Research Investigations at the Municapal (2×35) and Clinical (2×5 MW) Waste Incinerators in Sheffield, UK

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Abstract : After recycle of spent materials has been optimised, there remains a proportion of waste which must be dealt with in the most environmentally friendly manner available. For materials such as municipal waste, clinical waste, toxic waste and special wastes such as tyres, incineration is often the most appropriate technology. The study of incineration must take a process system approach covering the following aspects:

- Collection and blending of waste,
- The two stage combustion process,
- Quenching, scrubbing and polishing of the flue gases,
- Dispersion of the flue gases and disposal of any solid or liquid effluent.

The design of furnaces for the burning of a bed of material is being hampered by lack of an accurate mathematical model of the process and some semi-empirical correlations have to be used at present. The prediction of the incinerator gas phase flow is in a more advanced stage of development using computational fluid dynamics (CFD) analysis, although further validation data is still required. Unfortunately, it is not possible to scale down many aspects of waste incineration and tests on full scale incinerators are essencial. Thanks to a close relationship between SUWIC and Sheffield Heat & Power Ltd., an extended research programme has been carried out ar the Bernard Road Incinerator plant in Sheffield. This plant consists of two Municipal(35 MW) and two Clinical (5MW) Waste Incinerators which provide district heating for a large part of city. The heat is distributed as hot water to commercial, domestic (>5000 dwelling) and industrial buildings through 30km of 14" pipes plus a smaller pipe distribution system. To improve the economics, a 6 MW generator is now being added to the system.

During the last decade, many investigations have been catrried out (Ref. 1 to 16) and a SUWIC laboratory is located at the plant.

Some of our specific research studies are as follows:-

1. Determination of the temperatures and gas compositions (experimental measurements) at all acess points in both the municipal solid waste plant and the clinical waste plant, including the flue gas scrubber system. This has provided a data base against which models can be tested.

2. Computational Fluid Dynamics (CFD) has been used to study the flow through the heat removal and gas scrubbing systems. The design of such systems has evolved rapidly in recent times as incinerators have developed from simple coverd bonfires to sophisticated process equipment. An important observation from these studies is that there is often a large "dead water"

region in the radiation shaft. Techniques to eliminate this region by suitable use of baffles and secondary air jets have been investigated. Implementation of design changes derived using CFD has successfully reduced incinerator CO emissions.

3. The fate of contaminants such as heavy metals merited specific attention. Low volatile matals and compounds are found to remain in the ash, while some find their way into scrubber liquor. The latter have been successfully removed by TMT15. More volatile material such as mercury may be captured in an activated charcoal filter.

4. Dioxin emissions are subject to very tight legislation and can pose problems in their removal. Fortunately, they also can be captured in activated carbon. Our tests carried out on the Sheffield clinical incinerators before and after cleaning the boiler have been shown that the unit before cleaning produces 300% more dioxin than after cleaning.

5. Legislatiopn calls for a gas residence time of 2 seconds above a specified temperuture. A technique has been evolved to actually measure the residence time in the large MSW and Clinical Incinerator Plants based on the principle of injecting a pseudo-ramdom tracer of methane. This produces variations in the concentration of carbon dioxide in the flue which can be sensed with a specially developed infra-red detector. The cross-correlation of the input and output signals gave the impulse response of the system which confirmed the by-passing predicted by the CFD analysis.

6. The mixing of the secondary air has been found to be weak in both the MSW and the Clinical incinerators. The application of a mixing theory based on the turbulence structure and mathematical modelling incicates how the mixing may be optimised. This concept can be applied also to the injection of ammonia/urea for the control of NO_x.

7. Corrosion in boilers can be expected to take place at some time in the boiler's life whether it is fired by coal, oil or municipal waste. The rates of corrosion however are very different for these different fuels and are dramatically influenced further by boiler design, operating conditions and protective mearures. Computational Fluid Dynamics has been used to assess the overall incinerator design features such as height/width ratio, inlet velocities and inlet geometry on corrosion rates in boilers. The power of the technique in enabling the modelling of superheater inlet velocity contouring by secondary injection, and demonstrating the areas most at rick by particle impingement is of enormous value in time and cost saving both at the design and the commissioning stages of incinerator plants.

8. The total toxic fly-ash produced in the UK is approximately 750,000 tonnes/year from municipal incinerators alone. We have studied a novel technique to detoxify/recycle the generated toxic fly-ash. Our approach is based on the fact that sintering or melting of this ash results in destruction of its tixic organic components, and also fixation of its hweavy metal content to form an unleachable material which can be used in foundations and building roads. A key aspect of this work is the technique used to ensure the energy efficiency of the sintering/melting process. This is based on the application of a regenerative heating concept. The conclusions of the research are expected to have an impact on future codes of practice and standards dealing with toxic fly-ash. Thus the harzadous material which is now being landfilling by the waste incineration industry may be converted to an innocuous product which can be used safely by the construction industry.

9. Another research programme which is being carried out at Sheffield is risk assessment studies of waste incinerator plants. The overall objective of this project is to provide a methodology for assessing the risks to human health(the work-force inside the incinerator plant) posed by municipal/clinical waste

incinerators, which can be used directlyn by the incineration industry in the UK, Europe and the USA. Use of the methodology will improve the basis for decision making in assessments of the comparative benefits of alternative waste management stratigies.

Thus practical experience shows that incineration is a maturing technology which is rapidly developing to fulfil an urgent requirement in society for the removal of polluting materials.

Sheffied MSW Incinerator (35 MW) Plant

The Sheffield incinerator plant became fully operational in 1978. It is a twin stream unit designed to burn up to 20 tonnes/hr of raw municipal waste (10tonnes/hr per grate). The facility takes approximately 80% of Sheffield city's domestic waste and a limited quantity of commercial and trade waste which provide a totoal weekly input of some 2500 tonnes. The incinerator is fitted with steam raising boilers of conventional water tube design and the steam generated is used to heat 5,000 houses and many commercial premises in the area.

Figure 1 shows a schematic layout for one of the streams. The refuse is tipped by the collection vehicle into the reception pit and using a tulip grab crane the refuse is transferred onto a chain conveyer. From this conveyor the refuse drops down the feed chute at the bottom of which a ram feeder pushes the waste onto the gate. The ram feeder speed determines the feed-rate and tne sensors fitted in the chute monitor the refuse level and control the feed conveyor. The grate is inclined and made up of 6 independently driven variable speed rollers, each roll is reversible and has its own primery combustion air supply. Secondary combustion air is also be supplied over the grate. The refuse moves slowly down the grate and is normally burnt out before reaching the final roller. The grate ash drops into a water quench bath, which provides an air seal for the combustion chamber, before discharging onto a transfer conveyor to the ash skip. The combustion gases pass over the boiler and steam drum before passing through the electrostatic precipitator. The fly-ash is collected in skips, the cleaned gas is discharged to atmosphere via the chimney. When steam demand from the housing complex is low, heat can be dissipated using air cooled condensors.

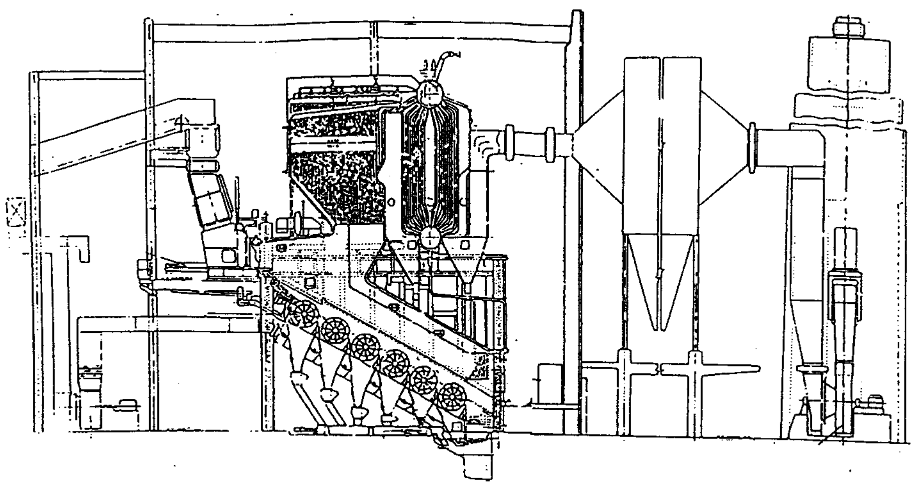


Fig. 1

Sheffield Clinical Incinerator (5 MW) Plant

The Sheffield clinical waste incinerator became fully operational in March 1991. The throughput of this twion stream system is up to 2 tonnes per hour, 8 hours per day. Operation is no more than 6 days per week. The daily throughput is limited by the computer controls on the incinerator units. The estimated annual throughput is 3300 tonnes. The equipment (Figure 2) comprises two identical streams each of which consists of a hydraulic power loader and tipper, sub-stoichiometric first stage, gas co-fired secondary stage, steam raising boiler, exhaust gas. Waste is fed to the incinerator units by an automatic system which weighs individual skips and empties them into a hydraulic ram which loads the incinerator. This system is linked to the computer controls and automatically limits the daily burn to 6 tonnes per stream. After the waste has been fully combusted, the ash is manually removed on a daily basis into specially designed skips to minimise the losses. Both incinerator units operate on a two stage combustion principle, each unit comprises two interconnected combustion chambers, mounted one above the other. Waste is loaded into the primery chamber into which a small flow of air is fed, and tne material is initially ignited by auxiliary burners.

The supply of air to the primery chamber is limited such that the waste decomposes under quiescent conditions so minimising the carry over of particulate material, which could subsequently contribute to stack emissions. The partial combustion products pass upwards to the after-burner chamber tertiary air is added and the gas temperature is elevated if necessary by the addition of heat from a natural gas burner. The flue gases then pass from the upper chamber and are normally drawn, via the induced draft fan, through the fire tubes of a single pass waste heat boiler. The untreated flue gas from the incinerator passes through the tube side of a gas to air heat exchanger and into the gas scrubber. The scrubber is fitted with high and low level switches, and an over temperature switch. In the event of over temperature, the emergency water spray will commence. A pH meter controls kthe addition of caustic soda solution to the scrubber liquor to maintain a reasonably constant pH of around 8. The caustic liquor filtration system comprises a plate pressure filter, 2 filter pumps, a filterate storage tank and discharge pumps. The cleaned saturated gas discharged from the scrubber is then ducted directly into the inlet of the main fan. A forced draught fan passes clean ambient air through a steam heater. The heated air is ducted through the shell side of the gas to air heat exchanger.

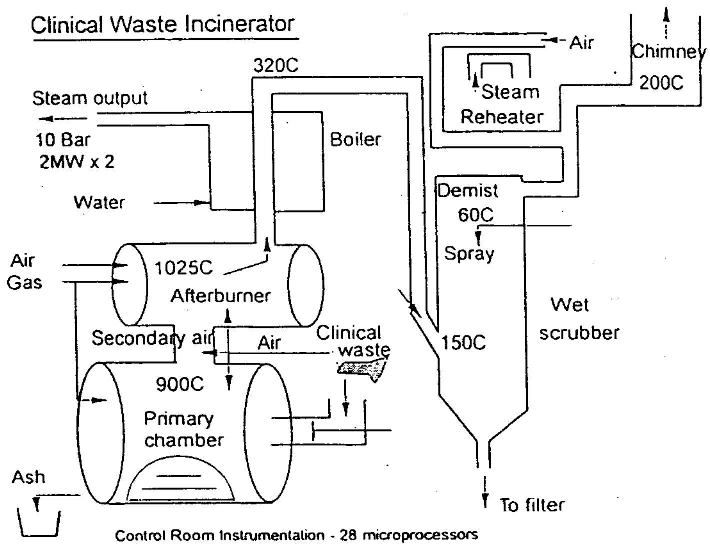


Fig. 2

This heated air is then discharged into the common flue downstream of the main fan. A bleed of part of the heated air is put directly into the scrubber outlet duct to ensure that the cleaned gas temperature to the main fan exceeds the dew point. Control of the heat output from the steam heater is determined by a preset temperature sensor positioned in the common duct downstream of the two main fans. The steam heated air system on both streams are run simultaneously 24 hours per day, 7 days per week. The heated air maintains a sufficiently high temperature of the flue gas duct work down line of the gas scrubbers to prevent condensation within the ducting as well as the formation of a steam plume at the outlet of the stack during plant start up. In the event of only one stream being operational the running of both heated air systems ensures that untreated flue gases do not enter the non-operational system at the confluence fo ducting at the connection into the common flue to the stack. The steam air heater consumes approximately 15 to 17 tonnes of steam per day, corresponding to about 30% of the total steam generation of the incinerator. The flue gas is discharged to atmosphere via the 75 metre stack attached to the adjacent municipal incinerator.

Experimental Programme

The experimental program at the Sheffield municipal and clinical waste incinerator plants consisted of the following stages:-

1. Analysis of the waste feed and incinerator residues;

2. Determination of the temperature profile/ combustion air distributions within the incinerators;

3. Gaseous emission testing; dioxin/furan, total particulates, HCl/HF, CO, CO_2, O_2, VOC, NO_x and SO_2 emissions, heavy metals measurements, gas flow rates and moisture content.

Several other miscellaneous measurements are also made to monitor the effect of variation of operating parameters on the performance characteristics of the incinerators. Typical analysis of Sheffield municipal and clinical wastes are given in Table 1 and 2. Typical gaseous emission levels at the electro-static precipitator outlet for the MSW incinerator are shown in Table 3.

A summary of the results obtained from one of our emission trials at the Sheffield clinical waste incinerator plant is given in Table 4. The unburned carbon content of the grate ash varied between 2.1 to 8.7%. An additional test was also carried out to determine the unburned carbon content of fly ash(particulates) which were deposited on the surface of the boiler tubes. The test showed a relatively low value of 1.2% unburned carbon for phasee particles. The measured O_2 content of flue gas after the boiler (before the scrubber) varied between 8.9 to 12.5%. The CO concentrations at the boiler exit (before the scrubber)were between 230ppm and 657ppm. The measured moisture content of gas at the boiler exit was about 12 to 13%. The mean emitted carbon monoxide (CO) concentration at the base of the chimney (after the scrubber) was 157 mg/m^3 (STP, dry, cirrected to 11% O_2). The lower levels of CO and CO_2 at the base of the chimney (after the scrubber) inducated that some of the CO and CO_2 react with the caustic solution in the scrubber to yield corbon salts (e.g. $NaCO_3$). The addition of heated air to the main flue duct also results in dilution, hence lower unaccounted concentration of CO and CO_2 at the base of the stack. The measured O_2 level at the base of the chimney was up to 17.1%. Heavy metals concentrations were measured using Inductively Coupled Plasma Spectrometry (ICP). Measured heavy metal concentrations in the flue gas, ash, scrubber liquor and filter cake are given in Table 5. Much of the mercury and cadmium released in the incineration process was found in the scrubber liquor and filter cake. Additional tests were also carried out in shich the scrubber liquor was treated with Degussa TMT 15 solution before discharging to the sewer. The aim was to investigate the efficiency of this solution in lowering the heavy

Table 1

	weight %	volume %
Screening	12.31	4.30
Vegetable and putrescible	35.46	25.85
Paper	31.12	38.91
Metals	5.34	8.65
Textiles	1.70	3.41
Glass	9.31	6.44
Plastics	2.97	10.43
Unclassified	1.79	2.01

Table 2

Paper	20
Plastic	25
Glass	10
Metal	10
Organic waste	5
Miscellaneous hospital waste	30

Table 3

	Mean	CoV %	Max	Min
Particles	500	124	2795	16
CO(ppm)	176	113	787	5.5
Acid Gases:				
SO_2	338	38	672	176
HCl	689	26	949	345
Heavy Metals :				
Pb	10.37	125	49.6	0.09
Cu	1.47	85	4.18	0.13
Cd	0.60	128	3.47	nd
Cr	1.11	117	4.85	nd
Ni	0.70	108	2.87	nd
Hg	0.26	23	0.39	0.21

Table 4

CO concentation, ppm	57
CO_2 concentration, %	3.1
O_2 concentration, %	16.9
Particulate emission, mg m^{-3}	31
NO_x, mg m^{-3}	51
SO_2, mg m^{-3}	17

metal content of the effluent. The results dbtained from these tests are shown in Table 6. The mean hydrogen chloride content of the flue gas measured before the scrubber was well above 1000mg/m^3 which is due to the high plastic content of the clinical waste. Concentration of hydrogen chloride (after the scrubber) averaged 150mg/m^3 (STP, corrected to 11% O_2), whilst sulphur dioxide gave a mean of 11 mg/m^3 compared to the limit value of 300 mg/m^3. The average NOx level in the flue gas was about 36 mg/m^3 also well below the specific limit of 350 mg/m^3.

Emitted levels of tetrachloro-dibenzo-p-dioxins(TCDD) and tetrachlorodibenzo-furans(TCDF) in the flue gas were well below and furans were found in the filter cake. Very little dioxin/furan were found in the grate ash (well below 1ng/g). The experimental and modelling data show that the incinerator generally performs in accordance with the design requirements. The level of the major flue gas constituents, O_2 and CO_2 confirm that the required rich/lean operation of the primery and sfter-burner chambers is achieved. As expected for a clinical incinerator, the levels of SO_2 and NO_x emissions are low and well below the specified limits. The HCl levels upstream of the scrubber were found to be high due to the combustion of the PVC content of refuse but they were reduced dramatically at the scrubber exit. Particulates were also removed efficiently by the scrubber and were then collected in the filter press. The observation that practically all the dioxin/furans were collected in the

Table 5

Element	Ash $\mu g\ g^{-1}$	Scrubber liquor (before treatment), mg/litre	Filter cake $\mu g\ g^{-1}$	Flue gas (particulates), $mg\ m^{-3}$	Flue gas(vapour phase), $mg\ m^{-3}$
Hg	<2	2.09	3294	0.03	0.17
Cd	9	<0.02	1649	0.06	0.50
Pb	679	506	11831	2.12	4.7
Cu	3740	0.06	920	0.22	1.1
Ni	159	<0.02	69	0.02	0.02
Cr	1420	<0.02	1154	0.02	0.02
Zn	3790	6.1	34890	0.01	1.5

Table 6

Element	Untreated liquor mg/litre	Treated liquor with TMT 15, mg/litre
Hg	6.03	0.08
Cd	37.5	0.29
Pb	37.4	0.24
Cu	3.73	0.03
Ni	0.27	0.12
Cr	<0.02	<0.02
Zn	242	61

filter cake is consistent with other investigations of incinerator emissions. Whenever particulates are formed in the combustion, either as fly-ash from the silica/metal content of the waste feed, or as carbonaceous material formed in the situation of imcomplete combustion, the major part detected dioxins and furans are adsorbed onto the surface of the particulates. Dioxins and furans rarely exist in the vapour phase under such conditions. The very low level of dioxion/furan found in the scrubber liquor is also entirely consistent with literature observations. Dioxin and furans are almost insoluble in water. Where particulates and water from an incineration process condense together, dioxins and furans are always adsorbed onto the solid particles. Our tests showed that low volatile heavy metals were mostly retained in the grate ash whilst most high volatile metals were found in the filter cake and the scribber liquor. Wet scrubbing processes have proved to be successful in removing heavy metals from the flue gasas, in which case the metals usually end up in the waste water. The results obtained from our tests at the Sheffield clinical incinerator showed that an optimal application of Degussa TMT 15 to the waste water could lead to acceptable residual concentrations of heavy metal ions which are well below the specified limits. Depending upon the type of heavy metal and composition of waste water, residuals between 0.01 and 1 mg heavy metal ion per litre waste water were obtained.

Use of Computational Fluid Dynamics (CFD) to simulate the Effects of Design and Operating Parameters on the Overall Performance of the Sheffield MSW & Clinical Incinerator Plants:

The need for a better understanding of incinerator flows is growing due to the increasing use of incineration as a solid waste management tool, shifts in the economics of incineration, and public concern over emissions. The directly fired water-walled, municipal-waste mass-burn incinerator is the dominant design and its over-fire water wall region is the crucial link between the grate section designed to burn heterogeneous waste stream and the heat transfer and gas cleaning sections with their own input requirements for optimal performance.

Incineration is one of the most complex unit operations presently in use. The processes occurring within a burning refuse bed include:- pyrolysis, solid and gas combustion, conductive, convective and radiative heat transfer, mass transfer, and gas flow through randomly packed beds of material whose size, shape and orientation is continuously changing. In view of the complexity of these processes, it is not surprising that the design of incinerators has developed more as art than a science.

The many design variables open to the designer (e.g. type of grate, number of grate sections, amount of exess air, primery and secondary air distribution, refuse bed height, grate speed and the radistive transfer to the top of the refuse bed) strongly suggests that present designs and mode of operationn are far from optimum. This is partially confirmed by the wide variations reported for maxumum burning rates, and for exess air, air distribution, and grate and furnace configuration in different units, as well as by the wide variation in residue quality observed in practice. It should be possible to reduce the capital costs of incinerators as a better understanding of the effect of different variables is obtained, particularly those pertaining to air flow rate and distribution because of their profound influence on burning rates, rates of particulate emission and on the size of the required gas cleaning equipment. From the operational standpoint the major difficulties appear to be dynamically adjusting operating conditions to compensate for the rapid changes in refuse quality and quantity, and the lack of techniques available for rapidly evaluating residue quality (i.e. unburned carbon in ash). The operator has less flexibility than the designer in dealing with the variations in refuse quality and quantity and must cope with wide variations in refuse composition and moisture content by adjusting the grate speed and air flow rate and to a lesser extent air distribution.

One of the major reasons for studying the existing incinerator design is to enhance the mixing processes inside the furnace. The existing designs have been shown to have very poor mixing characteristics. In the case of a constant quality fuel combistion system, the undergrate and the secondary air ratios could be established and would depend largely on the stoker characteristics and furnace configuration. Such a system can be operated at practically constant temperatures with minor manual ratio adjustments when required. In the case of a refuse combustion system, however, such operation becomes very difficult, if not impossible. The variable quality of the refuse, changing not only from one hour to another, but actually from minute to minute, ideally requires continuous adjustments in the undergrate/secondary air ratios to offset the varying combustion rate characteristics and the resulting heat release per unit time of various refuse constituents.

The following section presents the findings from our CFD modelling studies of Sheffield MSW and Clinical incinerators.

a) Effects of Installing different Baffle Configuration on the Overall Performance of the Sheffield MSW Incinerator:

As shown in Figure 3, our computational fluid dynamics(CFD) model of the Sheffield MSW incinerator plant cinfirmed the existence of a large re-circulation zone inside the vertical shaft. The temperatures at the boiler exit were about 1000K and the key residence times in the furnace and shaft ranged between 0.5-1.5 seconds. Using the mathematical modelling technique to remove this re-circulation zone, a baffle was introduced into the mainstream inside the shaft. Conventional design technoligy for passive (baffle) systems is an empirical art, often based on isothermal physical modelling using water or air models. However, modern computation technology permits the effect of geometrical design and process operational changes to be investigated economically and quickly using more realistic non-isothermal flow fields.

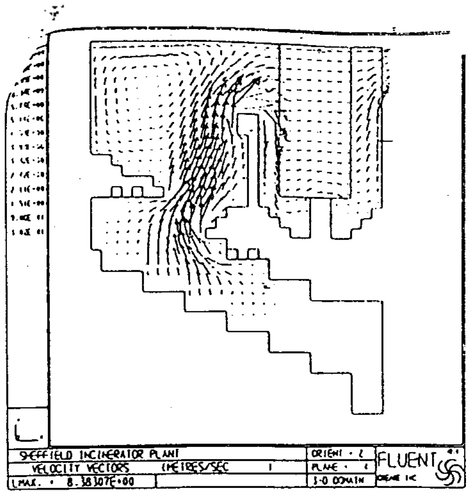


Fig. 3

The comparison between the predicted performance of the existing incinerator design and the suggested modified design showed that the introduction of a water cooled baffle into the gas mainstream inside the vertical shaft and increasing the use of the secondary air by 57% could give rise to a significant change in flow field inside the Sheffield incinerator. This will reduce the temperature and improve the temperature profile at the boiler exit, increase the gas residence times and reduce the pollutant emissions from the stack. In addition, the boiler efficiency increases by nearli 8% and it is estimated that there will be an 18% reduction in running and maintenance costs as a result of the new modified design.

Four different baffle configurations based on the concept of eliminating the re-circulation zone in the shaft were studies and the resulting flow fields obtained from these cases are shown in Figure 4 to 7. The computer code(FLUENT) was used to perform the calculations. For each case, a detailed description of the flow field was calculated and key information was calculated such as; velocity vector plots, temperature profiles, CO levels and estimates of the re-circulation zone inside the shaft compared to the other three cases.

Althrough temperature profiles for all four cases inside the furnace are similar, the temperatures at the boiler exit for case one, have the lowest value compared to the other cases. Cases 2, 3 and 4 show little improvement in terms of lower exit temperatures over the original design. Appreciable cold and hot spots are seen in the shaft for these cases which make their design unattractive compared to the evenly distributed temperature profile in the shaft for the case one. The predicted carbon monoxide levels at the exit for all four cases are relatively low compared to the original design.

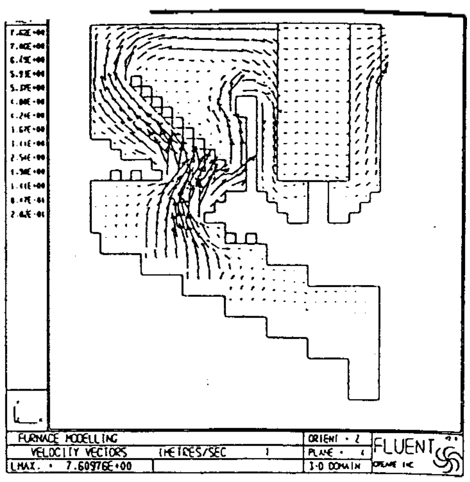


Fig. 4

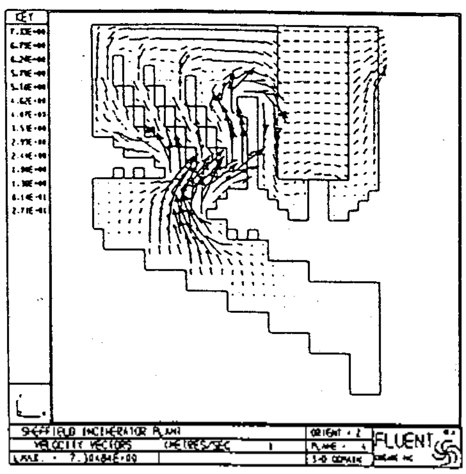


Fig. 5

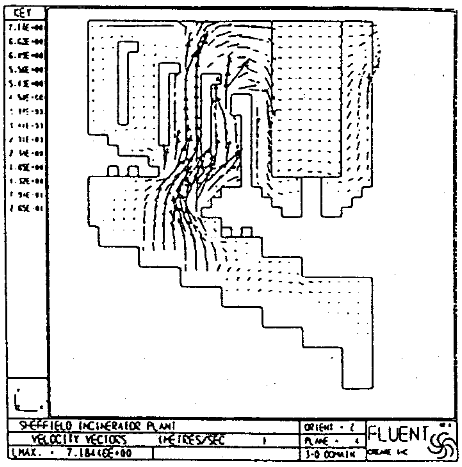


Fig. 6

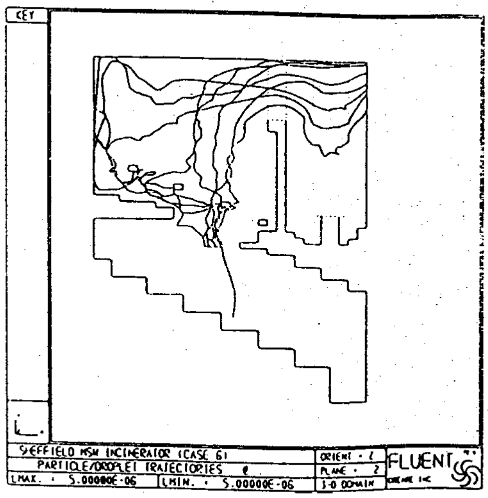


Fig. 8

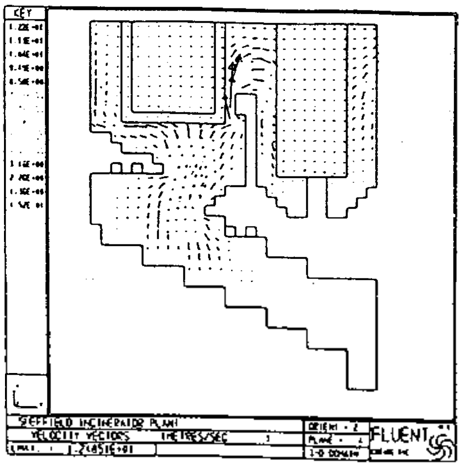


Fig. 7

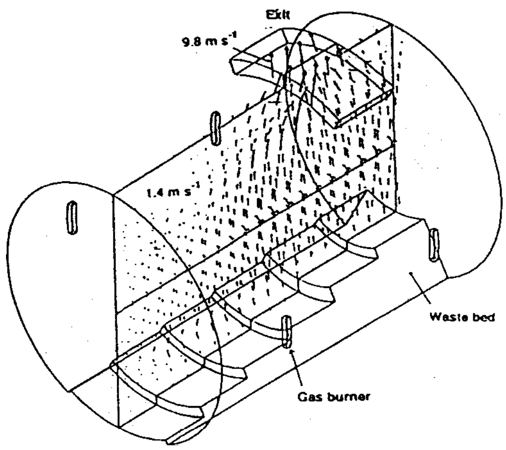


Fig. 9

Residence times in all other three cases are relatively long.

b) Effect of Large High Speed Jets on the overall Performance of the Sheffield MSW and Clinical Incinerators.

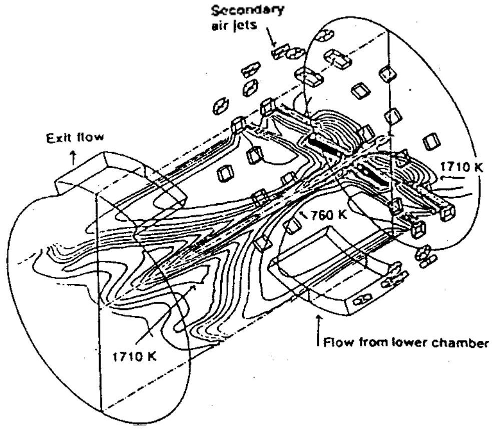


Fig. 10

The clinical role played by the large high speed secondary air jets acheiving a desirable state of mixing and optimising the overall performance of the incinerator plants were investigated using CFD models. The effect of high speed secondary air jets on both the

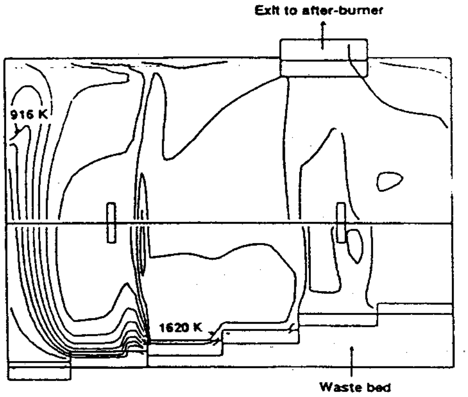


Fig. 11

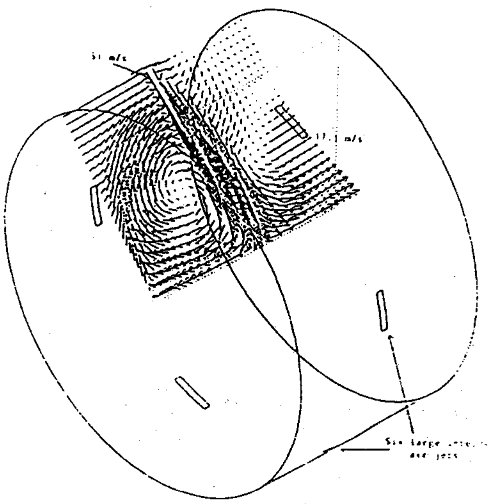


Fig. 12

overall performance of the Sheffield MSW incinerator and the gas residence times was investigated using CFD models. Here, in the proposed design, instead of having a very large number of secondary air injecttion pots(44 jets in total) in the same horizental plane, eight large secondary injection ports are situated on a plane at an angle of 45° to the vertical (Figure 8). Each jet is positioned on the side wall at 75 cm separation and is fired into the main flow tangentially to a rotational circle at 30° angle to the horizental. The main feature of this design is the formation of a very strong re-circulation zone due to the high speed secondary air injections. Unlike the existing incinerator drsign in which a re-circulation zone occurs in the shaft, when the eight high speed injections are itroduced, the flow field is changed dramatically. The re-circulation zone inside the shaft which was present in the existing incinerator design, has disappeared and the main flow out of the furnace is directed towads the middle of the shaft. As expected from the structure of the flow field in this design, the entire volume of the radiation shaft is used as true combustion space with no dead spaces and hence marked improvements in heat exchange are acheived with this system compared to the original incinerator design. The results show marked improvements in mixing characteristics and mean gas residence times in this design compared to the values obtained for the existing incinerator design.

FLUENT was also employed to predict the three dimentional reacting flows(gaseous phase) within thw Sheffield clinical incinerator geometry(Figure 9, 10, 11). The main objective of this modelling work was to investigate the influence of the design and operating parameters on the overall performance of the incinerator. The modelling work showed that the use of six large high speed secondary air jet firing toward a common cetre in the inter-connecting duct and employment of 12 high speed air jets inside the after burner, produce longer residence times and improve the temperature profile at the exit. The novel feature of the proposed secondary air injection system is the formation of a large size and significantly strong re-circulation zone located in the interconnecting duct. The presence of this strong re-circulation zone improves the overall performance of the incinerator due to intensive mixing of hot gaseous products(CO, volatile matter and hydrocarbons) evolving from the refuse bed with the combustion air supplied as the secondary air, and thereby greatly improves the gas phase combustion and helps to reduce emissions of toxic gases. As shown in Figure 12, the main feature of this design is the formation of a very strong re-circulation zone in the downstream area of the incoming flow from the primery chamber due to the high speed secondary air injections. Unlike the existing inter-connecting duct design in which the main incoming flow from the

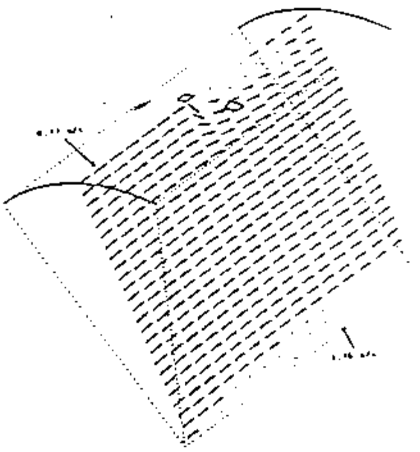


Fig. 13

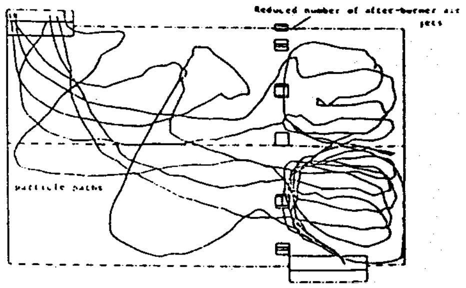


Fig. 14

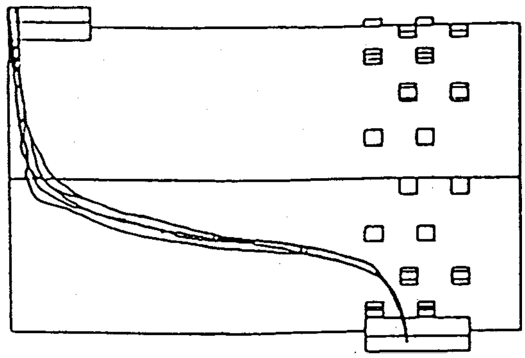


Fig. 15

lower chamber passes through the duct with relatively high velocities and no use is made of secondary air jets to enhance the turbulent mixing in the duct(Figure 13), when the six high speed injections are introduced, the flow field inside the duct has changed dramatically. Due to the injection of high speed secondary air jets, a rotary motion of gases is induced below the injection points, which contributes greatly to the mixing process inside the duct.

The proposed design for the after-burner uses 12 equally spaced, high speed air jets, which are fired radially into the main flow towards a common centre (Figure 14). As shown, the main characteristic of this design is the formation of a strong re-circulation zone upstream of the air ports and near to the gas burner injection point. In this design, the entire volume of the chamber is used as true combustion space with no dead spaces and significant improvements in mixing characterictics and combustion efficiency are acheived compared to the existing Sheffield clinical incinerator. Other studies have shown the benefit of baffles in the afterburner chamber to improve mixing and residence time.

Mixing

Modelling studies of particle trajectories using computational fluid dynamics shows the utility if simulation for the determination of residence time distribution in incinerators. These studies indicate that residence time distributions contain valuable information that is important to the understanding and evaluation of mixing processes in the incinerator ober-fire region. Recent legislation specifies the residence time above a defined temperature in new incinerators, and these rules are to be applied to all large incinerators in the near future. CFD can be used to obtain the residence times by solving the trajectory equations for infinitesimal particles. At Sheffield University Waste Incineration Centre, we have carried out such calculations using the two-phase capability of the FLUENT code for a number of commercial and clinical waste incinerators and we have found that they typically exhibit unacceptably short residence times due to the fact that there are dead space regions in the radiation shaft(Figure 3)

The solution to this problem has also been derived using CFD models. The technique which we have used is based on our mixing concepts. These show that the maximum mixing that can be acheived is related directly to the mixing power, however, since power can be expended mixing like with like, the actual mixing acheived also depends on ensuring that alternate micro-scale (Kolmogorov) layer must consist of the two materials being mixed respectively. This criterion can be satisfied by ensuring that the macro-scale eddies contain alternate material since it is these eddies which become the micro-scale eddies by the turbulent stretching process. Thus if we require to mix uniformly air jets as are commonly fitted to incinerators, but it can be acheived by a small number of large secondary air jets.

Investigations into the Effect of Boiler Deposits on the Post-Combustion Formation of Dioxins/Furans in Incinerator Plants:

Recent research work has demonstrated that the dominant mechanism of Dioxin/Furans formation involves heterogeneous, surface catalysed between chlorinated precursors and/or the product of de novo synthesis, on fly-ash particles held in the relatively cool(200°C-400°C) post-combustion environment of the boiler or particulate arrestment equipment. The key requirements for PCDDs/PCDFs formation are an oxygen-rich environment, a source of chlorine, and the presence in the fly-ash of a metal capable of catalysing a Deacon reaction(e.g.copper). *De novo* systhesis is initiated by the formation of chlorine via the action of oxygen on hydrogen chloride:

$$MCl_2 + \frac{1}{2}O_2 \rightarrow MO + Cl_2$$
$$MO + 2HCl \rightarrow MCl_2 + H_2O$$

leading to :

$$2HCl + \frac{1}{2}O_2 \rightarrow H_2O + Cl_2$$

Hydrogen chloride is formed as a decomposition product of the chlorinated organocs such as PVC in the incinerator, along with fly-ash. Inorganic chlorides (for example sodium chloride or ferric chloride) are equally effective sources of chlorine. M(the metal catalyst in the fly-ash) is typically copper (the most effective catalyst material), though patassium, sodium, and zinc have also been positively correlated with PCDDs/PCDFs formation. Homogeneous gas phase reactions in the combustion zone generate a range of PICs, both chlorinated and non-chlorinated precursors on the fly-ash. These percursors react to form PCDDs and PCDFs. Taking dichlorobenzene and o-chlorophenol as typical precursors, the formation of monochloro-CDD can proceed innitially by oxygen attack on dichlorobenzene to form a phenoxy radical, which reacts with chlorophenol to form an intermeadiate diphenyl ether. Combination of the hydrogen form the hydroxy radical with chlorine on the adjacent phenyl ring allows the reamining oxygen to bridge between the two phenyl rings and complete the dioxin molecule.

The catalytic formation of PCDDs and PCDFs has been studied by a number of researcher. Two competing temperature dependent reactions operate;

(a) formation of dioxin (reaching a maximum rate in the region of 300°C), and
(b) dechlorination/decomposition of dioxin, a reaction whose rate increases exponentially with temperatire

Above about 200°C the rate of formation exceeds the rate of destruction, peaking at about 300°C. Above

Table 7

Sampling Period	Substances Reported	Measured Concentration
3 hours	Dioxin/Furan in the flue gas (Before Cleaning Boiler)	11.98 ng/nm^3
3 hours	Dioxin/furan in the flue gas (After Cleaning Boiler)	4.16 ng/nm^3

400°C the rate of destruction dominates, and dioxin levels decrease rapidly. A global heterogeneous mechanism has been proposed which has been shown to be in good sgreement with experimental data. this model is in four stages:

Stage 1: Dioxin Formation $P_g + P_s \rightarrow D_s$

Stage 2: Dioxin Desorption $D_s \rightarrow D_g$

Stage 3: Dechlorination $D_s \rightarrow$Products

Stage 4: Decomposition $D_g \rightarrow$Products

P_g and P_s are precursor concentration in the gas phase and on the surface of the fly-ash, and Ds and D_g are concentrations of dioxin on the fly-ash and in the gas phase. A proportion of PCDDs/PCDFs that are formed desorb off the fly-ash and exit the incinerator as a component of the gas phase. However, apart from the mono-, di-, and tri-chloro species, the major proportion of PCDDs/PCDFs remain adsorbed onto the fly-ash, and either exit the stack as a component of the particulate fraction or are arrested in air pollution control equipment such as fabric filters.

In order to investigate the effect of boiler deposits on the post-combustion formation of dioxin/furan in a large incinerator plant, a series of tests were carried out at Sheffield clinical incinerator. The main objective was to show that more dioxins/furans are formed in a dirty boiler than a cleaned boiler due to the greater region of suitable environment for their formation. Test were carried out before and after cleaning the boiler (2 weeks interval). Samples for Dioxin/Furan testing were collected using an Anderson Universal Stack Sampling System complying with the U.S Environmental Protection Agencies Modified Method 5 protocol. The samples were then analysed by high resolution gas chromatography and mass spectrometry. Samples were taken simultaneously at the inlet and outlet of the boiler. The results obtained from this work are shown in Table 7. Our results demonstrated 300% more dioxins/furans production from the boiler before cleaning compared with after cleaning.

Measurement of Gas Residence Times in Large MSW Incinerator Plants Using the Pseudo-random Binary Sequence(PRBS) Tracer Technique:

There is increasing public awareness and concern over emission from municipal solid waste incinerators. The value of knowing the gas residence times in large municipal incinerators and the serious error imposed by the traditional use of gas volume flow rate based average residence time with regard to these incinerators are well recognised.

Article 4 of the EC Directives on both new and existing MSW incinerators specified that the gases resulting from the combustion of waste must be raised, after the last injection of combustion airm in a controlled and homogeneous fashion and even under the most unfavouravle conditions, to a temperature of at least 850°C, for at least two seconds, in the presence of at least 6% oxygen. It is subsequently stated(Article 6) that the residence time of the combustion gases at 850°C as specified in Article 4 must be the subject of appropriate verification at least once before a new plant begins operating, or in the case of an existing plant, before 1st December 1996.

Residence time is normally measured by injecting a tracer such as helium, mercury vapour, sulphur components or radioactive material at a prescribed point, which for incinerators is usually specified as the secondary air entry. The time required for the tracer to pass through the system is determined by analysing the concentration of the tracer at the exit as a function of time. In many systems, this is unsatisfactory due to the larger number of secondary air inlets. More particulary, due to the scale of these plants, inconveniently large pulses of tracer are required to provide sufficient signal at the outlet plane.

Traditionally, time domain experimental methods have been used (e.g. step response and pulse response measurement). However, these measurements suffer from the drawback that, in the presence of noise, either the perturbation signal must be so large that the normal operation of the process is affected, or the experimentation time must be so long that difficulty arises in holding the process steady over a sufficiently long period of time. Any method which can give a good measurement of the dynamics in a affecting the normal operation of the process would be most attractive, and for this reason, we have used a correlation method.

Examples of the forcing functions are; pulses, steps, sinusoids, random(noisse) and pseudo-random binary sequence(PRBS). Althrough in principle the same information can be gained irrespective of the form of the input signal, the PRBS is a much more useful and powerful signal, and it is well established and widely used in the field of process control. On the other hand, step and pulse fuctions are dominant forms of input signals which have been used for years in cimbustion and reator designstudies, with little or no practical use of the PRBS. The advantages of the present approach are as follows:-

1. The PRBS is on the average a steady state function and the combustor can therefore be operated at practically steady state

2. The amplitude of the pulse or step signal would have to be relatively large compared to the PRBS disturbance and this can result in the system overloading and un-quantified non-linearities.

3. For a given signal/noise ratio the experimental time is relatively modest.

4. Many disturbance frequencies are generated for one easily generated code.

5. Quantitative estimates can be made of the turbulent mixing noise contribution to the response.

The main objective of our research programme was to study and develop a cheap, simple and reliable technical procedure for measuring gas residence times in the large incinerator plants. This has immediate importance to existing UK incinerator plants and as an available technology which has wider implications for Europe and the USA as well as the increasingly environmentally conscious Eastern block.

Our research progeamme consistes of four major parts;

Phase 1: Water model tests,

Phase 2: Gas injection tests in a small-scale incinerator unit,

Phase 3: Computational fluid dynamic analysis of residence times,

Phase 4: Residence time measurements on the full scale 35 MW incinerator using the PRBS tracer technique.

PRBS Tests at the Sheffield Plant:

The gaseous fuel uesd in the PRBS tests at the plant was methane (a portable cylinder). The methane gas flow rate was measured using a rotameter fitted in the gas line before it was fed into the furnace (approximately 700 litre/min of methane gas during each injection yielding a mean flow of 350 litre/min). The PRBS signal (methane gas) was introduced into the furnace on top of grate roller number 2, through a 2.5 inch diameter nozzle (water cooled probe) via a side port(Figure 9). The gas solenoid valve was fitted in the supply line to this port. Here a pseudo-random signal was used to perturd the process and the output response (CO_2 concentration) was detected by a simple IR absorption fast CO_2 analyser inserted into the duct at the boiler exit. This signal was then cross correlated with the perturbation signal to give a result which can be shown mathematacally to be identical with the impulse response of the process. As a preliminary check to make sure that the system was running satisfactorily, a blank test was carried out with no gas injected into the furnace. A series of tests were carried out using 15, 31, 63, and 127 bit sequence with bit interval of 1 sec, 333 ms, 100 ms, and 33.3 ms respectively. In the case, the input/output data were recored and then cross correlated to obtain the cross correlation function for each set of data. The cross correlation function plot for a typical 127 bit signal and 1 second bit interval is shown in Figure 16. These results show that the impulse response can be progressively extracted from the noise by increasing the number of cycles over which the signal is integrated. The log plot of integrated response Vs time for the above signal is shown in Figure 17. The impulse response showed a marked peak at 1500 ms, and the derived step response showed that most of this delay was due to plug flow with the remainder due to well strred flow conditions.

The measures gas residence time for the Sheffield MSW incinerator plant was 1.5 seconds. The comparison of the calculated gas residence time for Sheffield MSW incinerator using computational fluid dynamics (FLUENT model) and the measured gas residence time at the plant using PRBS technique showed very good agreement.

It should be noted that emissions of toxic organic micro pollutants (particulary dioxins and furans) from MSW incinerators do not entirely depend on furnace conditions alone. Conditions in the post combustion zone, where catalystic formation may take place, are believed to play a more important role. Therefore, setting simple criteria for incinerator gas residence time and temperature may not be sufficient to address the problem of dioxin emissions. However, accurate measurement of temperature and residence time parameters can provide important information on incinerator furnace operation, and this area should not be neglected.

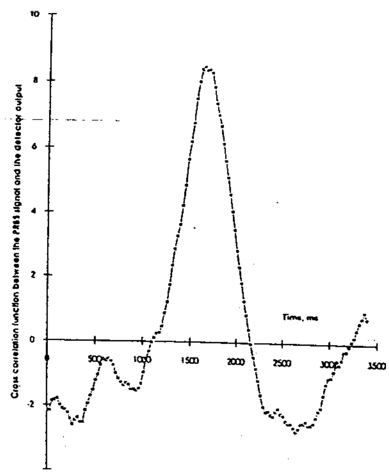


Fig. 16

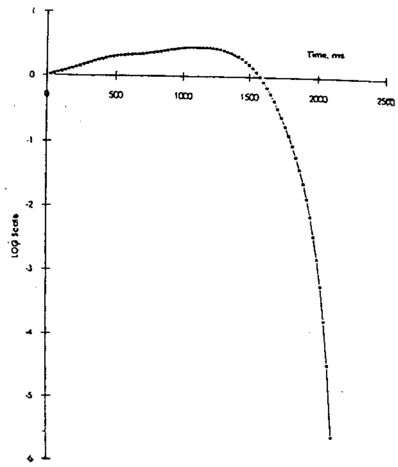


Fig. 17

Corrossion in Incinerators:

Before the growth of power production from incinerators, steam pressure would dften be supplied in the range 15-25 bar. Even though live steam temperatures could be up to 350 °C, this meant that for much of the heat transfer area of the boiler, the steam would still be at the relatively low temperatures of 180-217 °C and the metal surfaces are likely to be below 300 °C. The great benefit for those operating with saturated steam pressures in the range 10-25 bar is that lifetimes of up to 10 years can be expected without corrosion problems. By contrast the operating conditions for many waste incineration plants generating power typically in the range of 40-70 bar with delivered steam temperatures are in the range of 380-480 °C and saturation temperatures corresponding to these pressures are typically in the range 260-280 °C.

The flue gas conditions fo temperature and composition are known to vary considerably with time for waste incinerators and although they operate with overall excess air for a propotion of the time the gases are expected to have local regions in which the conditions are reducing. In particular, where there is partially burnt material carried through the first and second passes, the local condition will be fuel rich and reducing. If there are regions of the boiler where such material impinges regularly on a surface, then it is expected that these regions will receive:

a) a higher than average heat loading, and

b) conditions which have a greater reducing balance than at other parts of the boiler where impingement does not take place. In thhis situation, severe corrosion may be encountered in the radiation section of the boiler on the separating wall between the first and second passes and on the roof of the boiler between these passes.

For the water wall section, corrosion is expected to be around saturation temperature, and as an example, this can be taken bteween 260 and 280 °C. Considering the heat transfer through thin layers of ash deposit to water tube walls, then in general, for heat transfer loadings of around 60 kW/m^2, and thermal conductivities in the ash deposit of around 2 W/mK, temperature gradients in the region of the wall are expected to be around 20-30 °C/mm. The temperatures in these layers adjacent to the tube are therefore expected to run at around 50-60 °C higher than the local water tenmperature.

However, where impingement is taking place, then heat transfer rates will be higher and temperatures adjacent to metal for the above cases could be in the range of 360 °C to 385 °C. Such temperatures are substantially above that associated with the onset of iron oxide reduction in the 300-320 °C range and in that event such areas would be expected to show the greatest signs of corrosion.

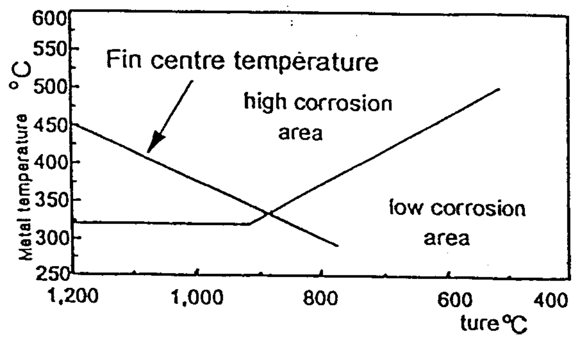


Fig. 18

This problem is at its greatest on the central parts of the fins connecting the tubes and this is shown approximately in Figure 18, which gives the variation of fin centre temperature with flue gas temperature. For flue gas entry temperature of 1100 ℃, it is expected that fin centre temperatures are likely to approach 400 ℃. Also superimposed on this graph expected variation of the limiting curve of metal temperature which divides the regimes of high and low corrosion, where it can be seen that only for flue gas temperatures below around 900 °C do fin centre temperatures enter a lower corrosion regimes. This information is relevant to corrosion of superheater tubes, however the effect of local flow velocity is then more important.

Our present studies have focused these aspects of the design and we have used computational fluid dynamics to illustrate the use of this tool in exploring ways of influencing inlet conditions to produce more satisfactory flow patterns through the early sections of a municipal waste incinerator.

Two designes were studies which differ principally in their overall heights. These are described as normal height and reduced height designs. Both incinerators have a wide inlet which has an initial short horizontal section. Particles were introduced at the inlet plane and parallel with the inlet flow. Only three positions were chosen in the inlet plane and these were contained in a vertical plane across the inlet. Velocities were chosen to be small and particles quickly attain the same velocity as the surrounding flow.

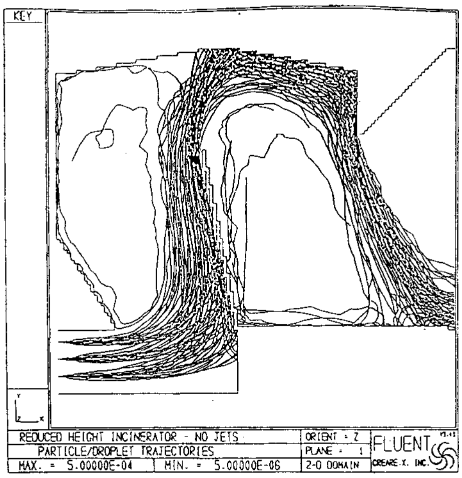


Fig. 19

In the case one, particle tracking was carried out for a distribution of sizes between 5-500 μm. These show severe impingement behaviour on the intersection wall and ceiling regions (Figure 19). There is also the likehood that due to the high localised velocities as the flow enters the radiation shaft, more unburned particles will be entrained and contribute an additional thermal load and reducing conditions in the impingement areas. It is expected therefore that for such a design, local hot regions which are receiving an uneven heat loading show premature failure.

In the case 2, the introduction of secondary flow has had a significant effect on the direction of the inlet flow, resulting in a reduction in the size of the re-circulation zone. The effect on particle trajectories is dramatically illustrated in Figure 20 which shows that these are now deflected from the intersecting wall.

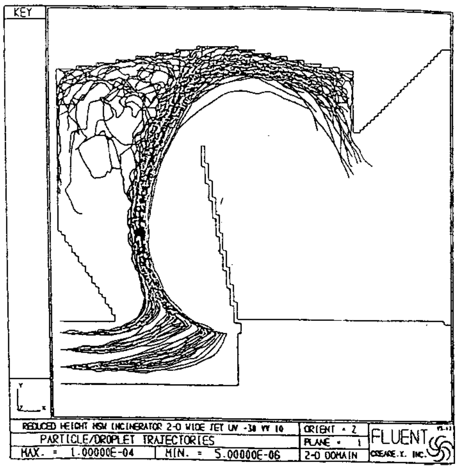


Fig. 20

Case 3 uses the same secondary flow velocity but only 1/3 of the injection slot width (Figure 21). This shows some improvement over case 1 but is still unable to significantly influence the large re-circulation zone in the radiation section. The non uniformity of velocity for these reduced height cases is still far from ideal and arises from uniform low velocity flow under the influence of a simple arrangement of secondary jets is unlikely to be successful.

Case 4 still shows the tendency of impinge on the intersection wall leaving the opposite wall unaffected (Figure 22).

In case 5, there is an improvement in the distribution of velocity at the entry to the radiation chamber although there can still be seen a stagnant zone the left hand wall. An improvement can be seen in the spartial distribution of particles, particularly in the second pass (Figure 23).

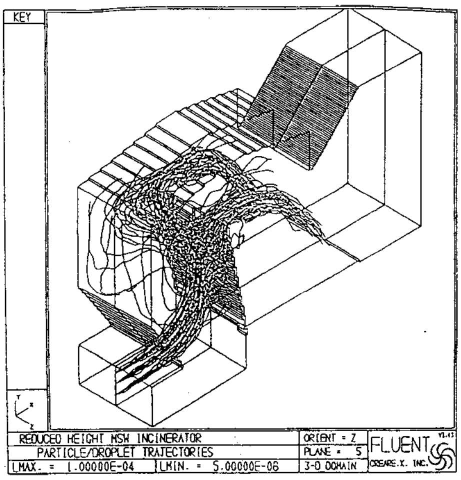


Fig. 21

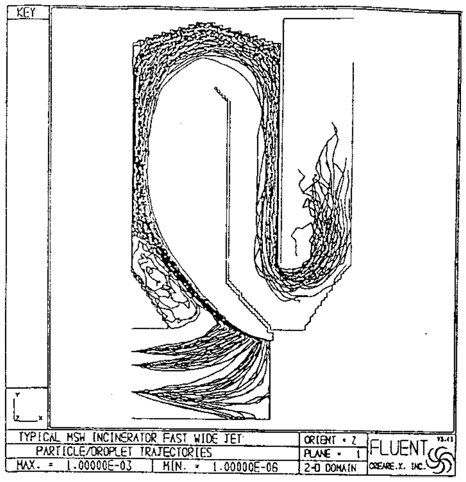


Fig. 23

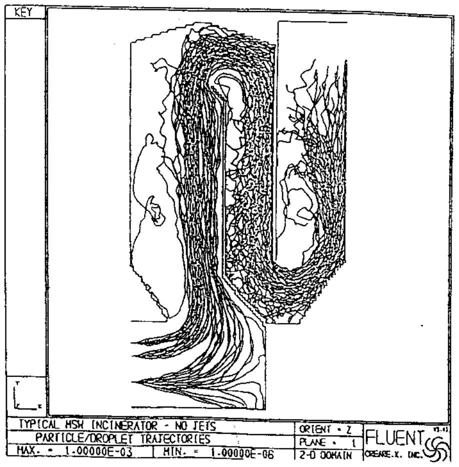


Fig. 22

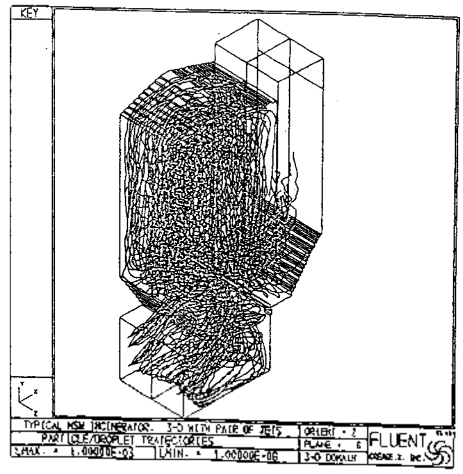


Fig. 24

The effect of the secondary slot injection for case 6 is given in Figure 24 and can be seen to be much more effective in penetrating the inlet flow and removing the re-circulation zone on the intersection wall and injection velocities therefore need to be chosen with care if impingement problems are not to be transferred to other parts of the chamber.

Case 7 usesn two secondary jets as before and due to the narrower chambers, these are much more effective than in the reduced height geometry. It can be seen that the trajectory pattern is more uniform throughout the first and second passes and therefore is likely to result in a minimum value for the particle velocities with real improvements in reduction of impingement as well as better mixing for faster combustion.

These results have shown that the uniformity if imlet velocity in incinerators is of central importance when studing the corrosion problems because of a number of reasons including minimising the maximum velocity and hence carry-over of ash, maximising the tendency to impact on tubes and distribution of the heat transfer load evenly over the cross section.

Development of a Novel Technology for the Detoxification/Re-use of Highly Contaminated Fly Ash Produced by theWaste Incineration Industry

During the last decade the debate concerning incineration has focused mainly on potential risks from air emissions. Today waste incineration will only gain public acceptance if the high quality of all residues with respect to levels of organic compounds and to the elution stability metal can be guaranteed.

It is well known that appropriate control of combustion parameters in incinerators is a powerful means to influence:- the burnout of carbon compounds, the fixation of lithophilic elements in the bottom ash, and the volatilisation of thermally mobile species into the gas phase. However, emission reduction strategy now requires development in the direction of high quality residues.

Data for bottom ash production indicate values between 0.25 and 0.42 kg/kg of burnt waste. Most of this data includes the grate siftings which are directly combined with the bottom ash in nearly all incinerators. Recommendations should be made to separate this siftings stream from the bottom ash and to feed it back into the combustion chamber. In some incinerators such facilities have now been installed.

The production of fly-ash grit from the convection section of the boiler depends on the type of boiler and on the amount of dust originally released from the grate. The flux of dust in this stream is in the range 2-12 g/kg of burnt waste. In some MSW incinerators the boiler grit is still combined with the bottom ash, but in future it should be treated together with the filter fly-ash due to its similar levels of toxic heavy metals and organics.

The estimated mean quantity of electrostatic percipitator (ESP) or bag filter ash is about 25 g/kg of burnt waste based on a dust load of 5 g/m^3 in the flue gas. Modern incinerator technology provides lower velocities in the combustor and results in dust loads down to less than 2 g/m^3. Corresponding values of filter ash production rates of about 10 g/kg have been reported.

The mass of air pollution control (scrubbing) residues may actually show the highest variation of all residue streams. A figure of 12 g/kg is a mean value for wet systems which operate close to stoichiometry. This value comprises the dry material (2-4 g/kg) and the soluble salts (5-12 g/kg). In semi-dry or dry systems the total amount in increased because of unreacted additivies which add to these residues.

The burnout level is a key parameter for utilisation as well as the disposal of ash residues. Even low concentrations of carbonaceous residues can be subject to biological attack forming simple organic compounds which may promote the leachability of certain metals such as Cu. Indeed, one continental directive for residenctal waste sets a total carbon limit of 1 wt% for catagory 1 landfill, whilist ash containing > 3 wt.% of carbon has to be treated prior to disposal. The carbon in bottom ashes from modern MSW incinerators can easily be kept < 3wt.%, and in grate design to allow good oxygen access, adequate temperature, and sufficient residence time of the bed material on the grate. However, to achieve high bed temperatires a sufficient calorific value of the waste is essential. The carbon content of bottom ash is mainly comprised of elemental carbon, but some organic compounds are also found covering the spectrum from short-chain compounds up to low volatile species such as PAH or PCDD/PCDF. It must be noted that the organic pollution level is much higher in the fly ashes than it is in the bottom ashes.

The PCDD/PCDF concentrations in the bottom ashes of modern combustion plants are of the same order of magnitude as found in uncontaminated soils. Thus in a recently performed test series, TEQ values of 0.8-2 ng/kg were found for bottom ashes from two German grate systems and a Danish incinerator, with rotary kiln incinerator residues among the lower values.

The concentration of some heavy metals are substantially enriched in bottom ashes compared to the mean values published for the earth's crust. Metals characterised by the high vapour pressure of most of their copmpounds, e.g. AS, Cd, or Hg, are obviously volatilised out of the fuel bed and may be ignored in most cases as far as the environmental compatibility of bottom ashes is concerned. On the other hand, due to the qench procedure used in the flue gas treatment, some volitilised heavy metals and their compounds will be deposited in the fly-ashes in addition to the carry-over of non-volatile heavy metals with this fly-ash.

The main objective of our present research programme is to convert toxic fly-ash from incinerators into a material which can be used in the construction industry. The approach is based on the fact that sintering or melting of this ash results in destruction of its toxic organic components, and also fixation of its heavy metal content to form an unleachable material which can be used to ensure the energy efficiency of the sintering/melting process. This is based on the application of a regenerative heating concept. The regenerators are a pair of pebble beds with novel hot valves which provide air preheat for the burners to a level of 1000 °C. Fuel is added to the preheated are to raise its temperature a few hundred degrees, then the ash is introduced as the hot gases enter a 'cyclone' separator. The fly-ash particles have an average size of 20-25 μm, and heat to the sintering temperature in the fraction of a second during which the particles reside in the cyclone. The particles are separated from the gas in the cyclone and pass into the pelletising or frit chamber. The gas is returned to the second pebble bed in the regenerator where its heat content is recovered.

In order to sinter the material, its temperature must be raised to the softening point. This is attained at a temperature of about 850 °C which is significantly lower than its melting point at 1300 °C. A key aspect of our work is the technique used to ensure the high energy efficiency of the sintering process. This is based on the application of an establishes regenerative heating concept as illustrated in the diagram. :-

The regenerators are a pair of pebble beds with novel hot valves which provide air preheat for the burner to a level of up to 1000 °C. Fuel is added to the preheated air to raise its temperature a few hundred degrees, then the ash is intruduced as the hot gases enter a cyclone chamber. The fly-ash particles have an average size of 20-25 μm, and heat to the sintering point during the fraction of a second that the particles reside in the pelletising chamber. The gases are separated to the second pebble bed in the regenerator where its heat content is recorvered. The cycle of reversing the flow through the regenerators by means of the four valves is repeated every 2 minutes.

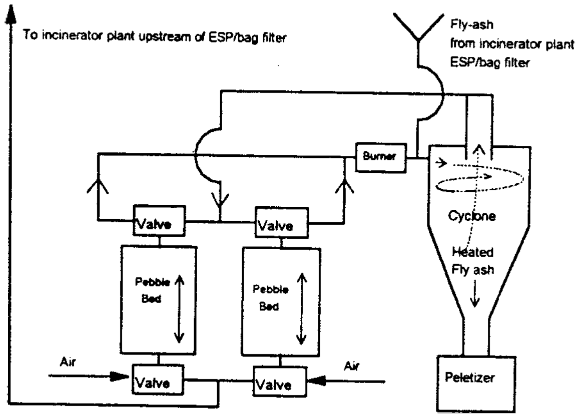
The same apparatus can raise the temperature of the particles to their fusion/slagging point at about 1300 °C. In this case the product is an unreachable frit produced by running the slag into a water quench. Although the use of the R.C.B. regenerative burner still ensures high energy efficiency for the process, in principle the sintering process should be somewhat more energy efficient. The choice between the two alternatives of sintering or melting will depend on our success in heating the fly-ash particles to the sintering point without melting the smallest particles. The optimum operating point will depend on the gas temperature and the ash fusion point. If they were to melt then they may stick to the walls and cause a bulid-up. In that case, we would increase the temperature to the point where the slag runs readily down the walls in the usual way. The walls would also have to be cooled to form a solid slag layer under the fluid layer in order to protect the walls from erosion. Thus both the sintering and slagging systems ate potentially viable and the optimum will be determined in the course of this research programme.

The calculation of the particle heat-up time is based on the conventional relationship:

$$m_p C_p \frac{dT_p}{dt} = hA(T_\infty - T_p)$$

where the heat transfer coefficient h is evaluatedn from the familiar relation:

$$Nu = \frac{hD_p}{k_\infty} = 2.0 + 0.6 Re_d^{1/2} \mathrm{Pr}^{1/3}$$



Schematic Diagram of our Sintering/Metling Pelletising Equipment

The ash particle heat up time must be matched to the residence time of the particles in the hot environment. If necessary, the ash can be introduced into the hot gas flow a significant distance upstream of the cyclone chamber. Calculations are being carried out/to check if there is any advantage in using two separate inlets into the cyclone chamber carrying swirling flow and axial flow respectively. This latter configuration may have advantages if ash fusion is to be used as shown in a recent Japanese study.

Finally, the total capability of the proposed equipment is of interest. As it happens, the output of the regenerative burner is 300kW, and this is sufficient heat to sinter about 0.2 kg/s. This is very approximately the amount of fly-ash produced by a typical municipal waste incinerator dealing with 10 tonnes/hour. Thus the results of the proposed research work may be applied almost immediately to solve an urgent industrial problem with world-wide potential.

The key parameters which are investigated in this project are;

- System operating conditions and design,
- The temperature and composition distribution,
- The decomposition conditions of dioxin/furan and fixation of heavy metals by sintering,
- The sinter properties (e.g. leachability),
- Investigation of heat recorvery (i.e. energy recycling),
- Process intensification.

Risk Assessment Studies of Municipal and Clinical Waste Incinerators:

The overall objective of this research programme is to provide a methodology for assessing the risks to human health (the work-force inside the incinerator plant) posed by municipal and clinical waste incinerators, which can be used directly by the incineration industry in the UK and Europe. Use of this methodology will improve the basis for decision making in assessments of the comparative benefits of alternative waste management strategies. The specific project objectives are :

- To review risk assessment methodologies with special reference to clinical waste incinerators,
- To establish a Best Practice Risk Assessment Methodology for municipal and clinical waste incinerators,
- To carry out a full risk assessment for a case study clinical incinerator (Sheffield clinical incinerator plant, 5 MW plant),
- To produce Specific Guidelines for use the incineration industry

Although the use of personal protective clothing and modern pollution technology should be able to minimise potential exposure to fly-ash and slag and the absorption of toxic chemicals from this source, work practice observation illustrating possible sources of dermal exposure are numerous (e.g. failure to wear protective clothing, direct handling of contaminated tools, equipment, failure to wash hands, forearms and face before smoking, eating or drinking). Several investigators have studied the potential exposures and adverse health effects that may ensue from exposure to the incineration by-products found in airborne emissions and the solid residues in ash and slag (plate 1&2). Potential toxic substances include heavy metals (lead, cadmium, mercury and arsenic), total respirable paarticulates, respirable quartz, dioxins/furans, polycyclic aromatic hydrocarbons and solvents including benzene.

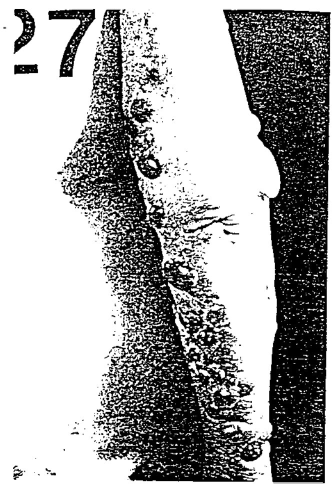


plate 1

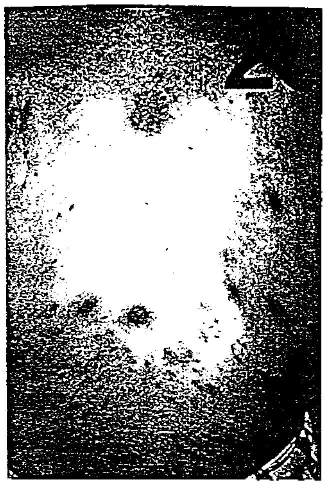


plate 2

In our preliminary environmental monitering programme carried out at the Sheffield clinical incinerator plant, we collected a number of wipe samples from 7 working surfaces in the plant where activities with the highest level of exposure to ash and incinerator waste were performed by the worker. These samples were then analysed for metals and organics. The adhesive tape method was used for particulate removal on working surfaces because of its superiority in recovery efficiency and suitability for application to irregular, curved and vertical surfaces. The results of the analysis by ICP-emission spectrometry showed significant amount of metals in the samples, in particular lead(Pb). The detected Pb levels ranged from 11.92 $\mu g/ 100\ cm^2$ in the boiler area (boiler door). Relatively high amount of arsenic, chromium, and cadmium were also found in the wipe samples taken from the boiler area (Table 8). Our preliminary results show the workers who clean the boilers tubes and the furnace can be classified as having the highest levels of exposure to metals in such an incinerator plant.

Conclusions

Waste disposal by incineration is now and will continue to be an important part of the solid waste

Table 8

	Lead	Arsenic	Cadmium	Chromium	Nickel
	μg/100 cm^2				
Sample 1-Ladder in Boiler area	134.53	3.27	1.02	9.2	2.38
Sample 2-Control room	11.92	2.95	0.47	2.62	1.05
Sample 3-Stairs indoor	122.95	5.44	1.42	14.29	4.04
Sample 4-Boiler door	11015.79	16.32	38.21	60.53	15.4
Sample 5-Furnace door	77.63	4.18	3.18	30.79	2.27
Sample 6-Filter press	786.32	6.03	3.22	30.05	9.38
Sample 7-Ash slagger trolley furnace area	239.63	5.07	0.38	35.89	4.08

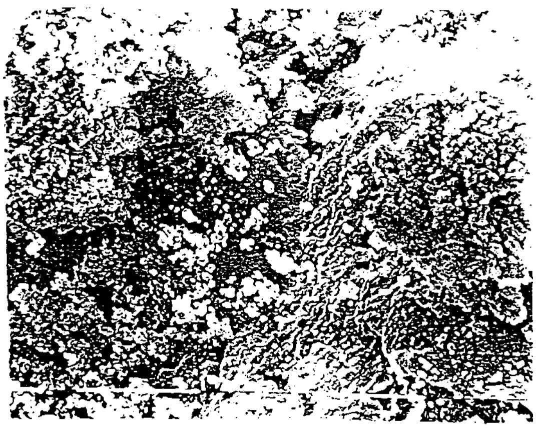


plate 3

Optical microscope and SEM/XPS examination of the fly-ash sample taken from a number of surfaces near to the boiler and furnace areas were also carried out (Plate 3). Lead(Pb) and arsenic(As) were detected in the first layer of the particles (10-30 Å).

Our preliminary theoretical dose calculation to estimate the uptake of lead at the OSHA PEL of 50 $\mu g/m^3$ suggests a dose of 0.4 mg for 8-hours shift. Assuming that a worker contacts approximately 200 cm^2 of work surface concentration of 2000 μg/ 100 cm^2 is required to give dose of 0.4 mg.

Conclusions

Waste disposal by incineration is now and will continue to be an important part of the solid waste management programme. Because of this reality and in the light of increasingly stringent environmental constraints and standards, reliable and effective incinerator designs and pollution abatement equipment fitted to waste burning facilities are urgently needed. Energy recovery can help to offset some of these costs. An understanding of the mechanisms of formation of TOMPs and PIC emissions is also essential for the design of control systems, and for setting appropriate operating conditions which optimise oxidative combustion. This is perhaps best illustrated in the case of PCDDs and PCDFs, where an application of the significance of post-combustion re-formation reactions has resulted in new strategies to minimise and control these emissions. Current advice on good combustion practice is based on a relatively small body of research and engineering experience, and there is considerable scope for further improvement in incinerator design and control in order to limit the formation of organic micro-pollutants. A particular challenge is to devise blending and control strategies that smooth out the transient upset conditions in incinerators.

It can also be concluded that the use of CFD models together with experimental data for incineration plants is a cheap and reliable technique for predicting plant performance and will be of considerable use to the Waste Incineration Industry world-wide. Research is now urgently needed to develop new Dioxin/Furan chemistry/physical models in conjugation with CFD so that accurate prediction can be made about the levels of TOMPs, their precursors and PICS having various combustion chambers.

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