LONG TERM HHV DETERMINATION OF MUNICIPAL SOLID WASTE — A PRACTICAL APPROACH

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ABSTRACT

The determination of waste HHV over extended time periods is achievable by applying the concept of a specific steam correlation method developed from results of multiple boiler calorimetry tests. This correlation, used in conjunction with appropriate corrections for critical boiler operating parameters, provides a practical and reliable method of waste HHV determination. The theoretical basis, calculations and limitations of this HHV determination technique are presented and discussed.

INTRODUCTION

Waste processing capacity and energy recovery rate are the two primary production parameters used to gauge the performance of a resource recovery facility and are typically guaranteed on a long term basis. A capacity throughput guarantee is based on combusting a minimum quantity of waste having a specific "reference" higher heating value (HHV) and is typically expressed in terms of tons of waste processed per month or year, adjusted for the reference heating value. An energy recovery guarantee is based on producing a minimum amount of energy from waste at the same reference HHV and is typically expressed in kilowatt-hours/reference ton or pounds of steam/reference ton of waste. The reference HHV is specified in conjunction with the waste processing or energy recovery guarantee due to the heterogeneous nature of waste and the large impact varying waste HHV has on these production parameters.

The determination of waste HHV is necessary to determine the difference between the actual waste HHV and the reference HHV for purposes of adjusting the actual production parameters to equivalent reference parameters which would have been obtained had waste of reference composition and HHV been processed. The performance of a facility can then be accurately assessed for purposes of:

(a) Demonstrating monthly or annual energy recovery and waste processing guarantees.

(b) Ensuring that the facility is being operated at the optimum capability and efficiency desired.

The purpose of this paper is to present a method for the determination of municipal solid waste HHV over extended time periods which is practical, accurate and economical to implement and also exhibits acceptable accuracy.

BACKGROUND OF HIGHER HEATING VALUE DETERMINATION

Conventional Fuels

The higher heating values of conventional fuels, such as coal, oil and gas are typically determined by regularly obtaining small representative samples of the fuel and performing an analysis for energy content (HHV) on a Btu/lb basis. This laboratory HHV determination is performed by utilizing a bomb calorimeter. The bomb calorimeter analysis consists of combusting typically a 1 gram sample of fuel in an airtight enclosure, surrounded by water. The heat generated from combusting the fuel is transferred to the water and measured by the temperature rise of the water jacket. The fuel HHV is then easily calculated.

Municipal Solid Waste

Municipal Solid Waste, with its inherent variability in composition and energy content (HHV), does not allow one to obtain a truly representative sample for laboratory analysis of HHV and thus leads to highly variable or questionable results when applying the conventional bomb calorimetry technique. Recognizing the difficulties with obtaining representative waste HHVs in a conventional laboratory calorimeter, the National Bureau of Standards embarked on the development of a larger calorimeter in the 1970s. Shortly thereafter it was determined that even with a larger calorimeter, representative waste HHV results were difficult to obtain. Because of these difficulties, the boiler-as-a-calorimeter test method gained wider acceptance and became the preferred method for waste HHV determination.

The boiler-as-a-calorimeter method is based on the similar concept of a laboratory calorimeter where all of the heat produced from the combusted refuse is measured across the boiler boundary, either as heat losses or recovered energy. The obvious and critical difference, however, is that instead of measuring several "representative" grams of refuse, one is literally measuring the heat released from tons of refuse. The boiler-as-a-calorimeter test method combines: *(a)* the heat loss method for boiler efficiency determination contained in the American Society of Mechanical Engineers (ASME) Power Test Codes (PTC) 4.1 and 33; *(b)* portions of the input–output method for boiler efficiency calculation contained in PTC-4.1; and *(c)* various equations and assumptions to combine the referenced documents into one cohesive test calculation method. The technical community within the resource recovery industry and the ASME have long recognized the need to develop a comprehensive, standardized Power Test Code for conducting and analyzing data from boiler calorimeter tests. This code, designated as PTC-34, Waste Combustors with Energy Recovery, is currently being developed by the ASME and in the near future will become the reference document for conducting tests and performing the required calculations for determining waste HHV.

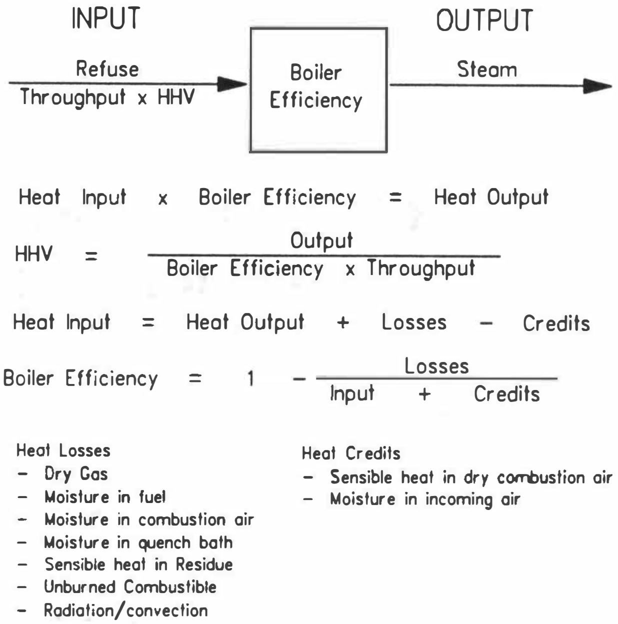


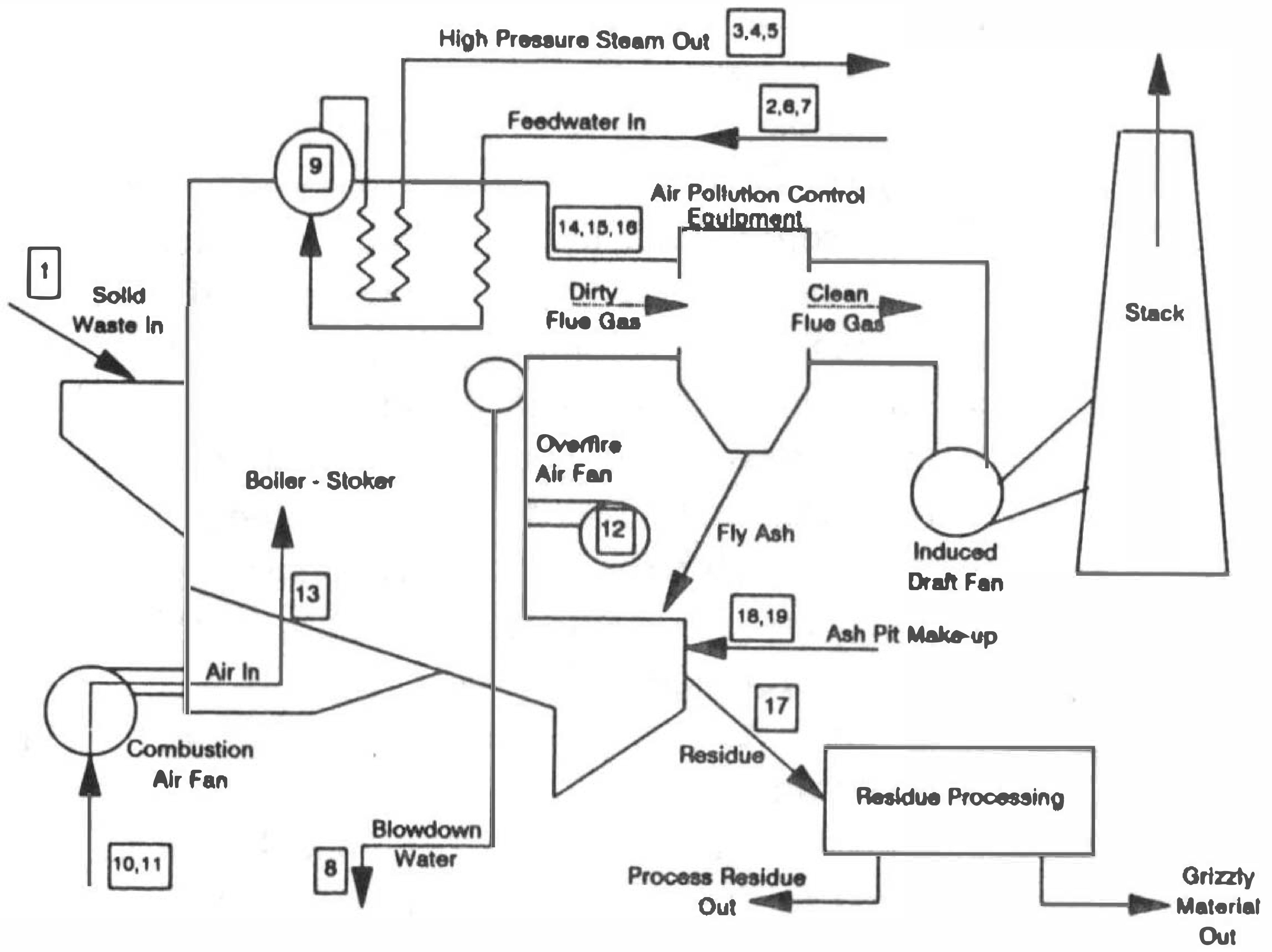
FIG. 1 BOILER AS A CALORIMETER TEST METHOD

The HHV determination performed in accordance with the boiler-as-a-calorimeter test method (refer to Fig. 1) is based on the premise that the HHV can be calculated by measuring the heat output of the boiler and translating it into heat input by determining one variable; namely boiler efficiency (i.e., heat output divided by boiler efficiency = heat input). The output is the product of the boiler steam flow and the energy required to generate and superheat the steam. The input is the product of the HHV and the measured quantity of the waste. The boiler efficiency is determined in accordance with the Heat Loss method in PTC-4.1/Reaffirmed 1979.

The test duration for a boiler calorimetry test is typically 8 hr. The determination of waste HHV for this relatively short period, in itself, poses a formidable challenge to the facility operator due to the costs associated with such a labor-intensive undertaking and the many data inputs required (refer to Fig. 2). For this reason, the boiler-as-a-calorimeter test method is primarily used during a facility's initial performance test and is not a practical option for long-term determination of HHV.

ALTERNATIVE METHODS FOR LONG TERM HHV DETERMINATION OF MSW

Any practical method considered for long term waste HHV determination must make a compromise between



1	Refuse Feed
2	Feedwater Flow
3	Steam Flow
4	Steam Temperature
5	Steam Pressure
6	Feedwater Temperature
7	Feedwater Pressure
8	Continuous Blowdown Flow
9	Drum Pressure
10	Ambient Dry Bulb Temp.
12	Ambient Wet Bulb Temp.
13	Overfire Air Flow
14	Combustion Air Flow
15	CO2,O2,H20 in Flue Gas
16	Flue Gas Flow
17	Economizer Exit Temperature
18	Residue Rate, Moisture, and Unburned Combustibles
19	Ashpit Water Temperature

FIG. 2 BOILER CALORIMETRY TEST DATA INPUTS FOR A TYPICAL MASS BURN RESOURCE RECOVERY FACILITY

test accuracy and the time duration over which the HHV determination can be performed.

Three methods typically considered for long term waste HHV determination are the extrapolation method, the instrumentation method and the specific steam correlation method. Each of these methods represents a different compromise between test accuracy and the duration over which boiler data and corresponding heat output data is measured.

Extrapolation Method

This method consists of conducting multiple 8-hr boiler calorimetry tests in accordance with the general guidelines outlined in PTC-4.1. and PTC-33. The 8-hr tests are performed at regularly specified intervals (i.e., daily, weekly, and monthly) and the results are extrapolated to provide an estimate of the waste HHV combusted during the remaining portion of that interval in which the HHV was not actually measured. For example, an 8-hr boiler calorimetry test might be performed weekly and the HHV determined for that 8-hr period would be assumed or "extrapolated" to be the same HHV for the entire week. The extrapolation method maintains the accuracy associated with the boiler-as-a-calorimeter method, but compromises on the duration of the analysis period. Since the actual HHV analysis period is less than 5% of the total time interval, significant errors in the HHV determination can arise. The concern over the impact of the limited analysis period becomes even more evident when one considers the heterogeneous nature of the waste and its correspondingly widely fluctuating HHVs. The error could be reduced by conducting tests more frequently, but the large expense and manpower needs associated with performing an ASME quality boiler calorimetry test (e.g., $10,000 or more) become prohibitive factors.

For these reasons, the extrapolation method is considered impractical for use in the determination of refuse HHV over extended time periods.

Instrumentation Method

The instrumentation method consists of implementing a system which continuously acquires the data necessary for determining the major boiler efficiency heat losses. Therefore, the duration of the analysis period is not compromised.

The continuous determination of the major losses and credits requires the acquisition of many data inputs, some of which can only be accurately and reliably obtained using prohibitively expensive manual test methods; namely, the determination of flue gas flow, flue gas moisture and residue unburned combustibles. Currently, the state of the art for instruments which continuously determine flue gas moisture and flue gas flow is not sufficiently developed or commercially proven where they may be deemed reliable or accurate in a harsh flue gas environment. Therefore, implementation of the instrumentation method for long term refuse HHV determination is considered unachievable.

Specific Steam Correlation Method

Recognizing that the extrapolation and instrumentation methods rely on techniques which are either unac-

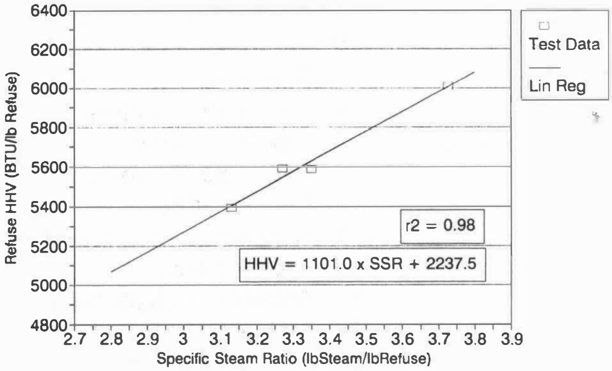


FIG. 3 SPECIFIC STEAM RATIO CORRELATION (Typical OMS Facility)

ceptable or unachievable from the standpoint of accuracy, cost, manpower and available instrumentation, a third method — the specific steam correlation method — has been investigated. The specific steam correlation method is based on continuous data input for the major boiler parameters and therefore no compromise is made in the duration of the analysis period. Furthermore, the method uses inputs from standard commercially proven plant instruments and therefore can be easily implemented.

The specific steam correlation method is based on a concept which establishes a relationship between waste HHV and two regularly monitored production parameters: namely, waste processed and steam produced. The ratio of these two production parameters (pounds of steam produced per pound of waste processed) is termed the specific steam ratio (SSR). The SSRs and corresponding waste HHVs obtained from multiple boiler calorimetry tests are used to establish a correlation for use in determining the waste HHV on a long-term basis (refer to Fig. 3).

The HHV determination for a given interval is accomplished by: *(a)* measuring the waste processed and steam produced for the entire interval; *(b)* calculating the SSR; and *(c)* obtaining the corresponding HHV from the correlation.

DEVELOPMENT OF THE SPECIFIC STEAM CORRELATION METHOD

Ogden Martin Systems has (OMS) conducted multiple boiler calorimetry tests at 11 OMS facilities as part of acceptance test programs. The results of 37 such tests are presented in Table 1.

To enable a meaningful comparison of the test results among the facilities, differences in boiler operating conditions from facility to facility were adjusted to a common or normalized basis. It was realized during this early stage of development that a general or overall correlation based on a large number of points would be more statistically valid than a correlation from an individual facility based on three points. OMS proceeded to develop the specific steam correlation method for long term determination of refuse HHV using this overall correlation as follows:

(a) Data Analysis: Data and results from nine facility acceptance test programs, performed in accordance with applicable ASME Performance Test Codes were analyzed to develop the overall correlation of specific steam ratios to HHVs.

(b) Operating Parameter Adjustments: A mechanism was established to adjust the HHVs obtained from the correlation for differences between the baseline operating parameters on which the correlation is based and those measured during the desired HHV determination period.

(c) Validation: The accuracy of the method was determined empirically using data and results of nine ASME boiler calorimetry tests. In addition, an analytical model was used to compare the test results to theoretical results.

(d) Implementation: The continuous data acquisition requirements were established, along with corrections, for obvious operational influences affecting the method, such as boiler downtime and auxiliary fuel usage.

Data Analysis

To normalize the test results among the facilities, each test specific steam ratio — SSR — (lb steam/lb refuse) was converted to an equivalent specific steam output — SSO — (Btu/lb refuse). In addition, the test results were adjusted to the most prevalent boiler operating conditions. The baseline values are listed below:

economizer exit gas temp = 430°F
ambient air temp = 80°F
air preheat heat credit = 0 Btu/lb
excess air = 90%
unburned carbon in residue = 2.25%
unaccounted heat loss = 0.25%

The overall specific steam correlation was developed from the results of 28 of 37 of these boiler calorimetry tests, with pertinent data shown in Table 2. The test results were transformed into a mathematical equation

TABLE 1

	Test Date	Steam Flow	Refuse Flow	Specific Steam Ratio	Refuse HHV
Plant		(LB/HR)	(LB/HR)	(LBstm/LBref)	(BTU/LBref)
Babylon, NY	21-Feb-89	173,087	57,889	2.99	4750
Babylon, NY	22-Feb-89	173,719	60,530	2.87	4693
Babylon, NY	23-Feb-89	178,161	56,186	3.17	4871
Babylon, NY	27-Feb-89	176,204	48,413	3.64	5556
Bristol, Ct.	03-Feb-88	135,670	51,639	2.81	4687
Bristol, Ct.	11-Feb-88	141,790	48,612	2.93	4851
Fairfax, Va.	21-May-90	731,216	274,456	2.64	4331
Fairfax, Va.	23-May-90	736,496	241,220	3.03	4740
Fairfax, Va.	24-May-90	740,008	255,890	2.87	4459
Haverhill, Ma.	25-May-89	394,609	126,273	3.13	5197
Haverhill, Ma.	26-May-89	416,523	146,924	2.83	5099
Haverhill, Ma.	27-May-89	416,491	140,573	2.96	5157
Huntsville, Al.	25-Jun-90	99,270	25,728	3.57	5095
Huntsville, Al.	26-Jun-90	95,707	21,784	4.24	5783
Huntsville, Al.	09-Jul-90	103,430	32,582	2.92	4163
Huntsville, Al.	10-Jul-90	99,133	27,772	3.28	4749
Huntsville, Al.	14-Jul-90	102,086	26,089	3.68	5345
Indianapolis	10-Nov-88	675,778	226,488	2.98	4180
Kent County, Mi.	04-Jan-90	156,460	47,834	3.27	5560
Kent County, Mi.	05-Jan-90	161,718	43,394	3.73	5979
Kent County, Mi.	08-Jan-90	157,040	50,168	3.13	5366
Kent County, Mi.	10-Jan-90	155,449	46,405	3.35	5558
Lake County, Fl.	15-Jan-91	137,501	45,015	3.05	5041
Lake County, Fl.	16-Jan-91	134,234	47,495	2.83	4704
Lake County, Fl.	17-Jan-91	134,864	46,898	2.88	4827
Lancaster, Pa.	26-Mar-91	306,859	95,154	3.22	5232
Lancaster, Pa.	28-Mar-91	315,365	100,345	3.14	5058
Lancaster, Pa.	02-Apr-91	312,225	104,938	2.98	5199
Lancaster, Pa.	04-Apr-91	310,416	97,818	3.17	5362
Lancaster, Pa.	05-Apr-91	310,115	99,388	3.12	5252
Pasco County, Fl.	15-Apr-91	274,717	95,220	2.89	4574
Pasco County, Fl.	17-Apr-91	282,051	94,480	2.99	4742
Pasco County, Fl.	19-Apr-91	279,919	95,101	2.94	4640
Pasco County, Fl.	22-Apr-91	270,865	101,130	2.68	4338
Stanislaus, Ca.	13-Dec-88	202,170	73,064	2.77	4657
Stanislaus, Ca.	16-Dec-88	208,940	68,658	3.04	4919
Stanislaus, Ca.	06-Jan-89	202,131	77,285	2.62	4474

by performing a linear regression analysis. Results from the remaining nine tests, not used in generating the original correlation, were then used for validation purposes by comparing the HHV results determined by the boiler-as-a-calorimeter method to the HHVs determined by the specific steam correlation method, as is discussed later.

The specific steam output correlation (HHV versus Btu/lb refuse) based on the 28 boiler calorimetry tests is shown in Fig. 4(a). The specific steam output correla-

TABLE 2 SPECIFIC STEAM CORRELATION DATA

					Operating Parameters						
	Test	Feedwater Temp	Steam Temp	Steam Press	Ambient Air Temp	Heated Air Temp	Heat Credit	Excess Air	Economizer Exit Gas Temp	Specific Steam Output	Refuse HHV
Plant	Date	(F)	(F)	(PSIG)	(F)	(F)	(BTU/LB)	(%)	(F)	(BTU/LB)	(BTU/LB)
Babylon, NY	21-Feb-89	241	700	641	53	225	182	79	406	3262	4779
Babylon, NY	22-Feb-89	244	703	637	47	232	193	85	420	3158	4678
Babylon, NY	23-Feb-89	245	700	639	44	238	215	83	412	3461	4833
Babylon, NY	27-Feb-89	246	705	640	48	241	259	78	422	3970	5601
Bristol, Ct.	03-Feb-88	243	830	848	32	244	250	98	421	3267	4680
Bristol, Ct.	11-Feb-88	238	828	850	40	204	208	97	419	3438	4797
Fairfax, Va.	21-May-90	246	825	867	70	271	242	98	421	3000	4414
Fairfax, Va.	23-May-90	247	819	867	62	275	236	103	405	3452	4823
Fairfax, Va.	24-May-90	248	820	870	63	282	221	91	404	3246	4542
Haverhill, Ma.	25-May-89	251	813	861	79	96	21	94	428	3683	5136
Haverhill, Ma.	26-May-89	250	831	855	80	95	20	104	457	3433	4834
Haverhill, Ma.	27-May-89	250	831	854	78	94	21	102	460	3593	5032
Huntsville, Al.	25-Jun-90	251	460	344	86	223	167	83	427	3500	5056
Huntsville, Al.	26-Jun-90	251	463	355	87	217	182	80	398	4066	5772
Huntsville, Al.	09-Jul-90	255	476	348	85	180	94	87	421	2911	4138
Huntsville, Al.	10-Jul-90	259	472	351	90	206	145	100	447	3273	4571
Huntsville, Al.	14-Jul-90	250	465	352	80	215	178	79	446	3634	5349
Indianapolis	10-Nov-88	243	708	512	58	294	232	100	452	2905	4104
Kent County, Mi.	04-Jan-90	249	836	879	58	186	179	82	452	3847	5557
Kent County, Mi.	05-Jan-90	250	832	887	49	252	296	82	451	4314	6090
Kent County, Mi.	08-Jan-90	244	840	892	54	175	171	86	458	3726	5320
Kent County, Mi.	10-Jan-90	246	828	881	52	180	181	90	450	3959	5668
Lake County, Fl.	15-Jan-91	242	812	864	69	220	226	94	397	3457	5111
Lake County, Fl.	16-Jan-91	242	816	863	74	254	260	99	399	3178	4761
Lake County, Fl.	17-Jan-91	242	814	863	63	218	218	102	399	3282	4905
Stanislaus, Ca.	13-Dec-88	242	820	863	66	267	215	104	434	3316	5311
Stanislaus, Ca.	16-Dec-88	242	809	858	55	265	216	95	413	3528	5163
Stanislaus, Ca.	06-Jan-89	243	830	856	56	269	174	89	422	3111	5273

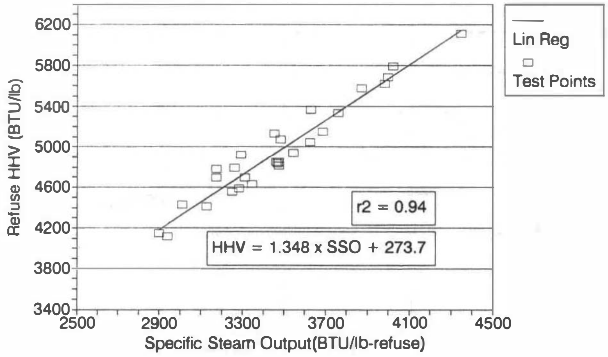


FIG. 4(a) SPECIFIC STEAM OUTPUT CORRELATION (0HtCr, 430°F, 80°F, 90% Xs, and Luac = 0.25)

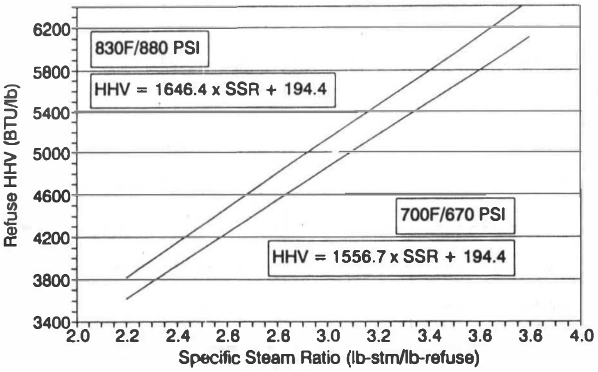


FIG. 4(b) SPECIFIC STEAM RATIO CORRELATIONS (0HtCr, 430°F, 80°F, 90% Xs, and Luac = 0.25)

tion (btu/lb refuse) is also presented on a specific steam ratio basis (lb steam/lb refuse) in Fig. 4(b) for two common final steam conditions in the waste-to-energy industry; 830°F, 865 psia and 700°F, 670 psia. The correlation method is presented on a specific steam ratio basis (lb steam/lb refuse), since in this form, it is expressed in terms of measured parameters familiar to the facility operator.

A statistical analysis of the data indicates that: *(a)* the resulting r^2 value equals 0.95 (i.e., 1.0 representing a theoretically perfect correlation); and *(b)* the standard error of *Y* estimate (i.e., the HHV) equals 113 Btu/lb. This standard error, expressed as a percentage of a typical HHV of 5000 Btu/lb combusted at a mass-burn facility, would yield an overall HHV determination tolerance of less than 2.3%.

Operating Parameter Adjustments

The boiler operating parameters with the greatest impact on boiler efficiency consist of:

(a) Economizer gas outlet temperature.
(b) Ambient air temperature.
(c) Preheated combustion air temperature.
(d) Flue gas oxygen concentration (i.e., excess air/flue gas flow).
(e) Unburned carbon.

The relationship of each of these boiler operating parameters to boiler efficiency and waste HHV content was established by individually varying the parameters in a mathematical model which uses the heat loss formulas in PTC-4.1. Specifically, the following heat losses were evaluated:

(a) Heat loss due to heat in dry flue gas.
(b) Heat loss due to moisture in the air.
(c) Heat loss due to moisture in the fuel and combustion of hydrogen to form moisture.
(d) Heat loss due to unburned carbon.

Using these equations, calculations were performed varying the three temperature parameters in 10 deg. increments, the excess air parameter in 10% increments and the residue unburned carbon in 1% increments to yield the respective changes in boiler efficiency. The analysis was performed using a typical waste composition (ultimate analysis) corresponding to a waste HHV of 5000 Btu/lb. The HHV of 5000 Btu/lb was selected as the baseline waste for the analysis since it represents the midpoint of the typical range of HHVs combusted at a mass-burn facility. The analysis yields the following relationships (refer to Fig. 5):

Economizer Exit Gas Temperature

A 10°F increase (decrease) in economizer exit gas temperature from the baseline economizer exit gas temperature equates to a 0.4% change in boiler efficiency and a corresponding increase (decrease) of 0.57% in the refuse Btu content obtained from the correlation.

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Ambient Air Temperature

A 10°F increase (decrease) in ambient air temperature from the baseline ambient air temperature equates to a 0.5% change in boiler efficiency and a corresponding decrease (increase) of 0.71% in the refuse Btu content obtained from the correlation.

Preheated Combustion Air Temperature

For every 10°F rise in combustion air temperature across the steam coil airheaters (supplied by steam from outside the boiler boundary), the refuse higher heating value obtained from the correlation will decrease (increase) by 12 Btu/lb.

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Excess Air

For every 10% increase (decrease) from the baseline excess air percentage, the boiler efficiency will change by 0.6% and the higher heating value obtained from the correlation will correspondingly increase (decrease) 0.86%.

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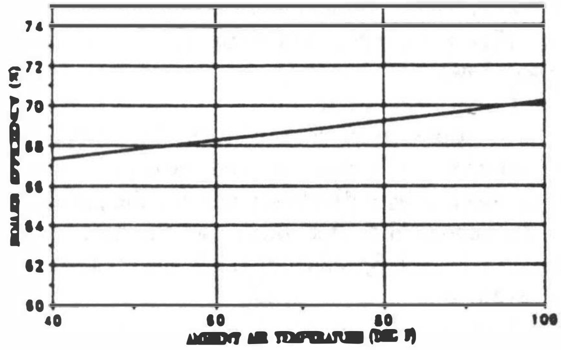

FIG. 5(a) AMBIENT AIR TEMPERATURE VERSUS BOILER EFFICIENCY

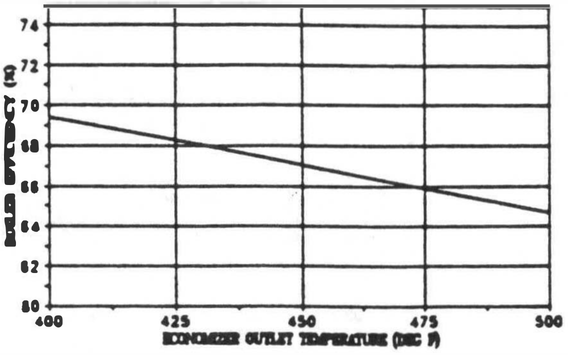

FIG. 5(b) ECON OUTLET TEMP VERSUS BOILER EFFICIENCY

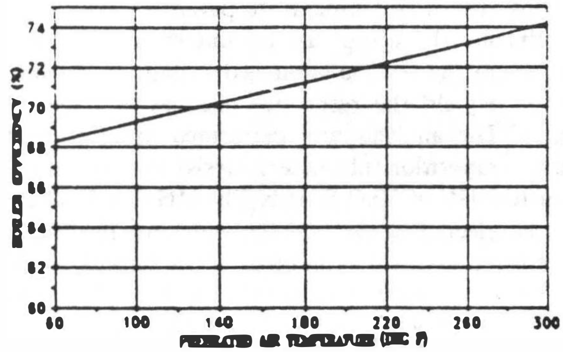

FIG. 5(c) PREHEATED AIR TEMPERATURE VERSUS BOILER EFFICIENCY

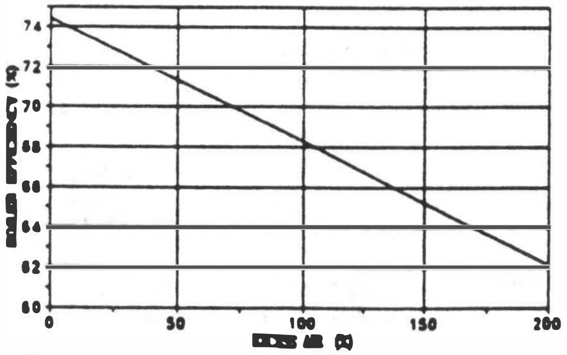

FIG. 5(d) EXCESS AIR VERSUS BOILER EFFICIENCY

Unburned Combustibles

For every 1% increase (decrease) from the baseline unburned combustible percentage, the boiler efficiency will change by 0.6% and the higher heating value obtained from the correlation will increase (decrease) 0.86%.

Validation

The validity of the specific steam correlation method was demonstrated empirically, using the results of nine boiler calorimetry tests and supported theoretically using an analytical model.

Empirical Validation

HHVs calculated using the boiler-as-a-calorimeter test method were compared to the HHVs determined using the correlation method. Data and results from the two most recent boiler calorimetry test programs were used. The data for these test programs are presented in Table 3 and the results of the comparison are included in Table 4. The HHVs determined by the correlation method averaged 0.2% lower for the four Pasco tests and 1.9% higher for the five Lancaster tests than HHVs calculated by the boiler-as-a-calorimeter test method. The agreement within ±2.5% of the more rigorous boiler-as-a-calorimeter method demonstrates the empirical validity.

Theoretical Validation

Typical waste compositions corresponding to HHVs ranging between the extremes (for mass-burn waste) of 2500 Btu/lb and 9000 Btu/lb were used to develop a theoretical model. Keeping boiler operating parameters at their constant baseline values, calculations were performed to determine the boiler efficiency and specific steam ratio (SSR) for each of the respective waste compositions. The results of the analysis are summarized in Table 5. A plot of the theoretical specific steam correlation results is included in Fig. 6. When the re-

TABLE 3 SPECIFIC STEAM CORRELATION TEST DATA FOR CORRELATION VALIDATION

					Operating Parameters							
	Test	Feedwater Temp	Steam Temp	Steam Press	Ambient Air Temp	Heated Air Temp	Heat Credit	Excess Air	Economizer Exit Gas Temp	Specific Steam Output	Refuse HHV
Plant	Date	(F)	(F)	(PSIG)	(F)	(F)	(BTU/LB)	(%)	(F)	(BTU/LB)	(BTU/lb)
Lancaster, Pa.	26-Mar-91	250	805	862	72	258	274	83	423	3597	5232
Lancaster, Pa.	28-Mar-91	250	805	863	82	252	248	82	434	3517	5058
Lancaster, Pa.	02-Apr-91	250	824	862	72	151	112	85	447	3490	5199
Lancaster, Pa.	04-Apr-91	250	816	862	75	183	160	91	450	3689	5362
Lancaster, Pa.	05-Apr-91	250	812	861	69	177	154	89	445	3620	5252
Pasco County, Fl.	15-Apr-91	298	833	878	82	230	150	90	455	3229	4574
Pasco County, Fl.	17-Apr-91	299	840	873	81	230	159	87	447	3331	4742
Pasco County, Fl.	19-Apr-91	298	823	872	79	227	153	89	445	3266	4640
Pasco County, Fl.	22-Apr-91	297	830	873	74	226	147	90	452	2998	4338

TABLE 4 COMPARISON OF BOILER-AS-A-CALORIMETER RESULTS VERSUS CORRELATION PREDICTION

		Measured	Predicted			RMS
		HHV	HHV	Difference	Difference	Difference
Plant	Date	(BTU/LBr)	(BTU/LBr)	(BTU/LBr)	(%)	(%)
Lancaster	26-Mar-91	5232	5115	116	2.3	
Lancaster	28-Mar-91	5058	5003	55	1.1	
Lancaster	02-Apr-91	5199	4991	208	4.2	
Lancaster	04-Apr-91	5362	5269	93	1.8	
Lancaster	05-Apr-91	5252	5174	78	1.5	2.4
Pasco	15-Apr-91	4574	4640	-66	-1.4	
Pasco	17-Apr-91	4742	4769	-27	-0.6	
Pasco	19-Apr-91	4640	4686	-46	-1.0	
Pasco	22-Apr-91	4338	4334	5	0.1	0.9

sults of the 37 boiler calorimetry tests are also plotted on Fig. 6, it can be seen that there is excellent agreement between the theoretical model results and boiler calorimetry test results.

Implementation

Ogden Martin Systems (OMS) has implemented the specific steam correlation method at all OMS operating facilities. A specific steam correlation summary sheet, containing the data inputs, calculations and adjustments performed as part of this method is included in Table 6. The HHV determination using the specific steam correlation concept is accomplished as follows:

Step 1: Acquiring and Inputting Data

The following process parameters are used as data inputs:

Monthly Totals:
(a) Refuse Throughput.
(b) Boiler steam flow.
(c) Auxiliary fuel usage.
Monthly Averages:
(a) Boiler steam temperature.
(b) Boiler steam pressure.
(c) Boiler feedwater temperature.
(d) Boiler economizer exit gas temperature.
(e) Boiler heated combustion air temperature.
(f) Ambient air temperature.
(g) Boiler flue gas oxygen content O_2.

Step 2: Determining of Refuse Throughput

It is recommended that the minimum HHV determination interval consist of a one month period. This recommended period stems from the need at most facilities to rely on the truck scale weights with adjustments for pit volume difference for determining the quantity of waste combusted.

Step 3: Converting the Measured O_2 to Excess Air

The measured O_2 concentration on a "dry" volumetric basis is used to calculate the excess air.

Step 4: Calculating the Average Hourly Heat Output for the Month

The heat output is based on the measured flow using the permanent plant feedwater or main steam flow elements. Each respective facility must be evaluated on an individual basis to include any additional output streams (if existing) into the heat output determination. In most cases the continuous blowdown flow can be assumed as having a negligible contribution to heat output.

The as-measured steam flow is normalized to reference steam temperature and pressure and feedwater temperature. This is accomplished by multiplying the measured steam flow by the ratio of the actual feedwater to steam enthalpy difference to reference feedwater to steam enthalpy difference.

Step 5: Adjusting the Weekly Heat Output for Any Auxiliary Fuel Fired

Steam flow generated from auxiliary fuel usage is calculated using the measured average fuel flow, a boiler efficiency corresponding to the fuel being fired and the energy required to generate a pound of steam. The calculated steam flow attributed to auxiliary fuel firing is then subtracted from the total average steam flow to obtain the average steam flow generated from waste alone.

TABLE 5 ANALYTICAL MODEL RESULTS

(Waste Composition Versus Boiler Efficiency and Specific Steam Ratio)

BASE CASE CONDITIONS:	
STEAM PRODUCE	144,000 LB/HR
WASTE COMBUSTED	54,166 LB/HR (EQUIV. TO 650 TPD)
FINAL STEAM CONDITIONS	830°F, 865psia
BOILER FEEDWATER INLET	250°F
ECONOMIZER EXIT GAS TEMP.	430°F
AMBIENT AIR TEMP.	80°F
PREHEATED AIR TEMP	80°F
EXCESS AIR	90%

WASTE COMPOSITIONS/HHV (BTU/LB)	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500
(LB/100 LB WASTE)															
ASH & INERTS	23.27	23.49	23.81	22.44	21.19	20.26	16.57	14.53	12.21	9.95	7.90	5.86	4.04	4.07	4.26
MOISTURE	45.00	38.50	32.00	27.20	22.40	17.50	16.00	13.00	11.00	9.00	7.00	6.00	5.00	3.20	1.50
CARBON	14.38	17.23	20.07	22.92	25.74	28.51	31.13	33.77	36.25	38.73	41.18	43.48	45.72	47.82	49.90
HYDROGEN	2.03	2.43	2.84	3.24	3.64	4.04	4.43	4.81	5.18	5.54	5.90	6.25	6.59	6.90	7.22
OXYGEN	15.06	18.03	20.87	23.70	26.43	28.99	30.96	32.78	34.05	35.20	36.18	36.28	36.20	35.22	33.97
NITROGEN	0.25	0.31	0.39	0.48	0.58	0.67	0.87	1.06	1.25	1.50	1.75	2.03	2.33	2.65	3.00
SULFUR	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.10	0.12	0.14	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
AIR & GAS WEIGHTS (LB/LB WASTE)															
DRY AIR	3.230	3.870	4.526	5.177	5.830	6.487	7.152	7.828	8.508	9.192	9.882	10.606	11.325	12.068	12.834
WET GAS	4.040	4.686	5.347	6.020	6.694	7.369	8.080	8.786	9.497	10.188	10.933	11.686	12.433	13.185	13.960
DRY GAS	3.457	4.142	4.841	5.536	6.232	6.929	7.629	8.339	9.045	9.731	10.470	11.208	11.940	12.687	13.454
BOILER HEAT LOSSES (%)															
-DRY GAS	11.617	11.598	11.619	11.626	11.633	11.640	11.652	11.674	11.689	11.706	11.726	11.768	11.800	11.841	11.896
-MOIST. H_2/H_2O IN FUEL	0.293	0.293	0.293	0.294	0.294	0.294	0.295	0.296	0.297	0.298	0.299	0.301	0.302	0.304	0.307
-MOISTURE IN AIR	30.853	24.519	20.027	17.149	14.911	13.096	12.346	11.398	10.767	10.210	9.728	9.444	9.182	8.803	8.489
-FIXED LOSSES	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470	3.470
TOTAL LOSS	46.233	39.880	35.409	32.539	30.308	28.500	27.763	26.838	26.223	25.684	25.223	24.983	24.754	24.418	24.162
BOILER EFFICIENCY (%)	53.767	60.120	64.591	67.461	69.692	71.500	72.237	73.162	73.777	74.316	74.777	75.017	75.246	75.582	75.838
SPECIFIC STEAM RATIO (WITH BOILER EFF CONSIDERATIONS)															
(LB STEAM/LB REFUSE)	1.000	1.341	1.681	2.007	2.332	2.658	2.954	3.264	3.566	3.868	4.171	4.463	4.756	5.058	5.358
SPECIFIC STEAM RATIO (W/O BOILER EFF CONSIDERATIONS)															
(LB STEAM/LB REFUSE	1.329	1.555	1.814	2.073	2.658	2.591	2.850	3.110	3.369	3.628	3.887	4.146	4.405	4.664	4.923

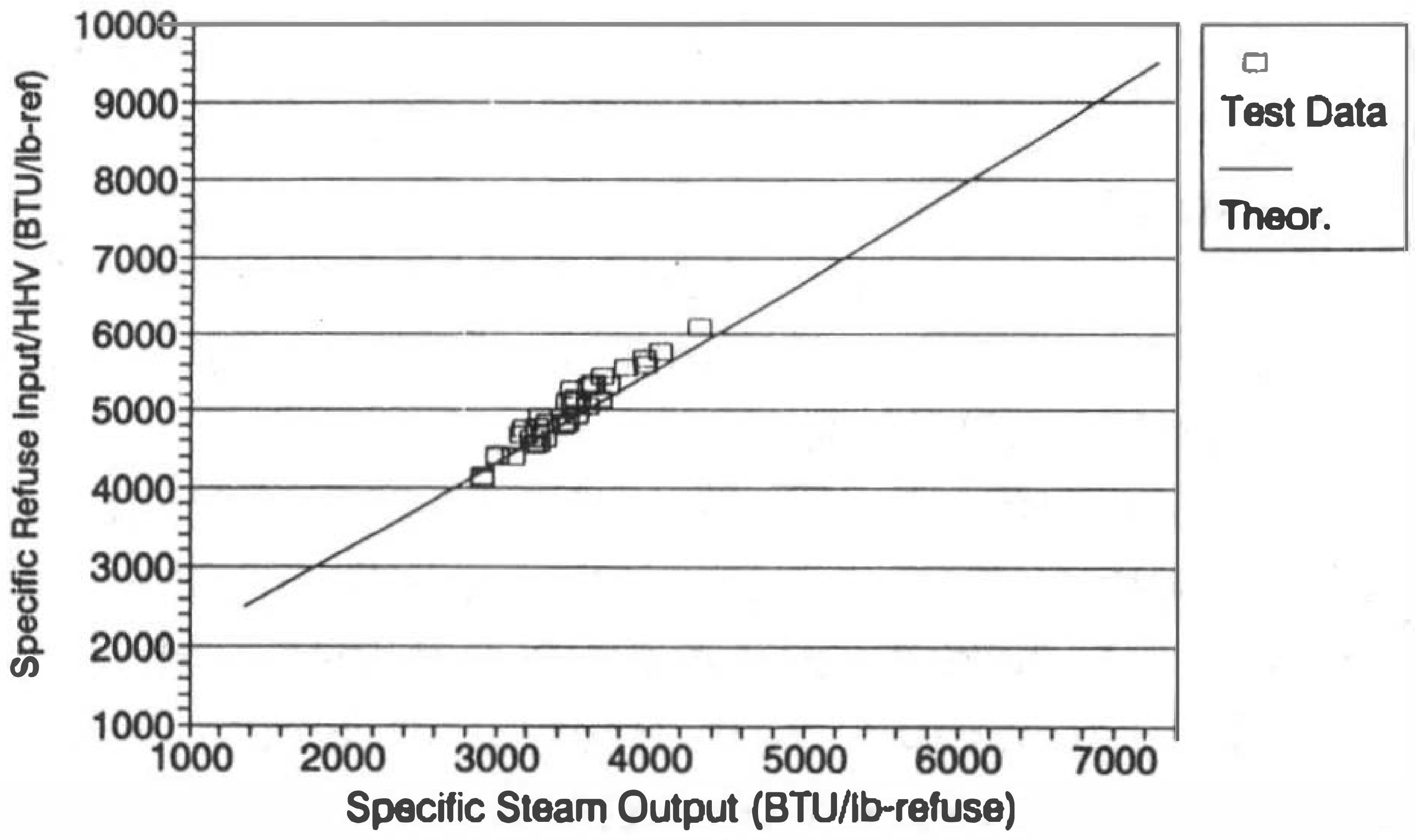

FIG. 6 COMPARISON OF THEORETICAL VERSUS TEST (Tg14 = 430°F, Ta8 = 80°F, 0 HtCr, 90% Xs, and Luac = 0.25)

Step 6: Calculating the Specific Steam Ratio

The specific steam ratio is determined by dividing the monthly quantity of steam generated by the total monthly quantity of waste combusted. Note that the steam quantity used in this Step 6 has been adjusted per Steps 4 and 5. The monthly processed tonnages are determined by using the waste quantity as measured by the calibrated truck scales and adjusted for changes in volume of waste in the pit between the beginning and ending of the monthly period.

Step 7: Determining the HHV from the Correlation (i.e., Using the Equation Determined from the Regression Analysis)

The unadjusted HHV is obtained from the specific steam correlation using the specific steam ratio determined in Step 6.

Step 8: Adjusting the Raw HHV Obtained from Step 7 for:

(a) Monthly average economizer exit gas temperature.

(b) Monthly average combustion air temperature.

(c) Monthly average ambient air temperature.

(d) Monthly average excess air percentage.

(e) Monthly average of residue unburned combustible.

Adjustments to the HHV for operating parameters are calculated by determining the deviations between the weekly average parameters and the reference "baseline" values for which the correlation was based. The relationships established in the theoretical model for operating parameter deviations are applied to determine the required adjustments to the unadjusted HHV obtained in Step 7.

TABLE 6 MONTHLY HHV CALCULATION SHEET

Month: SAMPLE

DATA INPUTS	Units	MONTHLY VALUE	REFERENCE VALUES
Refuse Throughput	tons	4375	
Boiler 1 Steam Flow	klb	12862	
Boiler 2 Steam Flow	klb	12862	
Boiler 1 Stm Temp (Avg)	°F	830	830 °F
Boiler 2 Stm Temp (Avg)	°F	830	
Boiler 1 Stm Press (Avg)	psig	850	850 psig
Boiler 2 Stm Press (Avg)	psig	850	
Boiler 1 FW Temp (Avg)	°F	250	250 °F
Boiler 2 FW Temp (Avg)	°F	250	
Boiler 1 Econ Exit Gas Temp (Avg)	°F	430	430 °F
Boiler 2 Econ Exit Gas Temp (Avg)	°F	430	
Boiler 1 Heated Comb Air Temp (Avg)	°F	80	80 °F
Boiler 2 Heated Comb Air Temp (Avg)	°F	80	
Ambient Air Temp (Avg)	°F	80	80 °F
Boiler 1 Econ Exit O2 (Avg)	%	8.7	
Boiler 2 Econ Exit O2 (Avg)	%	8.7	
Aux Fuel Usage – Natural Gas	kcfm	0	1000 BTU/CFM
ENTHALPIES			
Main Steam	BTU/lb	1414	1414 BTU/lb
Feedwater	BTU/lb	221	221 BTU/lb
CALCULATIONS			
% Excess Air from %O2	%	90	90 %
Total Blr Steam Ht Output	BTU	3.07E+10	
Ref Stm Prod due to Aux Gas	lbs	0.00E+00	85% Efficiency
Reference Total Stm Produced	lbs	2.57E+07	
Specific Stm Ratio (lb stm/lb refuse)		2.94	
HHV Raw Database Curve	BTU/lb	5000	
ADJUSTMENTS			*Factor*
Econ Gas Temp	BTU/lb	0	0.57 % raw HHV/10°F
Heated Combustion Air Temp	BTU/lb	0	-12 BTU/lb/10°F
Ambient Air Temp	BTU/lb	0	0.71 % raw HHV/10°F
Excess Air	BTU/lb	0	0.86 % raw HHV/%
Sub–total of adjustments	BTU/lb	0	
Net HHV		5000 BTU/lb	

DISCUSSION

The many factors which impact the HHV determination using the specific steam ratio method can be categorized into two distinct groups:

(a) Boiler operating parameters.

(b) Composition of the waste itself.

The influence of the major boiler operating parameters on boiler efficiency and in turn on HHV determination has been addressed by incorporating an adjustment mechanism. This adjustment mechanism accounts for the impact of these parameters on the specific steam ratio, as previously outlined in the section on Operating Parameter Adjustments.

The influence of varying waste composition on HHV determination is also accounted for by the specific steam correlation. This is achieved because implicit within the correlation are boiler efficiencies which reflect the effects of waste composition. For example, a boiler efficiency resulting from firing a lower waste HHV is less than a boiler efficiency resulting from firing a higher waste HHV. The higher waste moisture content that is typically present in a low waste HHV requires more energy from the combustion process in order to vaporize the larger quantity of water present (i.e., more latent heat of vaporization), thus resulting in a lower boiler efficiency. This waste composition

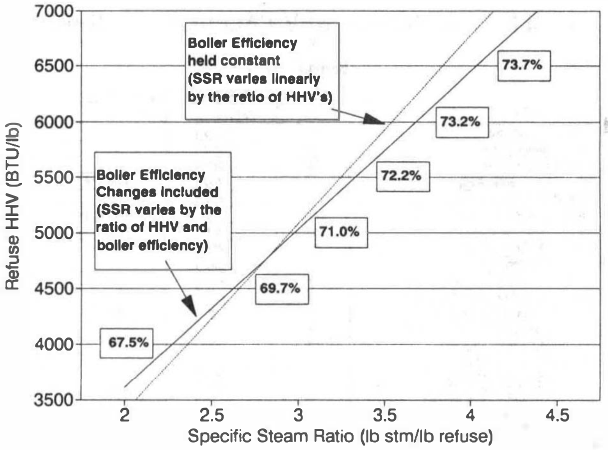

FIG. 7 THEORETICAL HHV VERSUS SSR WITH AND WITHOUT ADJUSTMENT FOR BOILER EFFICIENCY

impact on boiler efficiency and on the specific steam ratio is illustrated in Fig. 7. One of the two correlations in Fig. 7 includes the impact of waste composition on the correlation. In this case, the boiler efficiency corresponding to 6000 Btu/lb waste equals 73.2%, while the boiler efficiency corresponding to 4000 Btu/lb is equal to 67.5%, i.e., a boiler efficiency change of 5.7% results from a 2000 Btu/lb change in HHV, assuming identical boiler operating parameters (i.e., excess air, flue gas exit temperature, etc). If this influence of waste composition was not inherently incorporated into the correlation (e.g., if the boiler efficiency was incorrectly assumed to be constant over the HHV range), then a substantially different correlation arises (as illustrated in Fig. 7 by the second correlation). As indicated, the variation in boiler efficiency due to waste composition significantly impacts the correlation and corresponding HHV determination.

Waste moisture content has the most significant impact on boiler efficiency, but influences from other important waste composition constituents such as the carbon to hydrogen ratio, inerts fraction, carbon to oxygen ratio, etc. also exist. However, as evidenced by the excellent correlation, the collective influence of these other waste constituents can be deemed negligible.

CONCLUSIONS

The determination of municipal solid waste HHV, over extended time periods, is achievable using the specific steam correlation method. The test results of 37 boiler calorimetry tests at 11 different facilities, were used to develop the method.

The method is derived from recognized ASME Power Test Code methods and calculations and is, in essence, an extension of the theoretical basis of the boiler-as-a-calorimeter method. The method has demonstrated an accuracy of better than ±2.5%.

In addition to having a sound theoretical basis, the method is practical and can easily be implemented at minimal cost using data typically available from conventional facility instrumentation.