

ASSESSING THE CREDIBILITY OF THE CALORIFIC VALUE OF MUNICIPAL SOLID WASTE

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ABSTRACT

A study has been made at the National Bureau of Standards to establish the limits of reliability of the calorific value of municipal solid waste (MSW) determined by the bomb calorimetric procedure currently used in commercial test laboratories.

To test the bomb calorimetric procedure, a 2.5 kg (5 lb) capacity combustion flow calorimeter was designed and constructed for the determination of the enthalpies of combustion of kilogram-size samples of MSW in flowing oxygen near atmospheric pressure.

Calorimetric data from measurements using both the kilogram-size flow and a gram-size bomb calorimeter show that, if proper techniques are implemented, it is possible to determine the calorific value of a multiton pile of waste using gram-size test samples within $\pm 3\%$.

INTRODUCTION

The work described in this paper was performed to assist in resolving an industrial problem formulated by members of the ASME Research Committee on Industrial and Municipal Wastes, the ASME Performance Test Code Committee (PTC-33) on Large Incinerators, and the ASTM Committee (E-38) on Resource Recovery. At present, the calorific value of municipal solid waste (MSW) is determined at commercial

test laboratories by bomb calorimetry. The procedure uses gram-size samples of highly processed waste. The method is in dispute because many combustion engineers believe that one cannot accurately sample a multiton quantity of MSW down to 1–2g (0.035 to 0.07 oz) and obtain a representative test sample. Gram-size samples are prepared from the bulk MSW by separation and milling techniques to provide a pulverized test sample of approximately 2 mm (0.08 in) or less particle size. Some combustion engineers feel that this processing may significantly alter the composition of the test sample and, hence, the calorific value. This might occur because of changes in composition due to excessive local heating associated with some milling operations or due to sampling and handling of a material which is inhomogeneous and segregates easily.

To resolve the dispute about the validity of the current method of determining the calorific value of MSW, two problems were addressed. The first was the sampling problem: How does one obtain a representative gram-size sample from a kilogram-size quantity of processed MSW? The second was the processing problem: Does processing MSW down to 2 mm (0.08 in) particle size alter its calorific value significantly?

To address these problems, the National Bureau of Standards (NBS) initiated a research program in collaboration with the U.S. Department of Energy to

develop test procedures for accurately determining the calorific values of refuse and refuse-derived fuels (RDF). This research was also part of the NBS response to the Resource Conservation and Recovery Act of 1976. Subtitle E of this legislation mandated NBS to provide guidelines for the development of specifications for classification of materials destined for disposal.

To test the validity of the bomb calorimetric procedure, a 2.5 kg (5 lb) capacity combustion flow calorimeter was designed and constructed in order to determine the enthalpy of combustion of kilogram-size samples of both processed and unprocessed MSW in flowing oxygen near atmospheric pressure. Details of the design and construction of the calorimeter are given in Ref. [1]. In the following discussion we summarize the measurement protocol in Sample Preparation and Measurement Protocol, the results in Experimental Results, and conclusions in Discussion and Conclusions.

SAMPLE PREPARATION AND MEASUREMENT PROTOCOL

Both the sampling and processing problems were examined in context of the variability of MSW for 2 weeks, a time period appropriate to a specification test of an incinerator-boiler system. Thirteen to 23 kg (6–10 lb) of unprocessed MSW were obtained on each of ten consecutive working days (5 days/week for a 2 week period from January 10 to 21, 1983) from the Baltimore County Resource Recovery Facility in Cockeysville, Maryland. Each sample was removed from the conveyor belt immediately beyond the primary shredder before any further processing occurred. (The nominal particle size was such that 95 mass % passed through a 15 cm (6 in.) mesh screen.) The material was brought to NBS each day, weighed, dried in an oven for 12 hr at 105°C (221°F), and then reweighed to determine its initial moisture content. The material was stored at 5°C (41°F) until used.

The processing problem could be studied best by comparing the calorific value of identical pairs of kilogram-size samples of dried unprocessed and processed MSW. We attempted to prepare such identical kilogram-size samples by sorting each day's material into eight categories and then reconstituting the material into 2.5 kg (5 lb) samples having the same relative mass composition as the whole. Each sample was placed in a separate plastic bag and then again stored at 5°C (41°F) until used.

The material was hand sorted into metal, combustible, and noncombustible fractions. Metals were then

TABLE 1 COMPOSITION OF MUNICIPAL SOLID WASTE OBTAINED JAN 10–21, 1983 FROM THE BALTIMORE COUNTY RESOURCE AND RECOVERY FACILITY

| | Mass Percent (Dry) | | | | |
|----------------------------|--------------------|------|------|------|---|
| | Day | 4 | 6 | 7 | 9 |
| 1) Initial Moisture | 27.6 | 34.3 | 25.1 | 22.0 | |
| 2) Metal (Magnetic) | 5.0 | 6.0 | 2.6 | 2.2 | |
| 3) Metal (Nonmagnetic) | 1.3 | 1.5 | 1.3 | 0.6 | |
| 4) Wood, Vegetable | 0.8 | 1.3 | 0.4 | 2.5 | |
| 5) Textiles | 1.6 | 3.2 | 5.2 | 13.8 | |
| 6) Plastics | 3.3 | 6.2 | 8.2 | 6.6 | |
| 7) Paper | 66.2 | 55.8 | 67.7 | 64.3 | |
| 8) Glass, Ceramics | 2.6 | 2.4 | 0.8 | 0.3 | |
| 9) "Fines" | 19.2 | 23.6 | 13.8 | 9.7 | |
| ----- | | | | | |
| 10) Metals | 6.3 | 7.5 | 3.9 | 2.8 | |
| 11) Combustible Content | 71.9 | 66.5 | 81.5 | 87.2 | |
| 12) Noncombustible Content | 21.8 | 26.0 | 14.6 | 10.0 | |
| ----- | | | | | |
| Samples as Burned | | | | | |
| 13) Combustible Content | 76.7 | 71.9 | 84.8 | 89.7 | |
| 14) Noncombustible Content | 23.3 | 28.1 | 15.2 | 10.3 | |

separated into magnetic and nonmagnetic components. The combustible fraction was separated into wood/vegetable matter, textiles, plastics, and paper. The noncombustible fraction was divided into glass/ceramics and "fines" (primarily grit and sand). Four of the 10 day's material were selected for our study: days 6 and 9, which had the largest and smallest noncombustible content, respectively, and days 4 and 7, which had intermediate noncombustible contents. A summary of the results of hand sorting plus the initial moisture content for these four days is given in Table 1. The compositions according to main groups are given in lines 10 through 12. In preparing the reconstituted samples, the metals were omitted. The combustible and noncombustible compositions of the reconstituted samples actually burned in the flow and bomb calorimeters are listed in the last two rows. All experimental measurements were made on reconstituted samples.

Processed MSW consists of a low density component, fluff, which resembles chopped up cotton fibers, and a high density component which resembles sand or metal particles. Some high density material is entrained in the fluff; this entrainment is not uniform. Sampling problems arise because of segregation of the high and low density components. The sampling technique used in the first NBS study [2] of the variability of MSW consisted of blending (in drums filled with

steel balls), of coning and quartering, and of taking gram-size grab samples. This method was found to be unsatisfactory.

For this study, we introduced a new technique for obtaining gram-size test samples from the processed [2 mm (0.08 in) particle size] material. A rotary riffler, a Brinkmann Co. Sample Divider PTZ,^a was used. It consists of a central cup from whose bottom surface eight tubes extend outward and downward to collector bottles. The cup, tubes, and bottles rotate around the central vertical axis of the cup. The sample is introduced into the divider through a funnel feeding a horizontal vibrating trough which teases the sample into the divider cup.

An initial assessment of the new sample division technique showed this method to be superior to the coning and quartering procedure used in the earlier variability study [2]. This conclusion is confirmed by the results to be cited in Experimental Results.

The measurement protocol adopted for our study is summarized in Table 2. Four bags, labeled A through D, of the reconstituted kilogram-size samples of unprocessed MSW were selected from each of the 4 days. The contents of two of the bags, designated A and B, were burned in the large flow calorimeter (Step 2C, Table 2) without further processing to reduce the particle size. The samples were weighed before and after drying to determine the residual moisture (Step 2A). A known amount of water was added to each of the samples before they were compacted to form pellets (Steps 2B or 4A). The water was added to improve the cohesion of the pellet. All kilogram-size pellets of MSW were prepared by placing the sample in a 22 cm (8.7 in) diameter die piece and compressing it with a total force of 534 kN (120,000 lbf). Flow calorimeter measurements on A and B will characterize unprocessed MSW.

The contents of the remaining two bags, designated C and D, were independently processed to 6 mm (0.25 in) sieve size using a Williams Hammer Mill and then to 2 mm (0.08 in) sieve size using a Wiley Mill (Step 3A). Powdered dry ice was mixed with the material in the throat of the Wiley Mill to prevent excessive local heating. Gram-size test samples were then obtained from the milled material of bag C and bag D using the rotary riffler (Step 3B). The gram-size samples C and D will be used to characterize processed MSW by the conventional bomb calorimetric mea-

TABLE 2 MEASUREMENT PROTOCOL FOR RECONSTITUTED SAMPLES

| | |
|---|---|
| 1. Select four 2.5 kg (5 lb) samples from each day. For example: Day 4, label samples A4, B4, C4, D4. | |
| 2. A4, B4 | A) Dry. B) Add water and pelletize. C) Burn in flow calorimeter. |
| 3. C4, D4: | A) Reduce to 2 mm (0.08 in) particle size. B) Divide each bag to obtain gram-size test samples (2 g (0.07 oz) each). From each bag obtain: two combustion bomb calorimeter samples, two residual moisture samples, and two furnace ash samples. C) Divide remainder of C4 and remainder of D4 into two equal parts D) Combine one-half of C4 and one-half of D4 to obtain bag E4. Combine the remainders of C4 and D4 to obtain bag E'4. |
| 4. E4, E'4: | A) Pelletize. B) Burn in flow calorimeter. |

surements. In Step 3C, the remainder of each bag was divided into two equal parts. In Step 3D, one part of bag C and one part of bag D were combined to form the sample of bag E and the process was repeated to produce an identical bag E'. Flow calorimeter measurements on E and E' will characterize kilogram-size samples of processed MSW and will be compared with the bomb calorimeter measurements on gram-size samples of processed MSW. This will be done by comparing the E and E' results with the weighted mean of the measurements on C and D. The weighting factors are the mass fractions of C and D in E or E'.

Individual measurements made in both the bomb and the flow calorimeter were carried out in a random order.

It should be noted that the sample labels C and D refer to the gram-size test samples withdrawn from bags C and D, respectively, before step 3C in which the remainder of bags C and D were split and recombined to obtain bags E and E' (Step 3D). Having prepared identical gram-size samples in Step 3B, we prepared identical kilogram-size samples in Step 3D. Hence, differences in the enthalpy of combustion of each pair of E and E' samples for a given day afford a direct measure of the measurement precision of the 2.5 kg (5 lb) capacity flow calorimeter on an actual sample of MSW (as distinct from a sample of pure cellulose which does not contain noncombustible components). While labels E, E', A and B refer to kilogram-size samples, the samples of bags E and E' differ from

^aThe commercial sources cited in this paper are included to adequately describe the experimental procedures. Such identification does not imply recommendation or endorsement by the National Bureau of Standards.

those of bags A and B in two important respects. Bags E and E' contain processed MSW while bags A and B contain unprocessed MSW. The samples in bags E and E' are essentially exact replicates while those in bags A and B are only approximately identical (i.e., to the extent that hand sorting into the general classifications given in Table 1 permits). The flow calorimeter measurements on the kilogram-size bags A and B of unprocessed MSW will be compared with measurements on bags E and E' of processed MSW.

EXPERIMENTAL RESULTS

The Sampling Problem—Combustion Bomb Calorimetry

The gram-size test sample results consist of duplicate measurements for each bag (two bags for each day) of the enthalpy of combustion (ASTM Method E711-81). Bomb ash (dried residue from a combustion bomb experiment) and furnace ash (ASTM Method E830-81) measurements were also made. All results were converted to a dry basis using moisture contents obtained with ASTM Method E790-81. In the furnace ash test, the sample is combusted in air in a furnace at 575°C (1070°F) for 2 hr.

Table 3 summarizes the statistical analysis of the results; the procedures used are summarized in references [3] and [4]. The percent coefficient of variation, %CV^b, for the within-bag, between-bags (within day), and between-day variability is calculated for furnace ash, bomb ash and calorific values. HHV2 and HHV3 are the negative of the enthalpy of combustion on a dry and a dry, ash-free basis, respectively. HHV3-B refers to the use of the bomb ash value in the calculations; HHV3-F refers to the use of the furnace ash value in the calculations. For sake of comparison, the corresponding results for the 1980 variability study, in which the sample division was done by coning and quartering, are given in the lower half of Table 3. The total %CV in column 6 is the square root of the sum in quadrature of the %CV's given in the preceding three columns.

In this work, the within-bag %CV, which corresponds to the combined measurement error and sampling variability for gram-size samples, is substantially less for all properties than in the prior variability study [2]. The small value for the HHV2 within-bag %CV and its close agreement with the within-bag values for HHV3-B and HHV3-F indicates that the new sample division procedure has reduced our sampling error for

^b $100 \times (s / \text{average of the property being measured})$, where s is the standard deviation of a single measurement.

TABLE 3 SUMMARY OF STATISTICAL ANALYSIS OF ASH AND COMBUSTION BOMB CALORIMETRY RESULTS FOR 2 g (0.07 oz) TEST SAMPLES

| Property (Dry basis) | Components of Variability, %CV | | | | |
|-----------------------------------|--|---------------|--------------------------------|-----------------|-------|
| | Average | Within Bag | Between Bags ^(a) | Between Days | Total |
| | January 1983 Study (4 days, this work) | | | | |
| Ash, Furnace, % | 28.8 | 1.2 | 4.1 | 29.9 | 30.2 |
| Ash, Bomb, % | 27.4 | 1.7 | 4.8 | 31.1 | 31.5 |
| HHV2, MJ/kg (BTU/lb) | 16.11 (6925.) | 0.5 | 2.0 | 10.9 | 11.1 |
| HHV3-B, MJ/kg (BTU/lb) | 22.19 (9540.) | 0.6 | 0.6 | 1.9 | 2.1 |
| HHV3-F, MJ/kg (BTU/lb) | 22.65 (9738.) | 0.8 | 0.3 | 2.5 | 2.6 |
| January 1980 Study (10 days, [2]) | | | | | |
| Ash, Furnace, % | 31.8 | 6.5 | 23.0 | 29.8 | 38.2 |
| Ash, Bomb, % | 28.9 | 10.6 | 15.6 | 33.7 | 38.6 |
| HHV2, MJ/kg (BTU/lb) | 15.39 (6617.) | 3.2 | 6.6 | 11.2 | 13.4 |
| HHV3-B, MJ/kg (BTU/lb) | 21.66 (9312.) | 1.6 | 1.5 | 3.7 | 4.3 |
| HHV3-F, MJ/kg (BTU/lb) | 22.52 (9682.) | 5.1 | 5.4 | 3.1 | 8.0 |

(a) Between bags within the same day.

gram-size samples to less than 0.8%. The between-bag (within day) %CV for HHV2, 2.0%, suggests that the extra error introduced in failing to prepare equivalent bags C and D for each day by hand sorting and recombination is somewhat larger in size than the combined measurement and within-bag sampling error.

The Sampling Problem—Flow Calorimetry

The flow and bomb results on processed MSW are given in Table 4. The first four rows show the average difference and imprecision^c of the paired differences for values of flow ash minus furnace ash, and flow minus bomb values for ash, HHV2 and HHV3. Furnace ash, bomb ash, bomb HHV2, bomb HHV3 are calculated from the averages of the gram-size test measurements on C and D weighted by the amounts of sample from bags C and D which form the flow calorimeter samples E and E'.

The first two rows of Table 4 show that the average flow ash is $2.7 \pm 1.5\%$ greater than the average bomb ash and $2.5 \pm 1.9\%$ smaller than the average furnace ash. These differences are consistent with the relation-

^c For this and all other statements labeled "imprecision", we are using the product of the standard deviation of the mean and the appropriate Student t factor at the 95% confidence level.

TABLE 4 ANALYSIS OF FLOW AND BOMB CALORIMETRY RESULTS ON PROCESSED MSW

| Property Difference (Dry Basis) | Average Difference | Imprecision ^(a) |
|---|------------------------------|----------------------------|
| 1) Ash, Flow - Bomb ^(b) , % | +0.76 [+2.7%] ^(c) | 0.41 [1.5%] |
| 2) Ash, Flow - Furnace, % | -0.69 [-2.5%] | 0.54 [1.9%] |
| 3) HHV2, Flow - Bomb, MJ/kg (BTU/lb) | -0.02 [-0.1%] (-9.) | 0.18 [1.1%] (77.) |
| 4) HHV3, Flow - Bomb ^(d) , MJ/kg (BTU/lb) | +0.20 [+0.9%] (+86.) | 0.19 [0.8%] (82.) |

| Components of Variability, %CV | | | |
|---|------------------|----------------------|----------------|
| Property (Dry basis) | Average | Measurement Error | Between Day |
| 5) Ash, Flow, % | 28.11 | 0.3 | 30.0 |
| 6) HHV2, Flow, MJ/kg (BTU/lb) | 16.09 (6918.) | 0.4 | 11.3 |
| 7) HHV3, Flow, MJ/kg (BTU/lb) | 22.39 (9626.) | 0.5 | 1.5 |
| 8) Ash, Bomb, % | 27.35 | | |
| 9) Ash, Furnace, % | 28.80 | | |
| 10) HHV2, Bomb, MJ/kg (BTU/lb) | 16.11 (6926.) | | |
| 11) HHV3 ^(d) , Bomb, MJ/kg (BTU/lb) | 22.19 (9540.) | | |

(a) Product of Student t for the 95% confidence level and the standard deviation of the average.

(b) Flow minus bomb differences given are the average of the quantities: the mean of E and E' values minus the weighted mean of C and D values for each day.

(c) Percent of flow value.

(d) HHV3-B.

ship between the combustion zone temperatures (i.e., bomb > flow > furnace). They are also consistent with the observed variation in the amount of furnace ash formed as a function of furnace temperature [5].

The average differences of the flow minus bomb values for HHV2, given in row 3, is $-0.1 \pm 1.1\%$ of the average HHV2 flow value. This difference is not statistically different from zero as the 95% confidence interval is from -1.2 to $+1.0\%$. The average difference of the flow minus bomb values for HHV3 is $+0.9 \pm 0.8\%$ of the average HHV3 flow value. The difference is statistically different from zero as the 95% confidence interval is from $+0.1$ to $+1.7\%$. However, the interval misses zero by such a small amount that we do not regard the non-overlap to be practically important.

The average difference of the flow minus bomb values for HHV2, -0.1% , completes the evidence for the conclusion, drawn in the previous section, that the new sample division technique provides representative gram-size test samples. The results of this section show that, within the imprecision of measurement, $\pm 1.1\%$, HHV2 is the same for the kilogram-size parent and the gram-size test samples; the results of the previous section showed that gram-size test samples from the same bag were practically the same.

The measurement errors given in the fifth through seventh rows of Table 4 are obtained from the analysis of the flow ash, HHV2, and HHV3 using paired differences from replicate samples E and E' for each day. Between-day variability was computed in the usual manner [4]. The precision of a calorimetric measurement on kilogram-size samples of dry, processed MSW (0.4 and 0.5%) are comparable in magnitude to those on dry cellulose (0.3% - as obtained on auxiliary measurements on pure cellulose). The small measurement errors shown in rows 5 through 7 show that E and E' are indeed replicate samples.

The Processing Problem—Flow Calorimetry

An analysis of the data on kilogram-size samples of unprocessed and processed MSW is given in Table 5. Average difference values and imprecisions in the differences of the unprocessed minus processed values for ash, HHV2, and HHV3 are given in the first three rows of Table 5. All differences have 95% confidence intervals that overlap zero and, thus, are not significantly different from zero. The average effect of processing kilogram-size samples of unprocessed MSW is such as to increase HHV2 by 0.5% and leave HHV3 unchanged. The 95% confidence intervals for the HHV2 difference, -3.4 to $+2.4\%$, and the HHV3 difference, -2.0 to $+2.0\%$, are larger than those for the corresponding differences of the flow minus bomb values given in Table 4 because hand sorting and reconstituting, as we carried it out, did not produce completely identical bags.

The between-bags (within day) and between-day components of variability of the data for unprocessed samples are given in rows four to six of Table 5. The between-bags (within day) %CV for HHV2 and HHV3 are in general agreement with the corresponding bomb values listed in Table 3.

SUMMARY OF STATISTICAL RESULTS

(a) The new rotary riffler sample division technique used in this study provided gram-size test samples, from the same kilogram-size parent sample, that have a %CV for a single measurement of 0.5% for the enthalpy of combustion ($-HHV2$, on a dry basis). This technique is clearly superior to the coning and quartering used in our previous study [2] where the corresponding %CV was 3.2% (See Table 3.).

(b) The new rotary riffler sample division technique provided gram-size test samples from kilogram-size samples of processed MSW which have the same av-

TABLE 5 ANALYSIS OF FLOW CALORIMETRY RESULTS ON KILOGRAM-SIZE SAMPLES OF UNPROCESSED AND PROCESSED MSW

| Unprocessed-Processed Property Differences (a) (Dry Basis) | | Average Difference | Imprecision (b) |
|---|--|------------------------------|-----------------------|
| 1) Ash, % | | +0.36 [+1.3%] ^(c) | 1.70 [6.0%] |
| 2) HHV2, MJ/kg (BTU/lb) | | -0.08 [-0.5%] (-34.) | 0.47 [2.9%] (202.) |
| 3) HHV3, MJ/kg (BTU/lb) | | +0.00 [+0.0%] (+0) | 0.45 [2.0%] (193.) |

| Components of Variability, %CV | | | |
|-------------------------------------|------------------|-----------------------------|-------------|
| Unprocessed Property (Dry Basis) | Average | Between Bags ^(d) | Between Day |
| 4) Ash, % | 28.47 | 4.9 | 31.4 |
| 5) HHV2, MJ/kg (BTU/lb) | 16.00 (6879.) | 0.3 | 12.3 |
| 6) HHV3, MJ/kg (BTU/lb) | 22.39 (9626.) | 1.7 | 2.3 |

(a) Unprocessed minus processed differences given are the average of the quantities: the mean of A and B values minus the mean of E and E' values for each day.

(b) Product of Student t for the 95% confidence level at 3 degrees of freedom and the standard deviation of the average difference.

(c) Percent of average processed value.

(d) Between bags within the same day.

erage enthalpy of combustion (on a dry basis) as the kilogram-size parent sample to within $0.1 \pm 1.1\%$. (See Table 4, line 3.)

(c) Processing of kilogram-size samples of MSW having a sieve size of minus 15 cm (6 in) down to a 2 mm (0.08 in) sieve size alters the enthalpy of combustion of the material (on a dry basis) by less than $0.5 \pm 2.9\%$. The main contribution to this 2.9% imprecision is the variability in the supposed identical samples prepared by hand sorting. (See Table 5.)

(d) Kilogram-size samples of dried unprocessed MSW having the same enthalpy of combustion (on a dry basis) to about $\pm 2\%$ can be prepared by matching the relative mass compositions according to the following categories of: textiles, plastics, wood/vegetable matter, paper, glass/ceramics, and "fines" (residual grit and sand) (See Table 5, row 6, between-bag %CV.)

DISCUSSION AND CONCLUSIONS

Our results show that processing from 15 cm (6 in) to 2 mm (0.08 in) particle size does not alter the calorific value of the MSW within the imprecision of our experiments. The average of the unprocessed minus processed difference in the calorific value on a dry basis is -0.5% and on a dry, ash-free basis is 0.0% of the

corresponding mean calorific value. The imprecisions in these differences are 2.9% on a dry basis, and 2.0% on a dry, ash-free basis of the corresponding mean calorific value. Most of the imprecision is due to the fact that completely identical pairs of samples were not prepared by our hand sorting and reconstituting of unprocessed MSW. An important qualification is that excessive local heating of the unprocessed MSW during milling was avoided. In our case, powdered dry ice was added to the sample as it was fed to a Wiley Mill in the final step of processing.

In regard to the kilogram-to-gram sampling problem, our results show that it is possible to obtain gram-size test samples that have the same calorific value as the kilogram parent of processed MSW if one uses the sample division technique described in this work. We show that gram-size test samples taken from a single parent kilogram-size processed MSW sample have the same calorific value as the parent within the imprecision of our experiments. The average difference of the parent minus gram-size sample calorific values is -0.1% on a dry basis and $+0.9\%$ on a dry, ash-free basis of the corresponding mean calorific value. The imprecisions of the differences are 1.1% on a dry basis and 0.8% on a dry, ash-free basis of the corresponding mean calorific values.

The new sample division technique was successful because it is insensitive to the effects of sample segregation, whereas our earlier coning and quartering method was not. Because the technique employed in this study is time consuming, it is recommended only as a reference procedure. An apparatus with more rapid throughput is needed for routine testing. We definitely do not recommend coning and quartering plus taking of grab samples as a technique for the preparation of gram-size test samples of processed MSW. However, it can be used if a within-bag %CV in the calorific value (on a dry basis) of 3% or more is tolerable.

In summary, this work shows that if 2.5 kg (5 lb) increments are collected to characterize the calorific value of a MSW stream, each increment can be processed and then be sampled using the sample division technique cited here to obtain representative gram-size test samples. Combining^d the results on the processing to small particle size (see Table 5) and the kilogram-

^d Averages of the results on each basis (i.e. dry or dry, ash-free) were obtained by adding; the imprecisions were obtained as the square root of the sum of the squares, i.e.:

$$\text{Dry: } (-0.5) + (-0.1) \pm \sqrt{(2.9)^2 + (1.1)^2} \%$$

$$\text{Dry, ash free: } (0.0) + (+0.9) \pm \sqrt{(2.0)^2 + (0.8)^2} \%$$

to-gram sampling (see Table 4), we show that the average difference in the calorific values of the minimally processed kilogram-size sample minus the processed gram-size sample is -0.6% on a dry basis and $+0.9\%$ on a dry, ash-free basis of the corresponding mean calorific values. The imprecisions in these values are 3.1% on a dry basis and 2.2% on a dry, ash-free basis of the mean calorific values.

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Key Words: Calorific Value; Combustion; Standard; State of the art; Testing

ABSTRACT

This paper describes a statistical analysis of data taken for a study of municipal solid waste calorific value. The study was conducted by the U.S. National Bureau of Standards, Office of Recycled Materials, and the Michigan Department of Energy, Office of Renewable Technology. The study was conducted in 1981.

INTRODUCTION

The County of Wayne County, Michigan, Authority's municipal incinerator plant, owned by the City of Detroit, Ecorse, Grosse Ile, Livonia, Warren, and Westland, is located in Wayne County in southeastern Lower Michigan. The incinerator plant has a capacity of 300,000 tons per year and a 1984 State Department of Public Health (SDPH) license of 100,000 tons per year. The plant has a long history of producing a high quality refuse-derived fuel (RDF) which is sold to the City of Detroit.

The Authority's incinerator plant operated successfully for 14 years in the early 1970s. The plant was operated by the City of Detroit. The plant was then transferred to the Authority in 1974. The Authority has since then operated the plant successfully. The Authority has since then operated the plant successfully. The Authority has since then operated the plant successfully.

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