

Assessing the credibility of the calorific content of municipal solid waste

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Abstract - A study has been carried out to establish the limits of reliability of the calorific content of municipal solid waste (MSW) by the bomb calorimetric procedure currently used in commercial test laboratories. This procedure involves using gram-size samples derived from MSW that have been processed down to a particle size of 2 mm or less. Critics argue that one cannot sample a multi-ton quantity of MSW and extract gram-size samples which are representative of the entire gross sample. They argue further that processing down to 2 mm or less significantly alters the composition of the sample.

In order to test the bomb calorimetric procedure, a 2.5 kg 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 on processed MSW were obtained using both the kilogram-size flow and gram-size bomb calorimeters. The effects of processing on sample composition were determined by intercomparison of flow calorimetric results on kilogram-size samples of unprocessed and processed MSW that are nominally identical.

We conclude that if proper care is taken in sampling large quantities of MSW and similar care is paid toward sample size reduction and subdivision, meaningful values can be obtained for the calorific content of MSW using the conventional bomb calorimetric procedure at the $\pm 1\%$ level. Differences in values for processed and unprocessed samples can be as much as $\pm 3\%$, and are related to experimental difficulties in preparing "exactly identical" kg samples of MSW.

INTRODUCTION

Incinerator-boiler systems used to dispose of MSW are bought and sold on the basis of thermal specifications. To determine whether a system meets its thermal specifications, the calorific content of the of the input waste stream must be known.

At the present time, as well as in the past, the calorific content of MSW is determined by at commercial test laboratories by combustion bomb calorimetry using gram-size test samples. The gram-size test samples are usually prepared from kilogram-size increments obtained from a larger-scale sampling of an MSW site. The increments are dried, sorted to remove nonmillable components (i.e., metals), and milled to 2.0 - 0.5 mm particles. In this work, the milled material is called processed MSW. The processed MSW is then subdivided, usually by coning and quartering to obtain gram-size test samples.

THE CREDIBILITY PROBLEM

For many years combustion engineers have felt that one could not sample a multi-ton quantity of MSW and extract representative gram-size samples for bomb calorimetric measurements. The method of test was also in dispute because many combustion engineers believed that the composition of the test samples differed from that of the original increments. This might occur because of changes by excessive localized heating during milling or by nonrepresentative subdivision of the MSW, which segregates easily. Segregation occurs because processed MSW consists of a low density component, which resembles chopped cotton fibers, and a high density component, which resembles grit or sand. Part of the high density material is entrained in the low density material and this entrainment is nonuniform. Henceforth, we have this problem regarding the validity and credibility of the bomb calorimetric determination of the calorific content of processed MSW because of an implied

inability to perform the sampling operation and/or because of the compositional changes which occur during comminution. Groups which have identified this problem are: the Research Committee on Industrial and Municipal Wastes of the American Society of Mechanical Engineers (ASME), ASME Performance Test Codes Committee (PTC-33) on Large Incinerators, and Committee E-38 on Resource Recovery (and now merged with Committee D-34 on Waste Disposal) of the American Society for Testing and Materials (ASTM).

To address this problem, the National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards (NBS)) initiated a research program in collaboration with the U.S. Department of Energy (DOE) and the U.S. Environment Protection Agency (EPA) to develop test procedures for accurately determining the calorific content of MSW and refuse-derived fuels (RDF). This research was also part of the NIST (then 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 the classification of materials destined for disposal.

Two questions were addressed in order to resolve the credibility problem. The first was the sampling question: How does one obtain a representative gram-size sample from a kilogram-size quantity of processed MSW? The second was the processing question: Does milling MSW to 2 mm or less alter its calorific content significantly. The remaining problem of extraction of kilogram-size increments in sufficient number and in such a manner as to characterize a multi-ton quantity of MSW was considered important, but outside of the scope of this study. However, in order to address the two questions, increments were extracted from a multi-ton stream of MSW using a selected sampling method.

An initial study of the day-to-day variability of the calorific content of MSW was carried out at NIST in 1980 (refs. 1,2) using the selected method. We concluded from the results of that work that the sampling and processing questions could be answered with a calorimeter in which we could burn a kilogram-size sample with a total uncertainty of less than 1% in the enthalpy of combustion.

DEVELOPMENT OF A MULTI-KILOGRAM CAPACITY COMBUSTION FLOW CALORIMETER

We chose to build a calorimeter for the combustion of kilogram-size samples in flowing oxygen near atmospheric pressure rather than scale-up the conventional oxygen combustion bomb calorimeter, which operates at 30 atmospheres, for reasons of safety. Instrumentation of a small commercial incinerator was rejected it was felt that the time required to modify such a unit and validate the calorimetry would be longer than needed to build a new calorimeter.

Initially, work began with the development of a 25 gram capacity oxygen bomb (constant volume) calorimeter (refs. 3,4). This was followed by the construction of a 25 gram capacity flow (constant pressure) calorimeter (refs. 5,6). In both calorimeter systems, the processed MSW was compressed into a 25 gram pellet rather than being left in loose form because this configuration reduced the dispersion of the sample and thus simplifies the collection of ash. The next step consisted of the construction and testing of a prototype calorimeter for kilogram-size pellets of unprocessed MSW (refs. 7,8). Our unprocessed MSW samples were prepared by withdrawing increments of about 20 kg from the output of the Baltimore County Resource Recovery Facility at Cockeysville, Maryland. The increments were dried for 12 hours and then sorted to remove metals. The average particle size was 15 cm. The work in the prototype calorimeter indicated that the general design and operation of the large scale system was satisfactory. Kilogram-size pellets of unprocessed MSW burned rapidly and completely with minimal scattering of ash in the prototype system. As a result of the success with the prototype system, the multi-kilogram capacity isothermal combustion flow calorimeter was designed, constructed, and placed into operation (ref. 9). A cross-section of this calorimeter is shown in Fig. 1. The flow calorimeter consists of two basic parts: a constant temperature jacket and calorimeter proper. The latter contains the sample combustor. Nominally, sample sizes of 2.5 kilograms were used. Heat liberated in the combustion reaction is transferred to the stirred water in the calorimeter vessel, the outermost container of the calorimeter proper. The rise in temperature of the calorimeter water, after correction for heat exchange with the jacket and for heat transport by flowing gases, is proportional to the enthalpy of combustion of the sample. The calorimeter is calibrated by determining the temperature rise produced by the combustion of a known mass of microcrystalline cellulose whose enthalpy of combustion has been established by bomb calorimetry (ref. 10). The important dimensions and calorimeter properties are listed in Table 1. All metal components were fabricated from 316 stainless steel. A detail description of this calorimeter and its operation can be found elsewhere (ref 9).

SAMPLING AND PROCESSING STUDIES

A measurement protocol was devised and adopted to answer the sampling and processing questions (ref. 11). Daily increments of unprocessed MSW were collected from the Baltimore County Resource Recovery Facility over a 10 day period in January 1983. The daily increments consisted of 4 to 6 plastic bags which contained the unprocessed MSW and varied in mass from 13 to 23 kg. The increments were brought to NIST each day, dried for 12 hours at 105 °C to determine its initial moisture content, and then stored in a refrigeration unit at 5 °C.

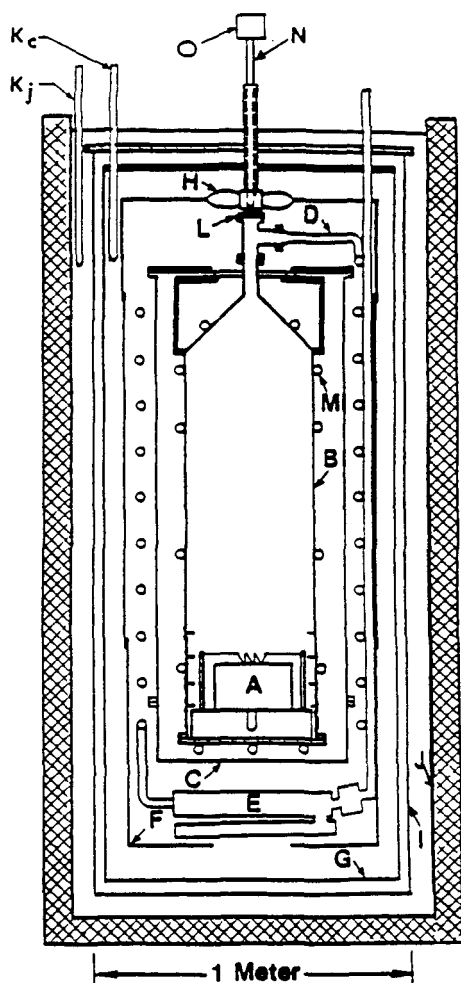


Fig. 1. Diagram of the multi-kilogram capacity flow calorimeter

- A sample pellet,
- B combustor,
- C combustor enclosure,
- D exhaust coil,
- E collector,
- F flow shield,
- G calorimeter vessel,
- H stirrer,
- I submarine jacket,
- J jacket water,
- K quartz thermometer,
- L window,
- M quick-cool exchange system,
- N boroscope.

Increments from four days were chosen from the 10 days of sampling for our combustion measurements. After drying these increments of the unprocessed MSW, we attempted to prepare identical increments by hand sorting of MSW into various component categories (i.e., paper, metals, wood, plastics, etc.) and reconstituting the categories (except for metals) into 2.5 kg samples having the same mass composition as the whole. Four bags of the reconstituted 2.5 kg samples were selected from each of the four days. Two bags with 2.5 kg samples from each day were milled to 2 mm particles, and then, to obtain gram-size test samples, each of these parent samples was subdivided using a rotary riffler rather than the usual method of coning and quartering. The two remaining bags with 2.5 kg samples were burned in the large calorimeter without any size reduction, after being dried to determine their residual moisture content. Additional details regarding these procedures can be found in ref. 11.

TABLE 1. Specifications for the multi-kilogram capacity flow calorimeter

Component	Dimensions				Additional Specifications	
	Height (cm)	Outside Diameter (cm)	Wall Thickness (mm)	Total Mass (kg)		
Combustor	155	41	3.2	74	Calorimeter water	980 liters
Combustor Enclosure	163	61	4.8	196	Submarine Vessel water	2160 liters
Flow Shield	213	79	1.6	73	Heat Capacity of Calorimeter	0.4 MJ/K (assembly) 4.1 MJ/K (water) 4.5 MJ/K (total)
Calorimeter	236	91	4.8	390		
Submarine Vessel (Isothermal bath)	243	97	4.8	454		

RESULTS AND DISCUSSION

The average difference in the calorific content of gram-size samples of dry, processed MSW minus that of their kilogram-size parent dry, processed MSW of -0.1% of the mean calorific content of the parent sample. We have chosen to use the percent coefficient of variation (%CV) as the statistic to indicate the variability or imprecision of our results; $\%CV = s/A$ where s is the standard deviation of an individual measurement and A is the average value for a set of measurements. The imprecision of the average difference of the parent minus gram-size sample calorific content has the %CV equal to 1.1% and can be accounted for by examining the %CV of the bomb calorimetric measurements, 0.5%, and the %CV of the flow calorimetric measurements, 0.4%. The subdivision process using the rotary riffler is less sensitive to the effects of segregation than the subdivision process carried out by the usual coning and quartering technique, hence, the latter was not used.

The average difference in the calorific content of MSW of kilogram-size samples of dry, unprocessed MSW minus that of dry, processed MSW is -0.5% of the average calorific content of the processed MSW. The imprecision of the difference shows the %CV equal to 2.9% of the average calorific content. We avoided excessive localized heating during milling by adding powdered dry ice to the sample as it was fed to a Wiley mill in the final step of size reduction. The larger imprecision here, 2.9%, as compared to the first, 1.1%, is largely due to the fact that kilogram-size samples of unprocessed MSW (one of which is then milled) could not be prepared by the procedure we used so that they were identical. Our hand sorting and reconstituting of unprocessed MSW just did not produce exactly identical kg samples.

CONCLUSIONS

We conclude that the calorific content of gram-size test samples of processed MSW is the same as the calorific content of their kilogram-size parents of unprocessed MSW within 1%. Thus, it is not necessary to burn the entire kilogram-size increment and one should believe and accept the calorific content of the gram-size sample as representative and valid provided some precautions are followed. These precautions include: (1) an acceptable sampling procedure has been used to extract increments from the multi-ton quantity of MSW, (2) the extracted increments are reduced to small particles, 0.5-2.0 mm, without producing any localized heating as might occur during the milling operation, and (3) sample subdivision is performed so that segregation of low and high density components is avoided.

We also conclude that the calorific content of the unprocessed and processed MSW are equivalent within 3%. This imprecision level is three times larger than that obtained for the difference between the calorific content of kilogram-size parent minus gram-size processed MSW samples. Our hand sorting and reconstituting procedures unavoidably contained a subjective component which influenced and did not allow for the preparation of exactly identical kilogram-size samples for calorimetric measurement.

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