

INVESTIGATIONS ON THE COMBUSTION OF VARIOUS WASTE FRACTIONS INSIDE A GRATE FURNACE

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ABSTRACT

The influence of various waste mixtures on the combustion process in a grate furnace was investigated at the test plant TAMARA. Measurements were carried out inside the combustion chamber by monitoring temperatures and sampling gaseous combustion products and heavy metals. The data were verified by element and energy balances.

The different fuel fractions influence the combustion process by producing a faster carbon burnout when processing fuels having increased heating values. Above the fuel bed the concentration of products of incomplete combustion like CO and total organic compounds increase with increasing heating values, too. The specification and the partitioning of the mayor C-H compounds inside the combustion chamber are not influenced significantly by the different fuels.

The release of heavy metals from the fuel bed to the flue gas takes place only in the region of the highest temperatures.

INTRODUCTION

The combustion of municipal solid waste in grate furnaces has been an established procedure for more than 100 years. During the last years the emission standards and residue qualities were lowered consequently by legislative regulations. The limits were complied with by the installation of expensive flue gas treatment systems. Therefore the costs of municipal solid waste incineration increased substantially.

Aims of today's research are the optimization of the economy by simplification of the technology with out changing environmental standards. One possibility is to optimize the combustion process itself. In this way it should be possible to lower levels of some pollutants like PCDD/F in the raw gas and to improve bottom ash quality by lowering TC concentrations. In both cases carbon burnout is correlated to these aims. Therefore detailed knowledge of the incineration process and especially of the carbon burn out is needed.

The test facility TAMARA is well suited to acquire data in order to operate waste incinerators under optimized conditions. First investigations on the influence of different fuels on the carbon burnout, primary products in the flue gas inside the combustion chamber and the location of metal release from the fuel bed were carried out. The results are described in this paper.

TEST FACILITY "TAMARA"

The name TAMARA is a German acronym and stands for "test facility for waste combustion, flue gas cleaning, residue treatment and water purification". TAMARA (Fig. 1) is designed for a waste throughput of 150-300 kg/h and a max. flue gas volume flow of 1000 Nm³/h. The max. thermal capacity is about 0,5 MW. The combustion chamber allows contra, center and parallel flow configuration by installing variable roof elements. The experiments were carried out under center flow conditions. The grate has a length of 3.2m and a width of 0.8m and is divided into 4 individual zones. Each zone can be adjusted in grate movement and primary air supply. Secondary air can be added at the entrance of the first flue.

Testing Performance The axial temperature profiles of the grate bars, fuel bed and flue gas above the fuel bed could be measured by installed thermo couples.

Gas had been sampled at 5 locations (S₁-S₅) above the fuel bed along the grate (Fig. 2). The concentration profiles of individual gaseous compounds documents the reactions inside the fuel bed on its way along the grate. These data together with temperatures and local gas velocities are also important as input parameters to model the burnout of the flue gas inside the combustion chamber (Nasserzadeh 1993 and Dos Santos 1992).

By sampling directly above the fuel bed (about 10 cm) along the grate path, axial concentration profiles were determined for various compounds in the center of the grate width. As shown in Fig 3 sampling took place by means of cooled sampling probes with subsequent dust filtration (metal and carbon analysis of the dust) and water condensation for H₂O determination. The following gaseous compounds were monitored online: O₂, CO₂, CO, H₂, Σ org. C and CH₄. To identify and quantify the major C-H-species offline analyses were carried out by GC/MS using filter, condensate and separate gas samples. The sampling was carried out at each position (S₁-S₅) for a period of 15 minutes in each position. This procedure is repeated 5 to 6 times. The total time for one experiment is about 7 to 8 hours. The concentration profiles through the single runs during one experiment showed good reproduction.

In the raw gas the following online measurement equipment is installed: O₂, CO₂, CO, Σ org.C HCl, SO₂, NO and H₂O. Fly ash sampling is carried out by an isokinetic sampling system.

TEST PROGRAM

During two test campaigns the influence of various fuel mixtures on the incineration process has been investigated. The fuels applied (Fig.4) consisted of crushed and homogenized domestic waste mixed with RDF (refuse derived fuel), PVC, electrical/electronic scrap and automotive shredder residue. In comparison to the waste fuels two bio mass fractions (wood chips and straw pellets) were burnt. When burning biomass a small amount of inert material (sintered schist, 5-15mm) is added to protect the grate bars from heat radiation. Each fuel was burnt over a period of 24 h. Sampling took place 16 h after changing the fuel.

The primary air supply as well as the grate movement were kept constant in all experiments. The varying calorific values of the fuels were taken into account by adjusting the mass flow of the fuels such that the thermal input was almost constant. This caused exhaust gas temperatures in the range between 900 and 1000°C when entering the first flue of the boiler.

RESULTS

Concentration profiles above the fuel bed As an example the concentration profiles calculated from the obtained data from the sampling points along the grate for the mixture of 75% municipal solid waste together with 25% RDF are depicted in Fig 5. The oxygen profile shows a marked minimum in zone 2/3 where the oxygen concentration tends to 0.

In this region the incineration is incomplete and pyrolysis and gasification reactions take place. This produces high concentrations of products of incomplete combustion (PIC's) like CO, C-H compounds (Σ org.C), hydrogen and soot (C) in this section.

Element balances From the local concentrations of the individual compounds and the corresponding gas volume flows the mass flows for each compound could be calculated. Under assumption that there are no differences over the grate width element mass balances for total C, H and O were calculated. The results are shown in Fig 6-8 The balances between the gas outlet above the fuel bed and the raw gas downstream of the boiler as well as in relation to the furnace input could be calculated within the framework of measurement accuracy. When using the data of local temperatures and gas composition, energy balances Fig 9 could also be calculated. The results are very satisfying, too. These findings confirm experimental procedure and calculation methods.

Carbon burnout over the grate length The characteristics of the individual concentration profiles are quite similar burning the different fuels. As an example the concentration profiles of oxygen for all fuels are shown in Fig.10. Only shifts of the location of the minimum/maximum and distribution of the individual concentration profiles can be recognized. The maximum local concentrations of PIC's were found when burning straw pellets and the waste mixture with electrical/electronic scrap. The maximum local concentrations of CO reached up to 150g/Nm³, that of Σ org.C up to 50 g/Nm³. In Fig.11 the calculated values of the local mass flows of carbon containing compounds integrated along the grate length is shown in relation to the carbon input. The graphs depict that increasing heating values of the fuel leads to increasing shares of PIC's and decreasing shares of CO₂ in the flue gas leaving the fuel bed under the same experimental conditions. The highest local transfer rates of carbon from the fuel bed to the flue gas were detected when burning fuels with high calorific values. The calculated profiles of the carbon release rate along the grate are shown in Fig 12. The maximum carbon release rate is located at the minimum of the oxygen profile. Here the carbon burn out is limited by the low oxygen availability from primary air.. On the other hand the decrease of the carbon reaction rate downstream the maximum could be explained by cooling effects from the high amount of primary air at this location (see also Fig.10). This findings show that the distribution of primary air supply is not optimized.

Carbon burn out as function of time Another important parameter is the residence time of the fuel

bed on the grate. By adding small pieces of rock wool to the fuel and visual observation of the time until the sample leaves the grate together with the bottom ash the total residence time could be calculated. Using the same technique by connecting a thin thermo couple to a special sample the local residence time of the fuel on its location along the grate could be detected. When passing the air nozzles of the grate bars there is a significant decrease in local temperatures (Fig 13). The total residence time of the method using the thermo couple was in good agreement to that using pieces of rock wool. The results of these experiments show there is a nearly constant ratio of about 1.8 between fuel to grate movement in all individual grate zones. Using these results the carbon burnout could be calculated as a function of time. For all fuels the time of defined carbon burn out (10, 50 and 90%) was calculated. The results are depicted in Fig 14 as a function of the heating values of the different fuels. The graphs show that the burn out of high calorific fuels takes place within a shorter period of time.

Drying and carbon burn out When looking at the temperature curves of the grate bars, fuel bed and flue gas above the bed (Fig 15a) it could be expected that combustion takes place from the surface to the bottom of the fuel bed. There is no strict separation of single regions of drying, gasification/pyrolysis and burnout of residual carbon. They must overlap each other along the grate length. The same finding is obvious when looking on the calculated carbon burn out and the drying curve along the grate in Fig 15b. The drying curve is calculated from the total H₂O profile and the simplified assumption that water formed by burning the hydrogen content of the fuel follows the carbon conversion using a constant C/H mass ratio of 7.3 which is typical for municipal solid waste. The drying curve is shifted to the front of the grate in reference to the carbon burnout. This effect must be attributed to the poor vertical mixing of the installed feeder grate.

PIC's inside the combustion chamber The offline measurement of the major C-H compounds in the dust, condensate and gas showed that highly volatile hydrocarbons form more than 90% of the total organic compounds. By identification and quantification by GC/MS as well as by online IR measurement methane was found to be the major component in all tests. The comparison of the results by GC/MS in relation to IR measurement showed very good agreement. In Fig 16 the methane concentration for all fuels is correlated with the sum of organic carbon (Σ org.C) detected by FID. The figure shows a constant ratio of methane to Σ org.C. This finding is independent of all fuel fractions revealed with exception of wood chips.

Offline analyses of the gas samples indicated ethene, acetylene and benzene occurred in relatively high amounts, too. They are well correlated with the methane concentration (Fig 17). When analyzing the condensate and the samples, a series of PAH with the main products naphthalene and phenanthrene were found. They correlate with the methane concentration, too (Fig 18). Therefore the spectrum of C-H compounds identified was not found to be influenced significantly by most of the various fuel fractions under the experimental conditions. The C/H ratio of the total C-H-compounds is nearly constant (0.45 ± 0.04 mol/mol).

METAL RELEASE FROM THE FUEL BED

Heavy metals are important for the quality of the bottom ash. Especially the leaching behavior but also the absolute concentration of these elements in the bottom ash is of interest

The determination of metal concentration profiles above the fuel bed was carried out by analyzing the filter samples. In spite of non isokinetic sampling inside the combustion chamber there was a relatively good agreement when balancing the element mass streams of Cu, Pb and Zn in relation to their corresponding raw gas mass flows. This finding leads to the conclusion that these elements must be released either as gaseous compounds (chlorides) or as fine dispersed aerosols. The comparison of the local metal release from the fuel bed in reference to the carbon burn out curves showed that only in the region of the major carbon burn out (not in the sintering zone) a release to the flue gas takes place (Fig. 19, 20, 21). This must be attributed to the highest temperatures inside the fuel bed at this region. These findings confirm earlier experiments where the parameters chlorine content of the fuel (Hunsinger 1994, Vehlow 1996) and temperatures inside the fuel bed (Nüßlein, F. 1994) were identified as the major parameters influencing the partitioning of these elements into the several output streams like bottom ash, boiler ash and fly ash.

SUMMARY AND OUTLOOK

The experiments on the influence of various fuel fractions on the combustion process under constant combustion parameters could be summarized as follows:

- The velocity of the carbon burnout from the fuel bed increases with increasing heating value of the fuel.
- Absolute concentrations of PIC's inside the combustion chamber increase with increasing heating value. The partitioning of major C-H

species is not influenced significantly by the fuel composition.

- The release of heavy metals takes place only in the region of highest temperatures inside the fuel bed.

Future work will be done by experiments on the influence of combustion parameters like primary air supply, fuel mass flow, grate movement The results of this work are used as input parameters to model the burn out of gas phase and solid.

REFERENCES

Dos Santos, A.M. Collin, R. 1992 "Study of MSW incinerator: overall operation and on-site measurements over the grate", *Proceedings. of the fifteenth Biennial conference* Detroit Michigan may 17-20 pp. 133-143

Nasserzadeh, V. Swithenbank, J. Schofield, C. Scott, D. W. Loader, A. Leonard, A. Russel, R. Winn, D., 1993 "Three-dimensional modelling of the coventry MSW incinerator using computational fluid dynamics and experimental data", *Trans IchemE*, Vol. 71 Part B

Hunsinger, H. Merz, A. Vogg, H., 1994, "Beeinflussung der Schlackequalität bei der Rostverbrennung von Hausmüll", *Proceedings. GVC-Symposium* pp.185-202

Nüblein, F. Wunsch, P. Rampp, F. and Kettrup, A 1994, "Influence of combustion bed temperature on concentration and leachability of metals in slags from incineration plant", *Chemosphere*, Vol. 28 No.2 pp. 349-356.

Vehlow, J. (1996), Simple, reliable and yet efficient - modern strategies in waste incineration, *UTA Technology and Environment*, 2/96, pp.144 - 160

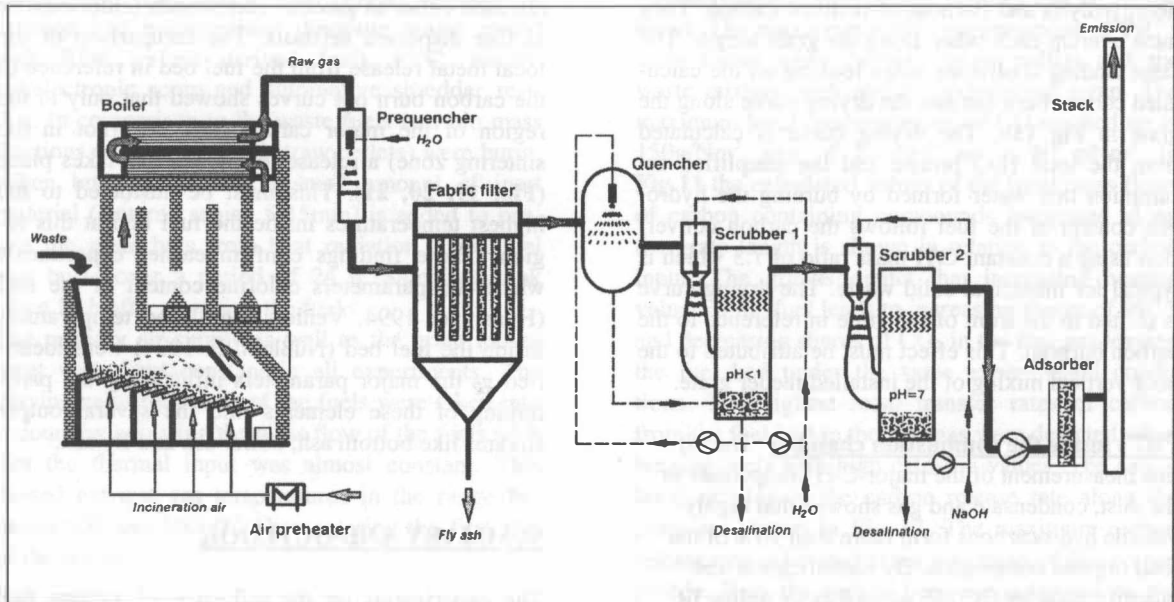


Fig.1: TAMARA flow chart

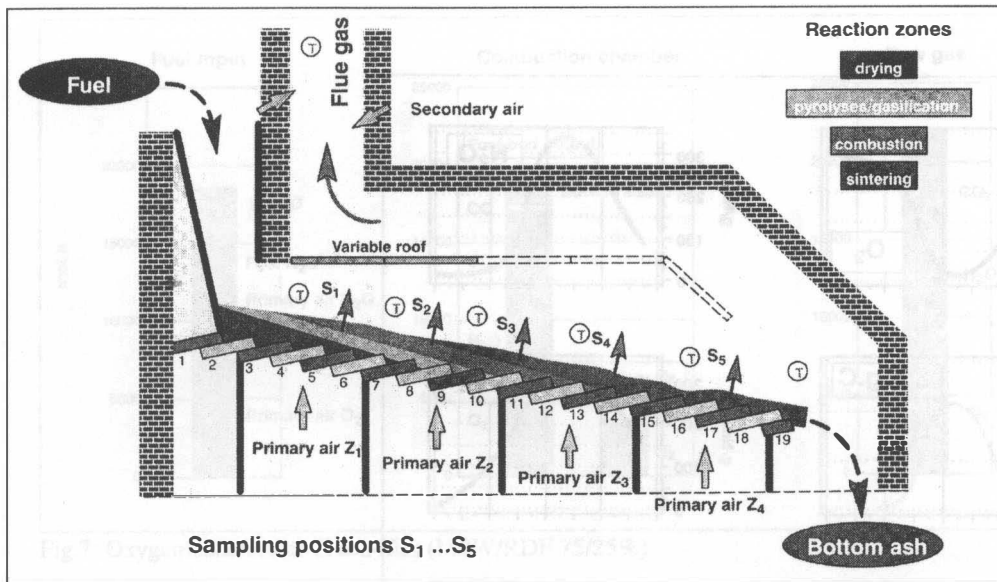


Fig.2.: Combustion chamber and sampling positions above the fuel bed

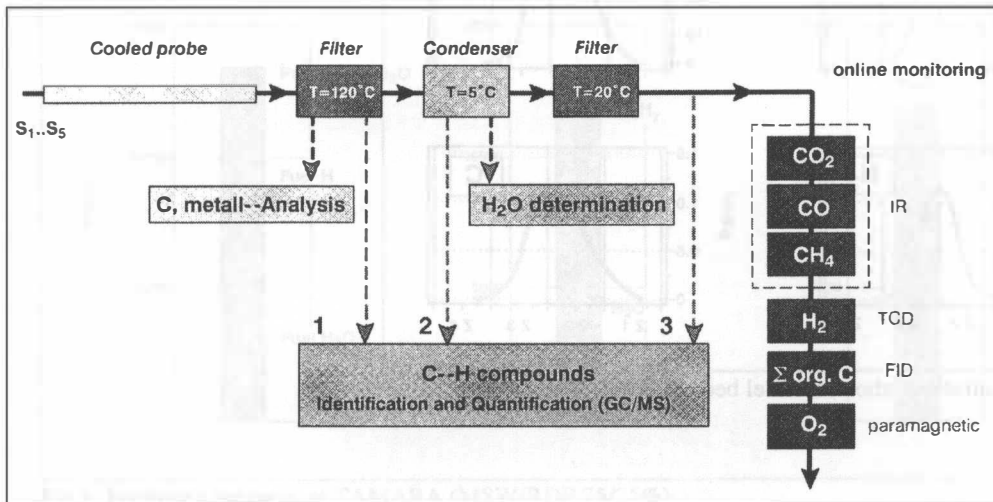


Fig.3: Sampling inside the combustion chamber

Exp.	Fuel	H _u [*] (MJ/kg)	H ₂ O [*] (%)	C ^{**} (%)	H ^{**} (%)	O ^{**} (%)
1.1	Wood chips	7.9	45.0	46.9	5.9	45.7
1.2	Straw pellets	11.9	7.5	43.5	5.8	46.4
1.3	Waste/RDF	8.3	29.0	32.4	4.5	40.7
1.4	Waste/RDF	7.8	30.6	31.4	4.4	41.3
1.5	Waste/RDF + ASR (20%)	7.9	24.2	28.4	4.0	39.7
1.6	Waste/RDF + E&E (15%)	12.0	26.1	41.4	5.0	33.9
2.1	Waste/RDF	8.2	34.7	35.1	4.8	40.1
2.4	Waste/RDF + PVC (5.2%)	8.2	34.6	35.1	4.8	37.0
2.5	Waste/RDF + E&E (14%)	11.2	32.5	43.0	5.2	33.2
2.6	Waste/RDF	7.9	34.9	34.2	4.7	40.3

* = wet base
** = dry base

Fig.4: Fuel data

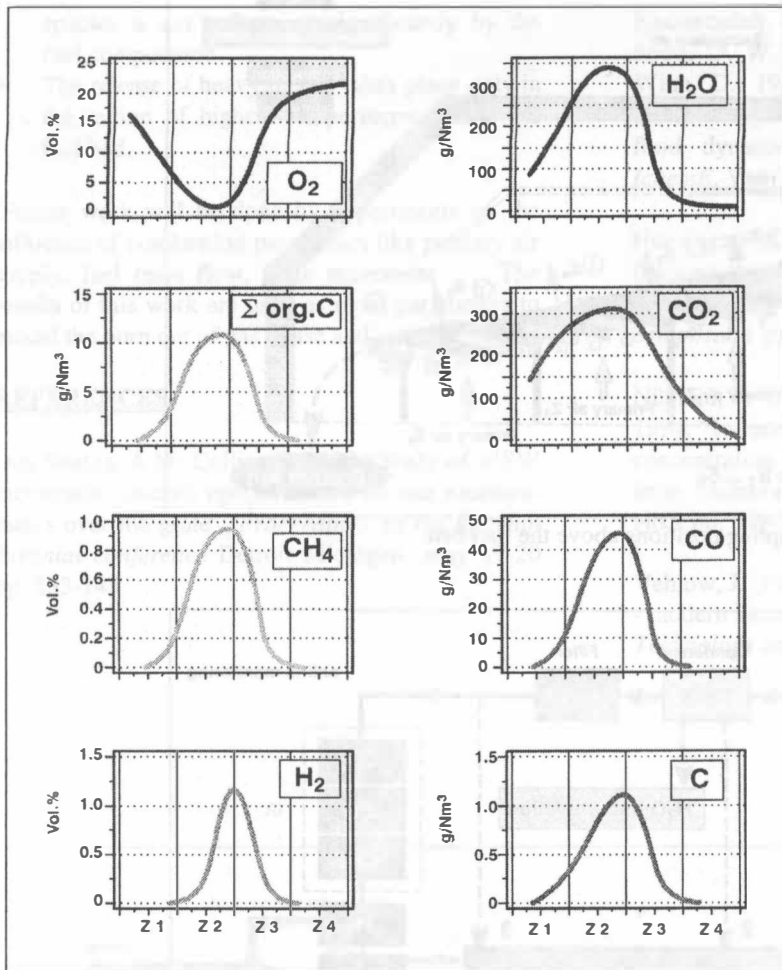


Fig.5: Gas concentrations above the fuel bed (MSW/RDF 75/25%)

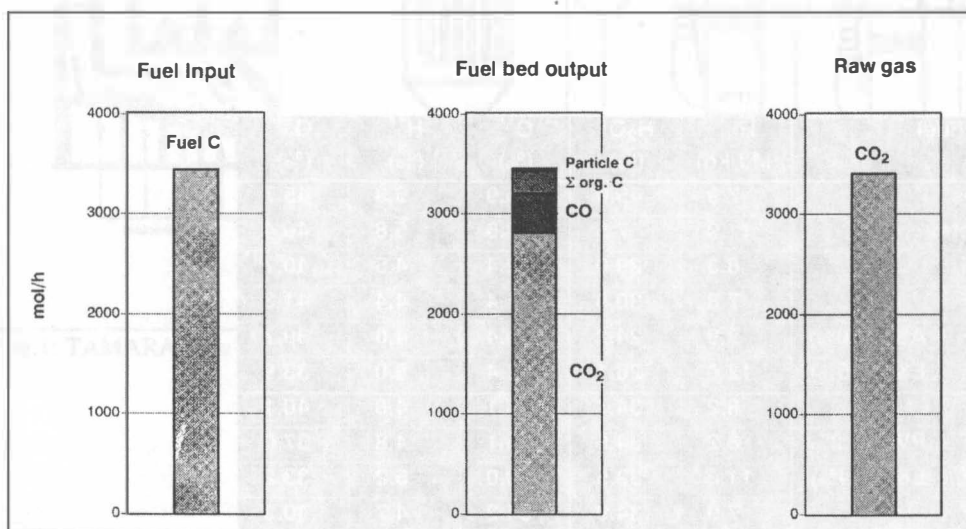


Fig.6: Carbon balances at TAMARA (MSW/RDF 75/25%)

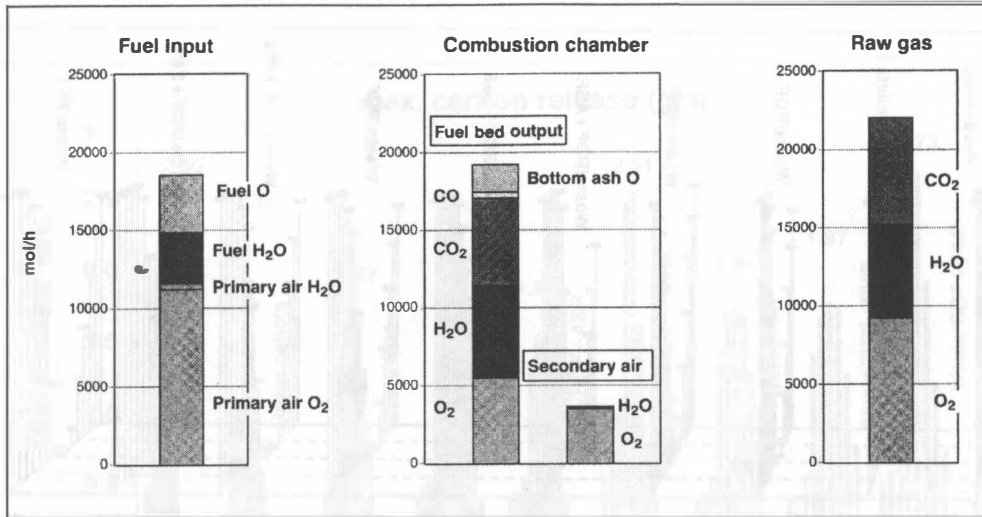


Fig.7: Oxygen balances at TAMARA (MSW/RDF 75/25%)

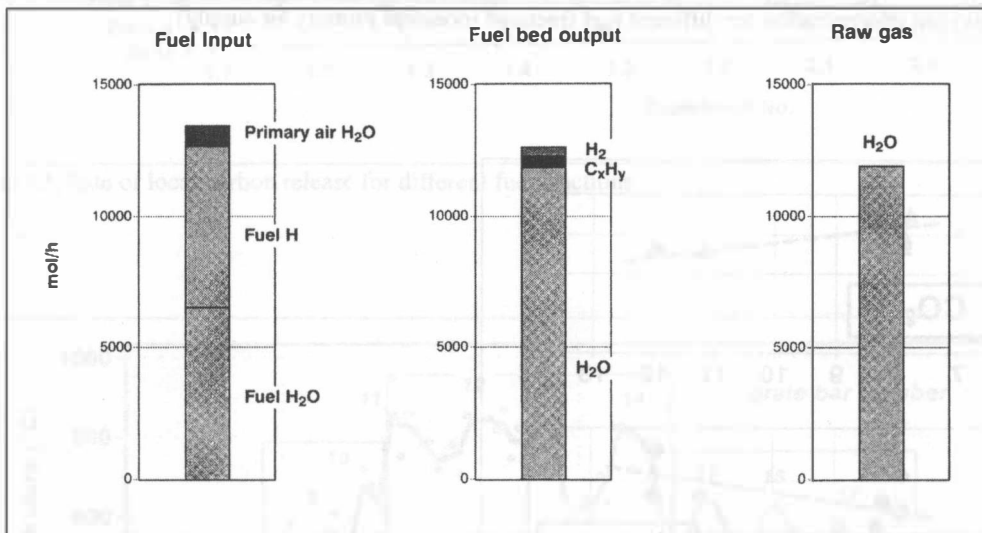


Fig.8: Hydrogen balances at TAMARA (MSW/RDF 75/25%)

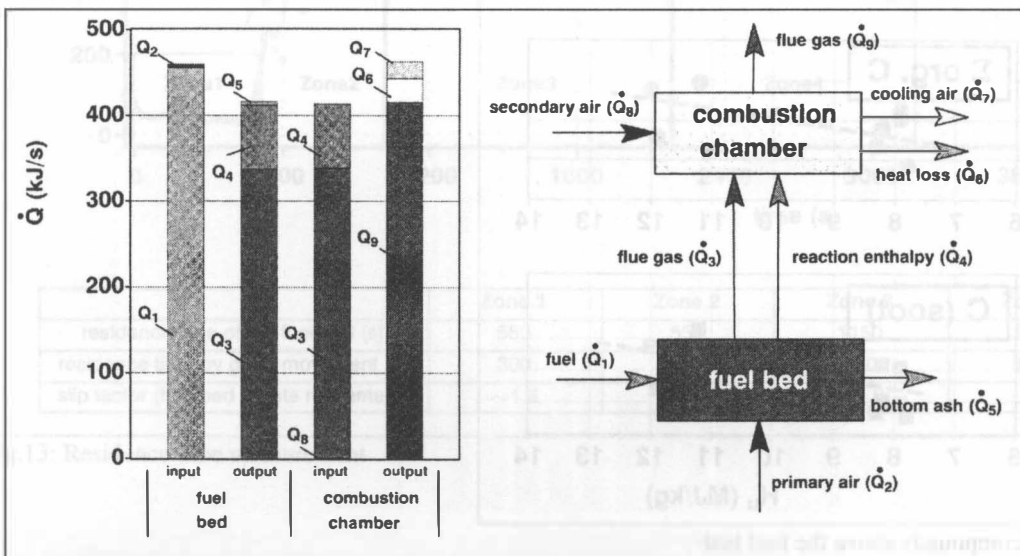


Fig.9: Energy balances at TAMARA (MSW/RDF 75/25%)

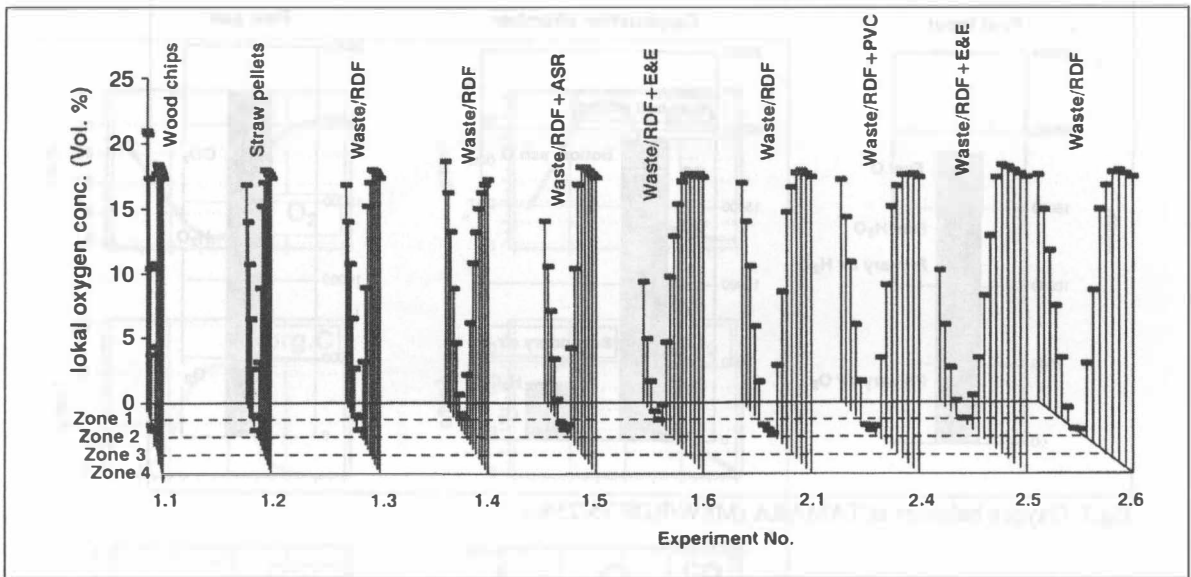


Fig.10: Local oxygen concentration for different fuel fractions (constant primary air supply)

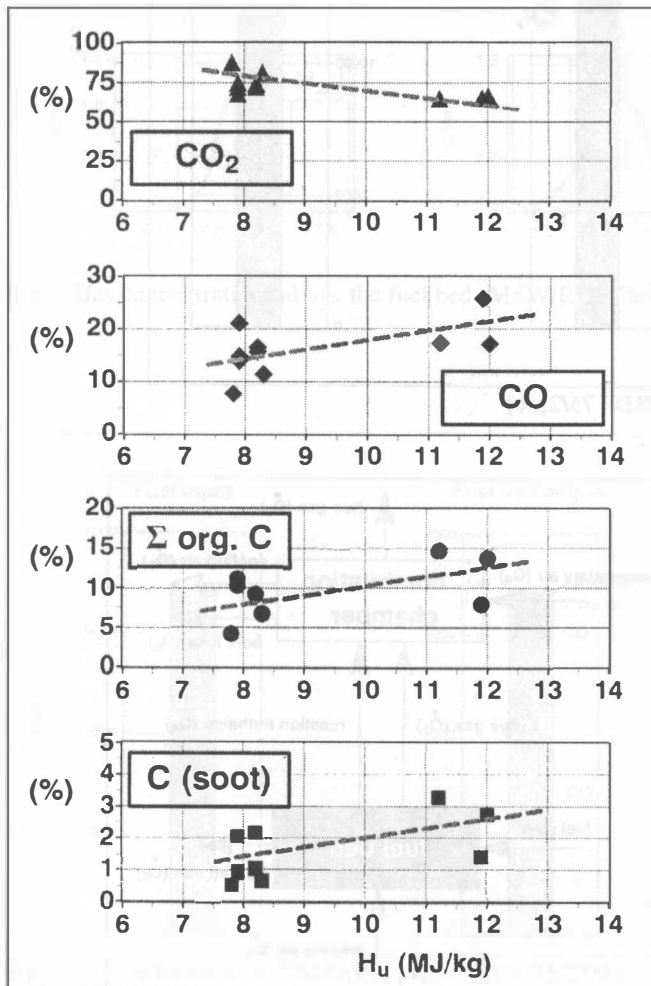


Fig.11: C-compounds above the fuel bed

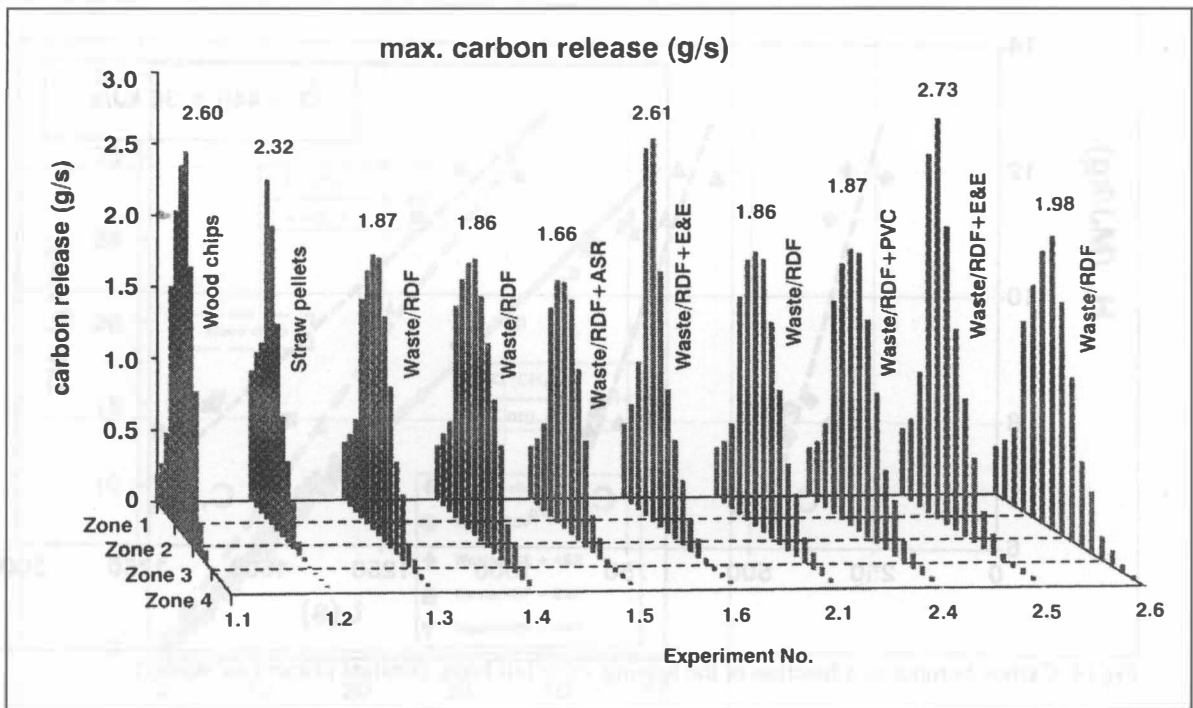


Fig.12: Rate of local carbon release for different fuel fractions

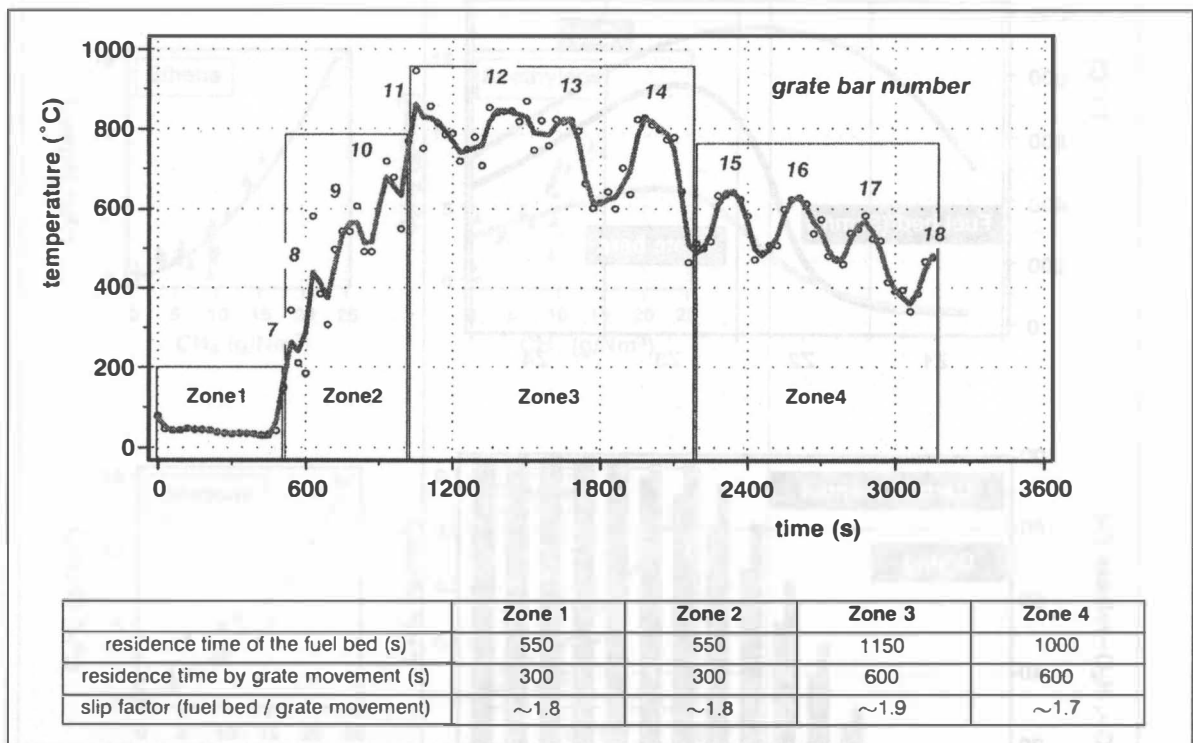


Fig.13: Residence time measurement

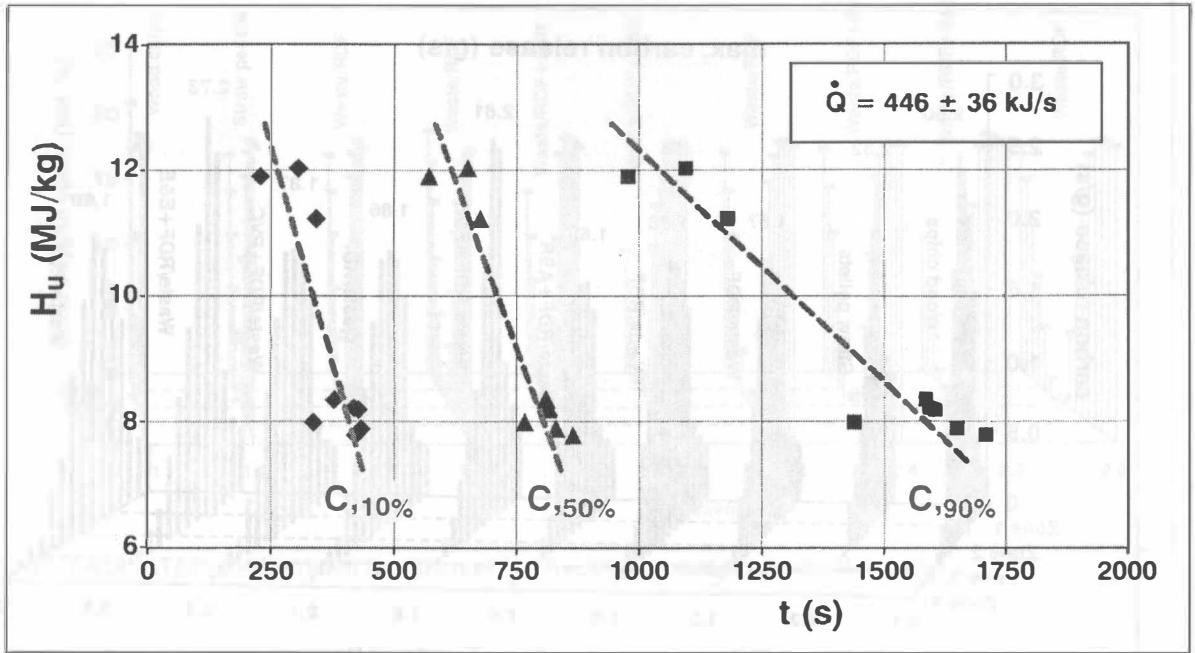


Fig.14: Carbon burnout as a function of the heating value (all fuels, constant primary air supply)

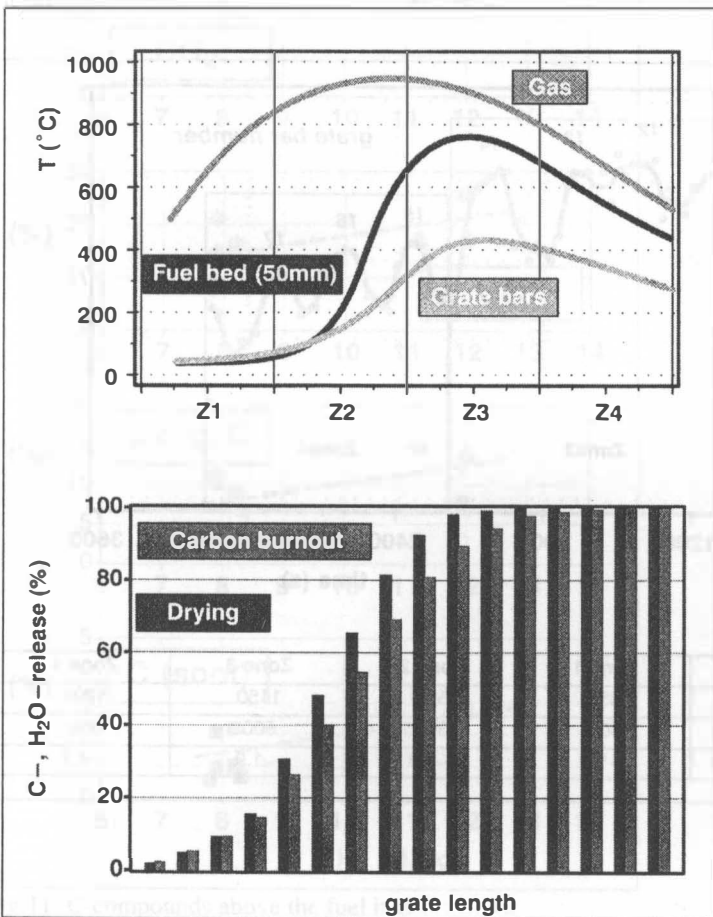


Fig.15: a) Temperature profiles, b) carbon burnout and drying curve (MSW/RDF 75/25%)

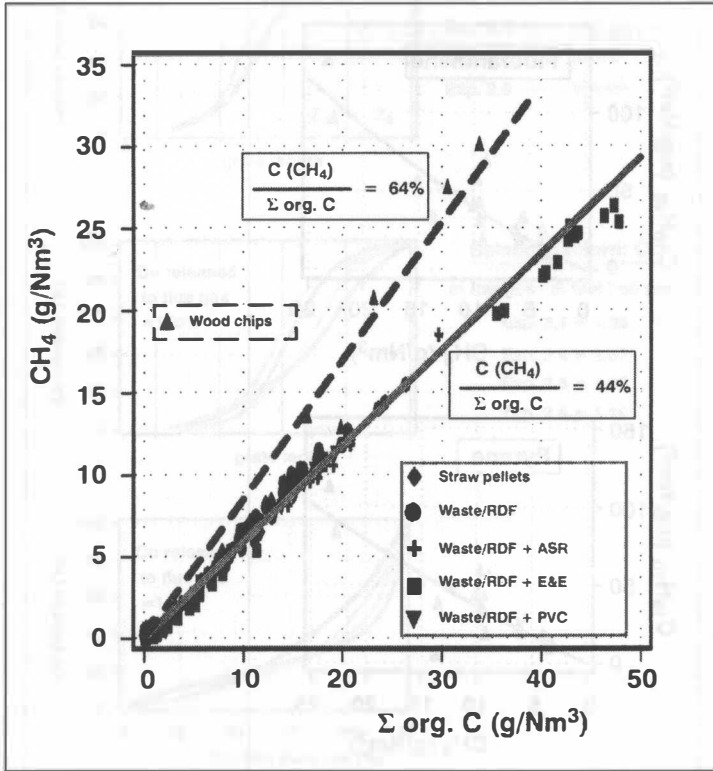


Fig.16: Methane concentration as function of $\Sigma \text{ org. C}$ (all fuels)

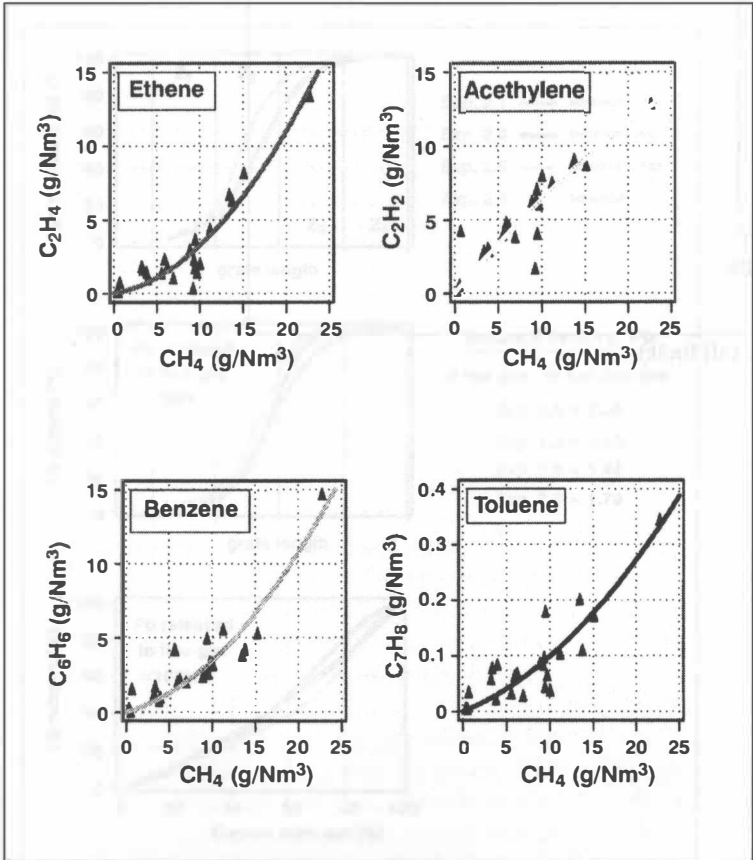


Fig.17: Mayor C-H compounds as function of methane (all fuels)

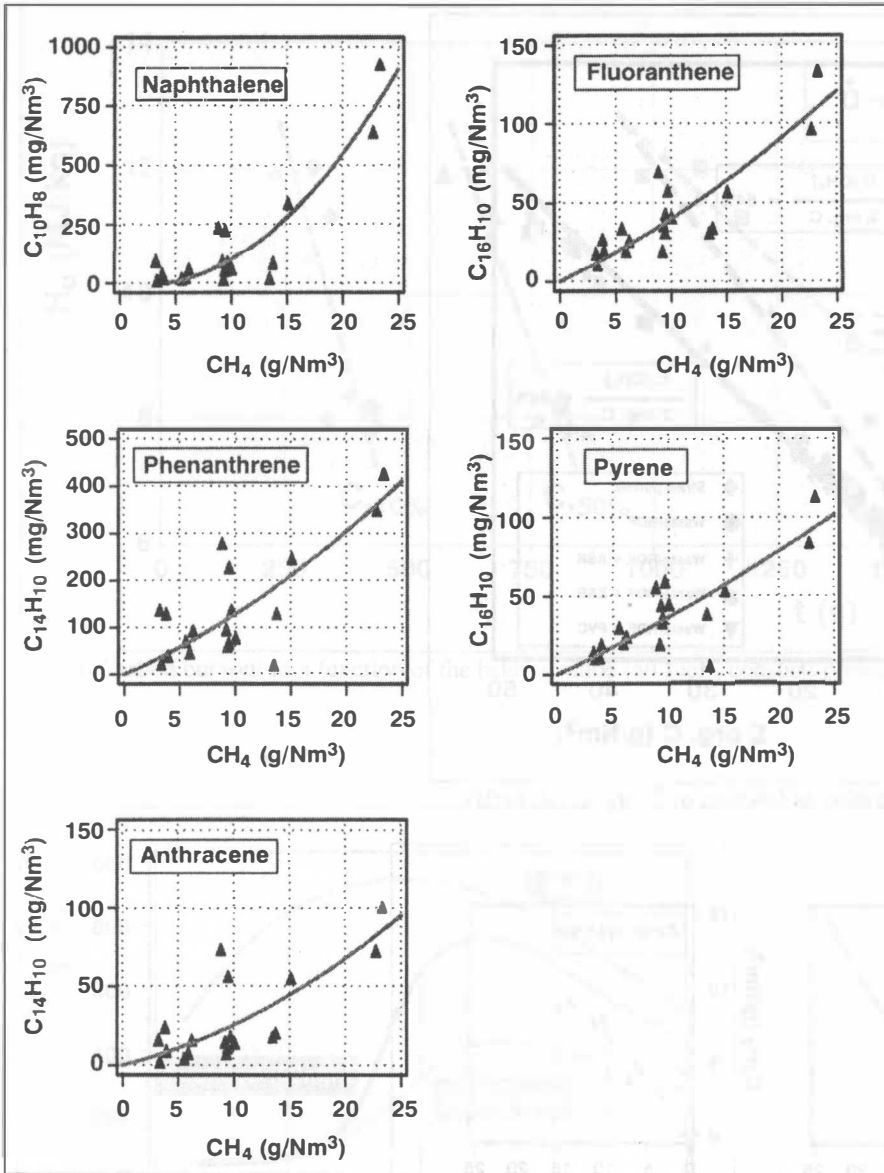


Fig.18: PAH's as function of methane (all fuels)

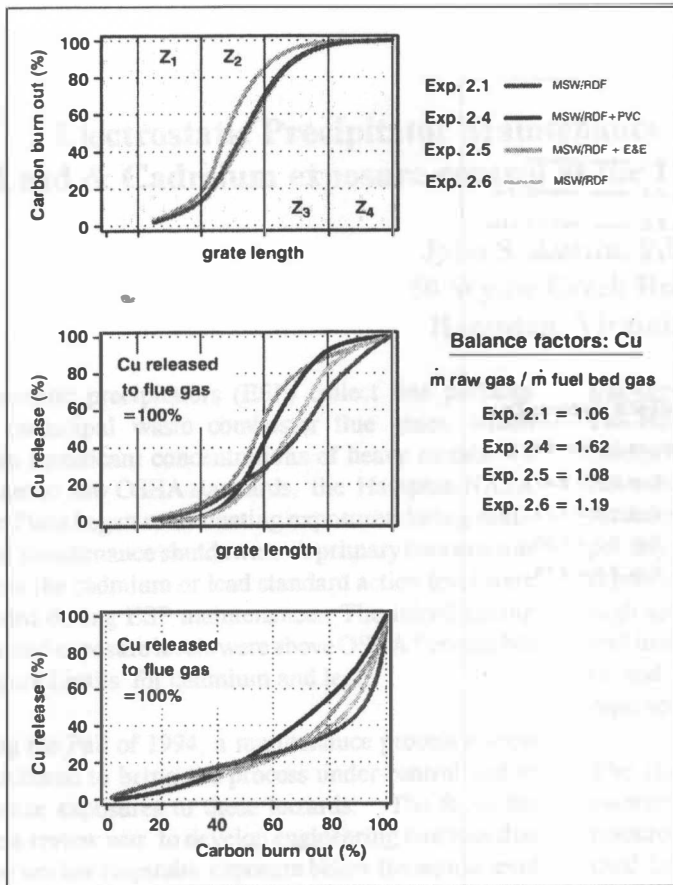


Fig.19: Cu release from the fuel bed

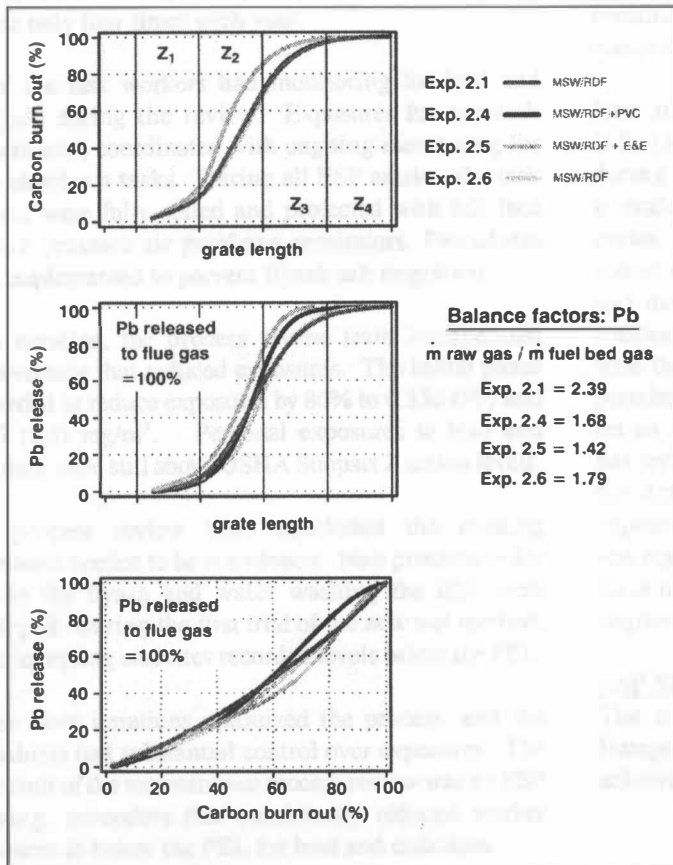


Fig.20: Pb release from the fuel bed

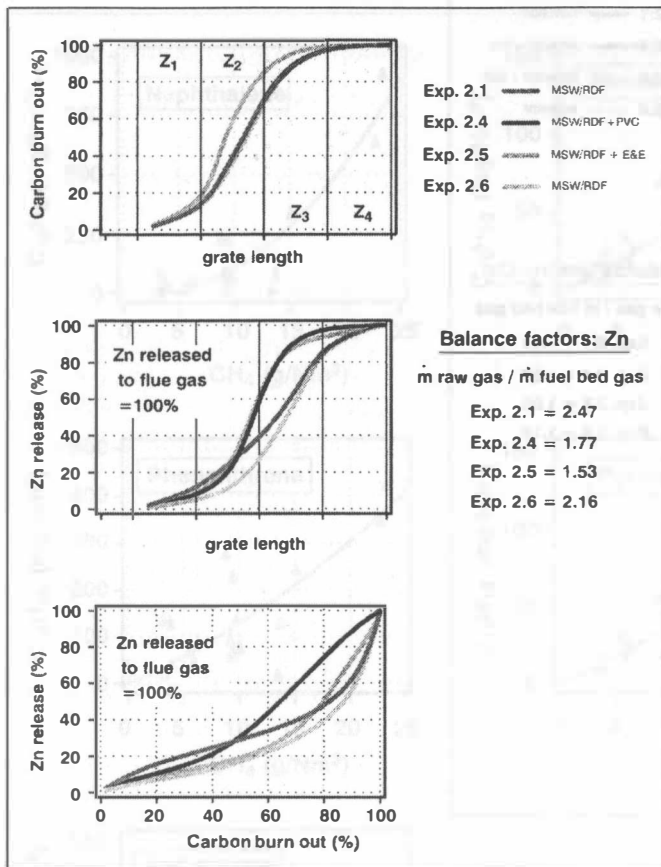


Fig.21: Zn release from the fuel bed