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WASTE SEPARATION - DOES IT INFLUENCE MUNICIPAL WASTE COMBUSTOR EMISSIONS?

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ABSTRACT

It has been suggested that MSW incinerator emissions show significant variations because of the heterogeneous nature of the waste fed to the furnace. This argument has even been used to propose banning certain materials from incinerators. However, data previously reported by the authors suggests that a large portion of the trace metals come from natural sources. Furthermore, full scale incinerator spiking experiments suggest that certain forms of trace metals have minimal effects on stack emissions. Similar studies with chlorinated plastics have failed to identify a significant effect on incinerator dioxin emissions. The implication of segregating the lawn and garden waste and other fines from the furnace feed is explored using data from a 400 tpd mass burn facility equipped with a conditioning tower, dry reactor and fabric filter air pollution control system [APCS] preceded by an NRT separation system. The stack emissions have been tested periodically since commissioning to characterize emissions for various seasons using both processed fuel and raw MSW.

Front end processing to remove selected portions of the waste stream based upon size or physical properties, ie. fines, grass, or ferrous materials, did not result in a statistically significant difference in stack emissions. System operating regime, and in particular those that effect the effective air to cloth ratio in the fabric filter, appear to be the principal influence on emission levels.

INTRODUCTION

Numerous suggestions about ways to improve municipal waste combustor emissions characteristics have been made over the last few years. Some people would have us believe that changing the amount of chlorinated plastic in the feed will reduce PCDD/F emissions; others have suggested that banning certain materials from the waste received at these facilities will reduce the trace metal emissions. While it is clear that if something is not put into the furnace it cannot come out, combustors are complex and can affect the chemical form and environmental availability of materials in the various waste streams. Hence, simply changing the amount of a substance or compound may increase, decrease or not affect specific releases in the stack emissions and the residue streams. Separating initiatives, however, could affect the products and materials used in society through bans imposed on the use of certain materials. Examples include the reformulation of products such as batteries to decrease the amount of cadmium, mercury and lead they contain. While thoughtful redesign is a positive aspect of the free market economy, outright bans are disruptive, costly and may produce little benefit. Installing separation equipment to remove materials and supposedly reduce emissions is also costly. The WASTE Program report (1993) and related papers examined the character of MSW and its trace metal composition. Unlike conventional wisdom that suggests trace metals in the waste stream are contributed by man-made products, that study found that much of the trace metal input came from materials derived from natural sources: yard and garden waste, wood, and paper. Along with the fines in the waste stream, these components contained over 50% of some trace metals. This finding suggests that the separation of man-made materials having high trace metal concentrations would have limited effect on the characteristics of emissions from MWC's. This is in contrast to a paper that appeared in the JAPCA several years ago and outlined testing of one mechanized separation facility (Sommer et al., 1989). These authors suggested that a waste separation system was directly responsible for significant, beneficial changes in trace metal emissions from the stack of the affected MWC facility.

In a recently released report on the relationship between chlorine in the waste stream and PCDD/F emissions from waste combustors (Rigo et al., 1995), the authors examined more than 1900 individual test data points from 169 different facilities including municipal waste combustors, medical waste incinerators, cement kilns and hazardous waste incinerators and bio-mass burners. The study concluded that there was little evidence to support the contention that there is a meaningful relationship between fuel chlorine content and combustor flue gas PCDD/F emissions. Indeed, in the limited number of cases where a relationship could be detected, the direction of the change in emissions went in both directions with increasing chlorine concentrations in the feed. This suggests that whatever effect chlorine in the fuel might have on PCDD/F emissions, it is smaller than the influence of other causative factors such as: APCS operating temperature; ash chemistry; combustion conditions; measurement imprecision; and, even local flow stratification.

Both The WASTE Program study and the chlorine vs. PCDD/F emissions study have provided information that differs from conventional wisdom. This paper presents additional information that illustrates the potential risks of drawing conclusions without considering the complex nature of the combustion process.

BACKGROUND

In 1991, while developing the permit conditions for an Energy from Waste (EFW) facility in the Province of Ontario equipped with a National Recycling Technologies (NRT) separation system, regulators required that the facility be tested while the furnaces were using both raw and processed MSW to ensure that the worst case emissions were measured. This testing approach suggested that there was some uncertainty about the actual effects of pre-processing. The facility has been tested a total of 12 times over the first 3½ years of operation under a number of different operating conditions. The data from these 12 triplicate series of tests provides a valuable insight into the question of the affect that waste variations have on the characteristics of stack emissions.

EQUIPMENT SUMMARY

Peel Resource Recovery Inc., (PRRI), operates a 400 tonnes per day (tpd) MSW EFW facility in Brampton, Ontario. The project converts domestic, commercial and solid non-hazardous industrial waste into steam and then electrical energy. Provision is made in the plant via two parallel NRT separation lines to process the as-received waste to remove ferrous and non-ferrous metals, and glass/grit and other fine materials from the waste stream before it is fed to the incinerators. Each NRT line consists of a rotating fuel homogenizer equipped with mechanisms to liberate the waste from the bags, permanent magnets to remove ferrous, and a series of lifters to trap and remove fines from the waste as it rotates and tumbles down the drum. Following the drum, aluminum is separated from the processed waste stream before the remaining material is discharge to output conveyors and transferred to the storage floor. Four 2-stage incinerators and associated waste heat recovery boilers rated at 11,530 kilograms steam/hour provide steam to a turbine-generator set having a nominal capacity of 9,000 kilowatts. Each furnace has a design capacity of 100 tpd of 12,800 kJ/kg processed MSW. The operating permit requires that the secondary chamber temperature be maintained above 1000°C at all times when waste is fed to the furnace. While the furnaces are equipped with natural gas burners to meet the startup and operating requirements of the permit, these burners were not in used during any of the testing described in this paper.

The exhaust from each boiler passes to a common hot gas duct and the air pollution control (APC) system. The hot gas duct splits the flow between two parallel APC trains consisting of a wet spray humidifier, venturi dry lime injection tower and pulse jet fabric filter. Each side of the APC system has a rated capacity matching the flow from 3 operating incinerators. After the initial year of operation, the system has only operated in this mode (3 incinerators to 1 APC) for testing purposes.

EMISSION LIMITS

The plant's operating permit specifies emission limits for:

- total suspended particulate matter (24 mg/dscm @ 7% O_2 3 test average);

- HCl (36 ppmdv or 60 mg/dscm @ 7% O_2 - 24 hour average from CEM system);
- opacity (less than 5% - 2 hour average; and 10% for 6 minute average); and,
- PCDD/F (0.6 ng TEQ/dscm @ 7% O_2 based upon a 3 test average).

In addition, there are operating windows for oxygen, carbon monoxide, total hydrocarbons and temperatures throughout the system. The plant continuously meets all these standards and also meets the point of impingement standards set out in Ontario Regulation 346. In effect, the latter imposes emission limits for many elements but testing normally includes only those elements included in typical laboratory metal scan lists. Emissions are deemed to be acceptable if the ground level concentrations, referred to as Point of Impingement (POI) levels, are met. For the PRRI facility the maximum POI occurs within 2 km of the stack. POI values are determined using a prescribed mathematical formula (simplified dispersion modelling) given in the Regulation. The maximum POI value for the PRRI facility is determined by multiplying the emission rate in grams per second by 0.0064 µg/m^3 per mg/s.

FACILITY TESTING

While CEM equipment and process monitoring are used to demonstrate that normal operating conditions meet the regulatory requirements, annual stack testing is required by the Ontario Ministry of Environment and Energy (MOEE) to prove that the facility continues to meet the emission limits. This testing is funded by the Regional Municipality of Peel and the work reported in this paper was conducted under the direction of an independent consultant hired by the Region. Such testing has included measurements of the performance of each baghouse separately at both: maximum air to cloth ratios (flow from three units routed to one APC train) and, typical air to cloth ratios (both in the single APC train operation case of flow from two units routed to one APC train; and, in the normal mode of operation of all four incinerators on-line venting through both APC trains). Of the 10 series of tests reported herein, the first 6 were conducted at higher than normal air to cloth ratios in the fabric filter (three incinerators discharge to one of the two APC trains). The last four series were at normal air to cloth ratios (either both fabric filters were on line and all combustors were operating or one APC was off line and only two incinerators were operating). In addition, the MOEE has required testing with both as-received MSW and the NRT processed waste to determine if there is a difference in combustor emissions characteristics.

During testing with NRT processed waste feed substantial portions of the fine fraction, including lawn clippings, were separated from the waste along with glass, ferrous and non-ferrous materials. Winter testing is included in the study and represents combustion with minimal yard and garden waste but a similar waste in all other aspects. In both cases, the removal of material from the waste stream will change the amount of chlorine present in the fuel; low chlorine materials are removed and replaced by materials of higher chlorine concentration. The direction of changes in trace metal concentrations are not as clear given the varying nature of waste (The WASTE Program report, 1993).

Each triplicate series of tests were conducted at a specific test condition. Permit conditions with respect to operating temperatures were required to be met in all cases. While the flow rates in the stack were seen to change between the various test series these changes were the result of different APC operating conditions, not large swings in waste feed, heating value, or excess air levels. Furnace feed rate was in excess of 90% of the design heat input rate at all times. Typically, the run average oxygen content of the gas leaving the boiler was in the range of 7.5 to 8.5% as measured by the facility instrumentation. No significant changes in performance were registered during any of the test programs. Bottom ash quality during the initial testing program showed loss on ignition values below 5%. Subjectively, this burnout quality has been maintained throughout the life of the facility as the monthly ash shipments correlate well with the total amount of waste received at the facility.

A total of 27 individual runs are available for most parameters. These data can be used to identify changes in the air emissions induced by separation activities as well as seasonal differences in the waste stream.

Stack Sampling

Particulate matter, metals, PCDD/F and other trace organic emissions were measured during the stack testing campaigns: starting immediately following commissioning in May, 1992; seasonal testing in December, 1992 and March, 1993; and, subsequent annual testing in September 1993; October, 1994 and November, 1995.

For each test series, a pre-test plan was submitted to the MOEE for approval. Test methods included:

- California Air Resources Board (CARB) Method 436 - similar to EPA Method 29 - for particulate matter, fluoride and metals with the exception of mercury (during the first campaign of 9 tests, CARB Method 436 was also used for mercury determinations in parallel with the EPA Method 101A). The stack samples have been analyzed for up to 30 different

metals over the course testing: (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Sn, St, Te, Ti, V, Zn, and Zr). After the initial campaign, which included 9 test runs, failed to detect either Te or Zr, these elements were dropped from the analytical list for subsequent testing.
- EPA Method 101A for mercury; and,
- Modified Method 5 train as described in EPA Method 23 for trace organics. The Method 23 recovery and analysis methods were extended to allow for determination of PAHs, chlorobenzenes, chlorophenols and PCBs in addition to PCDD/F.

All isokinetic stack sampling was conducted for 240 minutes. In all cases, three-run averages were compared to the permitted emission concentrations. The highest value from each triplicate was used to determine the POI values since these are short term limits.

Table 1 provides summary data for the 15 metals on the US federal regulatory lists (US 40 CFR 261 (BIF Rule Regulations) and Clean Air Act, Section 112.) and the other metals analyzed that had significant responses during the statistical analyses described later, along with NO_x, SO_2, and TSP.

Negative values in the data table indicate the below detection limit values for 4 hours of sampling (about 7 dscm sample volume). Initial evaluation showed that using the detection limit [DL] to characterize BDL results produced many false positive conclusions. This occurred because the DL is not an indicator of the actual concentration, rather it mirrored trends in analytical method and these moved by chance with the operating conditions, thereby confusing the interpretation. To avoid this problem, below detection limit values were eliminated from further consideration.

Table 2 provides the blank metals train data for the various test series. These values result from assembling and recovering an unused sampling train and converting the blank train analytical values into apparent concentrations using the average sample volume and oxygen level associated with a triplicate run test series. In many cases the stack data is of the same order of magnitude as the blank train value suggesting that either the source is very clean or the method seriously flawed. To examine the influence of this effect, the statistical analyses was carried out twice; once with all detectable results and once with only those exceeding the blank train.

Organics sampled with the Method 23 train included PCDD/F's and chlorobenzenes, chlorophenols, PCB's, and POM's. In the case of PCDD/F's the 17 isomers listed in the Method 23 analytical method were evaluated so that Toxic Equivalents (TEQ's) could be calculated for the tests. These results were also summed to produce total PCDD/F's as defined by the method. For chlorobenzenes and chlorophenols, individual isomer concentrations were determined, however, only the totals of the homoloques are shown in the data tables. Forty individual POM's were targeted during the analytical process; again only those judged to have significant coefficients during the statistical analyses are displayed in the Table 3. The statistical analyses were completed with both the totals of the various organic species based upon positive responses and with the totals based upon the sum of all isomers/species including an allowance for the detection limit.

STATISTICAL EVALUATION OF SAMPLING DATA

The stack emissions data are generally log-normally distributed. This is expected because there will be highs in the data at the same time as the data are censored at the lower end by the detection limits of the methods and the impossibility of having a negative concentration. Thus, all analyses were done using the logs of the data. The transformed data is normally distributed and the statistical methods employed have their intended power and interpretation.

The data analyses was carried out using Analysis of Variance (ANOVA) techniques. ANOVA partitions or assigns the variability in response, say concentration C, among the independent variables, say refuse processing and season. Due to cost and other considerations, field experiments of the type discussed above are usually neither complete nor balanced. Hence, traditional ANOVA approaches must be modified to analyze such data. Multiple linear regression using blocking (dummy) variables is one way to perform an ANOVA (Draper and Smith, 1988). A binary blocking variable with a value of 0 can be used to represent baseline conditions and 1 the specific change. For example, if a test is conducted with and without the use of the NRT process, a value of 0 indicates raw MSW and 1 the NRT processed waste. If we want to look at the influence of different operating regimes, such as 3 incinerators to 1 APC or normal operations with the two incinerators to each APC, a second blocking variable is used. Multiple linear regression estimates the regression coefficient associated with each blocking variable. The coefficient shows both the direction and magnitude of the effect. The sign of the coefficient indicates whether the emissions increase or decrease with the change. The statistical significance of the coefficient determines whether the effect is really different than zero. Dividing each coefficient by its associated standard error produces a statistic similar to a "t" statistic. This statistic can be used to judge the statistical significance of any effect.

As an example, consider the operating condition effects on stack emissions. Normal operating conditions produce variable emissions, but measurements were made during 7 different test series with planned system variations: the APC system tested; operating conditions (number of incinerators feeding APC system); different furnace feeds (MSW and NRT processed waste); and, different seasons (spring, fall, and winter). Each of these conditions also might influence stack emissions. For example, operating conditions change the air-to-cloth ratio and can increase fine particulate matter bleed through the bags. One of the major changes induced by seasonal testing is the change in the nature of the waste received. While no specific waste characterization testing has been completed at the facility, subjective observations coupled with NRT fines removal volume data suggest that more grass is found in the waste stream in the spring. Furthermore, during the fall leaves are readily visible in the processed waste stream. In the last year, the Region has instituted separate yard waste pickup programs and this has reduced the amount of grass and leaves entering the facility.

To address the question of whether waste processing has an effect on emitted lead (LnPb) analysis could proceed in the following manner: Define a series of dummy variables: D3INTO1 for the operating configuration with 1 assigned when three units feed into one APC; and, 0 for normal 4 into 2 or 2 into 1 conditions; DSPRING for spring testing; DFALL for fall testing; DWINTER for winter testing; (DSUMMER is not needed because this is the reference condition); and, DUMNRT to segregate the effect of using of processed waste. Use these factors to define a multiple linear regression equation of the form:

$$\text{LNPb} = a + b\ \text{DWINTER} + c\ \text{DFALL} + d\ \text{D3INTO1} + e\text{DUMNRT} + \mathit{error}$$

If the regression yields a statistically significant coefficient *e* for DUMNRT, then the NRT processed waste feed can be said to influence the lead emissions from the stack. The magnitude and the sign of the coefficient are also of interest. If the value of *e* were -0.5 it indicates that use of the NRT (i.e., when DUMNRT = 1) produces values of LNPb that are on the average 0.5 units lower than the baseline runs conducted with MSW. If the value of *e* is not statistically significant, it can be concluded that waste processing had no effect on stack emissions over the range of conditions tested.

Because we were undertaking an exploratory statistical evaluation of considerable data, the standard tabulated significance values for the "t" statistic could not be used to judge significance (they would produce too many false positives); rather we applied the Studentized Maximum Modulus statistic (Hochberg, 1974) for multiple means comparisons and determined significant values for "t" based upon the number of comparisons to be made in the full data set as well as the number of runs in a specific test series. This tends to reduce the likelihood of mistakenly identifying false positive results. The significant "t" values for the number of stack emissions comparisons made were:

3.8 @ 95%   3.6 @ 90%   3.4 @ 80% significance

To help ensure that results are not false conclusions the highest statistical significance levels should be used; however, lower significance levels will be reviewed in keeping with the exploratory nature of this analysis.

FINDINGS

The analyses outlined above was completed on several sub-sets of the overall data. The first analysis included all tests except the two 1994 series tests because they were not available at that time. Subsequently the 1994 tests were added and the series to that point were analyzed both with the detectable data included and with those values at or equal to the blank train values excluded. To date, each time the data set has increased in size, small yet significant changes in the statistical outcomes have occurred. This behaviour induced by processing different sub-sets suggests that, while the results may be categorized as significant, the relationships are relatively weak may be due to chance rather than the interventions.

Analysis of the full data set for all trace metal concentrations, PCDD/F's, trace organics, SO_2, NO_x, and TSP values according to the procedures outlined above resulted in statistically significant coefficients effects for only 4 trace metals: cadmium, copper, mercury, and sodium; statistically significant relationships were found for 4 chlorophenol isomers, and tetralin and naphthalene; a near significant coefficient was found for NO_x; and, no significant relationships were found for PCDD/F's. Analyzing the data set having removed those values less than the blank train level produced statistically significant effects for magnesium, phosphate, lead and tin.

The significant coefficients were caused by various operational conditions: three incinerators discharging to one APCS; NRT processed waste feed; and seasonal effects for the Winter period.

One factor that was not explicitly addressed by statistical analyses, but that might have a significant bearing on the outcomes, is the age of the fabric filter. The fabric media was virtually new during the initial tests (first fire in the incinerators was mid-March and testing started in late

April) whereas throughout the series of tests reported here, it got progressively older. The APCS's had been in operation for 9 to 12 months by the time the winter testing was carried out (Series 5 Dec. 1992; and, Series 6 Mar. 1993). Series 7 and 8 occurred at the 18 month point and the last two series reported on were conducted after 30 months of operation. The bags were replaced during the summer of 1995, after 36 months use. At that time, numerous bags were found to have been improperly installed and the holes they were inserted into were remeasured and honed to achieve a better fit.

The length of time that a filter bag operates between cleaning cycles is one factor in determining the amount of residual cake built up on the bag. Bag age also effects fiber deterioration and development of pin holes which can increase bleed through. Thus, given all other factors new bags would be anticipated poorer filtering performance than older bags. The effective air to cloth ratio can also have an influence on emissions: higher ratios induce more bleed-through. Combining both new bags and operation at higher air to cloth ratios could thus result in higher emissions, just the type of performance exhibited by cadmium at this facility. The emission levels declined steadily during the first nine tests run at the facility. This could bias some of the statistical determinations and care must be used in accepting the outcome of the analyses without considering this potential influence.

NRT Influence

Only cadmium and copper exhibited significant differences for the NRT processed waste feed case. Both situations were not noted during the initial evaluation of data, but were found when the 1994 data were added to the set. The increase in copper emissions when burning NRT processed waste is marginally significant (80% level) suggesting that this operating condition should be explored in more detail to determine if this effect is real. The cadmium reduction when burning NRT processed waste is significant at the 90% level. The use of NRT processed waste feed had no effect on the emissions of any other trace metal. Moreover, because normal expectations are that removing materials from the fuel stream would reduce the inputs to the furnace and thus reduce emissions providing all elemental sources partition in the same manner, the sign should be consistently negative for the NRT coefficient. It was not, as illustrated by the two values above; cadmium emissions decreased, copper increased when burning NRT processed waste.

It should be noted that both findings disappear when the statistical tests are conducted using only those runs with values at or above the blank train. These findings raise a question as to the nature and the source of the observed effects. Are they the result of natural variability and the results of testing limitations? Is the change in copper emissions due to changes in the combustion system that affect the partitioning of metals between the gas and residue streams or, is the material being removed changing the distribution of remaining metals in a way that does not manifests itself in changes in emissions? For cadmium, the question is one of how much influence the early test data, and thus new fabric filter bags had on the results.

The bottom line is that there is little apparent emissions benefit to processing MSW prior to combustion. The inconsistent direction of the sign indicates that random noise may describe the few apparently significant observations.

Seasonal Effects

Analyzing the data for the effect of fall and winter testing, shows that only winter produced any statistically significant effects; indeed, fall does not enter into any regression equation except that for mercury, and even then it was not significant. With full data, only two trace metals: cadmium, and mercury, were found to change significantly with winter operation. Two of the chlorophenol homologues rose in the winter and this trend was reflected in the total chlorophenol category too. Tetralin and naphthalene dropped significantly. When values in the range of the blank train levels were excluded, magnesium, tin and lead levels were found to be reduced significantly with the winter operation and the coefficient for cadmium increased in magnitude. Furthermore, all organic responses except that of total chlorophenol response were reduced to a statistically insignificant level.

Cadmium was the only metal that had a significant winter coefficient in the analyses. The coefficient was negative, suggesting that winter had lower emissions. The confounding factor in this finding could be performance of the fabric filter.

Reviewing the cadmium data for tests using MSW some observations are possible. The highest cadmium emissions were recorded for the first two series. The 1993 and 1994 data likely portray the variability that should be anticipated in such results and are substantially lower than the initial data. Comparison of the initial and later tests with the 5th and 6th series reveals that the winter numbers are comparable to the 1993 data but well below the other MSW data sets. Indeed, the winter data is similar to the data associated with NRT processed waste feed to the furnaces suggesting more than one mechanism may be responsible for the findings but that cadmium could be reduced during the winter. Otherwise all these differences may be attributed to the natural variability in the data.

Cadmium was found in high concentrations in the grass and yard waste by The WASTE Program (1993). The presence of negative coefficients for both the NRT operation and winter operation in the stack emissions at PRRI would support a conclusion that yard waste was a significant contributor to cadmium levels in the waste fed to the furnaces at this site. Charging MSW in the winter when it is devoid of grass has essentially the same effect on emissions as greatly reducing the grass component of the feed by NRT processing.

The winter reductions in lead, tin and magnesium were not evident until the below blank train results were removed from the data being analyzed. Eight results for lead, seven for tin and eight for magnesium were at the blank train level. One lead, seven tin, and three magnesium levels were below the detection limit. With the reduced data set, the sign of the significant coefficient for winter operation was negative indicating lower emissions. For lead this was a change in sign, although it was not for the other metals. The change in sign could suggest that different mechanisms were responsible for the noted reductions or simply, as noted before, the response reflects noise in the data.

The most likely explanation for the reduction in lead is removing the lead by eliminating the contribution of yard and garden waste. This conclusion is substantiated by The WASTE Program results. A large portion of the lead in that program was found in the yard waste and fines components that would not be present in the winter and would be reduced by NRT processing.

On the other hand, magnesium could be an impurity in the hydrated lime used in the APC system and the reduction in concentration under the same air to cloth ratio conditions could be a reflection of the influence of the initial three tests when the bags were not seasoned. To develop increased confidence in the conclusions, it would be necessary to repeat these tests at the inlet to the fabric filter and determine if the findings are similar. Unfortunately, the configuration of the facility does not allow this.

Tin appears to be dominated by one high value in the early series of results suggesting that the result reflects variability in sampling results or contamination, not a significant environmental situation.

The results for dichlorophenol homologue totals with all the data included disappear when the values that are at the detection limit are removed from the data analysed indicating a weak relationship. For the trichlorophenol homologue the initial value was reduced slightly with the removal of the BDL data but remains significant. Similarly, the total chlorophenol coefficient remains significant. Both naphthalene and tetralin exhibit significant negative responses in the winter testing. These could be caused by temperature conditions in the sampling system, although no data is available to check this theory.

Mercury analyses were carried out in a number of different ways, and are discussed in a later section.

Baghouse Operating Conditions

As noted above, the winter operation was different from either of the fall test sessions and the spring test results. One condition that could contribute to this was operating under the high air to cloth ratio condition of three incinerators discharging through one baghouse. This condition was the subject of early testing at the plant. Analysis shows that for cadmium, mercury and sodium this condition produced significant differences; positive for cadmium and negative for sodium. Removal of below blank train values increased the coefficient for cadmium and produced significant coefficients for phosphorous and tin. All sodium data were above the blank train levels.

As discussed above, cadmium emissions were higher for initial high effective air to cloth ratio condition testing than for the winter testing of the same condition. Testing under normal operation produced results that were in the same order of magnitude as the winter cadmium emissions. The positive coefficient may be attributed to testing a new fabric filter during the initial period, and improved performance of the fabric filter after the cake had formed on the bags.

For sodium the high ratio condition coefficient is negative suggesting the upset condition released less sodium. This is counter to the intuitive conclusion that higher flow should result in higher emissions. While the effect could be the result of noise in the data, two other explanations could be advanced. Either increased particulate emissions during the latest testing series or the burning of large volumes of leaves in the fall could have changed the trace metal distributions. While marginal changes in TSP concentrations were found between the normal and upset condition, they were not significant. Rather than over interpret the data, another set of tests in the fall should shed light on possible causality.

As noted under the discussion of winter operation, the tin coefficient for the reduced data set appears to be driven by one high number on an early test. This value was ten times any of the more recent test data and as such should likely be considered an outlier. The fact that only 12 of the 27 tests completed to date have found values of tin above the detection or blank train level indicates that this finding is likely of little environmental consequence.

Phosphorous results reflect the low levels recorded during normal operating conditions. Many of the tests were at the blank train level during the last series of tests, and removing three additional low values causes the data set to be heavily loaded with the higher emissions from early testing. This condition likely reflects the improvement in removal efficiency with seasoned bags.

Removal of the BDL results from the totals for chlorophenols results in a significant increase in the dichlorophenol coefficient as well as the value for trichlorophenols and for tetrachlorophenol. The total chlorophenol coefficient moves from statistically insignificant to very significant (>99%). The significance of these changes is not readily apparent.

Mercury

In analyzing the mercury test data a slightly different approach was taken. None of the tests were below the blank train levels so no consideration was given to this issue; however, 8 tests were conducted using a Method 29 equivalent procedure and 31 tests were conducted using Method 101A. Some of the latter tests were conducted at deliberately lower APC operating temperatures and these temperatures were noted to vary with ambient conditions. ANOVA's were completed using additional dummy variable to account for test method, (Dumeth29). Temperature has been shown to influence mercury removal efficiencies (Flakt Canada, 1986) and to assess this effect, the technically correct reciprocal of the flue gas temperature was added to the regression based ANOVA to determine if there was a significant effect.

When the regressions were conducted on the full data set while temperature was not significant, its inclusion in the analysis increased the value of the significant coefficient to the 95% level for winter testing data. Considering just the Method 101A data, the coefficient for winter testing was even larger and inclusion of temperature in the Method 101A regression revealed significant coefficients for inverse flue gas temperature, winter operation, and high flow conditions. The high flow condition became significant when the regression included both temperature and method variables a fact that illustrates the weak relationships in the data. Without the temperature included, the coefficient for the Method 29 test data was not significant although it became so at the 95% level when the temperature was included in the regression. In both cases the coefficient was negative suggesting that the Method 29 data were biased low compared to Method 101A. The sign of the coefficients for both NRT and winter operation are negative. The larger values for the winter operation suggest that less mercury was present in the system during this period. This agrees with The WASTE Program (1993) findings that a large percentage of the mercury in the waste stream is found in the yard and garden waste, a component that would not be a major portion of the winter waste stream.

Criteria Pollutants

Some suggestion has been made in the past that segregating yard and garden material would reduce the NO_x emissions from MWCs. The data allow this hypothesis to be tested. NRT processed material has lower grass concentrations than raw MSW; winter testing occurs with no grass in the waste stream. Results of the analysis show there to be no difference in NO_x emissions regardless of season or fuel type. However, there was a marginally significant coefficient recorded for the high baghouse flow operating condition (3.41). Since the APC does not remove NO_x, this must be attributed to variations in combustion operating conditions. The situation requires further study to isolate the cause.

Sulphur dioxide in the flue gasses will be removed by the lime reagent added to the system. The degree is independent of the input level since the controlling parameter is HCl measured by the CEMS at the exit of this system. That is, as the HCl fluctuates, so does the acid gas control reagent flow rate. To ascertain if there were any trends in SO_2 emission rates, the regression based ANOVA was conducted for this parameter too. The results of the analysis show no statistically significant relationships however both NRT and winter operation coefficients were negative suggesting a reduction in the emission levels occurred during these periods.

Trace Organics

Similar analyses were performed on the trace organic compounds. As noted earlier no significant effects were found for the PCDD/F TEQ values, nor for the Total PCDD/F values.

CONCLUSIONS

The results suggest that undertaking waste separation programs for the purposes of reducing stack emissions may be ineffective. More complicated relationships than simple proportionality between mass-in and mass-out characterize a modern MSW incinerators. The combustion processes can change the reactivity and chemistry of the species present in the waste stream and lead to different results than intuitively expected (The WASTE Program, 1993).

From these tests there appears to be no effect, neither a benefit nor an adverse consequence on air emissions, from processing waste prior to burning. Indeed, the counter intuitive and inconsistent behavior of some of the data supports a general conclusion of no meaningful difference and the few identified changes are attributable to noise. However, there are other reasons for processing including the production of a more homogeneous feed to the furnace. The well mixed feed reduces performance swings. For example, the plant operators have found NRT processed waste easier to burn during the spring when the waste stream has high concentrations of wet grass clippings. In addition, communities without effective post consumer recycling programs might benefit from such installations to recover materials that can be effectively recycled. This would save natural resources and energy while limiting the amount of residual material that needs to be landfilled. These benefits may justify the capital and operating costs of such installations, but this needs to be judged on a local basis.

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This paper describes a data collected during sampling work undertaken by BOVAR Environmental (formerly, Air Testing Services Inc.) for the Regional Municipality of Peel in Ontario. The work was supervised by MacViro Consultants of Markham, Ontario. The work was conducted under the ever watchful and encouraging supervision of the Vice-President and Plant Manager, Mr. John Pappain of Peel Resource Recovery Inc. The assistance and cooperation of these organizations and their staff are noted. This paper has not been reviewed in accordance with all the agency's administrative policies hence the contents do not necessarily reflect the views of the Region or Peel Resource Recovery Inc. and no official endorsement should be inferred.

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Table 1 Summary of Trace Metal and Acid Gas Data (ug/DSCM @ 7% oxygen unless noted)

Sample Series	APC #	Waste Type	TSP (mg)	NOx (ppmdv)	SOx (ppmdv)	Hg 101a	Hg Meth29	Sb	As	Ba	Be	B	Cd	Cr	Co	Cu	Pb	Mg	Mn	Ni	P	Se	Ag	Na	Sn
1	2	1	15	416	60.8	704	183	-0.4	-0.4	26.4	-0.1	262	719.6	1.4	-3.4	7.8	52.0	119.9	135.9	3.2	121	0.5	-0.7	556	12.8
1	2	1	2	377	46.7	494	346	-0.4	-0.4	2.1	-0.1	273	293.3	1.7	-3.4	8.2	5.9	3.4	151.3	2.9	190	0.3	-0.7	335	17.6
1	2	1	2	389	72.8	482	395	-0.4	-0.4	1.4	-0.1	296	73.7	1.5	-3.4	3.7	4.1	-1.6	2.1	8.1	25	0.4	1.4	250	17.6
2	1	1	4	383	64.3	699	482	-0.4	-0.4	1.4	-0.1	216	45.6	3.0	-3.4	5.1	3.6	-1.6	18.1	9.8	154	0.4	2.2	279	27.9
2	1	1	3	416	51.3		528	-0.4	-0.4	1.7	-0.1	269	12.7	2.9	-3.4	9.1	2.5	12.7	44.1	4.6	149	0.3	1.7	237	-1.5
2	1	1	4	450	58.0	518	546	-0.4	-0.4	2.0	-0.1	312	4.0	3.4	-3.4	6.1	3.0	15.2	6.8	5.6	187	-0.4	455.2	288	4.0
2	1	6				487																			
2	1	6				394																			
2	1	6				452																			
2	1	6				748																			
3	1	6	8	376	0.7	682	222	-0.4	-0.4	2.5	-0.1	126	1.2	108.4	-3.4	597.3	6.3	324.0	63.3	768.1	9	-0.4	1.8	425	3.6
3	1	6	10	409	21.9	681	313	-0.4	-0.4	2.2	-0.1	186	0.5	55.3	5.5	199.1	3.2	55.3	11.1	260.8	203	0.2	-0.7	257	7.9
3	1	6	8	372	41.0	651	626	-0.4	-0.4	1.4	-0.1	309	0.7	4.5	2.0	14.2	22.5	52.6	1.4	7.7	342	0.4	-0.7	350	142.2
5	1	1	21	339	22.6	161		0.1	0.1	0.5	-0.6	238	1.1	35.2	1.0	7.7	10.6	73.9	20.8	91.5	99	2.9	-6.0	1091	12.7
5	1	1	4	350	26.6	316		0.1	0.1	-0.5	-0.6	244	2.6	7.5	-0.4	2.7	7.5	20.2	3.9	14.2	92	2.4	-6.0	650	11.7
5	1	1	12	319	22.1	233		0.1	-0.0	-0.5	-0.6	267	0.8	12.9	8.1	3.0	9.4	17.7	2.4	10.4	129	1.8	-6.0	799	11.5
6	2	1	5	285	5.4	261		0.0	0.2	0.8	-0.6	289	1.0	12.4	-0.4	2.6	7.4	16.7	108.2	0.6	63	0.7	-8.1	445	13.0
6	2	1	3	311	4.3	240		0.0	0.1	0.9	-0.6	249	0.8	19.5	0.5	2.4	8.6	11.5	22.4	14.4	104	0.7	-8.1	284	8.6
6	2	1	3	325	11.3	473		0.0	0.2	0.9	-0.6	304	0.7	3.7	-0.4	1.1	7.0	8.0	6.3	2.0	106	0.7	-8.1	272	12.9
7	3	1	2	344	7.1	440		0.1	0.2	2.2	-0.3	323	0.8	1.4	-1.4	7.9	6.6	9.1	3.0	-2.7	15	-0.7	3.2	555	8.6
7	3	1	2	297	7.3	458		0.1	0.2	1.3	-0.3	259	0.8	-0.9	-1.6	7.7	-6.9	41.0	2.9	3.1	66	0.8	3.4	523	22.5
7	3	1	8	425	16.6	584		0.1	0.3	1.0	-0.3	248	1.0	3.1	-7.0	9.8	6.5	41.5	4.8	12.9	60	0.3	3.3	556	18.9
8	3	6	4	137	3.3	311		0.1	0.2	0.9	-0.3	227	1.3	2.5	-1.3	8.5	8.0	39.0	2.6	3.4	52	0.4	2.9	524	16.7
8	3	6	4	323	17.0	380		0.1	0.2	0.8	-0.3	228	1.3	1.5	-1.4	7.2	11.1	34.9	1.1	-2.7	45	-0.3	3.1	400	15.7
8	3	6	3	315	5.3	357		0.1	0.2	0.8	-0.3	271	0.9	4.2	1.7	8.3	6.3	25.5	3.8	6.6	29	-0.3	3.2	581	15.8
9	1	1	14	330	14.1	486		3.4	-2.2	6.5	-0.7	105	5.8	6.8	-3.3	8.9	62.5	71.4	44.5	42.8	31	7.9	-6.8	2142	-16.4
9	1	1	5	328	12.1	457		2.8	-1.3	3.1	-0.4	207	5.3	5.1	1.5	8.1	45.9	46.9	7.5	36.0	-17	1.5	-3.9	1189	-9.3
9	1	1	6	336	23.6	257		2.9	-1.2	2.8	-0.4	323	4.2	8.1	1.8	7.3	38.1	55.1	11.0	435.2	-16	1.7	-3.7	1230	-9.3
10	2	1	4	344	17.3	286		-1.3	-1.2	2.4	-0.4	301	2.7	13.2	29.9	4.6	29.3	28.7	37.8	11.0	-15	1.4	3.6	976	-8.7
10	2	1	4	334	23.3	328		-1.2	-1.2	1.5	-0.4	141	1.7	12.7	1.8	3.2	20.3	19.7	4.4	27.7	16	1.3	-3.7	568	-8.9
10	2	1	1	324	23.8	271		-1.1	-1.1	2.1	-0.4	222	2.2	5.3	1.4	3.6	26.6	24.2	2.5	9.0	-15	1.4	-3.6	1053	-8.5

NOTES Negative signs denote values that were less than the detection limit.
Series numbers designate the test series (no metals data for series 4)

APC # Key 1 = north 2 = south 3 = both
Waste Type Key 1 = MSW 6 = NRT

Table 2 Summary of Blank Train Data for Metals Sampling Runs (ug/DSCN @ 7% oxygen unless noted)

Sample Series	APC #	Waste Type	TSP (mg)	NOx (ppmdv)	SOx (ppmdv)	Hg 101a	Hg Meth29	Sb	As	Ba	Be	B	Cd	Cr	Co	Cu	Pb	Mg	Mn	Ni	P	Se	Ag	Na	Sn
2	1	6						-0.3	-0.3	1.2	-0.4	13	-0.7	-1.3	-3.2	4.0	-7.3	20.9	-1.6	-3.5	-21	-0.3	-3.6	222	-31.1
3	1	6						-0.3	-0.3	1.3	-0.4	14	-0.8	-1.4	-3.4	7.0	-7.7	22.2	2.7	-3.7	42	-0.3	-3.9	144	-33.1
5	1	1	2.64					0.1	0.1	0.3	0.0	15	1.1	1.0	2.4	0.4	2.6	3.1	0.6	2.2	0	0.0	-3.1	42	3.1
6	2	1	0.32					0.0	0.2	0.8	0.0	6	0.5	0.6	0.6	0.4	0.8	1.8	2.4	1.2	5	0.1	-4.2	17	0.6
7	3	1						0.1	0.2	0.9	-0.3	6	-0.6	0.8	-1.4	7.0	-6.1	15.3	1.1	-2.6	16	0.1	-3.1	228	10.6
8	3	6						0.1	0.2	1.2	-0.3	8	-0.7	1.1	-1.5	6.9	-6.6	29.2	4.3	-2.8	34	0.1	-3.3	150	14.0
9	1	1	7.44					-1.3	-1.3	2.4	-0.4	20	-0.8	1.6	-1.6	1.4	16.5	17.1	3.8	45.8	-18	1.4	-4.1	967	-9.8
10	2	1	0.77					-1.1	-1.1	1.7	-0.3	9	-0.7	0.8	-1.3	0.9	14.4	8.6	1.0	4.4	-14	1.1	-3.4	481	-8.1

NOTES Negative signs denote values that were less than the detection limit.
Series numbers designate the test series (no metals data for series 4)

Waste Type Key 1 = MSW 6 = NRT
APC # Key 1 = north 2 = south 3 = both

Table 3 Summary of Organic Emissions Data (ug/DSCM @ 7% oxygen unless noted)

Sample Series	APC #	Waste Type	DCB	TRICB	TCB	PECB	HXCB	Total CB's	DCP	TRICP	TCP	PECP	Total CP's	PCB's	Naphthalene	Acenaphthylene
1	2	1	857	183	211	156		1407	246	332	134	25	737	1389	2905	-29
1	2	1	520	132	149	131		932	185	212	91	-19	506	913	2533	-29
1	2	1	710	128	130	89		1057	172	193	104	33	502	1039	1917	-29
2	1	1	893	124	115	70		1202	142	174	76	-19	411	1165	2543	-29
2	1	1	2350	140	136	89		2715	238	313	112	-19	683	2697	1916	-29
2	1	1	1612	140	126	73		1950	243	320	114	-19	696	1932	11255	-29
3	1	6	1644	201	202	125		2172	199	333	152	29	713	2153	1430	-29
3	1	6	2004	799	871	460		4134	368	673	432	111	1584	4134	1934	-29
3	1	6	8697	466	504	331		9998	251	457	262	79	1049	9980	2978	-29
4	2	1														
4	2	1														
4	2	1														
5	1	1	488	273	268	140	50	1220	294	528	383	126	1331		1791	166
5	1	1	868	231	240	130	49	1518	250	343	131	-14	738		1064	79
5	1	1	1047	139	136	91	57	1469	256	408	238	74	977		1248	50
6	2	1	711	441	530	430	291	2403	490	868	333	156	1846		628	-14
6	2	1	3239	1020	1125	614	334	6332	398	721	264	120	1504		226	99
6	2	1	117	129	116	231	238	831	416	748	270	131	1565		246	41
7	3	1	488	426	313	287	-57	1571	553	763	407	164	1886		1638	-29
7	3	1	1091	303	210	90	59	1752	476	563	268	81	1388		988	-29
7	3	1	353	171	134	-57	-57	773	351	516	234	77	1178		1836	-29
8	3	6	284	150	107	63	-50	654	477	550	213	64	1304		698	-24
8	3	6	1852	167	111	-56	-56	2242	336	471	193	64	1064		925	-29
8	3	6	591	164	113	-54	-54	977	351	518	224	76	1170		1424	-27
9	1	1	2630	296	234	120	151	3431	553	840	338	114	1845		2188	83
9	1	1	787	143	136	67	61	1194	357	538	226	-67	1188		1487	44
9	1	1	867	147	110	164	160	1448	343	513	211	-67	1134		1572	-33
10	2	1	1604	267	236	106	99	2311	417	581	314	126	1438		1981	-34
10	2	1	2539	213	184	107	104	3147	454	614	228	-67	1364		2690	-34
10	2	1	1337	321	287	133	90	2168	448	613	326	110	1497		3076	59

NOTE: Negative signs denote values that were less than the analytical detection limit.
Totals of both homologue groups and species have been calculated on the basis of the sum of all values including BDL's
Series numbers designate test series (no metals testing during series 4)
Waste Type Key 1 = MSW 6 = NRT APC Designator 1 = north 2 = south 3 = both

Table 3 Summary of Organic Emissions Data (ug/DSCM @ 7% oxygen unless noted)

Sample Series	APC #	Waste Type	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Tetralin	Quinoline	Methylnaphthalene(1)	Methylnaphthalene(2)	Biphenyl	Total PAH's	Total PCDD/F's (ng)	TEQ (C'dn) (ng)
1	2	1	-29	47	90	-29	29	28	538	-94	502	273	118	7122	14	1.30
1	2	1	38	54	73	-29	-29	-29	499	-94	461	238	69	6586	7	0.52
1	2	1	33	46	49	-29	-29	-29	517	-94	246	119	67	5616	6	0.43
2	1	1	160	176	111	-29	-29	-29	848	-94	359	186	587	7591	11	0.57
2	1	1	-29	33	195	-29	-29	-29	920	-94	422	207	295	6639	10	0.54
2	1	1	171	239	324	-29	-29	-29	2217	-94	2046	1057	307	20238	4	0.26
3	1	6	57	31	233	-29	94	102	694	-94	364	176	278	6023	5	0.46
3	1	6	70	31	111	-29	40	45	864	-94	535	255	210	6660	5	0.54
3	1	6	-29	-29	134	-29	-29	60	1276	-94	1641	790	237	9767	4	0.51
4	2	1													1	0.16
4	2	1													2	0.22
4	2	1													1	0.15
5	1	1	43	-29	630	-29	228	146	203	-29	226	398	281	5364	27	1.00
5	1	1	-14	-29	206	-29	59	44	193	-29	203	378	254	3576	16	0.46
5	1	1	-14	-29	139	-29	44	34	243	-29	176	337	156	3511	6	0.54
6	2	1	-14	33	248	-29	241	176	60	-29	106	171	5621	8408	15	0.96
6	2	1	-14	69	376	41	297	228	51	-29	99	143	6476	9361	9	0.53
6	2	1	-14	30	126	-29	70	53	46	-29	91	116	6653	8535	15	0.49
7	3	1	247	-29	37	-29	-29	-29	604	86	94	141	6612	11837	5	0.52
7	3	1	-29	-29	-29	-29	-29	-29	290	87	-59	76	2033	6002	3	0.71
7	3	1	-29	-29	31	-29	-29	-29	688	86	-57	69	975	6148	2	0.23
8	3	6	-24	-24	47	-24	-24	-24	223	74	-50	74	1672	4927	3	0.19
8	3	6	31	99	44	-29	-29	-29	337	84	-56	76	1318	5269	2	0.18
8	3	6	83	34	64	-27	-27	-27	430	80	-54	73	591	5047	2	0.24
9	1	1	-51	151	834	136	156	146	573	-156	297	625	1198	11348	7	0.66
9	1	1	37	67	243	47	40	-34	440	-101	114	297	440	6329	3	0.24
9	1	1	47	53	217	50	33	-33	434	-100	150	368	870	6867	2	0.22
10	2	1	-34	89	280	59	41	-34	547	-103	410	154	547	7289	2	0.21
10	2	1	34	114	370	81	67	54	807	-101	605	216	605	8508	2	0.22
10	2	1	87	104	307	59	39	-33	744	-97	550	184	615	8574	2	0.33

NOTE: Negative signs denote values that were less than the analytical detection limit.
Totals of both homologue groups and species have been calculated on the basis of the sum of all values including BDL's
Series numbers designate test series (no metals testing during series 4)
Waste Type Key 1 = MSW 6 = NRT APC Designator 1 = north 2 = south 3 = both