_{sf}	1048	1037
T_{sb}	1007	947

FIG. 2 MAJOR ENERGY FLOWS

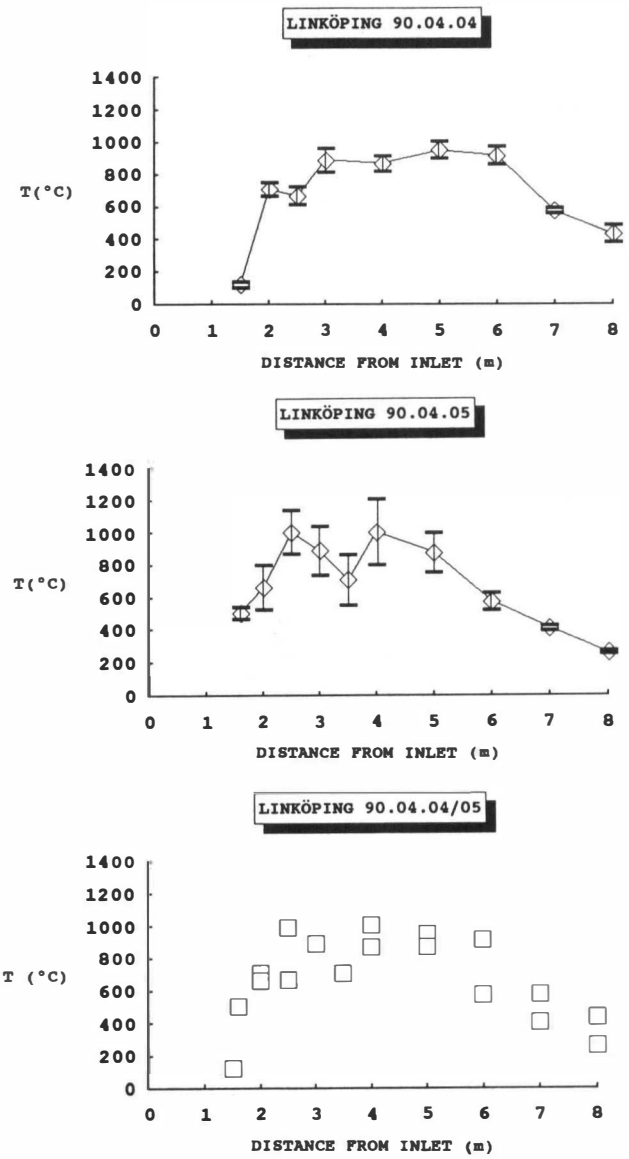


FIG. 3 OFF-GAS TEMPERATURE DISTRIBUTIONS AND STANDARD DEVIATIONS OVER THE WASTE BED

is very low in zone 4, means that good burnout is accomplished within the grate length.

(g) In zone 4, despite the excess O_2, we cannot completely eliminate the CO. This shows some equilibrium reaction at work — possibly the carbon gasification one:

$$C + CO_2 \leftrightarrow 2CO$$

We can conclude that there are different reactions (processes) controlling in each zone:

zone 1 low T's; high, moisture-derived water vapor

zone 2 $C_{n_1}H_{n_2}O_{n_3} \rightarrow aCH_4 + bCO + cH_2O + dC$
$CO + H_2O \leftrightarrow CO_2 + H_2$

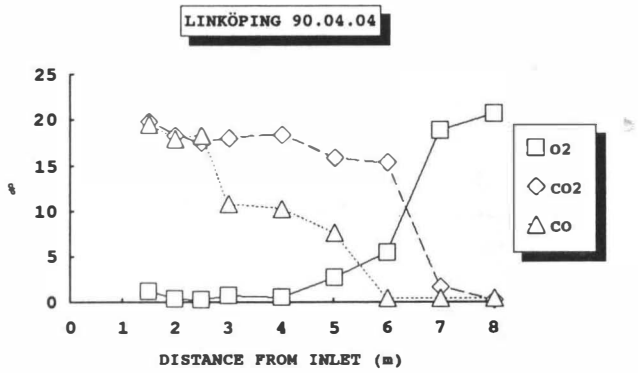
zone 3 $CO + H_2O \leftrightarrow CO_2 + H_2$
$C + H_2O \rightarrow CO + H_2$

zone 4 $C + CO_2 \leftrightarrow 2CO$
neglible reaction-formed water vapor

Oxygen Consumption and Channelling

Due to uneven distribution of the solids in the waste, the pressure drop will be uneven across the bed. Some spots will offer very low resistance to air flow — channels which allow the air to pass right through the bed without coming into contact with oxidizable material being released by the solid fraction. These channels are eventually covered up and new ones formed during the periodic grate movement. Air escaping through the bed we call bypassing air. Since the underfire air is less than the amount required for the complete combustion of the fuel we assume that all oxygen measured right over the bed is bypassing air. This implicitly assumes that all fuel-bound oxygen either reacts in the bed or is released still chemically bound.

Bypassing, which depends on factors such as waste type, loading and bed height, amount of underfire air, grate motion mechanism and periodicity, was estimated by:



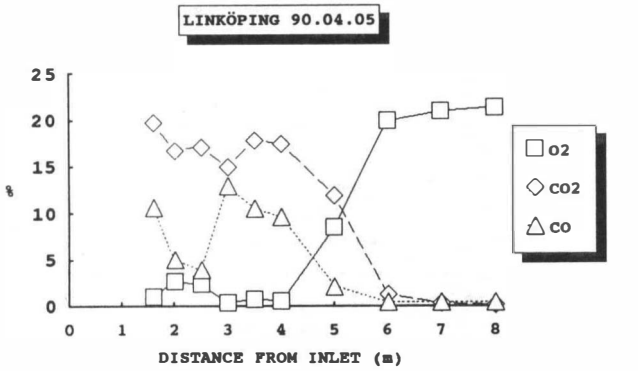
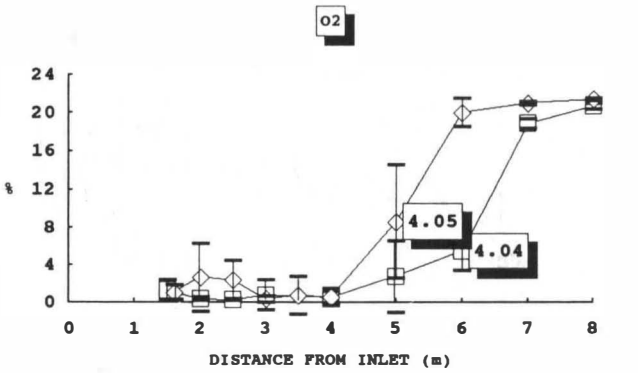


FIG. 4 CONCENTRATIONS OF OFF-GAS SPECIES, DRY BASIS



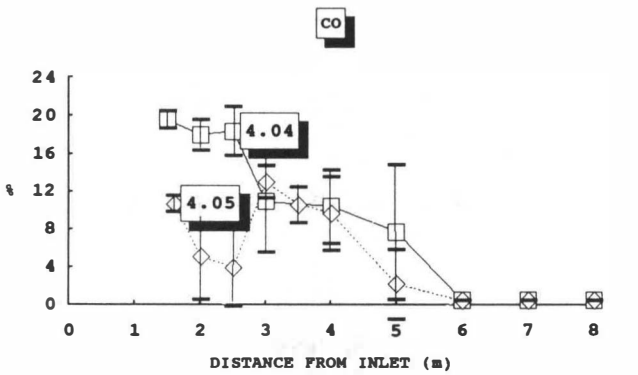


FIG. 5 CONCENTRATIONS OF OFF-GAS SPECIES, DRY BASIS, WITH STANDARD DEVIATIONS FOR APRIL 4TH (4.04) AND 5TH (4.05)

TABLE 6 ESTIMATED AIR BYPASSING (%); TOTAL AIR FLOW = 31410 Nm³/h

ZONE	1	2	3	4
%	9.1	6.3	36.4	85.9

$$A_b = 100\, m_{O_2}(z)/m_{u,O_2}(z)$$

where $m_{O_2}(z)$ is the amount of O_2 measured in the off-gas at zone of location z. We have neglected the penetration of clinker-zone air to the probe measuring location. Table 6 presents these results. Even though A_b is large in zone 4, it represents 30% of the estimated total by-passing air for all four zones, and only 6.4% of all primary air.

Grate Burnrate

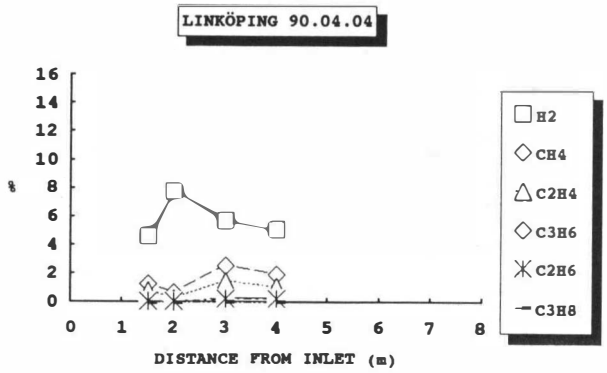
A qualitative estimate of the distributed burnrate over the bed can be made if we assume that the temperature distribution and the (CO_2) are proportional to it. Figures 3 and 4 reveal a pattern for Linköping which is qualitatively similar to others found in the literature for this type of incinerator.

A more quantitative estimate can be derived if we manipulate the data to determine the bed's mass-loss rate. To do this, the gas concentrations over the bed have to be scaled so that the element mass balance is consistent with the overall mass balance. This accounts for eventual measurement errors and also for the fact that the points on the curves are not taken simultaneously.

All concentrations, except (O_2), were reduced until the C, H, and O elements being released from the bed balance with the previously determined $C_{n_1}H_{n_2}O_{n_3}$ composition—the average calculated for the 2-day measurement period. As the water vapor content of the off-gas was not measured, some assumptions had to be made about its release from the bed:

(a) Two-thirds of waste moisture contents is released in zone 1, the "drying zone"; one-third is released in zone 3.

(b) Water vapor formed from reaction is released over zones 1–3 with the same distribution as C_xH_y.



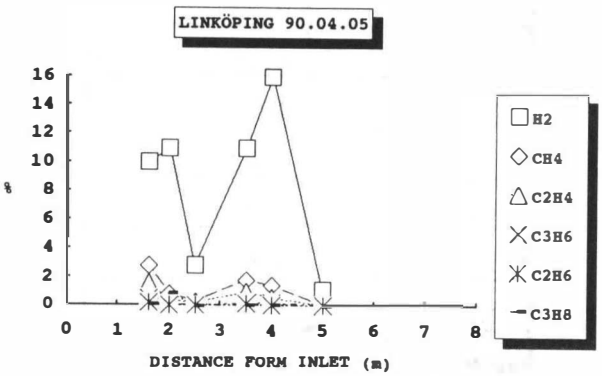


FIG. 6 CONCONCENTRATIONS OF OFF-GAS SPECIES, DRY BASIS; VALUE ± 10%

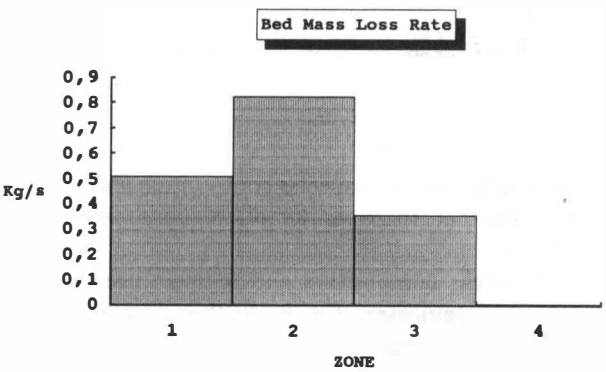


FIG. 7 WASTE-BED TOTAL MASS-LOSS RATE (Includes Total Water Vapor)

The result is shown in Fig. 7.

As we measured the off-gas temperature in each of the four zones, we can calculate the enthalpy of this gas mixture. Further, for convenience and for obtaining an easier correlation of trends, the measured C_1–C_3 were combined into an equivalent formula which was

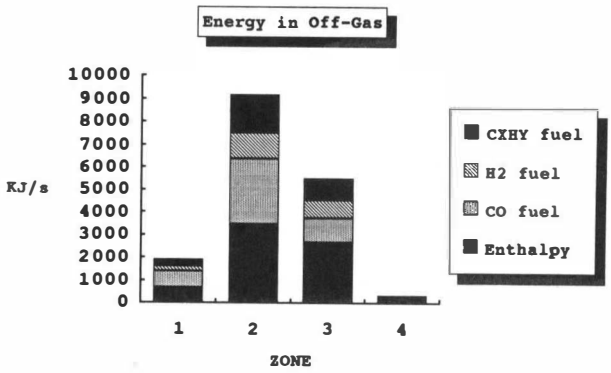


FIG. 8 ENERGY IN OFF-GAS ($C_{1.54}H_{4.28}$; LHV = 48700 kJ/kg)

TABLE 7 CO, HCl, NO, AND SO_2 FLUE GAS EMISSIONS; DRY BASIS

	Unit[1]	Swedish law	European law
CO	<10		
HCl	19[2]	100 mg/Nm^3 @ 10% CO_2	50 mg/Nm^3 @ 9% CO_2
SO_2	19[3]	200 mg/Nm^3 @ 10% CO_2	300 mg/Nm3 @ 9% CO_2
NO	217[3]	400 mg/Nm^3 @ 10% CO_2	

[1] ppm; 7.6 % O_2 and 12.8 % CO_2; measured before the convective section.

very closely the same for zones 1–3 as $C_{1.54}H_{4.28}$ with a LHV of 48700 kJ/kg. The total energy release over the bed is shown in Fig. 8. This figure suggests that for mass-burn modeling, it might be inadequate to use only CO and H_2 as off-gas fuels, as the energy contained in the C_xH_y fuel-equivalent is of the same order as that in these fuels.

If we add the heat of reaction contained in the fuels, we are led to conclude that only half of the energy in the waste, Q_w, was released in the bed itself.

EMISSIONS

Emissions from an incinerator are comprised of two streams: *(a)* ash — bottom, boiler, and gas cleaning (fly ash); and *(b)* flue gas. We have a very good idea of the constituents of these two streams because some of the potential pollutants were measured in the exhaust, and samples of the bottom ash were sent for analysis.

Table 7 lists the concentrations of CO, HCl, SO_2 and NO, leading us to conclude that the plant is operating within the limits set by the law, except for the NO

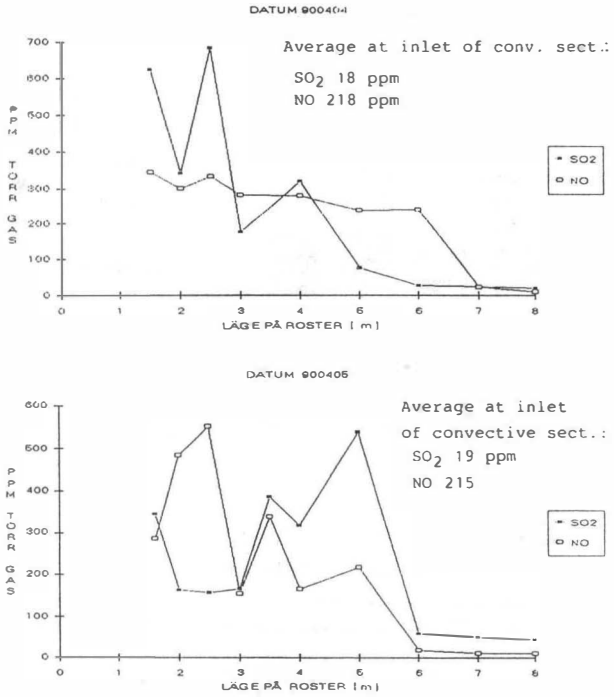


FIG. 9 NO AND SO_2 FORMATION OVER THE BED, PPM DRY BASIS

emission. Further, [CO] is taken as an indicator of combustion efficiency. Low [CO] emission, as is the case with Unit 1, is a sign of low hydrocarbon and, to a smaller extent, of low dioxin emissions.

It is also of some interest to compare the amounts of SO_2 and NO measured over the bed, i.e., at the point of production, to those measured at the end of the radiative section. Curves for these pollutants are shown in Fig. 9 taken directly from Viberg (1990).

The results of the bottom-ash analysis (from only two samples taken on the same day) are given in Table 8.

TABLE 8 BOTTOM-ASH ANALYSIS

% Unburned carbon	4.8
% Si	18.4
% Al	7.3
% C	2.6
% S	0.94
% Ti	0.76
% Pb	0.71
% Zn	0.56
% P	0.55
% Cl	0.39
% Cu	0.36
% N	0.045
% Ni	0.027
mg V/kg	<50
mg Ag/kg	<25
mg Li/kg	14.
mm Cd/kg	10.
µm Hg/kg	95.5

CONCLUSIONS

Despite the lack of data on waste composition and the rather simple measurement procedure, very useful performance values were arrived at for both the waste characteristics and the plant's performance, while avoiding the cost of producing and analysing a "representative" waste sample. The results come very close to information from the plant operator; average composition and LHV of Swedish waste; and the literature.

Even though the measurements taken over the bed are not simultaneous, the results for two different days show similar trends in species composition and temperatures. Further, these results follow those found in the literature.

The off-gas composition and temperature information is very important for the further development of models for the thermal decomposition of waste on a pusher grate.

After scaling of the species concentrations to be consistent with the overall plant data taken during the same period, they can be used as input to a three-dimensional numerical flow-reaction model.

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ACKNOWLEDGMENT

This project was funded by the Swedish National Energy Administration.