Comparison between MSW Ash and RDF Ash from Incineration Process

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presented to

Fifth North American Waste-to-Energy Conference

Research Triangle Park, NC

April 21-25, 1997

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ABSTRACT

Resource recovery plants with waste sorting process prior to incineration have not been successfully developed in many developing countries. The reuse potential of incineration ash in light of toxicity and compressive strength remains unclear due to the inhomogeneous composition and higher moisture content of solid waste in Taiwan. A comparative evaluation of the ash generated from two types of incineration processes were performed in this paper. The results indicate that fly ash collected from both types of incineration processes are classified as hazardous materials because of higher metal contents. The reuse of bottom ash collected from refuse-derived fuel incineration process as fine aggregate in concrete mixing would present 23% lower compressive strength as compared with the normal condition.

INTRODUCTION

In the midst of fast paced economic activities in Taiwan, the society demands and consumes a lot of natural resources and raw materials in the creation of products to enrich people's life. To cope with large amount of solid waste disposal with the landfill space at a preminm in this tiny island, over thirty municipal incinerators were planned to be built in the major metropolitan areas within the next decade. It is estimated that there will have over two millions tonnes of incineration ash generated every year after the year 2000 which would still accelerate the depletion of limited landfill space. However, continuous population growth requires more housing projects which inevitably request more production of river sand as part of the materials in concrete mixing. This further poses problems of erosion in light of the natural balance in the river eco-system. In recent years, several communities in Taiwan encounter an issue that the house they live were built using sea sand as surrogate raw materials in concrete mixing. The fast deterioration of those building would also create a hazard to the residents living in those communities. The term "sustainable development" has special meanings as the wellbeing of a population of twenty million in Taiwan, with the area no larger than thirty-six thousand square kilometers, must be sustained probably by the reuse of incineration ash as part of the raw materials in the future construction programs. This study tries to achieve part of the life cycle analysis of comsumer products as they are destined for final disposal in the municipal incinerators. The evaluation of reuse potential of those end products from incinerators can then be regarded as an action of resource conservation and recycling in the entire life cycle analysis.

Although Taiwan has set a bold agenda of solid waste incineration programs to conserve the landfill space in the last few years, the continuing thinking of an integrated incineration system with the sorting process as a pretreatment unit to improve the incineration efficiency and generate better quality of flue gas and ash has never been tempered. At least two proposals for installing such a sorting process prior to the large scale municipal incinerators, located in the City of Tai-Chung and the County of Taipei, were raised in 1996. In addition, such an integrated incineration system was also chosen for planning several medium size modular incinerators, that are located in the rural areas in Taiwan. But the property and reuse potential of those RDF ash remain unclear. The incineration ash from the MSW burning is currently being used for landfilling only in Taiwan. Backfilling of construction sites, subbase in road construction, and to some extent, reuse for concrete mixing have been fully carried out in several laboratory experiments. This analysis emphasizes the comparative study of property characterization and reuse potential of ash from MSW and RDF incineration processes, using local waste flow as fuels in Tainan area of Taiwan.

Two major facilities, located in Tainan area of Taiwan, were used as pilot plants in this experiment. One is a refuse-derived fuel process, and the other is a modular incinerator. Hence, two types of incineration processes can be arranged. One has a dedicated sorting process associated with a modular incinerator while the other has not such a sorting plant prior to incineration. The samples of municipal solid waste (MSW) in Tainan area of Taiwan were collected and then the refuse-derived fuel (RDF) were generated for the subsequent incineration. Incineration ash from the waste burning process were produced and collected from the bottom of ash discharge and the electrostatic precipitator hopper, as denoted by the "bottom ash" and "fly ash" respectively in this study. The properties of incineration ash were specifically characterized and the reuse potential of bottom ash as part of the raw materials in concrete mixing was also examined. In the first stage analysis, the unwashed incineration ash were tested and analyzed for TCLP (Toxicity Characteristic Leaching Procedure) metals and chemical composition using XRD and SEM/EDS techniques. In the second stage analysis, to further evaluate the reuse potential of bottom ash, the washed bottom ash from both types of incineration processes were tested by seieve analysis and compressive strenth analysis. Final suggestions were made based on the tested properties of those incineration ash.

LITERATURE REVIEW

In the last decade, a number of credible research efforts were carried out in both the European countries and United States ([1]~[3]) and the efficiency and effectiveness of resource recovery from solid waste associated with incineration system has been fully discussed ([4]~[12]). However,the impacts of solid waste sorting on incineration remain uncertain due to the higher moisture content and plastics in solid waste composition in Taiwan, which is not fairly representative of most other countries.

In addition, ash properties have been fully characterized in several municipal incinerators, such as in New York City, California, Singapore, and so on ([13]-[17]). Engineering evaluation of resource recovery for incineration ash has been performed ([18]-[19]). Specific purposes of ash utilization were fully discussed, such as the recovery and reuse of ash as the raw materials in concrete mixing ([20]-[23]), the reuse of ash as the subbase materials in road construction and gentechnical applications ([24]-25]), and even the recovery of fly ash as zeolite [26].

FACILITY DESCRIPTION

Solid Waste Sorting System

As is illustrated in Figure 1, the solid waste sorting process consists of three major units: shredding, air classification, and screening. The facility can process 30 tons/hr at maximum capacity per one line. The MSW is delivered to the facility by packer trucks. A bag-ripping unit, to open plastic bags, initializes the sorting process. Ferrous metal is then extracted from the MSW stream using magnets. Recovered ferrous metal is conveyed to a ferrous storage bin from where it is recycled. MSW is then processed in a vertical hammermill shredder to reduce it to a normal size. Shredded MSW is taken to an air classifier, using a belt-type conveyor. Non-ferrous materials, such as aluminum cans and combustibles are crushed by the vertical hammermill shredder. A manual sorting unit or eddy current separator could be added prior to the vertical hammermill shredder for the recovery of aluminum cans in the future. The air classifier, blowing with a regular air stream of 200 m^3/min from the vertical hammermill shredder, is intended to separate the inert materials, such as glass, ceramics, and so on, to reduce the content of heavy non-combustible material in he residual MSW streams. Light materials, passing through the air classifier, are sent into the trommel screen for advanced separation. The dimensions of the openings on the surface of trommel screen can be varied to fine-tune the processing function and assure maximum combustibles recovery. The trommel is designed with two concentric shells. The outer shell, with 2.33 meters in diameter and 4.3 meters in length, has many circular holes on the surface which is designed to remove the shredded materials smaller than 25 mm. The inner shell, with 1.9 meters in diameter and 4.56 meters in length, separates partial waste stream with the size between 25 and 100 mm. Three waste streams can be trommeled. In other words, particle size is controlled by the openings design on the surface of the trommel such that the material with the particle size less than 25 mm (trommel underflow) and the particle size between 25 mm and 100 mm (trommel middle flow) are separately arranged by two different sets of openings with a concentric shell configuration. The overflow, passing through this trommel screen, presents the most light portion in the MSW with the size greater than 100 mm (trommel overflow) , and can be identified as fluff-RDF. However, both outputs with particle size larger than 100 mm and between 25 mm and 100 mm can be used as fuels in the incineration facilities.

Solid Waste Incineration System

Figure 2 presents the system configuration of the modular incinerator. The 100 Kg/hour modular incinerator was designed is equiped with an electrostatic precipitator and a wet scrubber. From the silo the RDF or MSW is fed into the furnace where the combustion takes place on a 3-step movable grate system. The flue gases generated pass through the first furnace and is cooled down at the outlet of secondary furnace. The heat exchanger is installed at the outlet of secondary furnace for the preheating of auxiliary air. The flue gases are eventually led through air pollution control system, consisting of a conventional electrostatic precipitator (EP) followed by a wet scrubber. Reheat is provided to prevent visible flue gas emissions due to higher moisture content.

TCLP ANALYSIS

Samples of fly ash and bottom ash were analyzed in accordance with the TCLP requirements. Tables 1 and 2 list the analytical results of TCLP tests for both bottom ash and fly ash. Two replicates were prepared to meet the QA/QC requirements that generate the data ranges in both Tables 1 and 2. The leachability of regulated heavy metals is affected by waste composition, its combustion history, and handling method. This would differentiate the fundamental difference of ash from burning MSW and RDF.

The extracted metals from the fly ash in the RDF incineration process generally exhibit relatively lower concentrations. However, testing fly ash revealed that both types of fly ash generated from burning MSW and RDF can be classified as hazardous materials due to higher heavy metal content. But the extracted metals from the bottom ash of MSW and RDF burning exhibit relatively lower concentrations. The reason for the higher Zinc concentration leached from RDF bottom ash is still unclear. This is probably due to the higher percentages of paper content with printing ink in the RDF that is not Zinc-free products. Table 2 shows that extractable cadmium concentrations in both types of fly ash are far beyond the regulatory levels. This substantial differences would make the fly ash subject to post-treatment requirements, such as stabilization, solidification, vitrification, and even melting processes.

CHEMICAL COMPOSITION ANALYSIS

In order to have more comprehensive insight, tasks of phase identification of both fly ash and bottom ash by X-ray diffraction and SEM/EDS techniques have been performed in this analysis. Table 3 lists the chemical compositions of those fly ash and bottom ash. On the average, the ash mainly comprise of SiO_2, CaO, Al_2O_3, Fe_2O_3, ZnO, MgO, and Cr_2O_3. It appears that Fe_2O_3 constitutes the major part of fly ash. Besides, CaO is the highest content and SiO_2 is the second largest group in those bottom ash.

Sieve Analysis of Bottom Ash

Wider particle distribution exists in the bottom ash of MSW. The shape of the particles of MSW ash is relatively irregular and flaky. Higher amount of aluminum cans, metal tubes, iron wires and other ferrous metals exist in the MSW bottom ash that makes the recovery, recycle and reuse processes become much more difficult. After removing those impurities, Figure 3 illustrates the grading of the MSW and RDF bottom ash. Due to the poor setting of concrete were reported when "raw" incineration residues are used, washing process was therefore employed to remove part of light and fine materials before the samples were used in concrete mixing [21]. The results of sieve analysis of "unwashed" and "washed" ash samples were both listed in Tables 4 and 5. It shows that the particle size distributions of MSW and RDF bottom ash present similar patterns. But relatively higher percentage of light and fine materials exists in MSW bottom ash.

Compressive Strength Analysis

Table 6 lists the properties of normal sand, washed MSW and RDF ash. The fineness modulus of the MSW and RDF particles are 3.34 and 3.59 respectively, indicating a rather coarse grading. The specific gravity of the washed MSW and RDF samples are 2.27 and 2.38, respectively. The water adsorption values are 2.0%, 9.0%, and 7.4% corresponding to the normal sand, MSW, and RDF ash respectively. Although the specific gravity of washed incineration ash is similar to natural sand, the water adsorption value is three more times higher. In addition, the residual carbon contents in MSW and RDF bottom ash ranges from 2.63-2.66 (%) and 0.63-0.66 (%), respectively. These values indicate that MSW bottom ash has a higher amount of unburnt materials.

Tests of compressive strength were conducted using washed bottom ash as fine aggregate in a normal mix of 1:2:4 (cement:sand:coarse aggregate) at water cement ratio of 0.7. Ordinary Portland cement was used as it would be in the normal concrete preparation. The coarse aggregate is 20-mm maximum size crushed granite. The bulk density of concrete mixes using normal sand, MSW, and RDF ash as fine aggregate are 2,340 Kg/m^3, 2,100 Kg/m^3, and 2,110 Kg/m^3, respectively. The slump values of concrete mix with normal sand, MSW and RDF ash are 100 mm, 10 mm, and 20 mm, respectively. The initial setting time for the concrete with MSW or RDF ash is about 3 hr as compared to 2 hr for the concrete with normal sand. In general, concrete with incineration ash as fine aggregate have longer setting times than the samples with normal sand. It appears that all the mixes with incineration ash have lower workability. However, the setting times are well within the requirements of ASTM standards.

Cubic specimens (12mmx24mm) were then prepared and compressive strength of the specimens at various ages (i.e., 3, 7, 14, and 28 days) were tested according to ASTM Standards. Table 7 shows the ranges and averages of compressive strength of concrete mixes. The strength of different batch with normal sand mixes are generally higher than that of the mixes with washed MSW or RDF bottom ash. The compressive strength ratio versus age for those samples are depicted in Figure 4. The curve corresponding to the case using MSW bottom ash as fine aggregate present inconsistent trend as compared with the other two curves. This is probably due to the inhomogeneous nature of MSW ash samples. The average compressive strength of ash mixes are lower than that of the normal sand mixes at all ages. For concrete mixes with water-cement ratio of 0.7, the compressive strength of the MSW and RDF ash mixes are about 54.7% and 35.2% lower than normal sand mixes at the final stage with the age of 28 days, respectively. The reason why concrete mixes with RDF bottom ash presents higher compressive strength as compared with MSW bottom ash is mainly due to the existing of more uniformly distributed particle size in the RDF bottom ash. However, the design strength of normal concrete mixes is 210 Kg/cm^2 in Taiwan. This implies that compressive strength of concrete mixes with the washed RDF bottom ash as fine aggregate presents about 23% lower than the designed compressive strength of concrete mixes with normal sand. Such outcomes would limit the reuse potential of RDF bottom ash in some construction programs.

CONCLUSIONS

In recent years, the public is concerned about the changing characteristics of incineration in response to the increase of heating values, incinerator emissions and ash properties. This paper specifically investigates the ash property and reuse potential from burning two types of wastes (MSW and RDF) as fuels. The TCLP tests reveal that the bottom ash generated from burning MSW and RDF can be classified as non-hazardous materials. But both types of fly ash require post-treatment due to higher content of heavy metals. To evaluate the reuse potential of those bottom ash, compressive strength tests were also conducted using washed bottom ash as fine aggregate in a normal mix at general water-cement ratio conditions. These data are useful in determining which applications may be better suited for different sources of ash. Final suggestions of reuse potential of bottom ash as fine aggregate in concrete mixing can be made based on the tested properties of compressive strength and workability. Test results indicate that mass burn of MSW may result in a lower ash reuse potential due to inhomogeneous mixes. Overall, the inclusion of waste sorting process prior to the incineration facilities can provide RDF with better quality to the mass burn process and higher reuse potential of RDF bottom ash may be attained. However, due to relatively lower compressive strength as compared with normal concrete mixing, the reuse potential of incineration ash is rather limited in some construction programs.

Acknowledgement

The authors acknowledge the financial support from the National Science Council (NSC-85-2621-P-006-033) and helpful comments of anonymous referees in the review process.

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Table 1 ： TCLP analysis of bottom ash

	MSW	RDF	TCLP Standards
Pb(mg/L)	ND~ND<0.03	0.11~0.12	5.0
Cd(mg/L)	0.01~0.02	0.05~0.06	1.0
Cu(mg.L)	0.3~0.4	0.39~0.40	15
Zn(mg/L)	1.5~1.6	16.1~16.3	25
Cr(mg/L)	0.03~0.04	0.12~0.13	5.0
Hg(mg/L)	ND~ND<0.0002	ND~ND<0.0002	0.2
As(mg/L)	ND~ND<0.001	ND~ND<0.001	5.0
pH	11.8	10.2	—
Cr^{+6}(mg/L)	0.005~0.006	0.05~0.06	2.5
CN^-(mg/L)	ND~ND<0.002	ND~ND<0.002	—

Table 2 ： TCLP analysis of fly ash

	MSW	RDF	TCLP Standards
Pb(mg/L)	9.48~9.65	0.03~0.05	5.0
Cd(mg/L)	4.60~4.67	2.599~2.614	1.0
Cu(mg.L)	22.3~22.4	9.62~9.66	15
Zn(mg/L)	5.22~5.34	21.5~21.8	25
Cr(mg/L)	ND~ND<0.02	0.04~0.06	5.0
Hg(mg/L)	ND~ND<0.0002	ND~ND<0.0002	0.2
As(mg/L)	ND~ND<0.001	ND~ND<0.001	5.0
pH	5.6	5.0	—
Cr^{+6}(mg/L)	0.002~0.004	0.002~0.003	2.5
CN^-(mg/L)	0.002~0.003	ND~ND <0.002	—

Table 3 ： Chemical composition of ash

	MSW bottom ash	MSW fly ash	RDF bottom ash	RDF fly ash
CaO(%)	34.678	16.901	44.668	19.546
SiO_2(%)	18.653	12.481	19.861	20.186
Al_2O_3(%)	13.973	5.946	13.392	10.897
Fe_2O_3(%)	27.053	48.341	10.327	43.978
ZnO(%)	—	13.336	5.325	3.528
MgO(%)	5.492	—	4.577	1.590
Cr_2O_3(%)	—	2.926	1.836	0.164
total(%)	99.850	99.932	99.987	99.890

Table 4: Particle size distribution of RDF bottom ash

sieve no.	retained amount by weight (g)		accumulated amount by weight (g)		accumulated percent retained by weight(%)		accumulated percent passing by weight(%)	
	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed
#4	50	50	50	50	5.38	5.03	94.62	94.97
#8	96	96	146	146	15.70	14.69	84.30	85.31
#16	156	156	302	302	32.47	30.38	67.53	69.62
#30	178	178	480	480	51.61	48.29	48.39	51.71
#50	146	146	626	626	67.31	62.98	32.69	37.02
#100	176	176	802	802	86.24	80.68	13.76	19.32
#200	128	128	930	930	100.00	93.56	0.00	6.44
residual		64		994		100.00		0.00

Table 5: Particle size distribution of MSW bottom ash

sieve no.	retained amount by weight (g)		accumulated amount by weight (g)		accumulated percent retained by weight(%)		accumulated percent passing by weight(%)	
	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed
#4	56	56	56	56	6.35	5.81	93.65	94.19
#8	112	112	168	168	19.05	17.43	80.95	82.57
#16	96	96	264	264	29.93	27.39	70.07	72.61
#30	114	114	378	378	42.86	39.21	57.14	60.79
#50	104	104	482	482	54.65	50.00	45.35	50.00
#100	230	230	712	712	80.73	73.86	19.27	26.14
#200	170	170	882	882	100.00	91.49	0.00	8.51
residual		82		964		100.00		0.00

Table 6: Properties of normal sand, MSW and RDF ash

property	average or ranges		
	washed MSW bottom ash	washed RDF bottom ash	normal sand
fineness modulus	3.59	3.34	-
specific gravity	2.27	2.38	2.66
water adsorption (%) (at dry basis)	7.4	9	2.0
carbon content (%)	2.60~2.67	0.63~0.66	-

Table 7: Compressive strength of concrete mixes over different ages

choice of fine aggregate	age (day)	compressive strength (kg/cm^2)	
		ranges	average
normal sand	3	106.1~114.9	111.9
washed MSW bottom ash	3	44.2~70.7	58.9
washed RDF bottom ash	3	88.4~97.3	91.3
normal sand	7	150.3~185.7	167.9
washed MSW bottom ash	7	61.8~79.5	73.6
washed RDF bottom ash	7	70.7~128.2	107.5
normal sand	14	194.5~203.4	197.4
washed MSW bottom ash	14	88.4~114.9	106.1
washed RDF bottom ash	14	97.2~150.3	126.7
normal sand	28	221.1~274.1	241.6
washed MSW bottom ash	28	88.4~123.8	109.1
washed RDF bottom ash	28	132.6~176.8	156.2

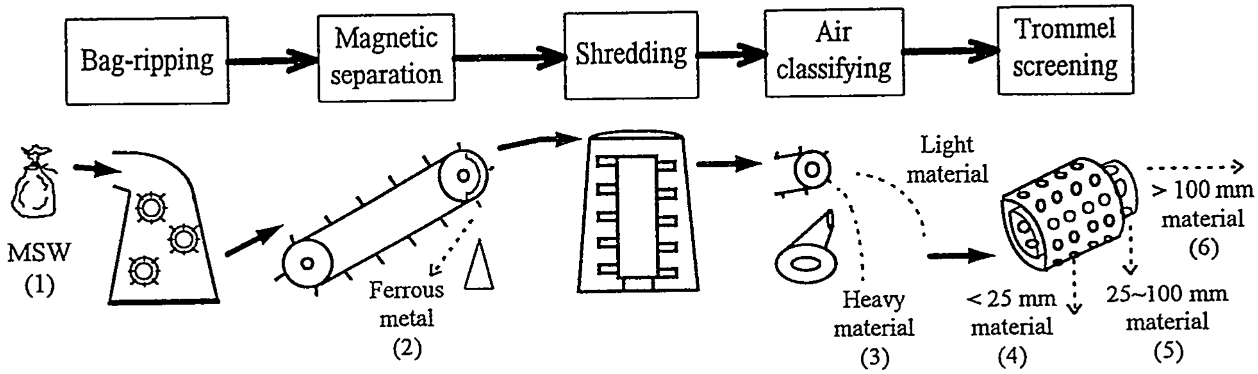

Figure 1: The system configuration of solid waste sorting process

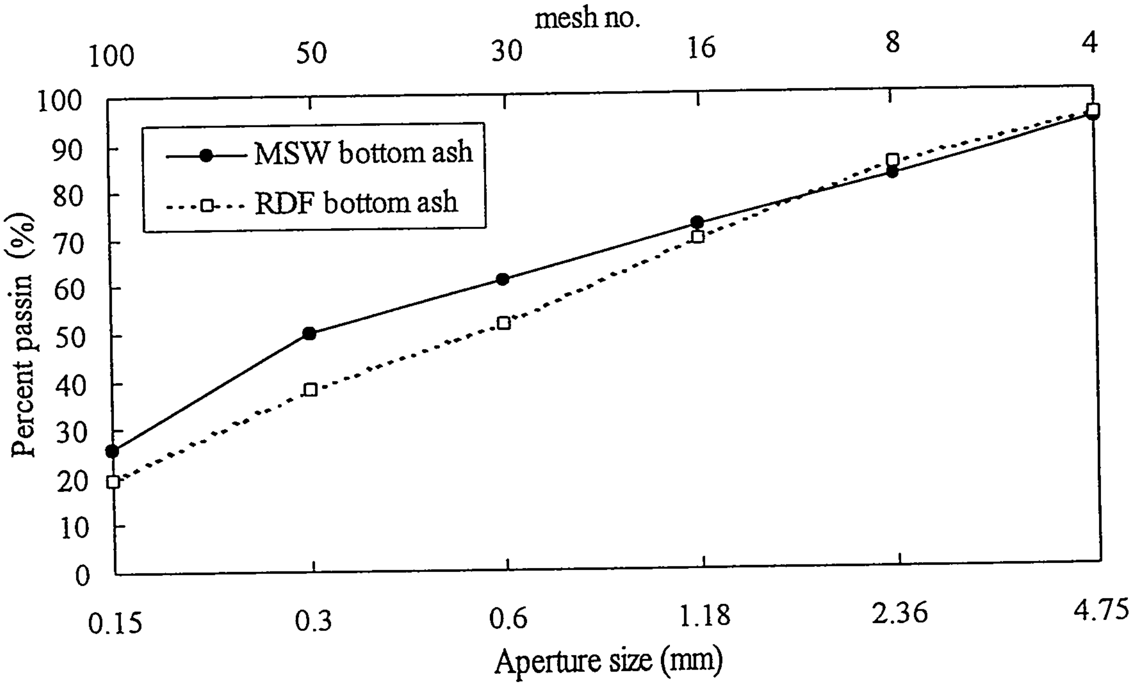

Figure 3: Grading of washed MSW and RDF bottom ash

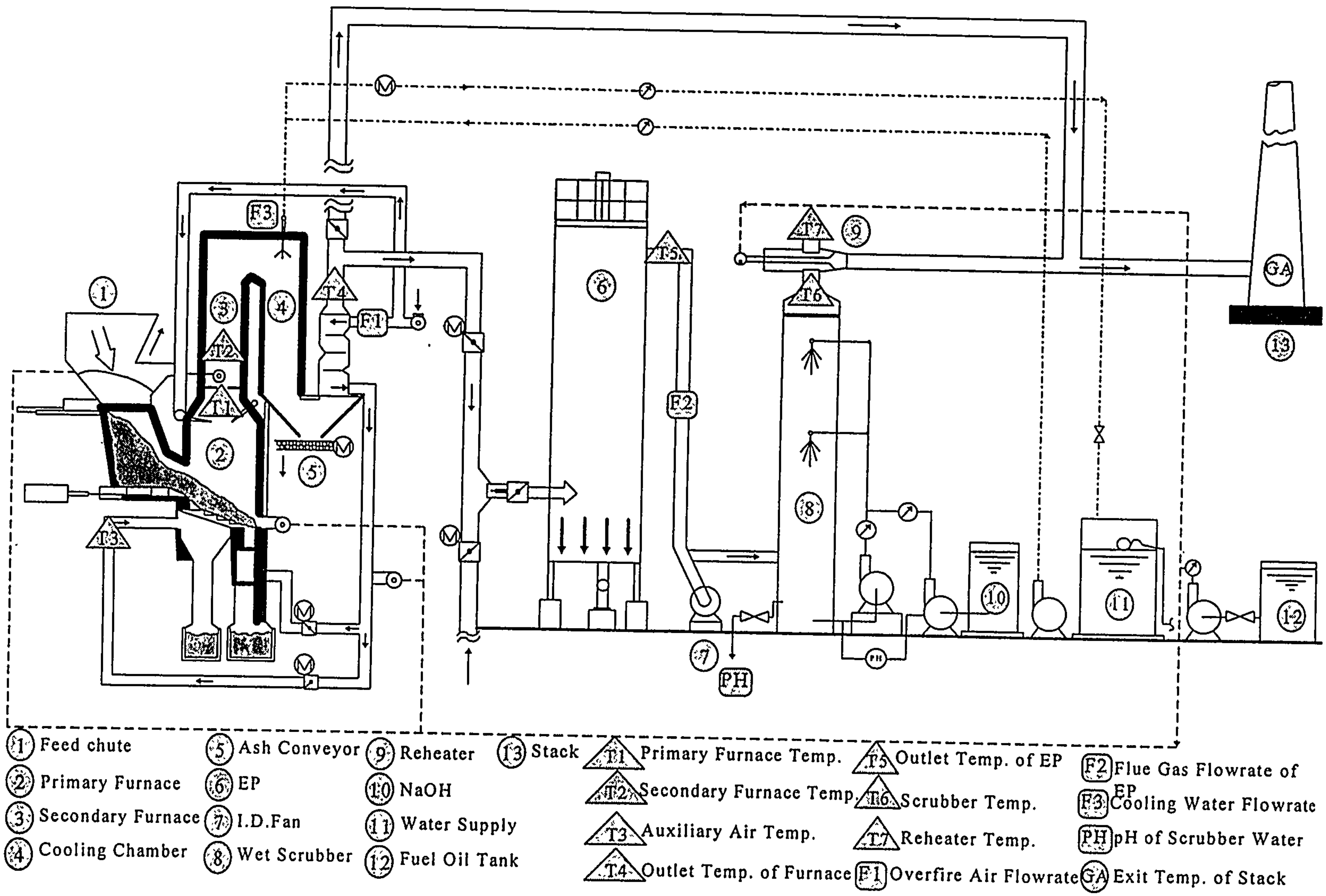

Figure 2: The system configuration of solid waste incineration process

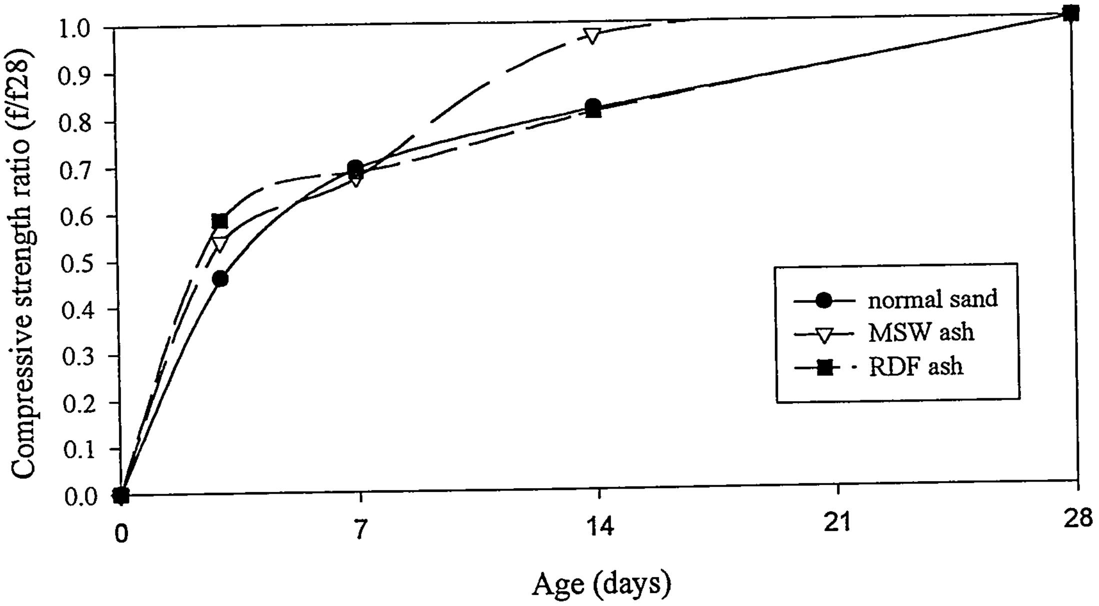

Figure 4: Compressive strength ratio versus age for different condictions of concrete mixing

Investigation into Seasonal Differences of Municipal Solid Waste Combustion Ash Leachate

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INTRODUCTION

Interests in the reuse and recycling of municipal solid waste (MSW) combustion ash have increased as practical uses for this material improve. Among factors that warrant further investigation as interests rise for ash reuse is the variability of ash and ash leachate characteristics due to seasonal variations in the composition of the waste stream combusted. Since the constituents of MSW can vary by season, (1) a logical assumption is that ash from the combustion of such waste also varies. Montgomery County, Maryland investigated the seasonal variations in the characterization of MSW ash and MSW ash landfill leachate from their Waste-to-Energy facility over a period of eighteen months.

BACKGROUND

Demographics

Montgomery County, Maryland, approximately 495 square miles in size, is located in the south-central portion of the state, northwest and immediately adjacent to Washington, DC. Population in 1996 was approximately 810,000 (2), the highest population of any Maryland jurisdiction and comparable to the population of Indianapolis or San Francisco. There are about 315,000 households in the County, with about 215,000 of those single-family households. There are approximately 20,000 businesses in the County. While the County is headquarters for companies such as Lockheed Martin and Marriott, most businesses are relatively small, with about 80 percent employing fewer than 100 individuals. There is very little manufacturing or heavy industry in the County. Most businesses are service oriented.

The Municipal Solid Waste Management System

Municipal solid waste generated in the County is managed through a comprehensive, integrated system that includes aggressive waste reduction measures, curbside and drop-off recycling services, waste-to-energy, composting and landfilling. The system employs five facilities including a materials recycling center for processing co-mingled recyclable material and newspapers; a yard waste composting facility; a transfer station complex that includes waste and recyclables drop-off by citizens, yard material grinding, small quantity hazardous waste drop-off, and MSW receiving and transfer to a rail transportation system; a waste-to-energy facility that receives waste only from the transfer station via the rail transportation system; and a landfill that provides disposal for non-processible waste and includes a separate ash monofill. All facilities are operated by the County or on their behalf through contracted operators.

The County generates approximately 900,000 tons per year of municipal solid waste, with about 540,000 tons from the residential sector and approximately 360,000 tons per year from the non-residential sector. Approximately 315,000 tons of waste -- a 35% recycling rate -- were recycled in 1995. Approximately 475,000 tons, are combusted in the County's waste-to-energy facility. The remainder, mostly from commercial generators, is exported from the County for disposal and/or recycling.

The County provides curbside recycling services for the collection of newspapers, mixed glass, aluminum and bi-metal cans, and High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) plastic containers. The newspapers are kept separate from other materials during collection and are transferred to a private processing facility. The other materials are co-mingled during collection and are separated and processed at the County's Materials Recycling Center. The County intends to expand residential recycling and initiate a mixed paper collection program during the early part of 1998. County law also requires that commercial facilities and multi-family dwellings institute recycling programs. At a minimum, commercial facilities must recycle corrugated cardboard, office paper, newspaper, aluminum and bi-metal cans, glass, plastic, and yard waste. The combination of residential, multi-family and commercial recycling programs has enabled Montgomery County to recycle approximately 35 percent of its waste stream. The County has a goal of achieving a 50 percent recycling rate by the year 2000.

WASTE COMPOSITION

A substantial portion of the current recycling rate is due to a yard waste ban which the County instituted in 1994. Yard waste is not accepted at disposal facilities and is now composted either by property owners, or is collected from residents and delivered to the County's yard waste compost facility. Therefore, the historic seasonal fluctuations previously associated with spring and summer surges of yard waste material have been largely removed from the disposal stream. County studies have shown that waste composition remains relatively consistent throughout the year, although volume decreases in winter months due to lower activity in general.

From 1994 through 1996, Montgomery County conducted quarterly characterization studies of municipal solid waste delivered to the County's Transfer Station. The intent of these studies was to generate data necessary to evaluate existing waste reduction, recycling and disposal programs, and to plan and implement new programs.

Waste sorters randomly selected 75 MSW samples during a one-week period in February, May, August and November. The minimum weight for each sample was 300 pounds, yielding a total weekly sample size of over 10 tons. Wastes were sorted by hand into over 50 categories for each of the three generating sectors: (1) single-family residential; (2) multi-family residential; and (3) non-residential.

Of the 75 samples taken each quarter, 30 were taken from vehicles delivering waste from the non-residential sector, 25 samples were taken from vehicles collecting from single-family residential homes, and 20 samples were taken from vehicles collecting from multi-family residential units exclusively. The County also calculated the aggregate composition of the full MSW disposal stream using weighted data from each of the three sectors.

Hazardous material segregated through the sampling included batteries, solvents, corrosives (typically cleaning fluids), fuels, and poisons (typically pesticides and herbicides). In each of the four seasonal samplings hazardous materials constituted less than one percent of the municipal solid waste processed by the County. Other major components of the waste stream also varied minimally from season to season.

Aggregated data for waste stream composition from calendar year 1995 is presented in Table 1. This is the only calendar year where sampling occurred in all four seasons.

LANDFILL LEACHATE

Landfill Design

The County is served by one active and permitted municipal solid waste landfill. The landfill became operational in June, 1982, and received approval for a vertical expansion in February, 1990. A separate area of the landfill was approved as a monofill for accepting ash from the waste-to-energy facility, and became operational with the waste-to-energy facility in May, 1995. The original landfill design included a prepared floor with compacted soil that met a permeability of $6x10^{-6}$ cm/sec or less. A leachate collection system was constructed with a series of trenches filled with crushed stone and perforated lateral collection pipe. These pipes lead to trenches with perforated header pipes also embedded in crushed stone. The design for the vertical expansion incorporated this older design into a new perimeter collection system. Design of the vertical expansion consisted of geonet with filter fabric placed over an 80 mil HDPE liner that was placed predominately over the top of the original landfill. One foot of highly permeable rounded stone overlays the geonet.

Leachate flows by gravity to HDPE perforated collection pipes at the base of the new cells and then to lateral HDPE pipes. These lateral pipes subsequently direct leachate to manholes located outside the disposal area and then to a common leachate conveyance system that transports the material by gravity to a leachate lift-pump station. Leachate from the original area of the landfill and the vertical expansion are co-mingled in the header piping surrounding the fill area. However, leachate from the ash monofill remains separated until it intersects the primary conveyance system that directs the leachate to the leachate lift pump. At that intersection a manhole provides access for separate sampling of the ash leachate and the MSW leachate.

Leachate is then pumped into one of two double-lined open leachate storage lagoons that hold the leachate prior to on-site pre-treatment. A total of approximately 7,000,000 tons of MSW have been placed in the landfill since operations began in June, 1982 through December, 1996. Ash from the County's RRF, which began test burning in May, 1995, has been disposed in the dedicated ash disposal cell with approximately 200,000 tons of ash disposed to date. No daily or intermediate cover is required for the ash since litter and vector control are not of concern, and the ash moisture content is such that dusting of the ash is minimized.

The volume of leachate generated ranged from zero gallons per month to approximately 140,000 gallons per month before the landfill's expansion. The range of volume generated has been higher after the landfill's expansion because the new HDPE-lined cells are more effectively collecting leachate compared to the older soil-lined cells. For example, the amount of leachate generated at the landfill in 1996 has ranged from approximately 46,000 gallons in August to approximately 1,650,000 gallons in November, with a total leachate influent from the landfill of approximately 10,000,000 gallons in 1996.

The County pre-treats the leachate generated by the landfill before disposing of the liquid in a sanitary sewer. The County selected a biological process system that uses a fixed film process for reduction of the leachate's organic content. The selected system also incorporates elements of physical and chemical treatment. The process system selected, and now operational, is capable of processing up to 30,000 gpd at 1,500 mg/l BOD concentrations. The system has the hydraulic capacity of handling up to 60,000 gpd. Biological activity occurs in two 36 foot by 9 foot by 8.5 foot bioreactors. Each bioreactor has four cells where organic reduction occurs. Each of the eight cells currently uses aerobic treatment to decompose organic constituents, with the capability for conversion to anaerobic treatment if leachate conditions warrant. Reactors are made of coated carbon steel and enclose corrugated polyvinylchloride sheets laminated together at opposite angles so that a cross flow matrix occurs. This design creates almost 105,000 square feet of effective surface area media. The media is the site for organism attachment and growth.

Untreated leachate is pumped from one of the two synthetically double-lined open storage lagoons, through a feed line to centrifugal influent pumps. Gentle agitation via the flocculation mixer creates growth and aggregation of particles, including metals. As much as 90 percent removal of metals can occur through this precipitation process. Clarified leachate from the precipitation process spills over a weir and flows by gravity to a splitter box. The splitter box directs equal liquid flow to the two bioreactors. Clarified effluent from the bioreactors flows by gravity to a 400 gallon effluent holding tank, where a horizontal centrifugal pump sends the pre-treated leachate to the synthetic double-lined storage lagoon. Pre-treated leachate is pumped into tanker trucks from the storage lagoon and hauled to a sanitary sewer where it is discharged for final treatment.

Sampling Protocol

Although the County is not required to sample ash leachate, it wanted to gather data regarding this material and began sampling in September, 1995. Samples of untreated ash leachate are taken monthly from a manhole that enables access for sampling the ash leachate separate from the other leachate. Sixteen constituents in the leachate are analyzed monthly (Table 2). Two constituents -- antimony and fats, oil and grease were detected in minimal concentrations, and are not included in Table 2. Grab samples are taken for fats, oil and grease analysis, while all other samples are composite samples. Samples are collected in 3.8 liter plastic containers, and then transported to a state-certified laboratory. Chain-of-custody controls are maintained through the conclusion of constituent analyses.

Ash Field Leachate Results and Discussion

Table 2 shows monthly sampling results for 14 constituents analyzed in the County's ash field leachate for the period between September, 1995 (when the ash leachate sampling program began) through December, 1996. There is no readily apparent pattern in constituent levels due to season or other factors. Most metals have been at non-detectable levels since April, 1996 (when the metal sampling program was broadened to include antimony, arsenic, cooper, chromium, mercury and nickel). Where there seems to be some evidence of possible seasonal effects -- total dissolved solids' levels are higher in October-December, 1995 than those in other months -- there is no replication of this phenomena in October-December, 1996. Levels for the latter period are similar to those of other months and seasons.

Values for the ash leachate constituents appear to be in the range reported in the literature (Table 3). County data presented in Table 3 is the mean for all observations of the particular constituent since the sampling program began for that particular constituent. Generally speaking, metal concentrations in the County's ash leachate appear to be in the lower part of the range reported in the literature. Table 4 displays 1996 data by season. The three month periods listed in the table are meant to correspond to the four seasons. The mean and standard deviation for these observations are also provided. No other statistical analyses were performed for these data because of the limited number of observations and the possibility that they might not provide an accurate representation of the actual situation. Indeed, there are some data where the standard deviation is larger than the mean (e.g., Biochemical Oxygen Demand) and other data where the standard deviation is comparable to the mean (e.g., Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS)). Comparing the mean and standard deviation provides a casual method of finding changes in the constituents.

There are instances where constituents seem to vary significantly from the mean and from other seasonal concentrations. COD in July-September and in October-December is less concentrated than its mean concentration and also compared to concentrations in other season. There is a similar pattern in TSS concentrations. A comparison of these data with constituent levels in pretreated leachate shows similar patterns (Table 5). Whatever factors causing these concentration variations in the ash leachate seem to be affecting the general leachate population. Other factors besides potential seasonal variation in waste characteristics that might affect leachate concentrations are age of the landfill and its waste, types of waste in the landfill, precipitation and volumes of raw leachate discharged from the landfill to the storage lagoons. It is difficult to ascertain a pattern of seasonal waste effects based on current landfill leachate data. More historical leachate data will help to clarify the question of possible seasonal effects from waste characteristics.

ASH CHARACTERIZATION

WTE Facility Design

Montgomery County's WTE facility is a mass-burn design with three 600 tpd units. The facility utilizes the Martin grate technology, and is operated by Ogden Martin Systems of Montgomery, Inc. The facility employs a semi-dry scrubber and reverse air baghouse as its principal air emissions control equipment. Fly ash is conveyed in enclosed augers from the baghouse, in reverse direction of the gas path, collecting spent scrubber residue and ash from various areas of the boiler. Fly ash and bottom ash are combined below the boiler and conveyed to a single ash storage pit before being removed for off-site disposal. In addition, dolomitic lime is introduced to the fly ash to help ensure that metals do not leach from the ash in unacceptable concentrations.

Acid gases are also controlled by injection of dry lime directly into the furnace area of the boiler. The furnace dry lime injection (FDLI) system operates in standby mode, and is secondary to the semi-dry scrubber. It functions in hand with the scrubber through a continuous emissions monitoring (CEM) system. The CEM reads the concentrations of SO_2 in the gas path at the scrubber exit. As acid gas concentrations rise in the scrubber exit, the feed mechanism of the scrubber is signaled and the system begins feeding additional lime into the scrubber. If the lime feed rate in the scrubber rises beyond a set point, the FDLI system is signaled and dry hydrated lime begins to feed into the boiler at a rate that is set to "catch" the rising concentrations and reduce them to a level managed only by the scrubber. Once controlled, the FDLI system is put back into a standby mode.

NO_x is controlled by a selective non-catalytic reaction (SNCR) which utilizes aqueous ammonia to reduce NO_x. Ammonia is injected into the furnace area of the boiler above the point of the FDLI nozzles.

Mercury and other organics and trace metals are controlled through the injection of dry activated carbon into the gas path before the scrubber inlet. The scrubber and baghouse help to control these parameters as well.

The CEM system reads seven parameters – CO, CO_2, O_2, NO_x, SO_2, HCl, and opacity – on a continuous basis. Data is averaged over various time periods, depending on the permit requirements for that parameter. The CEM system continuously sends signals to the operating equipment and control mechanisms to actively influence the feed rates of all reagents in the air emission control system and related operations such as fuel feed rate and combustion air volumes.

Sampling Protocol

In accordance with the requirements of the Maryland Department of the Environment (MDE), an ash characterization program was implemented at the facility. Discussions with MDE and USEPA staff, and the use of their guidance documents, formed the basis of the County's sampling protocol that was developed before the facility came on line in 1995. The program follows the widely used protocol identified in USEPA documentation.(3)(4)(5) Sampling has been conducted every calendar quarter since the facility became operational. In each sampling event the full complement of TCLP metal and organics testing was performed.

Combined ash is sampled across the width of a vibrating conveyor just before it is fed into containers for transport off site. This location is consistent with USEPA's January 1995 decision regarding the point of generation at WTE facilities, and properly represents the ash that leaves the site for disposal. The facility stores its ash in a pit before it is processed for ferrous metal recovery and containerized for transport. Because the pit can be excavated faster than the ash enters it, a determination was made as to how frequently ash is to be sampled to ensure a representative sample over an operating shift of the boilers. Sampling is scheduled to provide fourteen grab samples for each operating shift, based on the excavation rate of the pit. Because operations are based on a 12-hour shift, sampling represents a 24-hour operating period.

The grab samples that represent a single shift are combined to form a shift composite sample. Collecting for two shifts per day, fourteen shift composite samples are collected over the course of seven days of sampling. Each shift composite sample is derived by properly mixing, and quartering the grab samples for that shift. Four sub-samples are created from each shift composite sample. The sub-samples are mixed, screened for sizing material -3/8" and +3/8 -2", crushed where required and screened again, and weighed. Sample aliquots for TCLP extraction are prepared by mixing proportional amounts from both sizes of material.

All samples are labeled and protected throughout the process using chain of custody procedures. Laboratory procedures follow established protocol for TCLP testing and reporting.

TCLP Results and Discussion

Ash from Montgomery County's WTE facility continues to test as a non-hazardous material. As expected, organic compounds, herbicides and pesticides are non-detectable. The test results of the metals analyses are summarized in Table 6. Montgomery County has chosen to report and use all test data for calculation of the upper confidence interval (UCI) – including statistical outliers that are determined based on Chauvenet's Criterion. Their inclusion in the data raise the respective UCI for that analyte and that test event.

A review of the data suggests that three metals (Arsenic, Selenium and Silver) have not been detected in any test. One metal (Barium) has been detected twice, and Chromium has been detected once, all at levels that were approximately one-half of one percent or less of their regulatory thresholds.

Cadmium and Lead, generally the most closely observed analytes, were both detected. However it is worth noting that Lead was reportable in only two events (29%), and at only 6.4% to 8.8% of its regulatory threshold. Statistical outliers, based on Chauvenet's Criterion, are included in the data for Lead in both test events where it was detected. Cadmium was reportable in all seven events at levels that ranged from 1.9% to 46.6% of its regulatory threshold. Statistical outliers are included in the data for Cadmium in all but the May and August test events.

Mercury was detected in four of seven test events, but at levels that range from 0.3% to 1.9% of its regulatory threshold. It appears that capturing Mercury from the gas stream has indeed resulted in its deposit in the ash. However, because Mercury control technology is not operating on many WTE plants with a scrubber and baghouse, additional data is needed to substantiate this observation.

Because most tests did not result in consistent detection of analytes, Cadmium is the only analyte that can be compared seasonally. As with landfill leachate data, it is difficult to ascertain a pattern of seasonal effects on ash leachate by comparing the Cadmium results.

CONCLUSIONS

Data collected to date from the Montgomery County waste-to-energy facility do not clearly indicate seasonal affects on the leachate from the ash or leachate from the ash disposal cell, at least with respect to the parameters of regulatory concern which have been reviewed herein. One reason for this may be that the output of a waste disposal facility is in good measure a function of the input to that facility. The composition of waste entering Montgomery County facilities has not demonstrated marked seasonal variations. Given the consistency of the waste stream and the effect that lime has in stabilizing ash from the combustion process, the lack of hazardous constituents in ash leachate, and the general lack of definable seasonal variations is not necessarily surprising.

Montgomery County will continue periodic testing of ash residue and landfill leachate. A more substantial database will evolve over the next few years which will enable review of these findings.

References

1. Handbook of Solid Waste Management, F. Kreith, Editor-in-Chief, McGraw Hill, New York, 1994, Page 3.33.

2. Maryland National-Capital Park and Planning Commission, Washington, DC, personal communications, December 11, 1995.

3. Sampling and Analysis of Municipal Refuse Incinerator Ash, US Environmental Protection Agency, May 1994.

4. Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic, EPA 530-R-95-306, US Environmental Protection Agency, June 1995.

5. Manual SW-946 - Test Methods for Evaluating Solid Waste - Physical/Chemical Methods, US Environmental Protection Agency, March 1992.

6. Introduction to Environmental Statistics, Environmental Protection Agency.

Table 1. **Waste Stream Composition.** (1)

Material Type	Percent by Weight
Paper Products	44
Organics	30
Plastics	10
Glass	4
Ferrous Metals	3
Wood	3
Inert Materials	3
Yard Waste	2
Non-ferrous Metals	1
Hazardous Materials	<1

(1) Aggregated data from 1995. Paper, plastics, metals, glass and yard waste result from portions of the waste stream not captured by recycling programs.

Table 2. **Montgomery County (MD) Landfill Ash Leachate Analytical Results (mg/L).**

Month	pH	BOD	COD	TDS	TSS	Sulfates	Chlorides	Cadmium	Lead	Arsenic	Chromium	Copper	Mercury	Nickel
1995														
September	6.0	40	870	20,000	37	220	9,800	0.02	0.04	NS	NS	NS	NS	NS
October	6.2	16	1,200	37,000	66	520	20,000	0.05	0.86	NS	NS	NS	NS	NS
November	6.2	780	1,800	48,000	96	530	23,000	0.02	0.50	NS	NS	NS	NS	NS
December	6.7	110	2,000	80,000	48	860	42,000	0.05	0.60	NS	NS	NS	NS	NS
1996														
January	8.3	240	550	21,000	270	320	14,000	ND	0.30	NS	NS	NS	NS	NS
February	6.1	1,200	1,700	82,000	950	780	47,000	ND	1.00	NS	NS	NS	NS	NS
March	6.3	320	2,100	40,000	370	470	35,000	ND	ND	NS	NS	NS	NS	NS
April	6.0	160	1,100	32,000	310	450	16,000	ND	0.10	ND	ND	0.01	ND	0.14
May	6.1	75	620	21,000	33	290	12,000	ND	ND	ND	0.02	ND	ND	0.07
June	5.9	72	500	28,000	530	220	13,000	ND	ND	ND	ND	ND	ND	ND
July	6.2	70	340	38,000	160	500	19,000	ND	ND	ND	ND	ND	ND	ND
August	6.5	ND	200	23,000	70	240	13,000	ND	ND	ND	ND	0.06	ND	ND
September	6.5	15	140	20,000	240	240	10,000	ND	ND	ND	0.02	0.02	ND	ND
October	6.5	5	280	23,000	37	600	12,000	ND	ND	ND	ND	0.02	ND	ND
November	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
December	7.3	100	260	23,000	76	150	10,000	ND	ND	ND	ND	ND	ND	ND

NS- Not Sampled

ND- Not Detected within Methodology Limits

Table 3. Comparison of Montgomery County (MD) Landfill Ash Leachate Inorganic Constituents for 1996 with Literature Reported Results for Ash Leachate (mg/L).

Source	pH	Chloride	Sulfate	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel
Montgomery County	6.45	19,720	426	0	ND	0.003	0.007	0.227	ND	0.014
Bagchi-a	8.47-9.94	33-305	105-1,440	<0.2	0.004-0.3	0.01-0.044	.026-0.103	0.15-0.6	<0.0002	0.01-0.03
CORRE Study-b	6.41	NA	1,259	ND-0.4	ND-0.004	ND-0.032	ND-0.012	ND-0.054	ND	NA

NA-Not Analyzed

ND- Not Detected within Methodology Limits

a-"Design, Construction and Monitoring of Sanitary Landfill," A. Bagchi, John Wiley and Sons, 1990, p. 41.

b- "Characterization of Municipal Waste Combustion Ash, Ash Extracts and Leachates," U.S. Environmental Protection Agency, EPA 530-SW-90-029A, March 1990, p. 7-21

Table 4. Seasonal Average of Ash Leachate Inorganic Constituents, 1996 (mg/L).

Season	pH	BOD	COD	TDS	TSS	Sulfates	Chlorides	Cadmium	Lead	Arsenic	Chromium	Copper	Mercury	Nickel
January-March	6.9	587	1,450	47,667	530	523	32,000	ND	0.43	0	NS	NS	NS	NS
April-June	6	102	740	27,000	291	320	13,667	ND	0.03	ND	0.01	0	ND	0.07
July-September	6.4	28	227	27,000	157	327	14,000	ND	ND	ND	0.01	0.03	ND	0
October-December	6.9	53	270	23,000	57	375	11,000	ND	ND	ND	0	0.01	ND	0
Mean	6.6	192	672	31,167	259	386	17,667	ND	0.12	0	0	0.01	0	0.02
Standard Deviation	0.34	205	440	8,645	159	73	7,474	ND	0.16	0	0	0.01	0	0.03

Table 5. Comparison of Select Inorganic Constituents by Season, Ash Leachate and Pretreated Leachate, 1996 (mg/L).

	ash leachate	pretreated	ash leachate	pretreated	ash leachate	pretreated	ash leachate	pretreated	ash leachate	pretreated	ash leachate	pretreated
Season	pH	pH	COD	COD	TDS	TDS	TSS	TSS	Cadmium	Cadmium	Lead	Lead
January-March	6.9	7.1	1,450	287	47,667	4,933	530	85	ND	0.02	0.43	ND
April-June	6.0	7.5	740	213	27,000	6,567	291	73	ND	ND	0.03	ND
July-September	6.4	7.3	227	153	27,000	7,233	157	28	ND	ND	ND	ND
October-December	6.6	6.9	270	143	23,000	6,033	57	61	ND	ND	ND	ND
Mean	8.6	7.2	672	199	31,167	6,192	259	62	ND	0.01	0.12	ND
Standard Deviation	0.33	0.22	440	51	8,645	753	159	19	ND	0.01	0.17	ND

ND - Not Detected within Methodology Limits

Table 6. Montgomery County, Maryland MWC Ash Characterization Comparison of TCLP Statistical Results for Metal Analytes (1)

Analyte	90% UCI(2) Jul 95	90% UCI(2) Dec 95	90% UCI(2) Feb 96	90% UCI(2) May 96	90% UCI(2)(3) Aug 96	90% UCI(2) Nov 96	90% UCI(2) Feb 97	Regulatory Threshold
Arsenic	ND/0.06	ND/0.06	ND/0.5	ND/0.5	ND/0.5	ND/0.5	ND/0.5	5.0
Barium	ND/0.5	0.47	ND/10	ND/10	ND/10	ND/10	0.55	100.0
Cadmium	0.019	0.122	0.166	0.414	0.434	0.125	0.466	1.0
Chromium	0.018	ND/0.2	ND/0.5	ND/0.5	ND/0.5	ND/0.5	ND/0.5	5.0
Lead	ND/0.1	0.32	ND/0.5	ND/0.5	0.44	ND/0.5	ND/0.5	5.0
Mercury	0.0038	ND/0.0006	0.0012	0.0006	0.0006	ND/0.0005	ND/0.0005	0.2
Selenium	ND/0.06	ND/0.06	ND/0.1	ND/0.1	ND/0.1	ND/0.1	ND/0.1	1.0
Silver	ND/0.04	ND/0.04	ND/0.5	ND/0.5	ND/0.5	ND/0.5	ND/0.5	5.0

All units expressed as milligrams per liter (mg/l)
ND = Non-Detectable

(1) All other analytes were non-detectable. Statistical outliers (based upon Chauvenet's Criterion) are included in the data, resulting in higher UCI levels. Laboratory detection levels for non-detectable results are reported after the ND/.

(2) 90% Upper Confidence Interval as a single-tailed distribution is equivalent to an 80% Upper Confidence Interval as a two-tailed distribution, i.e., there is only a ten percent chance that the result could be higher.

(3) Testing of archived split sample for Lead showed lower concentrations. Worse case results are reported.

Removal and Recovery of Heavy Metals From Incinerator Ash Residues

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Peer Review

INTRODUCTION

This paper presents results of a novel and state-of-the-art patent-pending processes developed jointly by Forrester Environmental Services Inc. ("FESI") and Brookhaven National Laboratories ("BNL") for the extraction and recovery of lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn) and other heavy metals from heavy metal bearing wastes including but not limited to solid waste incinerator bottom ash, flyash and combined ash.

The heavy metal extraction and recovery processes were found to be capable of high percentage of heavy metals extraction and recovery at a relatively low cost under bench scale and full-scale refuse incinerator facility conditions. This paper presents empirical data from bench scale studies only, as the full-scale data is currently under review. The ash product remaining after extraction passed all TCLP regulatory limits and retained only minimal Pb, Cd, Cu, and Zn content and other water insoluble heavy metal compounds.

The extraction efficiency of the processes exceeded expectations for Pb, Zn and other key heavy metals at 90%+ levels, thus yielding post-extracted ash heavy metal contents well within current USEPA and state allowable levels in residential soils. The process capital and operating expenses were also determined to be highly cost competitive against conventional and currently used ash stabilization methods. The FESI/BNL Heavy Metal Extraction and Recovery Process is currently under contract for use at industrial applications throughout the world including waste incinerators and is expected to enhance the acceptance of incinerator ash use by significantly reducing the content, solubility and availability of heavy metals therein.

Results of heavy metals recovery and low cost from ongoing field applications of this technology are consistent with the bench scale data presented within this paper.

BACKGROUND

Waste-to-Energy Ash Production and Type

Waste-To-Energy ("WTE") facilities employ a form of recycling, involving the use of solid waste as a fuel to produce steam which in turn is used to produce electricity. In the combustion process the total volume of solid waste is reduced by 90%, resulting in an ash generation of nearly 10% by volume and 30% by weight. In most modern WTE facilities, refuse is combusted at temperatures approaching 1800 to 2500 degrees Fahrenheit. Most organic materials in the solid waste are reduced to base elements such as Carbon, Oxygen and Nitrogen. Inorganic materials such as iron, aluminum, calcium, sodium and silicates make up the major components of ash residue, along with much smaller weight fractions such as Pb, Cd and Zn which are regulated due to their relative toxicity and potential threat to the environment.

The ash residues are collected at various points throughout the system, producing three distinctive types -- bottom ash (BA), fly ash (FA), and flyash scrubber residue (FASR). As the words imply, bottom ash is collected at the bottom of the furnace grates following the combustion process. Flyash is composed of small particles which are carried by the combustion flue gas and then captured by the air pollution control devices or drop-out hoppers. Bottom ash typically represents roughly 85 to 90 percent by weight of the total ash produced in a mass burn facility, with flyash and scrubber residues comprising the remaining 10 to 15 percent ("scrubbers" are combustion gas cleaning systems that neutralize acid gases). The BA/FA+FASR ratio for Refuse-Derived Fuel ("RDF") combustion facilities which remove a fraction of ferrous, non-ferrous and certain non-combustible wastes prior to combustion has been measured by FESI at full-scale operations at 50/50.

The use of lime scrubbers can significantly alter the leachability of FA by increasing or decreasing Pb solubility and decreasing Cd solubility based upon the pH-log solubility characteristics of those elements and compounds thereof. The water solubility of FA without lime scrubbing is often relatively low due to the neutral pH condition of FA, yet as lime scrubbing products and unreacted lime as hydroxide are added, the water solubility of the Pb in the newly produced FASR can greatly increase ... this due to the amphoteric nature of Pb that remains water soluble under low and high pH conditions.

The use of the acidic TCLP #2 test to measure the leachability of FASR under an assumed acid leaching condition actually lowers the pH of the FASR in solution with dilute acetic acid, and now presents FASR Pb solubility at a semi-neutral pH condition, as compared to the more probable high pH condition likely to occur in the field under much less acidic leaching conditions. Consequently the TCLP test can greatly under-predict the leaching potential of FASR.

Current Ash Management

Most commonly, FA/FASR and BA are combined at the WTE facility and transported to permanent disposal sites. BA is usually wetted in a water quench system to allow for a boiler air seal and to cool the 1800 to 2500 degree F mass of silica and non-combustibles. The larger fractions of BA such as slag often fractures upon wetting due to sudden cooling in the water quenching tank.

FA and FASR are bone dry as generated from air pollution control devices after dry scrubbing towers, and are collected in enclosed hoppers due to their dust-like fugitive nature and human exposure risk. These FA/FASR residues are often wetted to control dusting, and thereafter added to the BA for disposal, thus producing a combined ash ("CA").

Landfill disposal remains the simplest and most cost effective method of disposing both BA and FA/FASR. The preferred practice is to dispose of the residue at the residue-only landfill, referred to as an ash "monofill".

Various concerns have been raised by regulators, public interest groups and scientists alike regarding the safe handling, disposal and possible use of ash residues. One of the most common concerns raised relates to the total compositional content of Pb and Cd in ash the fate of those elements over the long-term use and handling of ash products in the open environment.

Some opponents to ash use argue that: (a) heavy metals contained in residue are concentrated at unacceptable levels and (b) the metals are "leachable components" which have the potential to reach groundwater supplies. "Leachable components" are those elements or compounds which have the potential to dissolve in water. Ash use critics often also claim that as rainfall percolates through ash, it has the potential to leach these heavy metals and transport them into the water supply.

However, scientific tests throughout the international community have demonstrated that ash residues from modern WTE facilities, when properly managed at ash landfills do not leach contaminants at significant risk levels. In fact, CA leachate closely resembles seawater. As a matter of extra safety, these CA leachates are often collected and stabilized prior to disposal in accordance with strict federal and state environmental standards.

THE NEED FOR METALS CONTENT REDUCTION

In addition to the above mentioned leaching of heavy metal bearing wastes, human and biological exposure to heavy metal content has long been of concern to environmental regulators and waste producers. Under the Resource Conservation and Recovery Act (RCRA) solid waste is classified by the U.S. Environmental Protection Agency (USEPA) as hazardous waste if excessive amounts of heavy metals leach from the waste when tested under the Toxicity Characteristic Leaching Procedure (TCLP). EPA also regulates the land disposal of certain heavy metal bearing wastes depending on the content of the heavy metals regardless of the leaching potential. In addition, several state governments require solid wastes with elevated levels of heavy metals be disposed of as a hazardous waste. Disposal of waste at a hazardous waste landfill is typically more expensive than disposal at non-hazardous waste landfills.

In an attempt to reduce the expenses associated with the landfill disposal of heavy metal leachable waste, particularly lead bearing waste, various methods to control heavy metal leaching and reduce heavy metals have been developed. These methods include the stabilization of lead bearing waste with, for example, portland cement, silicates, sulfates, phosphates and combinations thereof as well as acid digestion and metals recovery. However, these methods are often expensive and involve complex handling equipment and operations. Additionally, some of these methods use chemicals, such as strong acids, which in the amounts used, are hazardous to workers and corrosive to the waste handling and treatment equipment.

The stabilization methods most commonly used do not reduce compositional level or bioavailability of Pb and other regulated metals, and thus fail to reduce the risks of direct exposure to the waste after treatment. Given that many states now require limitation of heavy metal content for use or RCRA Subtitle D solid waste disposal of industrial wastes, the stabilization methods fail to provide the required technology for waste reuse or local landfilling.

Accordingly, a need exists for means of reducing lead content beyond leachable fractions, particularly when considering reuse of the ash outside of a landfill where environmental sensitivity to newly introduced heavy metals such as Pb and Cu can be extreme.

FESI/BNL PROCESS

In late 1993 FESI and BNL entered in the first of two Cooperative Research Agreements (CRADA) for development of a safe, simple and inexpensive method of extracting and recovering inorganic compounds from industrial wastes. The process method is not disclosed herein given its pending patent status, although key results are presented.

The materials evaluated by FESI/BNL to date have included various heavy metal bearing wastes and materials, firstly bottom ash from solid waste combustion and the ferrous and non-ferrous metals normally produced along with the bottom ash, leaded paint contaminated soils, metal finishing sludges, foundry sands, K061 waste, Pb bearing soils and industrial site wastes. Such wastes, materials and residues often contain high levels of lead and cadmium which can be leached at levels in excess of 5 ppm (5 mg/l) and 1 ppm (1 mg/l) as determined by the USEPA TCLP leaching test and copper and zinc in excess of 25 ppm and 200 ppm as determined by the California state leaching test method. Such wastes also often contain total compositional heavy metals such as lead, cadmium, barium, chromium, copper, magnesium, manganese, nickel, strontium, tin, and zinc at levels which are higher than those allowed by the USEPA, state regulators and local officials for ash use in engineered products such as cement blocks and/or application to the environment such as roadbase aggregate.

Incinerator Bottom Ash Evaluation

Water quenched bottom ash from a solid waste combustion facility was first subjected to ten (10) separate composited baseline total metals and TCLP analyses in order to define the character of the ash prior to extraction. Total metal content in the ash was determined by acid digestion after grinding of an ash composite sample of 0.5 grams with a mortar and pestle.

Analytical Method: The composited bottom ash sample was placed in a 30-ml platinum crucible. Five ml of concentrated HNO3 was added to each crucible. The mixture was then heated on a hot plate to almost dryness. An additional 3 ml of HNO3 plus 2 ml of HCLO4 was added to the crucible. The mixture was then heated until fumes of HCLO4 appeared. The crucibles were cooled and then 5 ml of 30% HF was added. The mixture was then reheated and evaporated to dryness. Finally, 5 ml of concentrated HNO3 and 5 ml of deionized water was added, heated until the solution boiled gently, transferred into volumetric flasks, and diluted to 100-ml with deionized water. Metals were then analyzed by ICP-MS.

The bottom ash baseline sample was also subject to the Toxicity Characteristic Leaching Procedure (TCLP) as set forth in the Federal Register Vol. 55, No. 61 (Mar. 29, 1990) which corresponds in pertinent part to the procedure set forth in Federal Register, Vol. 55, No. 126, pp 26985-26998 (June 29, 1990). This test procedure is also referenced in EPA SW 846, 3rd Edition. The TCLP test produces an aliquot of filtered solution containing soluble metals which were analyzed by ICP-MS.

Extraction Method: In this first study, 100 grams of <3/4" size reduced BA was subjected to three separate solutions of a FESI patent-pending Modified Complexing Agent ("MCA") at an ash to solution ratio of 1:20 for 48 hours using a wrist action shaker to maintain mixing contact. During extraction, 5 ml aliquot samples were taken in order to assess the time variance of the extraction efficiency. After the 48 hour extraction period, the ash was dewatered via centrifuge (12,000 rpm, 20 min.) and then subjected to a post-extraction TCLP and total metals analyses. Extractions were conducted at 25 degree C and 85 degree C in order to assess the impact of temperature on the extraction of metals, given that the bottom ash incinerators often quench the bottom ash at elevated temperatures.

The use of an ash centrifuge for dewatering and removal of residual MCA solution from the ash solid matrix, 48 hour batch mixing of the ash with the MCA solution and contact with varied solutions were all considered by FESI to define certain upper boundaries of removal efficiencies of metals under aggressive mixing, dewatering and contact conditions. Field and laboratory evaluations of less aggressive and more likely full-scale applications of the technology including press dewatering, extraction in a semi-mixed batch reactor, contact times of 5 to 60 minutes and lower MCA concentration extract conditions were also conducted. These more probable field operating conditions don't preclude the use of one or more of the aggressive methods described if needed to achieve target removal percentages.

The chemical constituents of the extract remaining after the removal of ash from the extraction vessel was of great interest during the research effort. The recovery and management of complexed metals and free MCA in solution after contact with the ash through biodegradation and/or precipitation are an important aspect of commercialization of the process.

In order to define the ability to control residual MCA and soluble metal complexes in the ash porosity after extraction as well as define a possible supporting wastewater treatment scheme, the MCA extract was subjected to biological treatment to recover the metals from solution. For this purpose, a FESI patent-pending Engineered Bacteria ("EB"), was developed to consume MCA as a sole carbon source. A series of tests using EB were conducted to establish degradation efficiencies and rates.

After treatment, the extract samples were centrifuged (12,000 rpm, 20 min) to separate the solids biomass and metal precipitates from the solution which resulted in complete recovery. The solid phase was dried overnight at 70 degree C then weighed. The solid was dissolved in 5 ml concentrated Ultrex HNO3 diluted to 200 ml with deionized water and analyzed for metals by ICP-MS. Metal recovery was calculated as a percentage of the initial metal concentration of the extract correlated for relative mass.

Extraction Results

Metals Extraction. The ash baseline and post-48 hour extracted heavy metals concentrations and percent metal extracted are presented in Table 1 in rounded average values. The results clearly confirm the MCA extractability of major metals Aluminum, Iron and Magnesium as well as trace metals such as Cadmium and Lead in all solutions evaluated. The measurement of extract metals concentration over time indicated that a majority of the metals from ash were recovered in the first 5 hours with a classical inflection of diffusion rate from surface to bulk mobility occurring at 5 to 10 hours with a gradual transition to flat slope of extraction after 20 hours.

Total Pb was 85% extracted at only 5 hours ... having a very steep extraction rate from 0 to 5 hours, 100% of total extractable amount at 25 hours with a 10 degree slope from 5 to 25 hours and a flat extract-to-time relationship after 25 hours. This time-effect observation was important, as long-term extractions such as 48 hours would likely require separate ash handling facilities due to the high tonnage production of ash and the need to store 48 hours production of ash while waiting on batch baths, or the need to have a higher batch production system to handle batch reaction times. Shorter extraction periods would allow for extraction and ash processing in-line or along side existing ash production facilities.

Temperature Effects. The ash extractions were also found to vary with temperature. Most metals showed an increase in extraction efficiency at 85 degree C as compared to 25 degree C, with the exception of Fe, Sr and Ti. This temperature effect could prove useful when applying the MCA to ash quenching tanks or when timing the bath reactor loading such that hot ash is subjected to extraction. A hot batch extraction process may also prove very useful in post-combustion ferrous and non-ferrous scrap metal polishing and cleaning prior to sale, as the removal of surface oxidized metals and contaminants from the combustion process such as bottom ash or ash fines will increase the value of the scrap metal. Table 2 presents results of temperature effect on ash metals extraction. Extraction results were somewhat different from previous extraction testing due to sample variability common with incinerator ashes.

TCLP Control. The ash TCLP baseline and post-extraction, post-centrifuge dewatering results presented in Table 3 also confirm that the MCA removes the more readily soluble forms of metals as determined under the TCLP extraction method, thus reducing the residual metals available after ash dewatering for leaching within the buffered acetic acid solution used within the TCLP-1 test for BA.

Biodegradation. Biodegradation of residual MCA remaining in the extract after ash contact was found to occur rapidly and at a somewhat linear rate within 43 hours. The initial degradation rate of MCA was 80 mg per liter per hour. The removal of metals from solution and conversion of such to a precipitate was observed to be very high for metals as shown in Table 4.

The rate of metals removal varied, yet generally remained linear during the 48 hour period up to the point of reduction to levels less than 0.5 ppm where the metal concentration to time relationship flattened. Lead removal rates of 0.045 mg per liter per hour were observed. These results confirm that the residual metals in solution, and/or within the pores and on surfaces of the processed ash remaining after the ash MCA extraction, can be converted through biodegradation to insoluble precipitates within a liquid or solid ash matrix by addition of EB.

It is further possible that addition of common heavy metal precipitating agents could reduce the remaining soluble metals within the ash, yet such methods would not enhance the reduction of available MCA within the ash and thus would allow the residual MCA to remain available and possibly continue to allow for reduction and conversion of metals to soluble complexes. It is thus desired to reduce the MCA residual to a low level within the ash, as remaining MCA in solution will possibly increase the potential for metals to become water soluble at some time in the future, thus increasing the potential of metals release.

MCA Recycling. The use of EB for degradation of MCA in solution and/or within ash void liquids will provide useful for control of residual MCA and reduction of soluble metals when recycling of MCA to the primary extraction vessel is not considered necessary. As an alternative method, recycling of MCA from the ash batch reactor, ash drainage or ash rinsing solutions may be considered valuable to operators using high concentrated solutions of MCA.

Several evaluations of post-batch extractions revealed only 0.5 to 1.0 percent reduction of available MCA for bath durations of 5 minutes to 48 hours. Such a low consumption rate presents the opportunity to include MCA recycling in a process where loss of MCA by solution biodegradation is not desirable. Consequently, the heavy metal precipitating agents sodium sulfide and hydroxylapatite were evaluated in order to determine their capability to recover heavy metals from MCA recycle wastewaters and ability to return free MCA in solution to the reactor tank.

Both sodium sulfide and hydroxylapatite were found to precipitate over 99% of Pb out of solution within several minutes of contact. The recovery of MCA after addition of 1% sodium sulfide to extract of ash was found to be 98.7%. The comparison of fresh MCA against recycled MCA in the batch ash reactor as shown in Table 5 also supports that recycled MCA provides similar and often superior metal extraction efficiencies.

Process Costs

The process chemical costs for a full-scale extraction and recovery operation are less than $0.50 per US ton of waste processed. The scale-up process application can vary in cost from $150,000.00 capital and $60,000.00 operating and maintenance for a 100 ton per day extraction facility to $700,000.00 capital and $270,000.00 operating and maintenance for a 500 ton per day facility as determined by FESI at several ongoing industrial waste extraction projects. The amortized capital and operating cost is less than $2.50 per US ton, resulting in a net $3.00 per ton of waste processed operating and installation cost.

Given $60.00+ per ton landfill disposal costs in the Northeast, the $3.00 extraction to enhance ash reuse and consequently avoiding landfilling is highly attractive. The estimated $3.00 per ton processing cost is also competitive with existing TCLP stabilization methods and is often less expensive given that the extraction process reduces ash weight required for haul and disposal.

CONCLUSION

FESI and BNL researched and demonstrated a novel method for extraction and recovery of heavy metals from industrial wastes and materials. The projects primary objective of defining a safe, simple, cost effective method of extracting and recovering Pb from incinerator ash was achieved through use of a Modified Complexing Agent ("MCA") for single stage ambient temperature extraction of Pb in combination with an Engineered Bacteria ("EB") which targeted and consumed remaining MCA in the wetted ash and bioconverted MCA complexed lead in extract solution to insoluble Pb bioprecipitates.

Although the process method and application rates remain proprietary at this time pending patent issuance, the results of the extraction at 96% + for Pb, 90% (+) recovery rates by biodegradation, TCLP metals control to less than required by the USEPA and simple ambient temperature application confirm the method as beneficial for incinerator ash processing and production into a more reusable nature than baseline.

Table 1. Total Metals Extraction Results

Metal	Baseline (ppm)	Percent Metals Extracted A	B	C
Aluminum	33,700	40	51	52
Barium	873	25	28	26
Cadmium	31	14	18	16
Chromium	309	16	17	20
Copper	558	54	74	90
Iron	47,300	9	22	29
Lead	600	61	74	96
Magnesium	4,200	91	94	94
Manganese	534	46	73	97
Nickel	1,090	21	26	24
Strontium	324	43	60	60
Tin	120	39	41	47
Titanium	6,280	13	14	17
Zinc	3,170	61	83	87

Table 2. Temperature effects on extraction

Metal	Percent Metal Extracted	
	25 C	85 C
Aluminum	25	53
Cadmium	7	13
Chromium	8	21
Iron	23	20
Lead	>99	>99
Magnesium	95	>99
Manganese	75	>99
Nickel	18	68
Strontium	34	43
Tin	37	>99
Titanium	13	23
Zinc	>99	>99

Table 3. TCLP results pre and post-extraction

Metal	Baseline TCLP	Extracted TCLP
Cadmium	0.068	0.007
Chromium	0.050	0.001
Lead	3.2	0.50
Zinc	110	44

Table 4. Biodegradation recovery of heavy metals

Metal	Percent Metal Recovered from Extract
Barium	99
Cadmium	88
Iron	99
Lead	93-99
Magnesium	99
Nickel	87-91
Strontium	99
Tin	89-98
Zinc	99

Table 5. Recycled versus fresh MCA extraction

Metal	Baseline (ppm)	Percent Metal Extracted	
		Fresh MCA	Recycled MCA
Aluminum	35,200	44.9	52.8
Cadmium	22	63.2	67.7
Chromium	148	39.9	46.3
Lead	1010	70.2	76.1
Magnesium	7140	64.6	70.2
Manganese	578	58.3	63.7
Nickel	72	56	51.2
Zinc	4740	74.7	78.1

Benefit/Cost Analysis of RDF Process in Taiwan

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presented to

Fifth North American Waste-to-Energy Conference

Research Triangle Park, NC

April 21-25, 1997

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Benefit/Cost Analysis of RDF Process in Taiwan

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ABSTRACT

Reducing the waste stream through incineration is very important to minimize the use of landfills and to maximize the recovery of energy. The technology of mass burn waterwall incineration was widely used in the past two decades for solving the problems of solid waste disposal. In recent years, the sorting process is considered as an essential pretreatment unit prior to the incineration process. However, many engineering and economic disciplines are involved in the integration of refuse-derived fuel and waste-to-energy processes. This paper illustrates the related benefit/cost analysis issues during selecting an appropriate sorting process for Pa-Li municipal incinerator in Taipei metropolitan region of Taiwan.

INTRODUCTION

RDF (Refuse-derived Fuel) technology was developed in the US in the early 1970's. The first RDF facilities were based on firing RDF in coal-fired utility boilers. The initial reason for processing municipal solid waste prior to incineration was to remove a large fraction of the non-combustibles and to size the RDF so that some of it could more readily burn in suspension. The coupling of RDF preparation with new incineration systems designed exclusively for firing RDF is not an easy work. There were many technical and economic problems that had to be overcome. However, the RDF technology evolved slowly to where it is today has been a proven and reliable technology.

The original economic trade-off of RDF technology was primarily based on the capital and O&M cost savings of smaller boiler and air pollution control systems versus the added capital and O&M cost of the processing equipment. Also, RDF offered potential benefits for recycling part of the secondary materials, providing lower pollutant emissions, resulting in environmentally secure disposal of residues, and increasing energy recovery efficiency. Hence, cost-benefit or cost-effectiveness analysis is therefore an important indicator for the application of such a technology. The current focus of economic aspects using RDF technology as an auxiliary component in the solid waste management system is how to fully identify the related benefits while traditional costs become more apparent. These benefits may relate to the resale income from secondary material market, the improvment of recycling potential, the achievment of lower pollutant emissions, and the production of a clean bottom ash amenable to reuse. However, economics does not always adequately reflect direct benefits from waste sorting. The saving of management expenditure from a regional sense and the scarcity of physical resources from a national sense should be considered to a reasonable extent in order to justify the investment of large scale sorting and recycling programs. Hence, this analysis also tries to cover the intangible benefits and indirect costs associated with waste sorting and recycling activities.

Overall, the purpose of this paper is to present an integrated evaluation framework and summarize the profile of both tangible and intangible benefits as well as direct and indirect costs. Such information would facilitate a thorough evaluation of economic viability of burning RDF as fuels in the future. The case study conducts a series of description of the general situation of solid waste management in Taipei metropolitan region. A typical refuse-derived fuel system, developed by a local engineering firm in Taiwan, which consists of standard unit operations of shredding, magnetic separation, trommel screening, and air classifying is fully described. The benefit/cost analysis to characterize the economic feasibility of adding such a sorting process to Pa-Li incinerator is then discussed as the related management issues become more clear. Final integrated evaluation of MRF and RDF based on the entire Taipei metropolitan region is proposed as well.

LITERATURE REVIEW

The engineering efficiency using RDF process prior to incineration has been well known. While sorting process prior to incinerators has won public concern over the years, its economic viability has not developed as quickly due to the lack of front-end planning information of related benefit/cost. In recent years, Derks and Hadfield [1] presented an innovative method to figure out the price of RDF according to the discounted cost of fuel displaced by burning RDF and the discounted revenue received for excess energy recovery by allocating the boiler output energy to steam and electrical generation. Zach [2] developed a computer model for examing recycling system life cycle economic costs. Gershman [3] further discussed the factors affecting the costs of solid waste management from a broader sense. Hartman and Smith [4] emphasized the beneficial use of RDF technology with recycling and environmental protection goals. Lea and Kowalewski [5] tried to apply a computer model to evaluate the cost structure of an integrated solid waste management system in south Louisiana. The model has been used to predict the future cost of twelve waste management options available to local government. The articles written by Porter and Robert [6] in the book "Energy Savings from Waste Recycling" presented a thorough survey of the indirect benefit of recycling which further characterizes many intangible issues in solid waste management.

ANALYTICAL BACKGROUND OF CASE STUDY

Taipei City, located at the central part of Taipei County, is the largest city in Taiwan. The geographical location of this region is illustrated in Figure 1. The City of Taipei is divided into 12 administrative districts where each has its own garbage collection team in charge of individual clean-up work. However, 29 administrative districts are organized in Taipei County, and a single garbage collection team is also organized within each district in charge of waste shipping and disposal. The Taipei City and County Government handle their solid waste streams independently, although the resident's activities in both areas have amalgamated to form a unique metropolitan region. The 1995 population of Taipei City and County were about 2,600,000 and 3,500,000, respectively. This large metropolitan region with a total population over 6 million and an area of over 2,000 sq.km., requires solid waste management on a regional basis.

The Taipei metropolitan region currently generates over 6,500 tonnes of solid waste which is collected daily using a labor force of 6,741 and 1,008 collection vehicles. Six administrative districts have promoted their household recycling programs in Taipei City. Shan-Chu-Ku regional sanitary landfill is the only existing landfill, located at the eastern boundary of the city. In addition, two municipal incinerators (Nei-Hu and Mu-Cha) are currently in operation with the design capacity 900 TPD and 1,500 TPD, respectively, and the construction of a third (Pei-Tou) with the design capacity 1,800 TPD is in progress. Municipal solid waste streams in Taipei County are transported to two existing incinerators -- Shu-Lin and Hsin-Tein with the design capacity 1,350 TPD and 900 TPD, respectively -- or to the only regional sanitary landfill (San-Hsia) for waste treatment and disposal. The shaded areas indicated in Figure 1 represent the service region originally assigned for Shu-Lin and Hsin-Tein incinerators. Although a number of small landfills are operated by local public or private agencies in several administrative districts of Taipei County, they will be out of capacity very soon. New incinerator and landfill, both located at the Pa-Li area, are being constructed now. The design capacity of Pa-Li incinerator is 1,350 TPD, that is to be started up in the year 2000. No MRF or RDF facilities exists in the current solid waste management system.

Some observations about an apparently significant trend in the solid waste management system has developed due to rapid economic development in this region and the uncertain need for waste treatment and disposal in the long run. Tables 1 and 2 describe the quantity and quality information of MSW in Taipei County. It is estimated that about 40% of the waste streams can be recovered as the secondary materials. While the source separation programs was not so successful in the last few years, the need of MRFs or IPCs, and/or RDF plants in the existing system configuration is phenonmenal. The RDF technology would help make recycling compatible with waste incineration. Figure 4 illustrates the current and future solid waste management system configuration using RDF and MRF as new components.

In addition, the increase of heat values of waste streams results in a lower throughput in Shu-Lin and Hsin-Tein incinerators, which is almost one-third below the original design capacity. However, the heat value of MSW used to design Pa-Li incinerator is 8,000 KJ/Kg that is almost 50% higher than the existing average heat value of MSW in Taipei County. This will result in a possibility of siting RDF as a pretreatment unit in Pa-Li incinerator in the future. The first benefit in favor of the use of a sorting process in Pa-Li incinerator may be the increase of heat value of RDF destined for incineration. This would indirectly achieve higher energy recovery efficiency from a local sense and handle higher amount of waste flow at Pa-Li incinerator than originally planned level from a regional sense. Concurrent with attempts to impose a sorting process prior to Pa-Li incinerator, the Environmental Protection Bureau began effort to think about the idea of redistribution of waste flow according to the heat value of waste flow generated in different administrative districts so that the design capacity of these incinerators can be fully utilized.

Several economic-oriented issues encountered in this system include: (a) Is it necessary to build RDF process in this system to meet the growing demand of solid waste generation? (b) What are the impacts from the economic aspects through the use of such a RDF process? (c) Would the considerations of benefit/cost profile become different with respect to the scale of planning area? and (d) What is the possible incentives for the private sectors to perform BOT (Build, Operation and Transfer) or BOO (Build, Operation and Own) projects? These questions can be analyzed using the benefit/cost analytical framework in this paper.

RDF PROCESS DESCRIPTION

Various equipment are available for processing mixed or source-separated solid waste feedstocks for the recovery of secondary materials. The selection of the appropriate unit operations in a RDF or MRF system is a function of the characteristics of the feedstock, the specifications for the recovered products. The designed process of the first refuse-derived fuel process in Taiwan, as described in Figure 2, consists of three major subsystems: shredding, air classification, and screening. The impacts from the engineering aspects through the use of such a RDF process has been fully characterized by Chang, et al. ([7]-[10]). These engineering factors include throughput capacity, composition of the feedstocks, product specifications, and available technologies. Mass balance diagram can be made as illustrated in Figure 3. Table 3 lists the average energy requirements in this RDF process during two test runs in 1996.

BENEFIT/COST ANALYSIS

Benefits of Sorting prior to Incinerator

System economic benefits can accrue from the sale of recovered materials, which is itself a function of market demand, processing efficiency and separation efficiency. Revenues from the sale of materials can be estimated using information derived in a formal market investigation, as indicated in Table 4. Other funding sources may include tipping fees, subsidy, and even landfill diversion credits (or avoided cost). Direct avoided costs are calculated using the procedure corresponding to the saved shipping cost from incinerator to landfill and the disposal cost in landfill. But the indirect avoided cost might involve the calculation of the social value of nonrenewable resource (i.e., landfill space) conservation. The other indirect benefits might relate to improving the processing of waste prior to combustion so that greater amounts of energy are conserved during the reuse of those recyclables, achieving lower pollutant emissions, increasing the energy recovery efficiency, and producing a clean bottom ash amenable to reuse. Hence, they are summarized as below:

- ♦ Direct Benefits:
    - Revenues from the sale of materials
    - Revenues from tipping fees
    - Revenues from governmental subsidy
    - Revenues from the sale of compostables
    - Revenues from the sale of RDF as fuels to boiler utility or incinerator
    - Avoided costs from the saving of shipping and disposal expenditure
- ♦ Indirect Benefits:
    - Social value of nonrenewable resource (landfill space) conservation
    - Energy conservation due to the reuse of those recyclables
    - Lower pollutant emissions during incineration
    - Clean bottom ash amenable to reuse
    - Increase of energy recovery efficiency in boiler utility or incinerator

Costs of Sorting prior to Incinerator

Costs associated with RDF process include siting, building, and operation, process residue disposal, and material storage and shipping. The information of cost data, using the first pilot RDF process in Taiwan, becomes available in this study that is the first test run in this country. The essential items of cost analysis are summarized as below:

- ♦ Direct Costs:
    - Costs for siting
    - Costs for construction
    - Costs for operation and maintenance
    - Costs for process residue disposal
    - Costs for material storage and shipping
- ♦ Indirect Costs:
    - Costs for possible subsidy to the residents due to environmental impacts
    - Costs for possible payment for waste inflow due to unexpected flow control

- Costs for shipping the recyclables for disposal due to instability of secondary material market

THE DIFFERENCE BASED ON PLANNING SCALE

From Private Sector Point of View

The evaluation of using sorting plant as a pretreatment unit associated with incinerator might not be based on too broad profile of benefits and costs terms in engineering analysis. Direct benefit/cost with limited extent might be more helpful for the alternative selection. Since the stability of secondary material market is quite unstable, the designer of such a sorting system must fully grasp the characteristics of the waste feedstock and the end product property required by the recycling sectors. The unit cost of processing solid waste may include debt service, taxes, insurance, labor, fringes, administrative, parts, supplies, utilities, and other costs incurred for the operation and maintenance of the system. The debt service is basically the amortization of the initial capital investment. These costs are conveniently divided into fixed costs (debt service, taxes, insurance, etc.) and operating and maintenance costs. On the other hand, the benefit terms could be characterized by the resale income of recyclables from secondary material market as well as tipping fees charged for those users.

In this analysis, the determination of the level of debt service is based on a uniform interest rate of 7% within operational period of 20 years that would result in a yearly capital recovery factor of 0.09439. The value of 0.9 is assumed as the system availability rate and a yearly throughput of 78,000 tons is chosen as a operational basis. According to the power consumption profile and other information, the long-term operating cost can be estimated as approximately 800 NT$/ton (29 US$/ton) in average, including the amortization of the initial capital investment. On the other hand, the income by selling the ferrous metals in the secondary material market is about 125 NT$/ton (4.5 US$/ton). Therefore, the tipping fee required for a profitable operation is equal to 675 NT$/ton (25 US$/ton). However, the true benefit of such a sorting plant could be further justified from its indirect contribution (i.e., avoided cost) in a solid waste management system.

From Regional Point of View

Cost and benefit redistributions through the use of sorting or recycling process are the major concerns in system planning of solid waste management in the metropolitan region. It obviously shows that the income from electricity sale is the largest direct benefit and the cost spent for waste transportation is the major expenditure in many cases. Hence, an optimization analysis to reorganize the waste flow to those three incinerators such that the average heat value of waste inflow destined for each incinerator might be consistent with its original design level. To clearly understand such a methodology, Chang, and et al. have delineated the comparative structure of cost and benefit distributions for many different planning scenarios ([11]-[12]). The program calculates avoided labor, equipment and overhead costs, then integrates these values to produce an overall value for avoided cost. A simulated run was initialized by Chang, et al. to estimate the avoided cost by recycling according to the net benefit difference, recycling cost, and the corresponding electricity loss. It shows that the avoided cost per unit of material recycled is 963NT$/tonne (36US$/tonne). Hence, the indirect benefit of waste recycling might include such an avoided cost as well. Overall, the systematic evaluation methodology used for the regional analysis can be presented in Figure 5 for the purpose of demonstration. Costs and benefits which are directly or indirectly associated with either collection or processing must be considered in any economic life cycle analysis.

From National Point of View

Advanced considerations in the development of benefit/cost scheme might rest upon the possible extent to which the energy saving from waste recycling can be estimated from a broader point of view. Consumer motivation of waste recycling probably not only based on the direct income but also from resources conservation. The contribution which resource recovery from waste streams makes to the conservation of energy and materials may be measured conveniently by its implications for primary energy use. Hence, the appreciation of the environmental and conservation benefits which accrue should be emphasized. Direct energy recovery from MSW can be achieved through direct incineration methods. However, energy savings result from waste recycling if the energy used in collecting, separating and treating reclaimed wastes, and subsequent processing, is less than the energy used in originating and processing primary materials and disposing of wastes. There are considerable variations in material production processes both within and between countries. Also the age of plant and purity and form of the primary and secondary materials affects the energy consumption of manufacturing processes. Comparison of unit energy savings by appropriate recycling of secondary material were summarized as follow [6]: 1) aluminum: 222×10^9 Joules/ton; 2) waste paper: 7×10^9 Joules/ton; 3) glass: 17×10^9 Joules/ton; and 4) rubber: 44×10^9 Joules/ton. These values can be used as representative indicators when assessing a national policy related to the waste recycling or sorting actions.

INTEGRATED EVALUATION

Taipei metropolitan region is a highly populated area in Taiwan. Various non-hazardous types of waste disposal issues, such as the construction debris and scrape tire, can be handled together as part of the MSW streams. However, the need of material recovery facilities (MRFs) or intermediate processing centers (IPCs) to facilitate all types of recycling activities becomes at least equally important in the integrated solid waste management programs today. How to manage such an adapting change in the system become more and more critical. Since the Solid Waste Clean-up Law in Taiwan was just amended by the members of Legislative Yen in 1996. Multi-channel recycling programs are emerging in this country such that the MRFs would be an innovative technology to be used in the solid waste management alternatives. A new system configuration, as described in Figure 6, can be proposed, in which the MRFs and RDF plants are incorporated together to achieve a higher value of partnership. While RDF technology assisits in the incineration process, the MRFs consolidate and improve the purity materials collected from all possible waste streams before they are sent to markets.

CONCLUSIONS

Mixed waste processing, though apparently well established in Europe and USA, has a much less well established track record in Taiwan. Benefit/cost profile is an effective indicator for the justification of waste sorting or recycling programs. However, only part of those benefits and costs can be easily characterized and quantified for comparative analysis. The objective of this study was designed to assess the scope of acquired benefits and costs from waste sorting by a more broader point of view although some of them are difficult to be quantified for detailed assessment. It shows that additional benefits, such as avoided costs and energy savings, resulting from sorting and recycling program must be finally attractive. Compared to alternative disposal options, the tax reduction or subsidy from the governmental agencies would be an essential policy to encourage the privatization for solid waste management in the metropolitan region.

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PEER-REVIEW

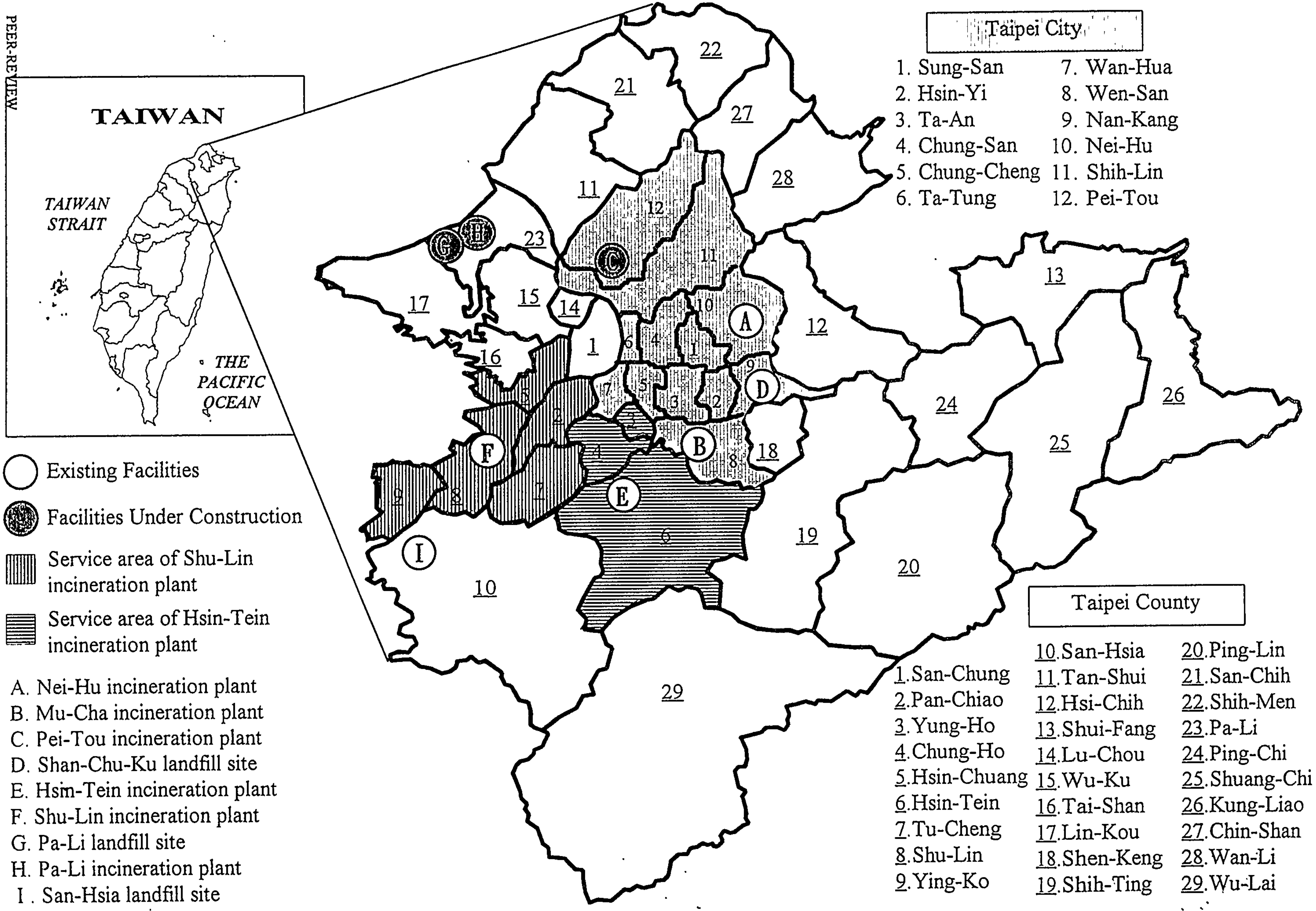

Figure. 1. The Planning Area, Incineration Plants and Landfill Sites

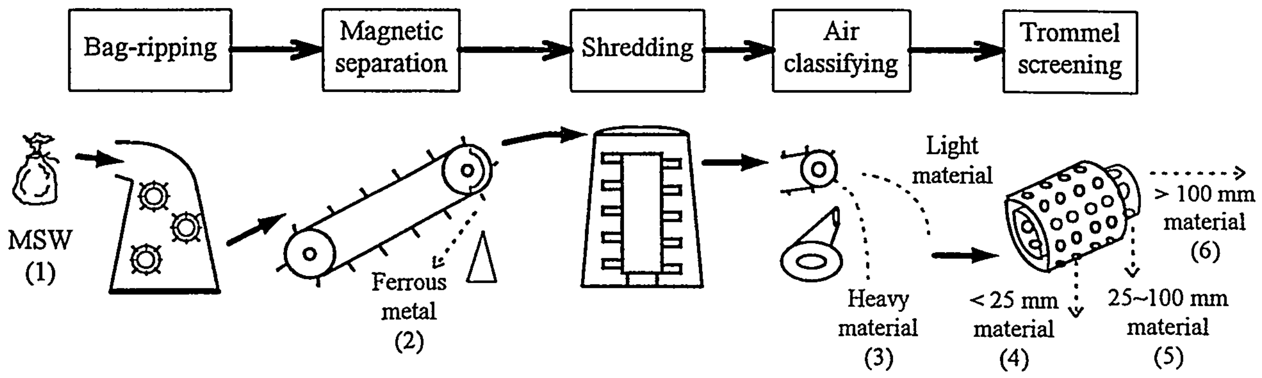

Figure 2. The system configuration of solid waste sorting process

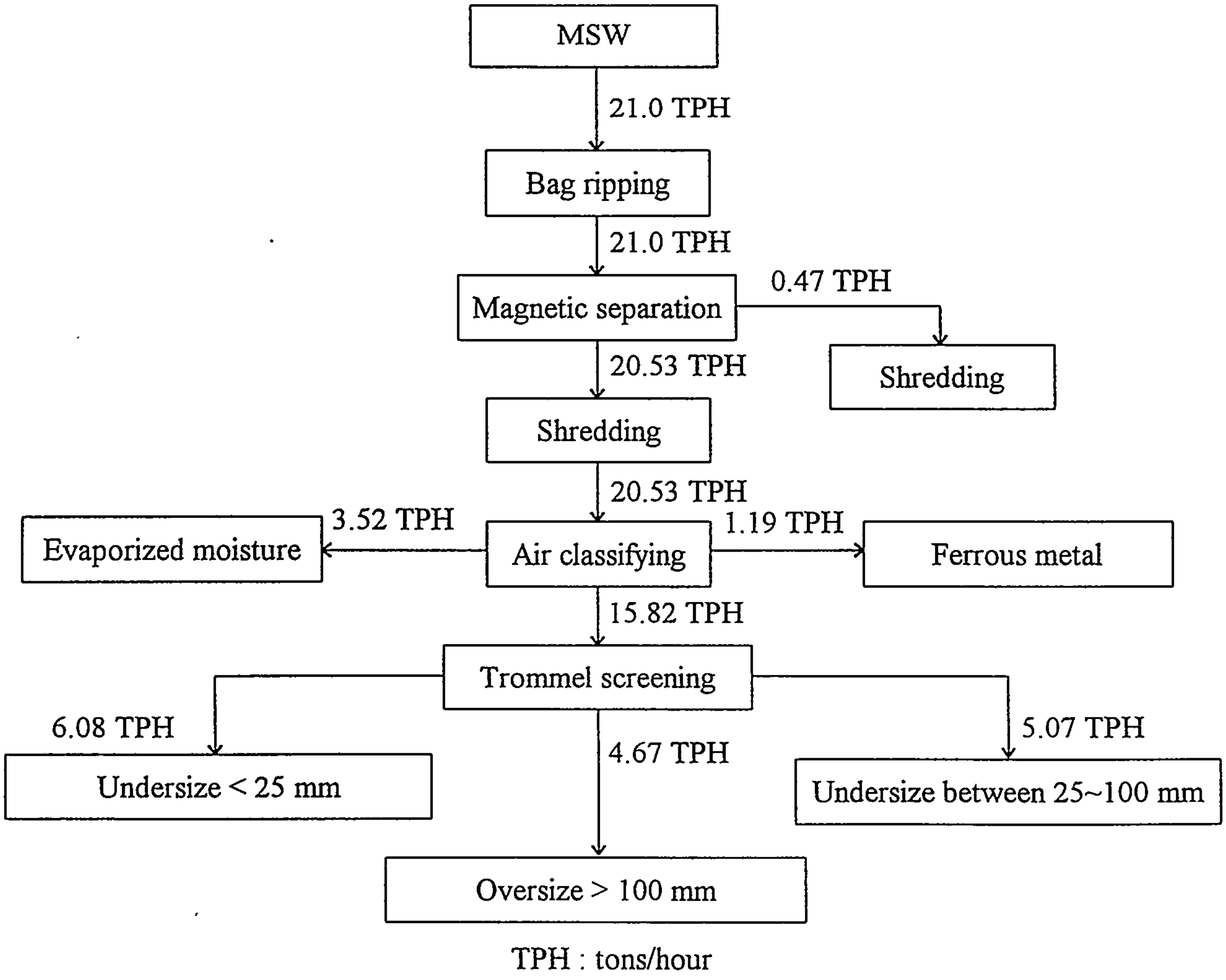

Figure 3. Mass flow diagram of sorting process

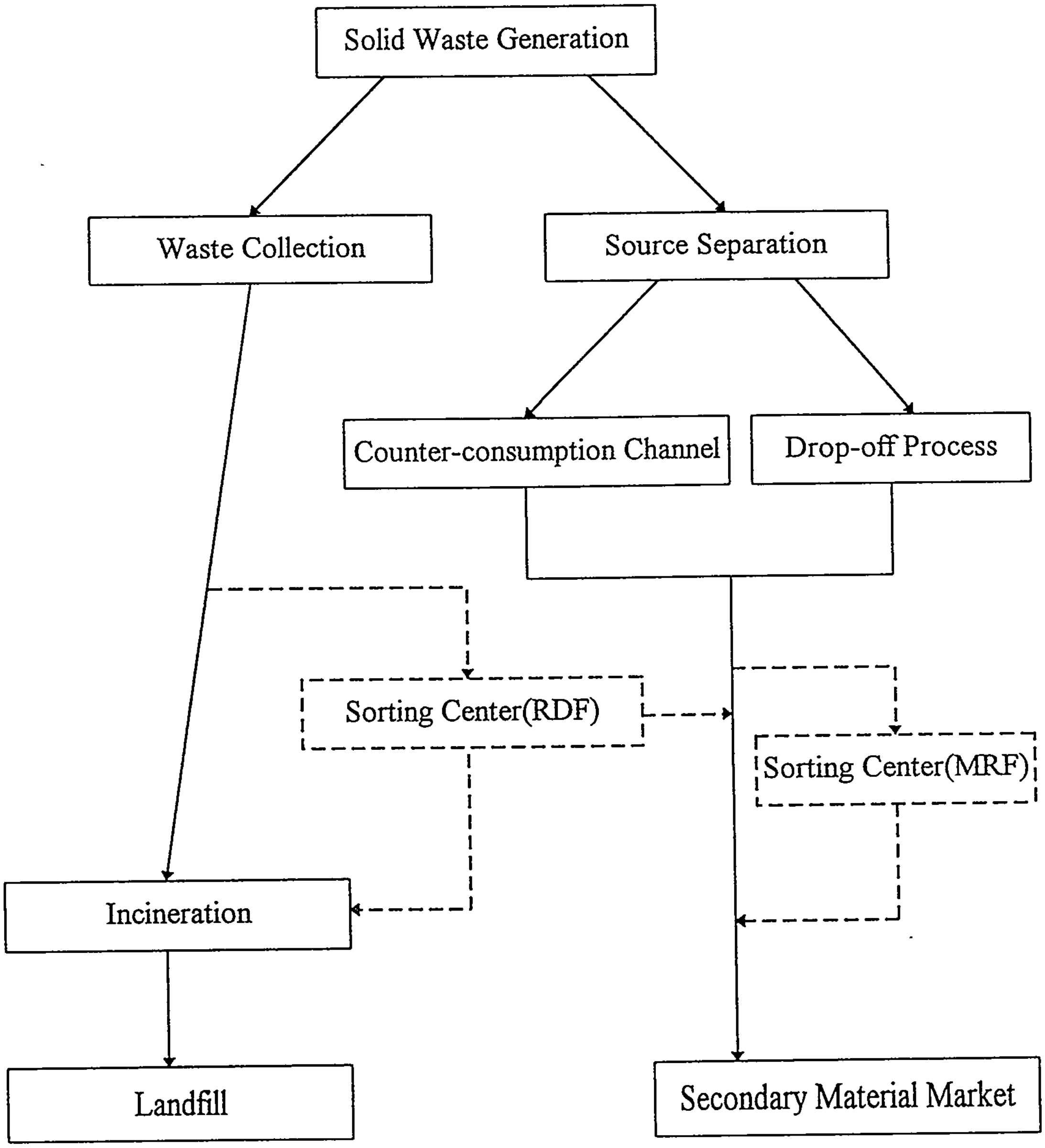

Figure 4. Schematic of solid waste management system in Taipei County

Table 1. The waste generation of areas in Taipei county

Area	Amount(tons/day)	Area	Amount(tons/day)
San-Chung	473.3	Tai-Shan	130
Pan-Chiao	565	Lin-Kou	34.2
Yung-Ho	250	Shen-Keng	24.6
Chung-Ho	391.7	Shih-Ting	9.8
Hsin-Chuang	323.3	Ping-Lin	17.5
Hsin-Tien	257.9	San-Chih	38.9
Tu-Cheng	235.9	Shih-Men	10
Shu-Lin	82.5	Pa-Li	61.4
Ying-Ko	65.4	Ping-Chi	21
San-Hsia	151.7	Shuang-Chi	13.1
Tan-Shui	162.5	Kung-Liao	21
Hsi-Chih	60	Chin-Shan	22.7
Shui-Fang	350.7	Wan-Li	42.5
Lu-Chou	150	Wu-Lai	9.8
Wu-Ku	82.9		

Total waste amount in Taipei county : 4059.2 tons/day

Table 2.Waste composition in Taipei County

Physical composition analysis(on dry base)	Percentage
Paper	37.99%
Textiles	6.11%
Garden trimmings	2.57%
Food waste	18.94%
Plastics	19.86%
Leather & rubber	1.24%
Metal	3.68%
Glass	7.28%
Ceramics &china	0.44%
Stone & sand	1.00%
Others	0.88%

Table 3. The specification of major equipments

Equipment	Capacity	Energy requirement (hp)
Bag-ripper	30 (tons/hr)	5
Magnetic separator	30 (tons/hr)	3
Shredder	30 (tons/hr)	500
Air classifier	200 (m^3-air/min)	20
Trommel	30 (tons/hr)	7.5
Cyclone	400 (m^3-air/min)	40
Conveyors	--	1~10

Table 4. The price of secondary materials in Taipei area

Item	Price	Item	Price
Waste paper	7.5 NT$/kg	Waste green glass	1.87 NT$/kg
Ferrous metal	3.9 NT$/kg	Waste dark glass	1.3 NT$/kg
Aluminar can	2.8 NT$/kg	Coke plastic bottle	2.8 NT$/item
Waste textile	25.3 NT$/kg	Plastic bottle for mineral water	0.5 NT$/item
Waste white glass	4.1 NT$/kg		

*The currency ratio is 27.5 NT$/1US$ in 1997

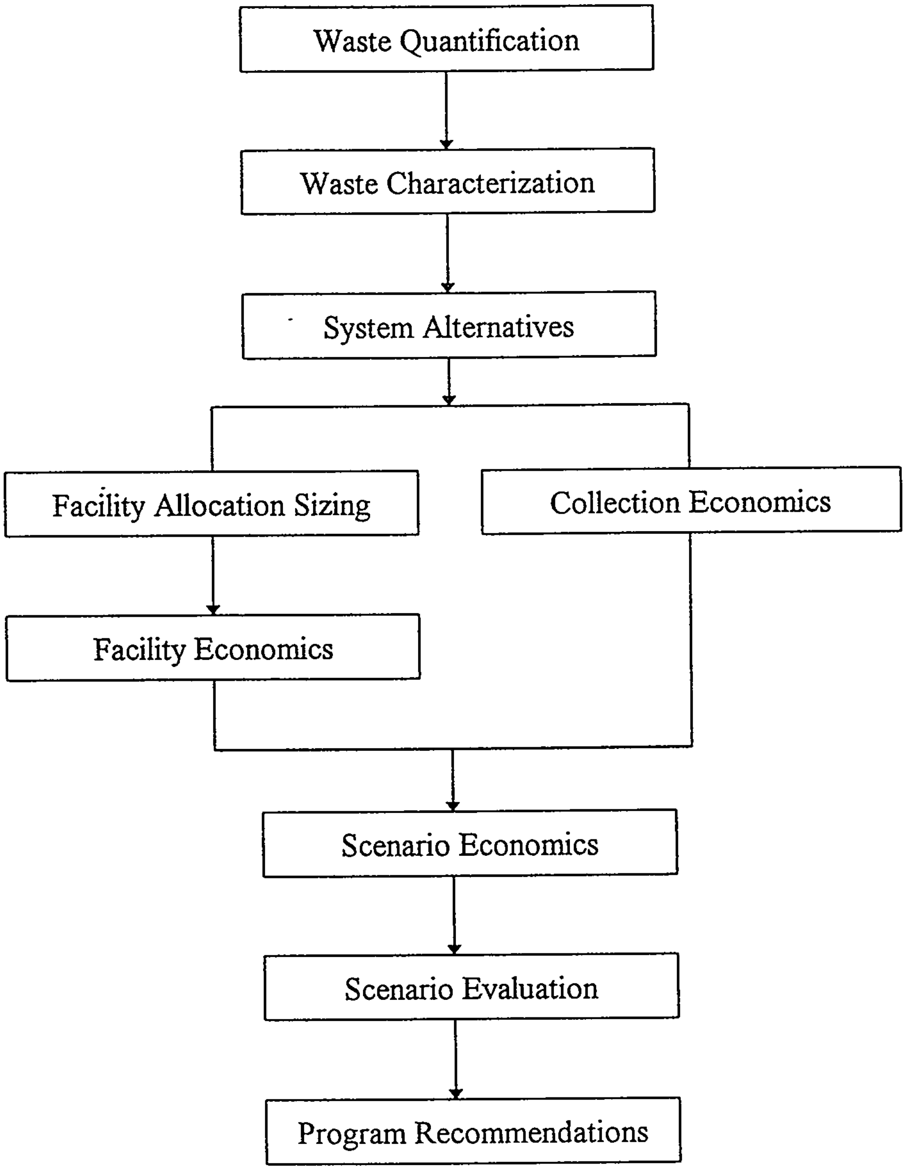

Figure 5. Integrated evaluation model for benefit/cost characterization

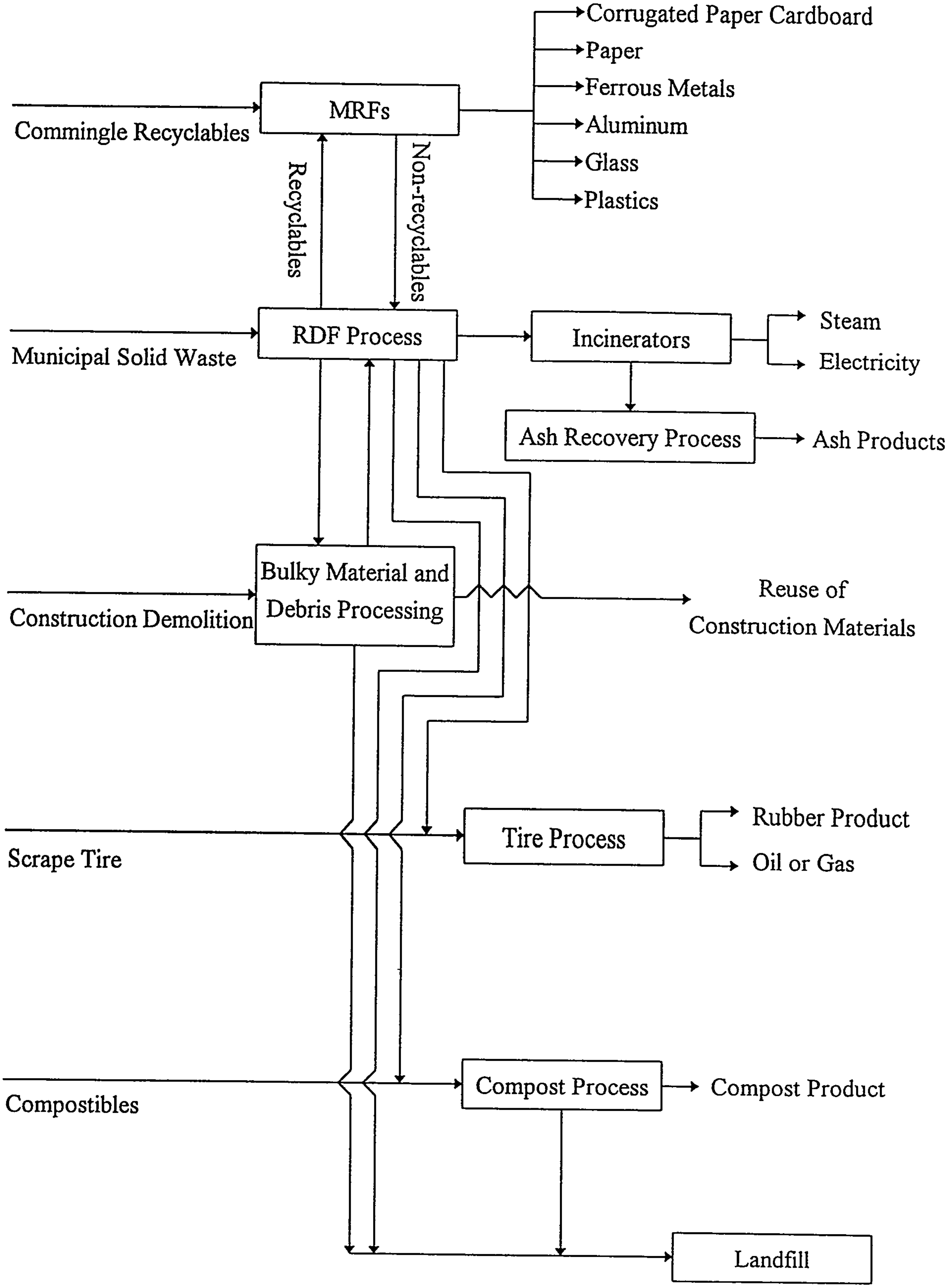

Figure 6. Future integrated system of MRF and RDF

TECHNICAL SESSION V

Emissions Control

Update of Dry Scrubbing Experience on European Waste-to-Energy Facilities

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INTRODUCTION

Disposal of municipal solid waste by incineration is a well established technology in Europe. Over the past decades emission requirements from these waste-to-energy facilities have gradually been tightened (1). The most stringent requirements in Europe are in the Central European countries like Germany, Holland, Switzerland and Austria. In these countries the latest, most stringent regulations, i.e. the German 17th Federal Immission Control Regulation (17th BImSchV) is setting the emission standard. In contrary, the emission standards set currently by the European Union (EU) are less stringent, but are expected to be tightened in the future, see Table 1.

Based on the difference in the emission requirements locally and presumably also based on the difference in attitude, countries like Denmark, Sweden, Finland, England, France, Spain, Portugal and Italy have chosen to comply with the emission standards by using less complicated and less expensive air pollution control equipment compared to the Central European countries. Air pollution control equipment in Central Europe has over the last decade advanced to such complexity and costs that the price of the air pollution control equipment far exceeds the incinerator per se (1,2). As prices for air pollution control equipment have sky-rocketed, the societies in Central Europe have realized that this is not a sustainable development and the trend has now reversed such that simpler and more cost-effective solutions are considered, while at the same time still fulfilling the 17th BImSchV-regulation.

One of the cost-effective options being considered is the spray dryer absorption technology, including a spray dryer and fabric filter. The paper describes four commercial spray absorption systems in different countries. They include various design modification, however they all are able to meet the most stringent European regulations.

DESCRIPTION OF PLANTS

The waste-to-energy plants in question are the following:

1. Amager - Denmark
2. Turku - Finland
3. IBW - Belgium
4. Mallorca - Spain

These facilities are geographically located far apart from the far North (Turku) to the Southern part of Europe (Mallorca). Design data for the waste-to-energy facility per se is given in Table 2.

The spray dryer absorption systems were all built by ABB under a license agreement with Niro. Of the four plants in question the Amager and Turku plants are designed as a traditional spray dryer absorption (SDA) process. The SDA process combines spray drying technology with efficient particulate collection in a down-stream filter, which usually is a fabric filter. The system is designed to removed acid gases and particulates from flue gases without saturating the flue gas and therefore producing a dry product for disposal. Figure 1 is showing a simplified diagram of the four SDA systems incorporating the general design features for the Niro system:

- Use of a single spray dryer per incinerator unit.
- Use of a single rotary atomizer per spray dryer producing a cloud of fine reagent droplets.
- Use of a single gas disperser to control the shape of the droplet cloud and achieve intimate mixing in the flue gas and the reagent slurry.
- Inclusion of a 2-point product discharge designed to ensure an open gas passage.
- Sufficient spray dryer residence time to ensure adequate drying of disposal product.

The SDA system consists of a reagent preparation system, a spray dryer absorber, a dust collector and an ash transport system. Most commonly the SDA system is designed for single-pass operation.

Quicklime is delivered by truck and conveyed pneumatically to a storage silo. From the silo, the lime is transferred to a paste or detention slaker, where an approx. 20% lime slurry is prepared. The lime slurry is transferred via a grid screen to a feed tank with final dilution of the lime slurry accomplished either in a small dilution head tank located above the spray dryer absorber, or in the rotary atomizer itself utilizing a dual-liquid distributor. By using the latter method, lime slurry and water are mixed directly in the atomizer wheel. The degree of dilution is controlled by a signal from an HCl or SO_2 analyzer located in the stack; the total liquid flow to the rotary atomizer is controlled to maintain a constant spray dryer absorber outlet temperature.

The atomized lime slurry enters the spray dryer, where it is mixed with the hot incoming flue gas; simultaneously lime reacts with the acid gases present and the reaction product is dried into free-flowing powder. A portion of the dried product is removed from the base of the spray dryer, while the majority is entrained with the off-gases and recovered in the particulate collector. Additional acid gas absorption takes place in the particulate collector, while the dust is being removed from the flue gas. The dried product from the spray dryer absorber and the particulate collector is conveyed either mechanically or pneumatically to a waste disposal silo. Normally, this product is hygroscopic due to the content of chlorides.The spray dryer outlet gas temperature is controlled as low as possible to give a high efficiency of acid gas removal, while simultaneously ensuring a dry product. Factors which influence the selection of spray dryer outlet temperature include: level of chlorides in the disposal product, water vapor content of the flue gas leaving the spray dryer absorber, solids content of the feed slurry and whether the system is operating in single-pass or recycle mode.

For additional control of vapor phase emissions such as mercury and dioxins, the SDA system can be augmented with an activated carbon injection system. This consists of a patented, dry additive system for injection of activated carbon, either up-stream, in or down-stream of the spray dryer, depending on the temperature level throughout the SDA system. The activated carbon injection technology for mercury control was developed and patented by Niro. It seems like this technology is the preferred technology for mercury control on waste-to-energy plants, and as a consequence Niro has through its licensee, the Babcock & Wilcox Co., and previously through Joy Technologies granted sub-licensees to main contractors of waste-to-energy plants, operators of waste-to-energy plants as well as vendors of air pollution control equipment. It is Niro's policy to continue this sub-licensing of the patented mercury control technology to any interested party.

The above description of the generic SDA system used at Amager and Turku applies for more than 65 waste-to-energy trains having installed the Niro SDA system.

Further development of the basis SDA system has been made at the IBW and the Mallorca plant. The basic layout of those two plants are shown in Figure 1.

The system at IBW is the so-called High-Performance Spray Dryer Absorber (HPSDA). The HPSDA-system consists of a normal spray dryer absorber system which at IBW includes a spray dryer absorber with down-stream electrostatic precipitator. In addition, the HPSDA-system further includes a fabric filter installed down-stream of the electrostatic precipitator. The flue gas between the two filters can optionally be cooled in a heat-exchanger to a lower and for the process more optimum temperature. In the fabric filter, hydrated lime is introduced by dry injection in the duct up-stream of the fabric filter. The spent and partially reacted hydrated lime from the second fabric filter may then be used for dry injection up-stream of the electrostatic precipitator. By this method, the overall disposal quantities are reduced to a level comparable to disposed quantities from the wet scrubbing system. The advantages of cooling the flue gas in a heat-exchanger is twofold. First of all heat is recovered and secondly mercury removal in the fabric filter is improved, even without active carbon injection. Thus mercury emission requirements can be met with no or very little active carbon injection.

The Mallorca incinerator plant is a completely new facility consisting of two 450 TPD incinerator trains each equipped with identical dry scrubbing units. The Mallorca dry scrubbers are designed with dry recycle to enhance the performance. The recycle system is designed as follows: Dry scrubber waste with excess lime from the fabric filter is transported pneumatically to an intermediate silo. Next to this silo is a silo with activated carbon. The alkaline dry scrubber waste is then mixed with activated carbon and pneumatically injected into the duct between the spray dryer and fabric filter. This process modification is increasing the alkalinity ratio into the fabric filter and thereby improving the absorption performance. The recycle rate of dry scrubber waste is set to 5 times the amount of solids being introduced via the rotary atomizer. The amount of active carbon injected is relatively high, i.e. 240 mg/Nm^3. This is due to the fact that the system has been designed for an outlet spray dryer temperature of 160^{o}C, at which temperature mercury removal is more difficult than at the normal dry scrubber outlet temperatures for incinerators (130-140^{0}C).

The plant is designed for emission limits according to the Spanish legislation, i.e. HCl emissions of 50 mg/Nm^3, and SO_2 emissions of 300 mg/Nm^3, both at 11% O_2 dry, so today the dry scrubber systems are fulfilling the present EU legislation.

Design data for the four air pollution control systems are shown in Table 3.

TEST RESULTS

Amager

The Amager incinerator plant has four 288 TPD incinerator trains, each equipped with identical dry scrubbing units. The plant was originally designed for emission limits according to the Danish 1986 legislation, i.e. HCl emissions of 100 mg/Nm^3 and SO_2 emissions of 300 mg/Nm^3 both at 10% O_2 dry. Today the dry scrubber systems are operated with a lower set-point for the HCl emission, fulfilling the present EU legislation, i.e. HCl emission equal to 50 mg/Nm^3 and SO_2 emissions of 300 mg/Nm3 both at 11% O_2 dry.

In the winter and spring of 1995, the Amager incinerator plant decided to enter into a test program with the purpose of demonstrating that the Niro dry scrubbing system was capable of meeting the 17th BImSchV emission limits regarding HCl and SO_2 and at the same time to estimate the corresponding lime consumption. The test program was carried out jointly by I/S Amagerforbrænding (Amager Incinerator), Kemp & Lauritzen A/S, MILJØKEMI Dansk Miljøcenter A/S and Niro A/S. The companies Kemp & Lauritzen A/S and MILJØKEMI Dansk Miljøcenter A/S were supplying a multi-component FT-IR gas analyzer type KL2000 developed by Kemp & Lauritzen A/S. I/S Amagerforbrænding was responsible for the daily operation, and Niro A/S was responsible for temporarily installed gas analyzers on the inlet and outlet side of the dry scrubbing system, calibration of analyzers and plant instrumentation using reference methods, data-logging and reporting of measurements. Hence, during the tests continuous emission monitors were installed both at the inlet of the dry scrubber and in the stack measuring HCl, SO_2, H_2O and O_2.

During the tests, the only modification to normal operation of the plant was the lowering of the spray dryer absorber outlet temperature to 135°C and an adjustment of the HCl emission set-point from 50 mg/Nm^3 down to 10 and 5 mg/Nm^3 respectively. The HCl emission signal was utilized to control the lime feed.

All measurements from the plant instrumentation or temporarily installed instruments were logged in a temporarily installed data-logging system. The data were logged as 1 minute, 5 minutes or one half hour averages. The test program was carried out without any major operational problems although the set-point for the spray dryer outlet temperature was lowered to 135°C and 130°C respectively. No drying problems or product handling problems were encountered.

The inlet HCl distribution during the test is shown in Figure 2. As can be seen most values are in the range from 600 - 1000 mg/Nm^3. The half-hour emission average with a HCl set-point of 10 mg/Nm^3 is shown in Figure 3, and the half-hour average using a set-point of 5 mg/Nm^3 is shown in Figure 4. From these results it can be seen that the dry scrubber without problems can meet the German 17th Federal Emission Control Regulation of 10 mg/Nm^3 and that it is further possible to meet half this emission standard.

During the test program also the inlet SO_2 concentration was measured as shown in Figure 5. The corresponding SO_2 outlet emissions on a half-hour averaging basis for a HCl set-point of 10 mg/Nm^3 and 5 mg/Nm^3 are shown in Figure 6 and 7 respectively. As it can be seen, the SO_2 emission can be kept way below the 50 mg/Nm^3 specified in the German 17th Federal Immission Control Regulation.

Turku

As mentioned before, the Turku plant consists of two 120 TPD incinerator lines originally built by Von Roll in 1975. The dry scrubber system that was retrofitted in 1995 was designed to treat the flue gas from the two existing incinerators plus a future 3rd train of 240 TPD.

The dry scrubbing system is characterized by having a 1-field electrostatic precipitator as a pre-collector, a spray dryer absorber and a downstream fabric filter. The dry scrubber system is equipped with an activated carbon injection system for mercury control.

This dry scrubber system is unique in the sense that this is the first Niro dry scrubbing system in which the German 17th BImSchV regulation of 10 mg/Nm^3 HCl was guaranteed.

The active carbon injection system is used for control of heavy metals like mercury and dioxins. The very small amount of active carbon is continuously injected into the flue gas duct between the absorber and the bagfilter. A static mixer is installed for distribution of the active carbon.

The Turku retrofit dry scrubbing system was started-up and tested in 1996. Responsible for the test program was the engineering company IVO International Oy.

The performance test data for acid gases and particulate are shown in Table 4. The particulate concentration into the SDA is low due to the use of an electrostatic precipitator as precollector. As can be seen from the performance test results, the plant clearly met the German 17th BImSchV regulation.

Results of the performance testing for heavy metals and dioxins are shown in Table 5. During the test, activated carbon was injected in a rate of approx. 40 mg/Nm^3. The flue gas flow during the performance testing was between 40,000 and 47,000 Nm^3/h.

IBW

The performance test of the IBW dry scrubbing system was accomplished in September 1996. The company SGS Ecocare Analytical Services was in charge of the measurements. Results of the testing are shown in Table 6, 7 and 8. As it can be seen from the results, the High-Performance SDA system is achieving very good emission values. The sulfur dioxide is the most difficult to remove in the spray dryer, but with the additional fabric filter, very low outlet emissions can be achieved.

The results from the IWB plant show that the dry scrubber system can achieve emission values corresponding to half the German 17th Imission Control Regulation.

Mallorca

The Mallorca incinerator system was started-up in the fall of 1996 and preliminary performance tests were made in late November 1996. At this point, the final performance tests have been made, but the data are not yet available.

As it appears from the preliminary performance test results in Table 9, the dry scrubber at Mallorca was easily able to meet the present EU legislation of 50 mg/Nm^3 HCl and 300 mg/Nm^3 SO_2.

CONCLUSION

Results from testing of four commercial dry scrubber units in Europe have proven that dry scrubbing technology today can meet the performance required by the most stringent European regulation enacted in the German 17th Federal Immission Control Regulation. The paper further documents that half the

German emission standards can be obtained with dry scrubbing technology. These emission values are comparable to what can be achieved with more complex systems using wet scrubber technology.

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Table 1: Emission requirements for European waste-to-energy facilities

Pollutant	German 17th BImSchV	EU 1989 -	EU Future expected
HCl	10	50	10
SO_2	50	300	50
Hg	0.05	0.2*)	0.05
Particulate	10	30	10

mg/Nm^3 at 11% O_2 *) Hg + CD

Table 2: Design data for waste-to-energy facilities

Plant	Amager	Turku	IBW	Mallorca
Capacity, TPD	4 x 288	2 x 120	1 x 120 1 x 240	2 x 450
Incinerator manufacturer	Vølund	Von Roll	B&S Bartholomeis	DBA
Type of kiln	Travelling grate + rotary	Travelling grate	Travelling grate	Travelling grate
Economizer	Yes	Yes	Yes	Yes
Type of waste	Household & hospital waste	Household	Household	Household
Plant start-up	1989/91	1994	1995 1997	1996

Table 3: Design data for air pollution control systems

Plant	Amager	Turku	IBW	Mallorca
Flue gas flow, Nm^3/h	95,500	77,000	35,000 60,000	110,000
Flue gas temp. °C	180-228	180-250	210-300	190-260
Pollutants Concentration				
HCl, mg/Nm^3 d, 11% O_2	≤ 1,636	1000-1500	≤ 2000	≤ 1800
HF, mg/Nm^3 d, 11% O_2	≤ 14	≤ 7	≤ 8	≤
SO_2, mg/Nm^3 d, 11% O_2	≤ 364	≤ 400	≤ 500	≤ 1200
Hg, mg/Nm^3 d, 11% O_2	0.35	0.1	-	1.0
Particulate, g/Nm^3 d	≤ 7	≤ 7	≤ 1	≤ 4
Emission requirements				
HCl, mg/Nm^3 d, 11% O_2	≤ 100	≤10	≤ 5	50
SO_2, mg/Nm^3 d, 11% O_2	≤ 300	≤150	≤ 25	300
HF, mg/Nm^3 d, 11% O_2	2	≤1	≤1	2
Hg, mg/Nm^3 d, 11% O_2	≤0.20	≤0.05	≤0.05	< 0.20
PCDD/PCDF, ng TE/Nm^3 d,11% O_2	-	≤0.1	≤0.1	≤0.1

Table 4: Performance test results - Turku
Acid gas and particulate removal

Component		System Inlet	System Outlet
HCl	mg/Nm^3	420	9.6
HF	mg/Nm^3	2.1	0.1
SO_2	mg/Nm^3	200	43
Particulate	mg/Nm^3	9	2

Table 5: Performance test results - Turku
Heavy metal and dioxin removal

Component		System Inlet	System Outlet
Pb + Cr + Cu + Mn	mg/Nm^3	2.2	0.74
Ni +As,	mg/Nm^3	-	0.007
Cd	mg/Nm^3	0.008	0.00006
Hg	mg/Nm^3	0.023	0.002
PCDD/PCDF	Eadon eqv. (ng/Nm^3)	17.5	0.007

Table 6: Performance test results - IBW
SO_2 removal - SO_2 concentration in mg/Nm^3

Date	Raw gas	Downstream electro-static precipitator	Downstream fabric filter
September 12, 1996	164	43	< 25
September 13, 1996	370	54	< 24

Table 7: Performance test results - IBW
HF removal - HF concentration in mg/Nm^3

	Raw gas	Downstream electro-static precipitator	Downstream fabric filter
September 10, 1996	0.1 - 1.5	< 0.1	< 0.1
September 11, 1996	0.1 - 0.8	< 0.1	< 0.1
September 12, 1996	0.1 - 3.4	< 0.1	<0.1
September 13, 1996	0.1 - 0.4	<0.1	<0.1

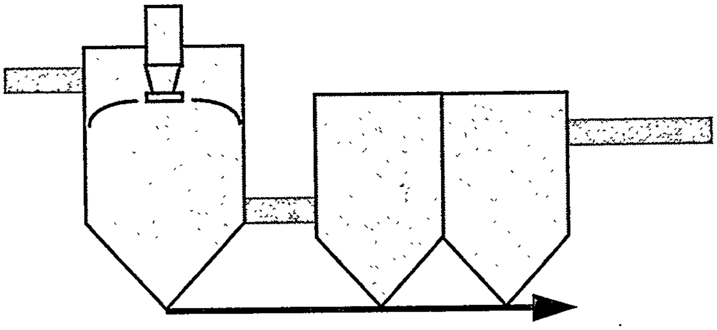
Table 8: Performance test results - IBW
HCl removal - HCl concentration in mg/Nm^3

	Raw gas	Downstream electrostatic precipitator	Downstream fabric filter
September 10, 1996	138 - 907	2.6	-
September 11, 1996	493 - 771	3.0	-
September 12, 1996	210 - 393	1.8	<1
September 13, 1996	1382 - 3618	<1	<1

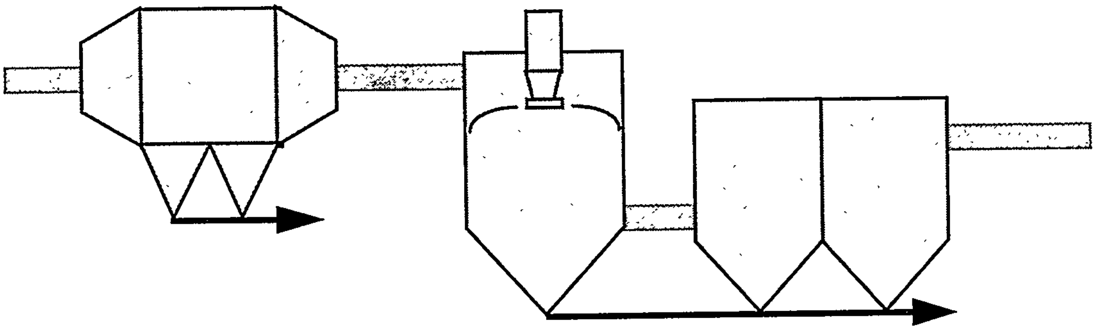
Table 9: Preliminary performance
Test results - Mallorca

Component		System inlet	System outlet
HCl	mg/Nm^3	753	33
SO_2	mg/Nm^3	97	38

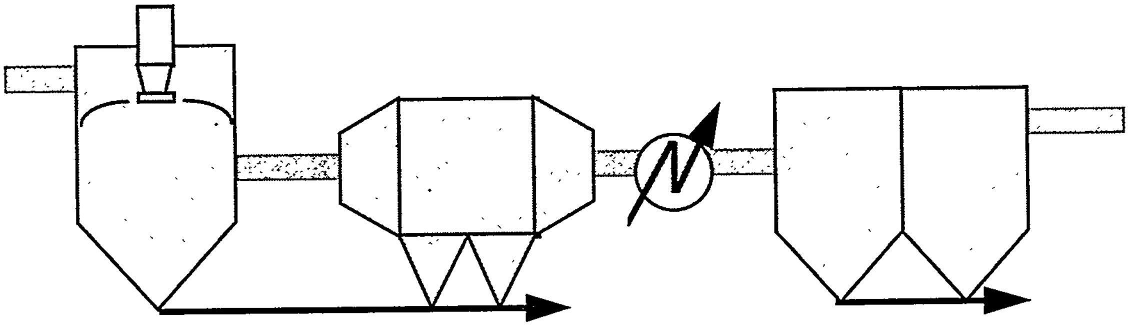
Amager



Turku



IBW



Mallorca

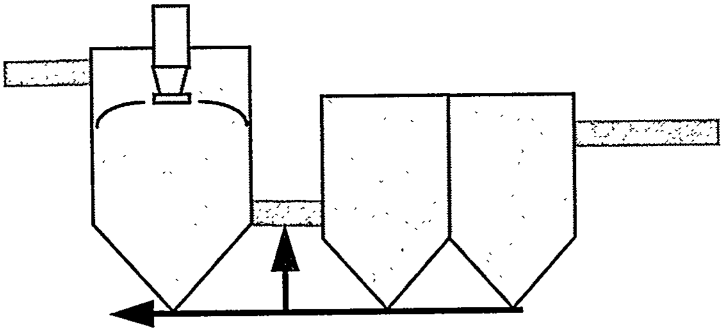


Figure 1: Design of air pollution control equipment

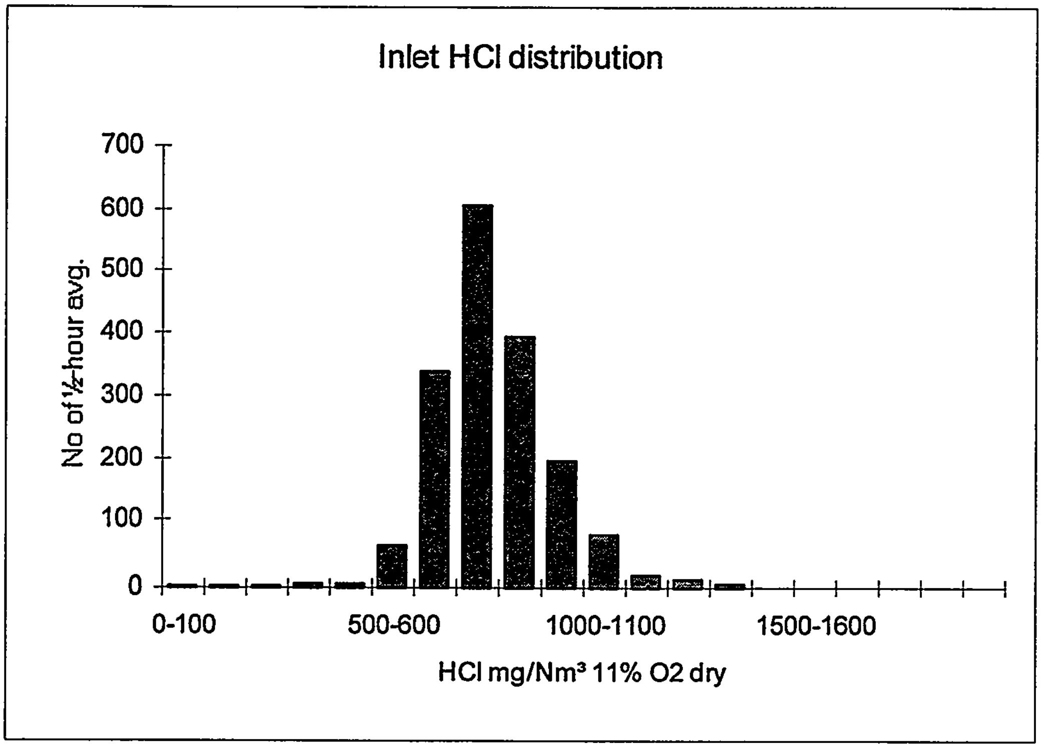


Figure 2: Inlet HCl distribution

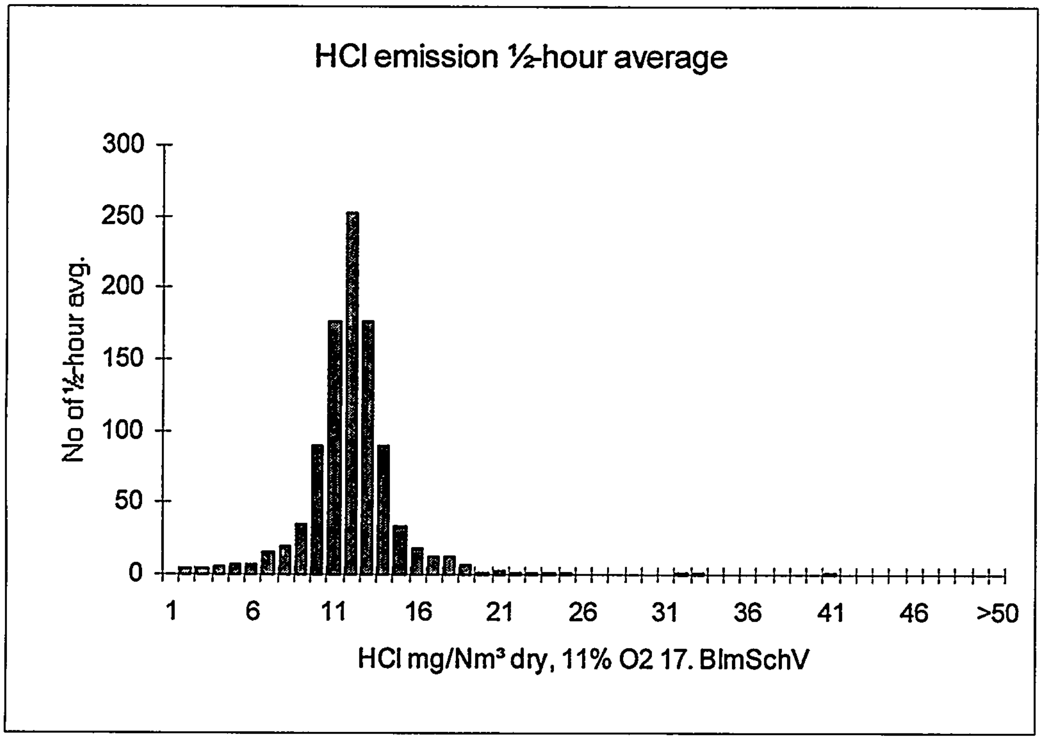


Figure 3: HCl emission ½ hour average
Temp. SDA outlet 130-140°C, Set Point HCl 10 mg/Nm^3 wet at actual O_2

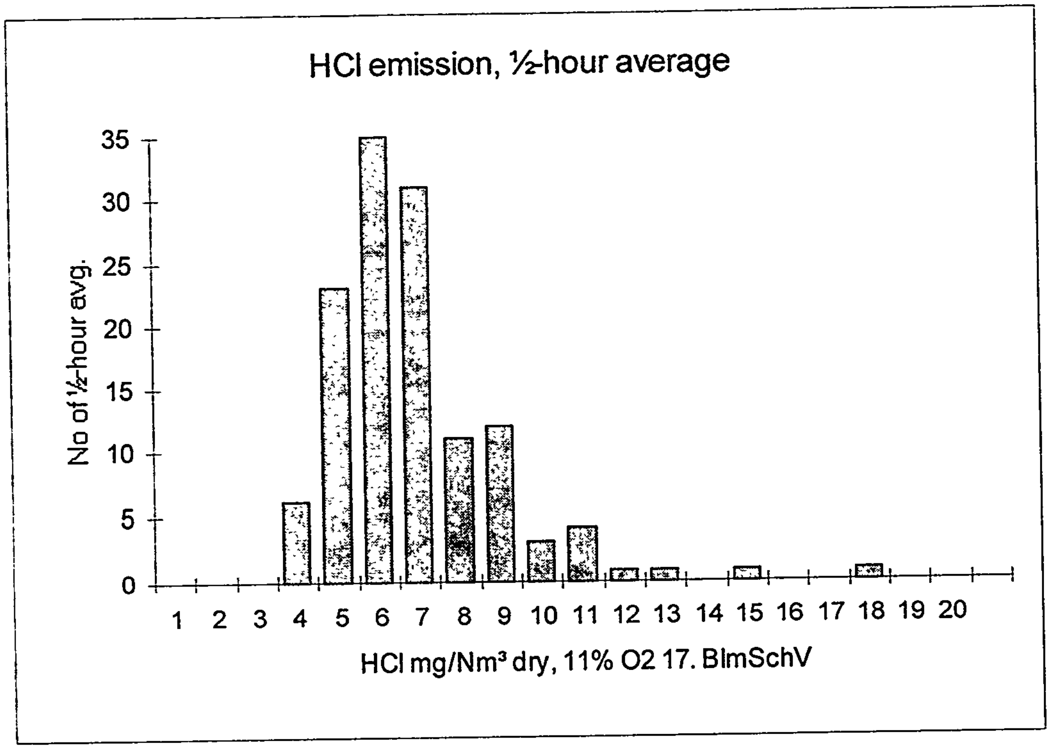


Fig 4: HCl emission ½ hour average
Temp. SDA outlet 130-140°C , Set Point HCl 5 mg/Nm^3 wet at actual O_2

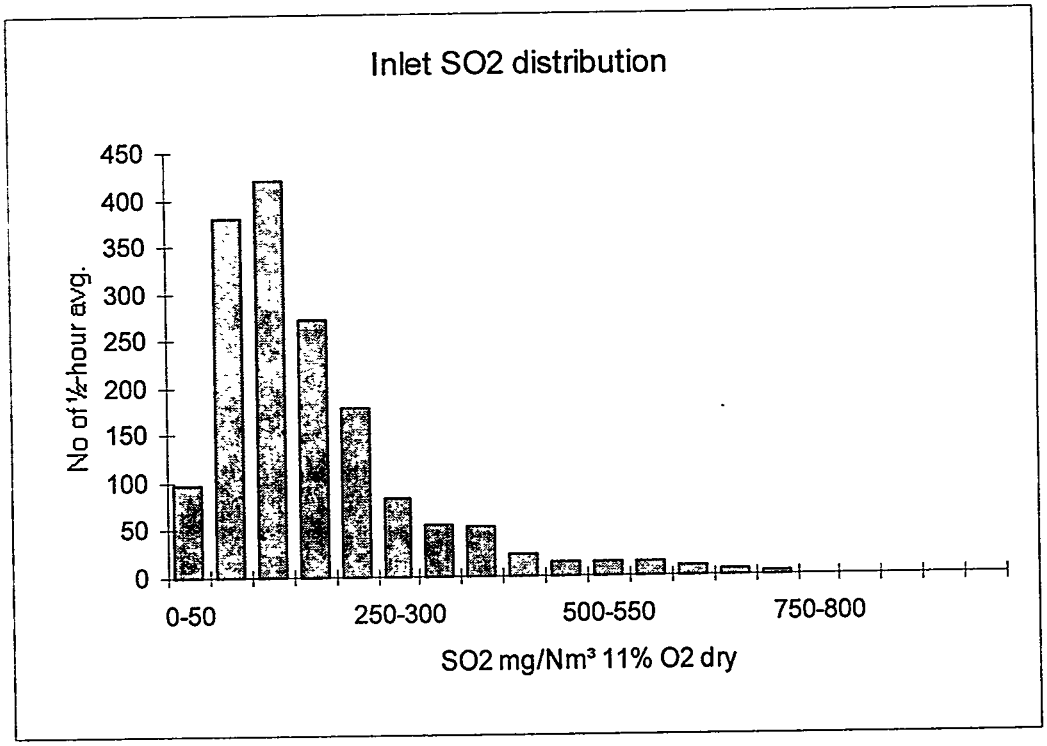


Figure 5: Inlet SO_2 distribution

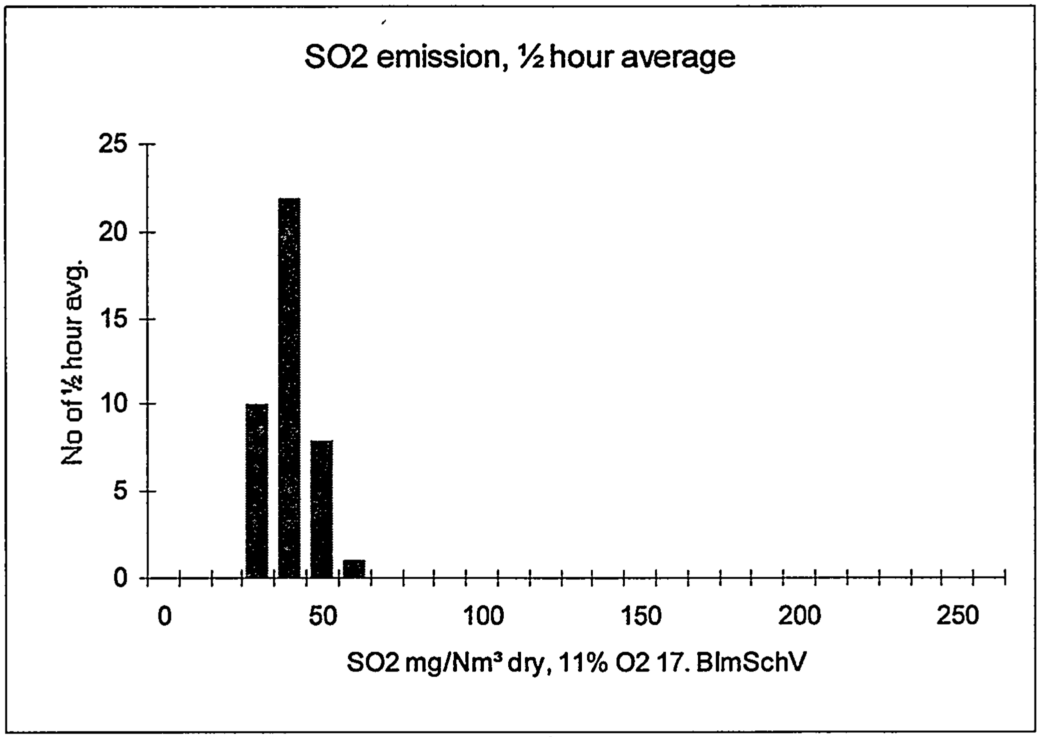


Figure 6: SO$_2$ emission, ½ hour average
Temp. SDA outlet 130-135°C, Set Point HCl 10 mg/Nm^3
at actual O$_2$

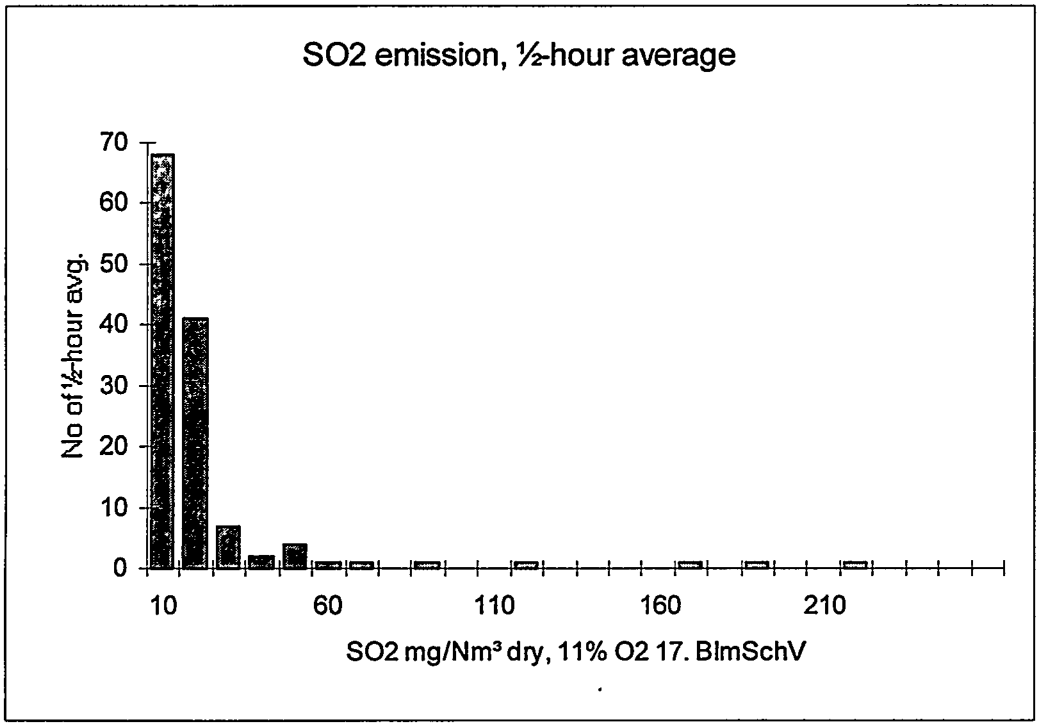


Figure 7 SO$_2$ emission, ½ hour average
Temp. SDA outlet 130-140°C, Set Point HCl 5 mg/Nm^3
at actual O$_2$

Experience with a Carbon Injection System at a Spray Dryer/Electrostatic Precipitator Equipped Waste-to-Energy Facility

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INTRODUCTION

American Ref-Fuel Company of Essex County obtained an air permit to construct the Essex County Resource Recovery Facility (ECRRF), a municipal solid waste resource recovery facility, in December 1985 from the New Jersey Department of Environmental Protection (NJDEP). Permit condition A.9.a. states that the emission rate of mercury from each unit shall not exceed 0.053 pounds per hour, based on the average value of three runs using EPA Method 101A. Testing for mercury was required to be performed on a quarterly basis during the facility's first year of operation. This emission requirement was met by the spray dryer adsorber (SDA)/electrostatic precipitator (ESP) equipped facility. Subsequently, the NJDEP chartered a task force to investigate the setting of a new statewide mercury emission standard for municipal solid waste (MSW) combustors. The task force in July of 1993 recommended a more stringent two phase emission standard requiring all facilities to achieve 65 ug/dscm at 7% oxygen dry volume or 80 % reduction by January 1, 1996, and to achieve 28 ug/dscm at 7% oxygen dry volume or 80% reduction by January 1, 2000. These recommendations and a requirement for installing a mercury control system were codified into a regulation in November 22, 1994. In order to comply with the new regulation the facility proceeded with a retrofit mercury control system.

FACILITY DESCRIPTION

The Essex County Waste-to-Energy Facility is New Jersey's largest waste-to energy plant, owned and operated by American Ref-Fuel of Essex County in Newark. In operation since late 1990, it serves the refuse disposal needs of 22 municipalities in Essex County and the surrounding region. The plant has three combustors which operate 24 hours per day, 365 days per year, and processes approximately 2,500 tons of municipal solid waste per day. The plant also produces, via two steam turbine-generators, about 70 megawatts of electricity for sale to Public Service Electric and Gas, New Jersey's largest utility.

Each incinerator utilizes the proprietary mass burn technology developed by the German firm of Deutsche Babcock Anlagen (DBA), which since 1961 has been installed in more than 60 facilities worldwide. Each unit at the Essex plant has six Duesseldorf roller grates, each with a width of 6.5 meters. The heat generated by the refuse combustion is used in a four pass boiler to produce steam of 650 psia and 750F. The flue gas generated by the combustion leaves the final economizer section of the boiler at a temperature between 432F to 520F, depending upon the degree of boiler surface fouling.

Each incinerator has a dedicated flue gas cleaning system, composed of two spray dryer absorbers (SDAs), or "dry scrubbers", in parallel, followed by an electrostatic precipitator (ESP). The system was supplied by Deutsche Babcock Anlagen. The flue gas flow from the economizer outlet, approximately 110,000 to 150,000 scfm wet, splits into two parallel streams that enter the SDAs at the bottom. In this inlet section, called the pre-cyclone, approximately 70% of the flyash is removed from the flue gas flow. The gas then flows upward through pipes which dampen the remaining turbulence into the main reactor vessel. Dual fluid nozzles deliver a lime slurry of approximately 15% concentration into the reactor vessel, using compressed air for atomization. The lime reacts with the acid gas components to form neutral salts of reaction that are collected in the SDAs and downstream in the electrostatic precipitator. The outlet concentration of SO_2 is the parameter that is used to determine the lime slurry feed rate. As the flue gas exits the SDAs at the top, the temperature is measured and additional dilution water is injected via the dual fluid nozzles to maintain the outlet temperature between 280^{o}F to 325^{o}F. Each

SDA is 105 feet tall with an internal diameter of 12 feet 2 inches. Upon exiting the SDAs, the two flue gas streams are combined and enter an ESP. These particulate collection devices used at the Essex Facility were supplied by DBA through subsupplier Flakt, Inc. Each ESP has three fields and has a particulate emission requirement of 0.015 grains per dry standard cubic foot at 7% O_2.

EMISSION HISTORY

The ECRRF was required as an initial permit condition to perform mercury testing, using Method 101A, along with a variety of other parameters on a quarterly basis during the first year of operation. Although the facility initially had one of the lowest mercury emission concentration rates in the state, it did not achieve the required emission rate of 0.053 pound per hour. As a result, additional monthly testing was mandated which demonstrated the facility's compliance with its mercury emission rate. In order to settle any claims related to prior compliance within the mercury emission rate, an Administrative Consent Order was entered into between the ECRRF and the NJDEP on January 14, 1994. This ACO required additional testing on a quarterly basis utilizing Method 29. Figure 1 presents the data from these test programs, all prior to any mercury control system being installed at the facility.

Before the NJDEP revised the statewide mercury emission requirements, the facility and the State of New Jersey had undertaken a number of actions to reduce mercury levels in the wasteshed. Some of these programs are discussed in greater detail in the two papers cited in the Reference section of this paper. The facility began a battery survey program designed to eliminate mercury batteries from the waste stream. Mercuric oxide batteries were commonly used in consumer items such as hearing aids, in institutional applications such as hospitals and in military applications. In addition, New Jersey passed the Dry Cell Battery Management Act which was intended to restrict mercury containing batteries in the state. Fluorescent light bulb recycling was also promoted by the facility and certain counties. As can be seen from the data presented in Figure 1, mercury emission rates were trending downward.

FACILITY MERCURY RETROFIT

In order to meet the new mercury requirements, bids were solicited from suppliers of systems that could inject carbon into the flue gas stream. Although a reduction in mercury concentration was the prime objective, a reduction in dioxin was also anticipated. Concerns were raised that performance would be more difficult to achieve with an ESP-equipped facility or that other emission concerns such as increased particulate might arise. Bids were accepted on a dry carbon injection system, on a carbon in water slurry system that mixes the carbon slurry with the lime slurry for injection through the existing dual fluid nozzles, and for a system in which carbon is added to the lime slurry tank and the combined lime/carbon slurry is injected via the existing dual fluid nozzles into the reactor vessel. The system chosen was a dry carbon injection system supplied by Norit Americas Inc. Some testing and data appear to indicate that a dry injection system is more efficient in carbon utilization, which is the major cost in a life cycle analysis of this system.

The Norit Americas Inc. powdered activated carbon, bulk storage and dosing system is composed of a bulk storage silo and three independently controlled dosing modules with associated carbon delivery piping. The system layout is shown in Figure 2. Fitting the system on the existing site posed numerous challenges. A decision was made to locate this system near the existing lime storage silos and lime slakers, and the phosphoric acid tank in order to keep bulk chemical storage in a centralized but accessible part of the plant. This decision, along with the required traffic patterns and access roads at this operating plant led to the layout shown. Air is blown by the blowers from the auxiliary building to eductors in the silo skirt. There carbon is entrained within the air stream and subsequently is conveyed to the flue gas streams in the plant.

The total volume of the carbon silo is approximately 5,000 ft^3, and can contain 2-1/2 truckloads (more than a month's usage) of carbon while maintaining 13 feet of freeboard. The silo is fed from road tankers carrying 40,000 pounds per truck. During silo filling, the carbon is pneumatically conveyed from the truck to the silo. The silo is equipped with three point level switches, and with one continuous level sensor. A bin vent filter is mounted atop the silo to minimize fugitive emissions during silo filling. In addition, the silo has two 39 inch x 40 inch blow-out panels based upon the National Fire Protection Association NFPA 68 requirements.

Figure 3 shows a schematic of the carbon dosing and supply systems. The silo skirt contains various components with the remainder located within the auxiliary building. Ten air fluidization nozzles are connected to each of the three discharge cones to promote the flow of carbon. For each of the three lines, carbon flows from the silo through a rotary valve to a volumetric feeder package. These packages contain a 6.0 ft^3 feeder supply hopper with three level switches and volumetric feeders with a variable speed controller allowing a 50:1 turndown. Adjustments in carbon feed rate can be made over a range of 0 to 150 pounds per hour. The carbon discharges from the volumetric feeder into a pneumatic conveying eductor where carbon is entrained within the air stream. Low pressure air is used as the motive force to convey the carbon to the point of injection into the flue gas stream.

Figure 4 shows a layout of the auxiliary building, which was designed for easy access to components requiring maintenance. A monorail and hoist were subsequently added to aid in blower and motor removal and maintenance. Each positive displacement blower is equipped with a single speed motor, and delivers 160 scfm air at 12 psig. Other equipment located within the auxiliary building include an air receiver for system instrumentation, motor control centers, and a main control panel. The original design concept was to have PLCs to monitor and control all system functions. However, a change was made to control the system from the plant main distributed control system (DCS) with local indication provided by Norit.

After the carbon is entrained within the air stream by the eductors it is conveyed through a piping system composed of schedule 40 carbon steel pipe with ceramic backed, 24" centerline radius sweeping elbows to one of two possible injection points. A hand operated diverter valve in each conveying line allows the carbon flow to be directed to either the flue gas ducts upstream of the SDA pre-cyclone sections or to the SDA vessels after the precyclone. Because of the need to fit the system into the existing facility, field routing resulted in discharge piping distances of between approximately 530' to 580', depending upon the destination chosen. In either case the flow is divided between the pair of ducts entering the two SDAs or between the individual SDAs by ceramic backed wyes. These two locations were chosen to allow a determination of the best injection point relative to carbon consumption. Preliminary tests indicated that adding carbon in the duct upstream of the SDAs was more efficient. It is believed that the longer residence time of the carbon within the flue gas stream resulting from using this location was the reason for this result. Once delivered to the flue gas stream, the powdered carbon adsorbs various volatile forms of mercury including mercuric chloride and elemental mercury present within the gas stream. The carbon is then collected before discharge from the stack by the ESP and is removed with the other flyash.

The carbon used within this system is DARCO FGD, supplied by Norit Americas Inc. It is a lignite coal based activated carbon manufactured specifically for the removal of heavy metals and other contaminants typically found in incinerator flue gas emission streams. According to Norit, it has been proven to be highly effective for the removal of gaseous mercury, dioxins, and furans in numerous full scale operating facilities. Its open pore structure and fine grind permits rapid adsorption, which is critical in this application.

SYSTEM STARTUP

The system installation was completed in December, 1996. Construction was completed under a tight schedule and incurred some delays due to the installation of mercury control systems at the other New Jersey facilities and due to a few site specific issues. Initial startup problems were limited to a few pipe leaks which were quickly fixed.

During initial operation a plug of carbon feed was not maintained in the feed hopper. When this plug is not maintained, the eductor tends to draw the carbon from the silo directly resulting in very high feed rates. It was also found that the eductor vent line cap was too small. This caused the vacuum on the system to be higher than desired compounding the carbon feed rate problem. The vent cap was enlarged correcting the problem. Several other minor modifications were made to upgrade the system for the facility.

In the design of this system, Ref-Fuel adopted an approach relative to the handling of carbon that was deemed to be very conservative. Carbon was considered to be a flammable and explosive material. Dusting, which could lead to an explosion via various means of ignition, was the primary concern where carbon was present as a pure compound and was not diluted with either water or fly ash. As a result, the design included features such as explosion vents on the storage silo in accordance with the National Fire Protection Association Standard 68 (NFPA-68). In addition, all motors and associated electrical equipment, where dry activated carbon was to be handled, was specified to conform to the Electrical Code for Wiring and Motors Exposed to Carbonaceous Dusts (i.e. National Electrical Code, Class II, Division 2, Group F). Once again, this approach was considered to be overly conservative by the system supplier, who has extensive experience with carbon handling.

SYSTEM OPTIMIZATION

It was required by the NJDEP to determine the optimal carbon injection rate for the facility. A test program was constructed to collect data at a baseline condition, as well as three various setpoints centered around the manufacturer's expected setpoint of 20 pounds per hour. Norit determined this value based upon the Essex County historical mercury emission rates. On one unit, three 2-hour runs of USEPA Method 29 were performed at each of the following conditions:

- Baseline Condition (No carbon injection)
- Low Injection Rate (15 pounds per hour)
- Mid Injection Rate (30 pounds per hour)
- High Injection Rate (45 pounds per hour)

To ensure that these injection levels were being achieved, a calibration check of the carbon feed system was performed prior to each group of runs at each setpoint to determine the actual injection rates. For the test program, injection rates of 14.5, 31, and 40 pounds per hour were achieved. Table 1 presents the data from this program.

To determine what the optimal injection rate was, the outlet concentrations of each carbon injection level were plotted, and the equation and slope of the trendline determined. This curve is included as Figure 5. Since the slope of the curve represents the change in mercury emission per unit of carbon used when no significant decrease in mercury emissions was gained when additional increments of carbon were added, this injection rate was determined to be the optimal setpoint. This calculation showed the optimal point to be about 21 pounds per hour. Since this agreed very well with the Norit Americas expected operating setpoint in their system proposal of 20 pounds per hour, the facility selected 21.5 pounds per hour as the operational setpoint.

ONGOING TESTING

Since the New Jersey regulations require quarterly testing for two years, with a provision to go annual thereafter should all results be in compliance, the ECRRF has been conducting inlet and outlet testing since January of 1996. These results are provided as Table 2. The facility, at the predetermined optimal injection rate of 21.5 pounds an hour, has been able to achieve compliance with the current regulation, as well as tentatively demonstrating the ability to achieve compliance with the January 1, 2000 standard. Limited dioxin emission testing has also been completed since the activated carbon system has been in operation. Test results were very favorable as presented in Table 3. The table also shows that particulate emissions were reasonable.

CONCLUSION

The mercury control system has performed very well since startup. Emission control is consistently within permit requirements and the system has been able to demonstrate the design performance objectives. Concerns of meeting the emission requirements for an ESP-equipped facility have not materialized and in fact, the additional dioxin control provided by the system is an extra bonus.

REFERENCES

1. Cooper, L. A.; *Battery Survey for Essex County, NJ*; Proceedings of 1993 Air and Waste Management Association, Municipal Waste Combustion Conference, Williamsburg, Virginia, VIP-32.

2. Suchan, M.; *Mercury Reduction Program for the Essex County Resource Recovery Facility;* Proceedings of the 1995 Air and Waste Management Association, Solid Waste Management: Thermal Treatment and Waste-to-Energy Technologies Conference; Washington, D.C., VIP-53.

Table 1. Essex County Mercury System Optimization Data.

Carbon Injection Setpoint (lb/hr)	Carbon Injection Actual (lb/hr)	Inlet Mercury Concentration (ug/dscm@7%O2)	Outlet Mercury Concentration (ug/dscm@7%O2)	Percent Removal (%)	Average Mercury Concentration (ug/dscm@7%O2)	Average Mercury Removal (%)
0	0		292	N/A		
0	0		176.6	N/A		
0	0		269.2	N/A	245.9	N/A
15	14.5	274.6	64.0	77%		
15	14.5	222.0	33.1	85%		
15	14.5	261.1	65.8	75%	54.3	81%
30	31	174.3	11.0	94%		
30	31	213.4	12.8	94%		
30	31	168.0	13.6	92%	12.5	93%
45	40	245.7	11.4	95%		
45	40	237.8	12.7	95%		
45	40	125.7	13.8	89%	12.6	93%

Table 2. Essex County Quarterly Mercury Emission Data for 1996.

	Boiler 1			**Boiler 2**			**Boiler 3**		
Quarter	Boiler Exit	ESP Exit	Removal	Boiler Exit	ESP Exit	Remo val	Boiler Exit	ESP Exit	Removal
	(ug/dscm@7%)	(ug/dscm@7%)	(%)	(ug/dscm@7%)	(ug/dscm@7%)	(%)	(ug/dscm@7%)	(ug/dscm@7%)	(%)
1st	135.0	21.5	84%	140.0	20.4	85%	130.0	22.2	83%
2nd	173.0	42.4	75%	151.0	17.0	89%	156.0	35.0	78%
3rd	124.0	27.3	78%	124.0	25.2	80%	140.0	32.1	77%
4th	116.0	16.0	86%	180.0	25.0	86%	109.0	18.0	83%
Average	137.0	26.8	81%	148.8	21.9	85%	133.8	26.8	80%

Table 3. Essex County Dioxin Emission Data with Mercury Control System Retrofit.

Parameter	Facility Average Corrected to 7% O_2 Unit 1	 Unit 2	 Unit 3
Total Dioxins①, ng/dscm	3.0	1.5	2.0
Particulate	0.0025	0.0010	0.0010

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① Total dioxins is inclusive of tetra-octa polychlorinated dibenzo-p-dioxins and tetraocta polychlorinated dibenzo furans reported on a total

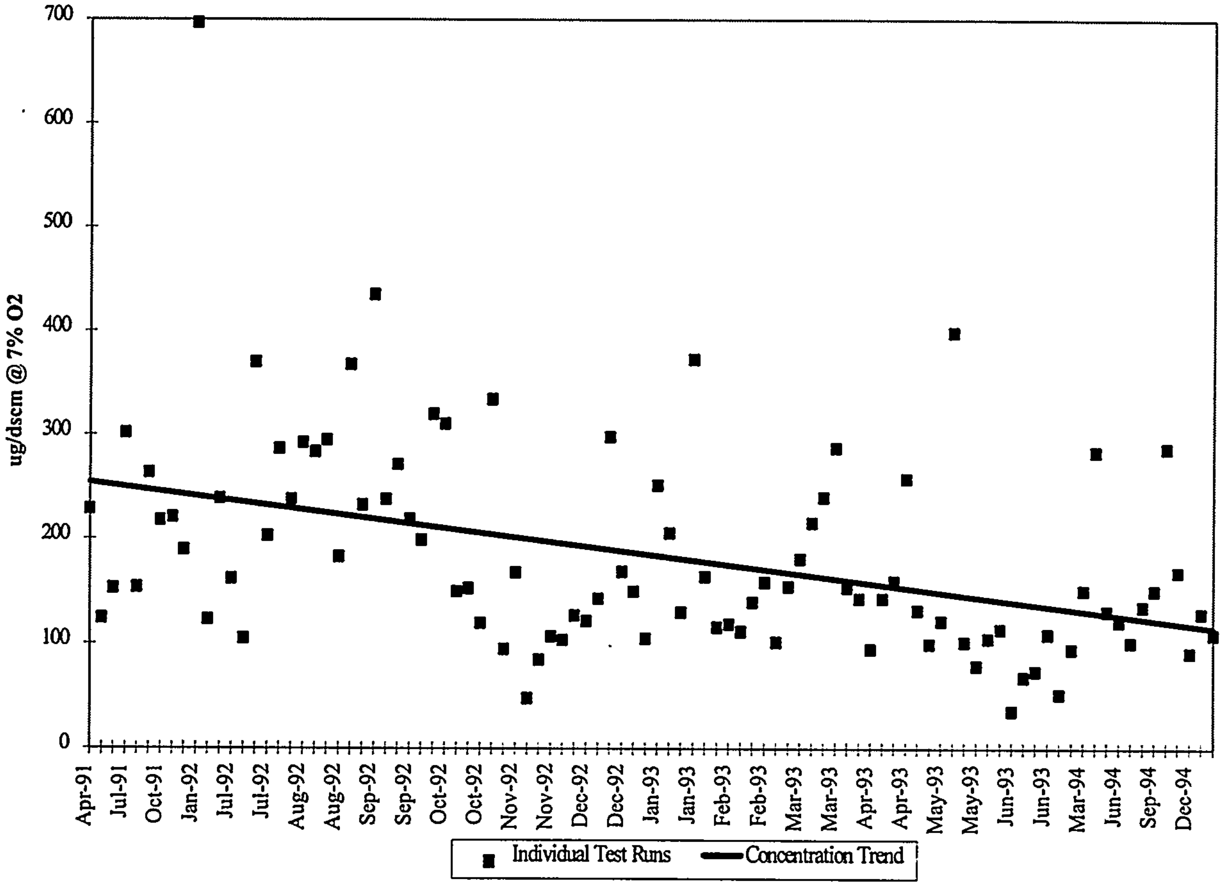

Figure 1. Essex County historical mercury concentrations.

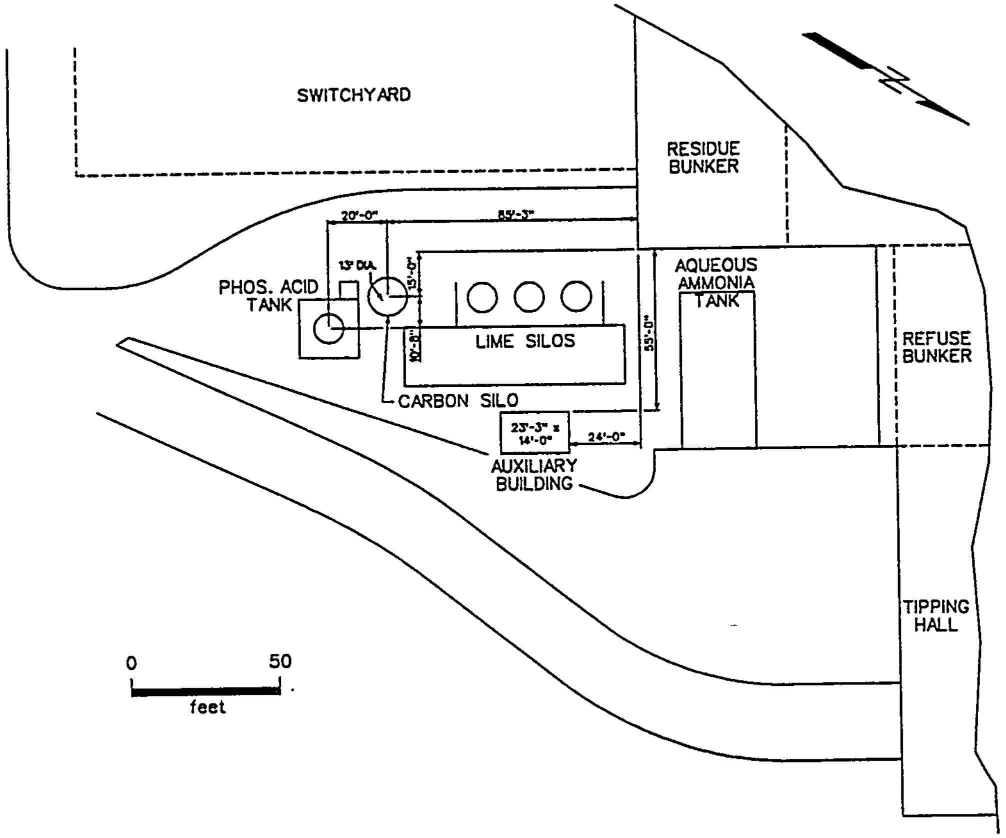

Figure 2. Essex County Resource Recovery Facility Dry Activated Carbon Injection System Layout

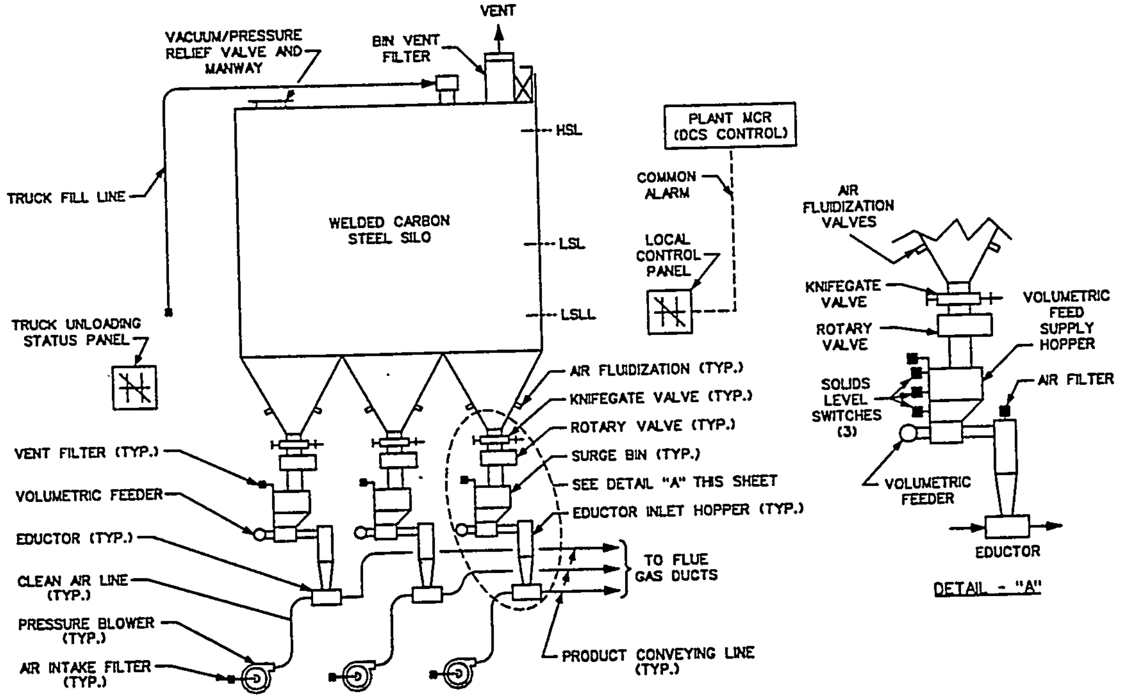

Figure 3. Essex County Resource Recovery Facility Dry Activated Carbon Injection System Simplified Process Floor Diagram

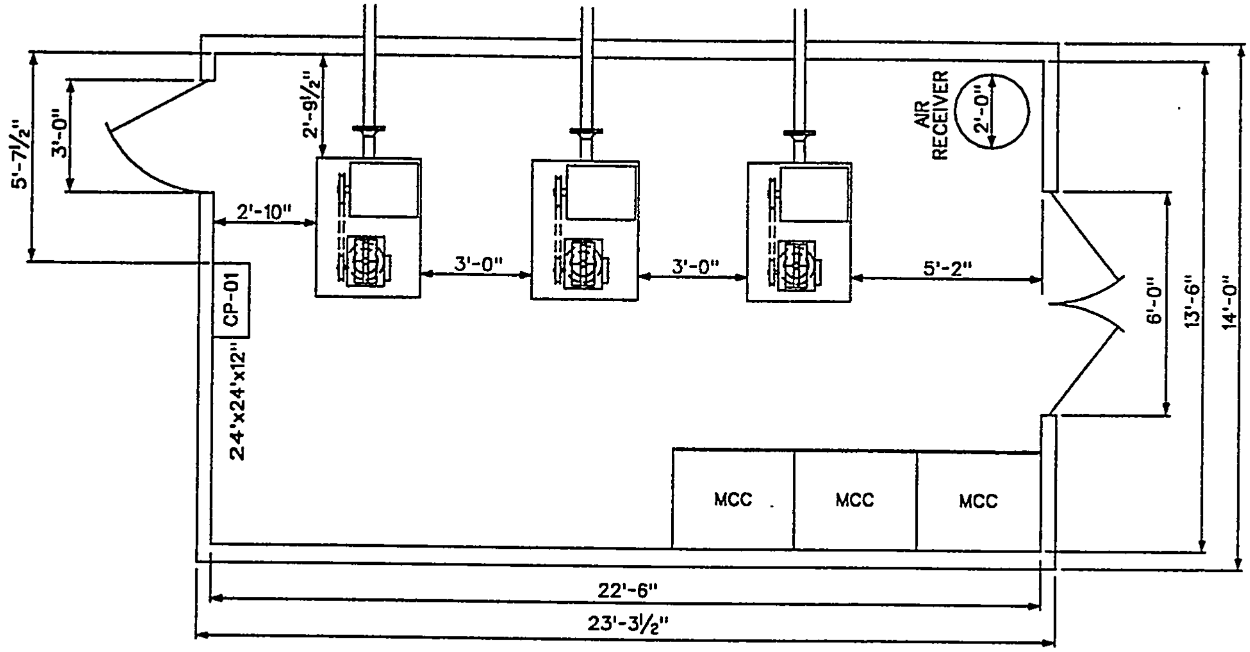

Figure 4. Essex County Resource Recovery Facility Dry Activated Carbon Injection System Auxiliary Building Layout.

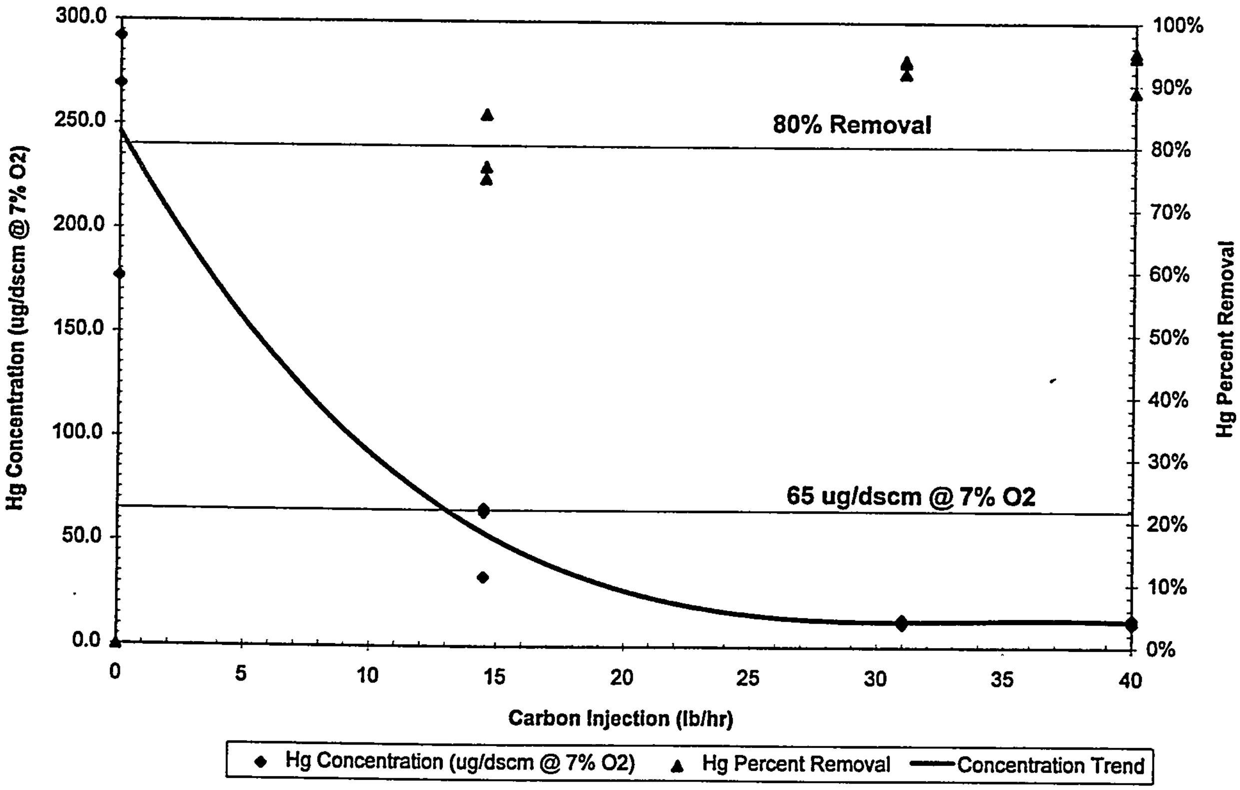

Figure 5. Essex County Resource Recovery Facility Mercury Control Optimization Curve.