MINIMUM DIOXIN WITH MAXIMUM RESOURCE RECOVERY

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Abstract

The Processed Refuse Fuel technology developed by Energy Answers Corporation (EAC) to maximize recovery of marketable materials and energy from municipal solid waste (MSW), in combination with modern emission control technology, demonstrates that dioxin* emissions from municipal waste combustors (MWC's) can be effectively controlled to extremely low levels. The combination of these technologies was incorporated into the 804 tonnes per day Unit No. 3 at the Southeastern Massachusetts Resource Recovery Facility (SEMASS) in Rochester, Massachusetts. Annual performance test data for this MWC unit show emission levels at, and for some pollutants including dioxin, far below stringent American, European Community (EC) and German standards for new MWC's. These low emission levels are met without compromising the maximum recovery of materials and energy from the waste stream, as evidenced by the Ecological Society of America awarding its 1996 Corporate Award for Resource Recycling to SEMASS, recognizing its "record of remarkable reduction of waste flow combined with environmental concern, done profitably and on a large regional scale."

Introduction

In the United States and many other areas of the world, there is a demand for options to manage MSW in an environmentally and economically sound manner. Programs to reduce, recycle, and compost are important first steps in managing MSW. However, these programs are credited with reducing the waste stream by only 22% [1] In the United States, most of the remaining waste is disposed of in landfills and the rest is managed at MWC facilities where materials and energy are recovered. In many areas, land use constraints, geographical features and concern for air and water quality preclude the development of new landfills.

Since the discovery of dioxin in the ash released from MWC's by researchers in the Netherlands, Canada, Japan, and Switzerland in the early 1980's, the combustion of MSW to recover energy and reduce the volume of the waste stream to be disposed of has been an increasingly high-profile and controversial waste management option. This discovery has resulted in close examination of the potential human health and ecological effects of dioxin emissions from MWC facilities. Extensive research has been conducted into the means by which dioxin is formed in, and emitted from, MWC units. The United States Environmental Protection Agency (USEPA) has studied MWC emissions and adopted increasingly stringent emission standards for new and existing MWC's, in both 1991 and 1995. Similarly, emission standards and guidelines for MWC's have been or are being

* *The term "dioxin" is used in this paper to refer to polychlorinated dibenzo-p-dioxin and furans.*

established in Europe and Japan. Although public concern and stringent regulations have contributed to the development of more efficient equipment designs and operational methods resulting in far lower emission levels, sometimes irrational public opposition continues to make the siting of new MWC facilities extremely difficult. As existing landfills reach capacity and the heretofore relatively unexplored risks imposed by landfilling are quantified and publicized to a greater degree, the siting of new landfills will likely meet opposition similar to that experienced by MWC's.

EAC, formed in 1981 to develop and build resource recovery systems, has developed a technology to manage MSW which both maximizes the recovery of materials and energy from MSW and, at the same time, minimizes air emissions to extremely low levels. Consistent with its philosophy of treating waste as a resource and its goal of achieving "zero disposal", EAC's technology provides a reliable source of recycled material for manufacturing, is a substitute for fossil fuel combustion to meet energy demands, and produces an alternative to quarried aggregates and traditional construction materials. Air emissions, most notably the emissions of dioxin, are effectively minimized by: 1) screening the waste stream to remove undesirable materials; 2) shredding the waste and magnetically removing ferrous metal to create Processed Refuse Fuel (PRF); 3) blowing the PRF into spreader-stoker boilers so that a significant portion burns most efficiently in suspension; 4) implementing good combustion practices (GCP) as defined by the USEPA; 5) rapidly cooling the flue gas downstream of the steam generating stages of the boiler; and 6) equipping the boiler with spray dryer absorber/fabric filter (SDA/FF) air pollution control technology. Annual performance test data for Unit No. 3 at SEMASS which incorporates these design and operational features show emission levels at, and for some pollutants far below, the stringent United States, EC and German standards for new MWC's. Dioxin levels in particular are extremely low and in some cases below the detection limit.

Waste Screening and Processing

At SEMASS, MSW is delivered to a large tipping floor where it is inspected both visually and with hand-held combustible gas detectors and radiation detectors for the presence of unacceptable waste (i.e. containers of hazardous materials such as solvents, oil, pesticides, and poisons, and materials which are not suitable for shredding such as carpets, rope, white goods, and large timbers). Unacceptable items removed from the waste stream are stored in a segregated area of the tipping floor for transport to more appropriate processing or recovery facilities. Approximately 1.6 percent by weight of the accepted waste stream is removed prior to processing. Plastic containers are not removed from the mixed waste received at SEMASS, but are processed and become part of the PRF. From the tipping floor, the MSW is pushed onto conveyors which feed hammermill shredders. The waste is shredded to six (6) inches or less in size, and then passed beneath a suspended overbelt magnetic separator. Approximately 40% to 50% of the ferrous metal in the waste stream is removed at this point for sale to markets. The remaining shredded material, now PRF, is a relatively uniform material which, at SEMASS, as a result of metal removal and moisture evaporation during processing, has an average higher heating value (HHV) of up to 3,000 kcal/kg as compared to unprocessed MSW with an average HHV which ranges from 2,400 to 2,800 kcal/kg.

In spite of front-end screening of the waste stream, it is likely that the PRF still contains organic compounds, including dioxin, but these compounds are destroyed by the high temperature (1,260 °C) attained in the suspension firing zone of the furnace. Of further significance, shredding and processing produces a more consistent waste heating value and moisture content, helping to prevent rapid changes in combustion air requirements and surges of highly volatile matter which can rapidly deplete local oxygen requirements. Such rapid changes are generally accompanied by elevated concentrations of organics and carbon monoxide (CO) [(2)]. These excursions, frequent in mass burn systems, are all but eliminated with the suspension burning of PRF.

Suspension Firing of PRF and Good Combustion Practices

Each MWC unit at SEMASS is designed to produce steam and generate electricity from the combustion of 804 tonnes per day of PRF having a HHV of 2,770 kcal/kg. The PRF is blown into the waterwall furnace of the MWC unit by a stream of distribution air at a point approximately 2 meters above a traveling grate. Lighter materials burn in midair while heavier portions of the fuel, including non-combustibles, drop to the rear of the grate where there is an exposure of approximately one (1) hour. The grate moves from the back to the front of the furnace at a speed adjusted to allow for complete burnout of any non-combustible material and an ash bed depth of 15 cm to 20 cm.

The furnaces of the MWC units at SEMASS are designed and operated such that those elements of GCP developed by the USEPA to maximize the furnace destruction of organics are implemented, thereby reducing the potential for downstream formation of dioxin. In addition to the distribution air used to blow the PRF into the furnace, underfire air is forced through the grate from a plenum and overfire air is injected through three (3) banks of nozzles, two (2) across the back of the furnace and one (1) across the front, providing turbulence to enhance mixing of the combustion gases. The height of the furnace is approximately 27.4 meters which allows for adequate residence time of the combustion gas at high temperatures. The flue gas is maintained above 980 ^{0}C for a period considerably longer than one (1) second after overfire air injection. The concentration of CO in the flue gas is typically within a range of from 45 mg/Nm^3 to 63 mg/Nm^3 at 11% O_2, well below the GCP level of 134 mg/Nm^3 at 11% O_2 for this type of MWC unit. Steam load, furnace temperature, and flue gas concentrations of O_2 and CO are continuously monitored and controlled to verify the destruction of organics in the furnace.

Suspension firing of PRF offers several advantages as compared to conventional ram-fed mass burn systems. These advantages include: 1) the fuel is combusted using significantly lower excess air, thereby increasing thermal efficiency; 2) the grate area is reduced by 2/3, thereby reducing the furnace footprint by over 60%; and 3) grate temperatures are maintained below the melting point of glass and most metals, thereby preventing slagging and producing a purer, granular bottom ash from which additional materials (ferrous and nonferrous metals) can be recovered and from which a substitute for natural aggregate can be produced. In terms of dioxin control, suspension firing does result in increased amounts of particulate matter (PM) carried out of the furnace, including some carbon particles. Although the higher PM levels are considered by some to contribute to the formation of dioxin, this apparent disadvantage is more than offset by rapid cooling of the flue gas downstream of the boiler and the unburned carbon content of the PM which is available to adsorb vapor-phase dioxin and mercury at lower flue gas temperatures in the air pollution control system.

Rapid Flue Gas Cooling

Despite best efforts to minimize organics leaving the furnace of an MWC unit, it has been found that dioxin can be formed in the intermediate temperature ranges that occur downstream of the combustion chamber. Current theory favors formation by de novo synthesis reactions on the surface of fly ash particles. This theory involves chlorinated phenol formation from benzene rings and chlorine atoms present in the flue gas. These precursor compounds are theoretically adsorbed on the surfaces of fly ash particles and then oxidized and further chlorinated to form dioxin. The dioxin then, in theory, splits into vapor and particulate fractions, with the vapor phase dominating at low flue gas temperatures [3]. The total amount formed is believed to be proportional to the amount of fly ash and the time the fly ash particles reside at temperatures ranging from about 150 °C to 450 °C. Maximum formation rates are observed at approximately 300 °C [4]. Thus, rapid cooling of the flue gas through this temperature range is a critical factor in minimizing dioxin emissions from an MWC unit.

At SEMASS, rapid cooling of the flue gas through the dioxin formation temperature range is achieved by a combination of heat recovery equipment and an SDA. The flue gas exits the primary heat recovery system at a temperature of approximately 425 °C and travels through an economizer and air preheater which reduces its temperature to approximately 200 °C. The flue gas then enters the SDA where a lime slurry is introduced for the purpose of controlling acid gases (primarily hydrogen chloride and sulfur dioxide). In addition to effectively reducing acid gas emissions, the SDA quickly lowers the flue gas temperature to about 135 °C, below the lower end of the dioxin formation temperature range.

Spray Dryer Absorber/Fabric Filter Control Technology

The final element which contributes to the extremely low dioxin emissions from Unit No. 3 at SEMASS is the use of SDA/FF technology. The importance of the SDA in rapidly cooling the flue gas is discussed above. Although some dioxin is captured in the residual SDA particulate, a portion of the dioxin is in the vapor phase and, therefore, the flue gas leaving the SDA must undergo particulate and vapor-phase organic pollutant removal. For Unit No. 3 at SEMASS, these final steps in the control process are accomplished with an FF. The porous cake which forms on the surface of the filter bags not only removes fine (inhalable) particles, it also retards the gas flow and provides a tremendous surface area to which the gas is exposed. These properties of the FF allow an opportunity for vapor-phase dioxin to be adsorbed from the gas stream onto the filter cake. This is particularly true for a suspension-fired MWC unit like Unit No. 3 where the carbon content of the PM collected in the FF averages about 2.7%. Simultaneous testing conducted at the inlet of the SDA and the outlet of the FF of Unit No. 3 demonstrated a dioxin control efficiency of 99.84%.

Emission Results

Unit No. 3 at SEMASS was permitted and equipped to meet the Subpart Ea standards (40 CFR Part 60, Subpart Ea) which were adopted by the USEPA in 1991. However, annual performance test data for this PRF-fired MWC unit demonstrate emission levels at the current, more stringent United States (adopted 1995), EC, and German standards for new facilities. In addition, for some pollutants including dioxin, emission levels are significantly lower than these standards for new facilities.

Summaries of the EC Directive, the German standards (17. BImSch V) and the USEPA's 1995 Subpart Eb Maximum Achievable Control Technology (MACT) standards (40 CFR Part 60, Subpart Eb) for new, large MWC's (converted to units of the EC and German standards) are shown in **Table 1**, along with permit limits and emissions performance data from Unit No. 3 at SEMASS for 1996. All of the emission standards, permit limits, and test results in **Table 1** are corrected to 11% O_2, dry basis, and standard conditions (0 °C and 1 atm). It should be noted that there are differences

TABLE 1 - MWC STANDARDS AND SEMASS TEST RESULTS

REGULATED EMISSIONS	USEPA MACT STANDARDS	EC DIRECTIVE	GERMAN STANDARDS	SEMASS BOILER NO. 3 PERMIT LIMITS	SEMASS BOILER NO. 3 1996 RESULTS
Particulate *milligrams / normal cubic meter*	17	39	10	26	0.350
Sulfur Dioxide *milligrams / normal cubic meter* *% removal*	61 80%	390	50 No Standard	61 80%	19.0 Test Not Required
Hydrogen Chloride *milligrams / normal cubic meter* *% removal*	29 95%	65	10 No Standard	29 95%	4.2 99.5%
Nitrogen Oxides *milligrams / normal cubic meter*	220	No Standard	200	264	175
Carbon Monoxide *milligrams / normal cubic meter*	134	130	50	134	57
Cadmium *micrograms / normal cubic meter*	15.3	Cd + Hg $\sum$= 200	Cd + Tl $\sum$=50	No Standard	<0.084
Lead *micrograms / normal cubic meter*	153	Pb,Cu,Cr,Mn, $\sum$= 500	Sb,As,Pb,Co,Cr,Cu Mn,V,Sn,Ni$\sum$=500	454	4.87
Mercury *micrograms / normal cubic meter* *% removal*	61 85%	Cd + Hg $\sum$= 200	50 No Standard	309 No Standard	2.80 Test Not Required
Dioxins/Furans ***nanograms / normal cubic meter (NATO Toxic Equivalent)***	**≈0.153 (No Standard)**	**No Standard**	**0.1**	**No Standard**	**0.00498**
nanograms / normal cubic meter (tetra-octa)	**9.97**	**No Standard**	**≈6 (No Standard)**	**23.0**	**0.319**

between United States and European standards with regard to regulatory flexibility for demonstrating compliance, as well as test methods used to measure emissions. There are also differences in waste composition between Europe and the United States. For example, MSW in the United States contains, on average, approximately twice as much mercury as MSW in Europe [5]. Factors like these should be considered when comparing emission requirements and serve to minimize the validity of strict comparisons.

Examination of the United States, EC and German standards and SEMASS performance data contained in **Table 1** supports two (2) noteworthy conclusions. First, it is evident that the sets of standards for new MWC units are similar in terms of the pollutants which are regulated and the magnitude of the emission limitations. The sets of standards require that new MWC units be equipped with control systems comprised of multiple, highly efficient technologies. Secondly, the performance data from Unit No. 3 at SEMASS show that the emissions from a MWC unit based on the PRF developed by EAC is effectively controlled to extremely low levels without segregation of plastics from the waste stream. The emissions of particulate matter, including metals, acid gases (sulfur dioxide and hydrogen chloride), nitrogen oxides, and CO from this existing unit are all at or below the sets of stringent standards for new MWC units. Most notably, the emissions of dioxin and mercury are well below their respective standards which are based on the use of carbon-based control systems on mass burn MWC units.

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