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Large Incinerators

PERFORMANCE TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

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ANSI / ASME PTC 33 - 1978

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FOREWORD

In the early part of 1966, the ASME Performance Test Code Committee recognized the need for a Performance Test Code for Large Incinerators. A Committee was formed in 1967 and charged with the task of developing a comprehensive Test Code for Large Incinerators; a task to be followed by a Short Form Test Procedure. This Committee was officially designated as PTC Committee No. 33 on Large Incinerators. Since its inception, the Committee has been reorganized twice and there has been a large turnover in membership. The names of former members of PTC 33 are included in this Test Code in appreciation for their outstanding efforts in the development of this document. This Code represents the highest state of the art in Incinerator Testing. It was submitted to Industry for trial use and comment in March 1977. This Code was approved by the Performance Test Codes Supervisory Committee on June 30, 1978, and was approved as an American National Standard by the ANSI Board of Standards Review on December 6, 1978.

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ASME PERFORMANCE TEST CODE
on
LARGE INCINERATORS

CONTENTS

SECTION 0, INTRODUCTION

0.1 This Code contains instructions for testing waste incineration systems. These facilities are defined as combinations of apparatus for reducing the combustible content of waste by heat of combustion processes. For the purpose of this Code, the performance will be a measurement of the available heat energy released during the process. The recovery of useful energy, or products from the process, although desirable, is not considered the measure of performance. It is not the intent of these testing procedures to obtain data on specific components of the incineration systems or to establish design criteria for these components or the process. Testing of individual components such as fans or steam generating units shall be conducted in accordance with their respective test codes.

0.2 It is intended that in using this Code a detailed examination will be made of the Code on General Instructions PTC 1 and all other codes herein referred to before starting preparations for the tests. Such study is for the purpose of assuring an orderly and thorough testing procedure since it provides the user with an overall understanding of the ASME Performance Test Code requirements and enables him to understand readily the inter-relationship of the various codes. Care should be exercised to obtain and use the latest revisions of the Codes.

0.3 While Section 2 of this Code is concerned with symbols and their description applying specifically to testing of waste incineration systems, the user is referred to the Code on Definitions and Values PTC 2 for a more complete discussion of the items which will be encountered.

0.4 The Supplements on Instruments and Apparatus PTC 19 referred to herein should be studied thoroughly because the value of the test results depends on the selection and application of the instruments, their calibration and the accuracy of the readings.

0.4.1 Other items of vital importance to the value of the test are the proper determination of the physical and chemical characteristics of the waste, the characteristics of the residue, and the characteristics of the effluent gas and water streams. The appropriate test and analysis procedures as listed herein should be followed carefully.

0.5 This Code is intended as a guide for the conduct of all waste incinerator system tests of units over 2000 pounds per hour capacity, but it could not possibly det a test applicable to every variation in the design of waste incineration systems. In every case, a qualified professio engineer must study the particular facility and develop procedures which are in agreement with the guiding principles, accuracy, and intent of this Code. Examples of th system variations at the time of preparation of this Cod include rotary kilns, refractory and waterwall furnaces, mechanical grates, semi-suspension and suspension burning, multiple chamber solid hearth units, pyrolysis and high temperature slag tap units. Such systems were considered as the Code was being prepared.

0.6 For systems fired either by waste or waste in combination with other fuels in which heat recovery is a major portion of the heat output, PTC 4.1 may be used along with appropriate sections of this Code. The user is cautioned to note the difference between capacity and efficiency as defined in PTC 4.1 and PTC 33.

0.7 Advanced instrument systems such as those usi electronic devices or mass flow techniques, may, by mutual agreement, be used as alternates to the specified Code instruments, provided that applications of such instruments have been demonstrated to be no less accurate than required by the Code.

SECTION 1, OBJECT AND SCOPE

1.1 The purpose of this Code is to establish on a thermal basis procedures to determine:

1.1.1 Efficiency

1.1.2 Capacity

1.2 A determination of the items specified above may be used for other purposes by mutual agreement, such as:

1.2.1 Checking the actual performance against design

1.2.2 Evaluating the system for an optimum method of operation

1.2.3 Comparing performance with regulatory codes

1.2.4 Determining the performance of component parts of the installation

1.2.5 Evaluating performance when firing waste of different characteristics

1.2.6 Evaluating the effects of changes to equipment

1.3 The rules and instructions given in this Code apply to the equipment defined in the Introduction, Section "0". The testing of accessory equipment shall be governed by the Performance Test Code applying specifically to the equipment in question.

1.4 Instructions are given for two (2) acceptable methods of testing incineration systems to determine capacity and efficiency. Method one is the direct measurement of input and output; hereinafter referred to as the "input-output" method. Method two is the measurement of heat liberation and is hereinafter referred to as the "heat balance" method. The method followed in conducting the tests shall be clearly defined in the report.

1.4.1 The "input-output" method requires the accurate measurement of the quantity and higher heating values (HHV) of the waste and supplementary fuel, heat credits, heat absorbed by the working fluid (or fluids), the residue, the dust, and the heat transmitted by radiation and convection.

1.4.2 The "heat balance" method requires the accurate determination of the quantities and higher heating values of the waste and supplementary fuel, heat losses, heat credits; quantity and heat content of the residue.

1.4.3 Throughout this Code, heat input is based on the HHV of the waste and supplementary fuel and respective rates of flow, plus heat credits added to the working fluid (or fluids), air, gas and other fluid circuits which cross the system boundary per unit time, as shown in Fig. 1. The system boundary encompasses the equipment to be included in the designated "incineration system." Heat inputs and outputs that cross the system boundary are involved in the efficiency calculations.

1.4.4 Heat output is based on the heat absorbed by the working fluid (or fluids), sensible heat in the solid, liquid and gaseous effluents plus heat to evaporate quenching fluids and transfers across the system boundary per unit of time, as shown in Fig. 1.

1.4.5 Heat credits are those amounts of heat entering the incineration system boundary other than the HHV of the waste and supplementary fuel "As Fired." These credits include quantities such as sensible heat in the waste and supplementary fuel, and sensible heat content of the entering air, and sensible heat content of cooling water entering the system.

1.4.6 For a better understanding of the relationship between heat input, heat output, credits and losses refer to Figs. 2 and 3.

1.5 The rated thermal capacity of the system is the design heat input per unit of time. The test thermal capacity is the actual heat input per unit of time during test. The system rating in percentage is (see Par. 5.2.1.2):

$$\frac{\text{Actual Heat Input}}{\text{Design Heat Input}} \times 100$$

1.6 The efficiency of the incineration system determined within the scope of this Code is the ratio of the heat output to the heat input.

1.6.1 The efficiency for methods one and two under the conditions of test is expressed by the following equations:

Method one:

$$\begin{matrix}\text{Input-Output Method}\\ \text{Efficiency, \%}\end{matrix} = \left(\frac{\text{Heat Output}}{\text{Heat Input}}\right) \times 100$$

Method two:

$$\begin{matrix}\text{Heat Balance Method}\\ \text{Efficiency, \%}\end{matrix} = \left(1 - \frac{\text{Losses}}{\text{Input}}\right) \times 100$$

1.7 The content of this Code should be read and thoroughly understood before the method of evaluation of incineration system efficiency is selected. While either method will produce results to the accuracies defined in Par. 3.3 of the Code, the various aspects pertinent to obtaining the physical and chemical measurements required should be reviewed as applicable to the specific system to be tested. Final selection of the method to be used should be based on the compatability of the required testing techniques with the incineration system. The calculations and procedures for either method of testing are specified in this Code. Where heat outputs and credits are to be adjusted for variations in waste and inlet air conditions the procedure given in Section 5.4, Corrections to Standard, or Guarantee, conditions of the Code should be followed.

1.8 Both of the test methods of this Code apply to incineration systems operating with solid, liquid or gaseous wastes.

1.8.1 This Code will apply when tests are perform on an incineration system burning waste of quantity a characteristics within the limitations agreed to by the parties to the test.

1.9 The determination of data of a research natu other special data is not covered by this Code.

1.10 It is recommended that a separate report be p pared for each test by either the "input-output" or the "heat balance" method. The report must include comp details of the conditions under which the test has been conducted including a record of test procedures and a data in a form suitable for demonstrating that the object of the test have been attained.

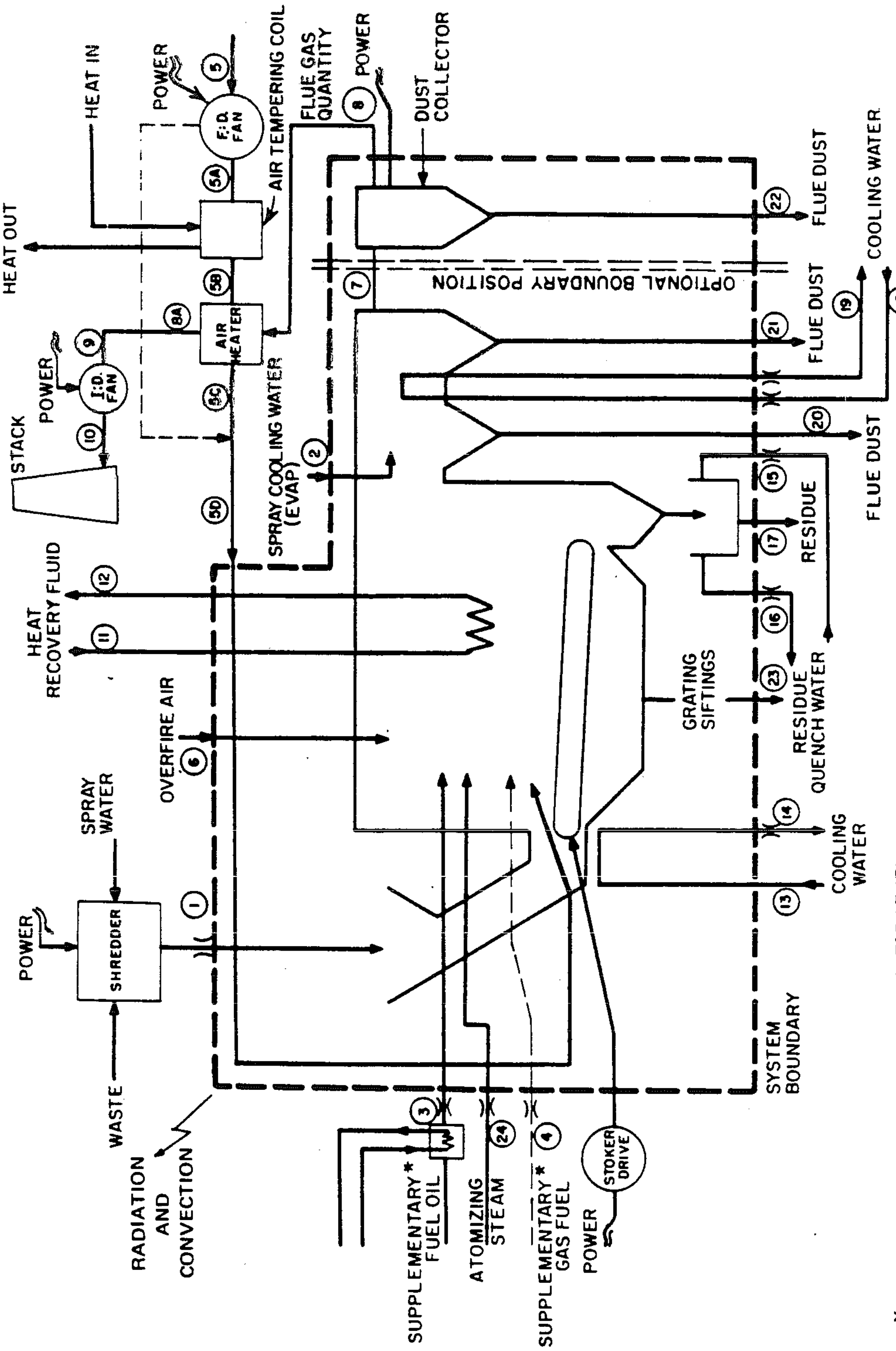
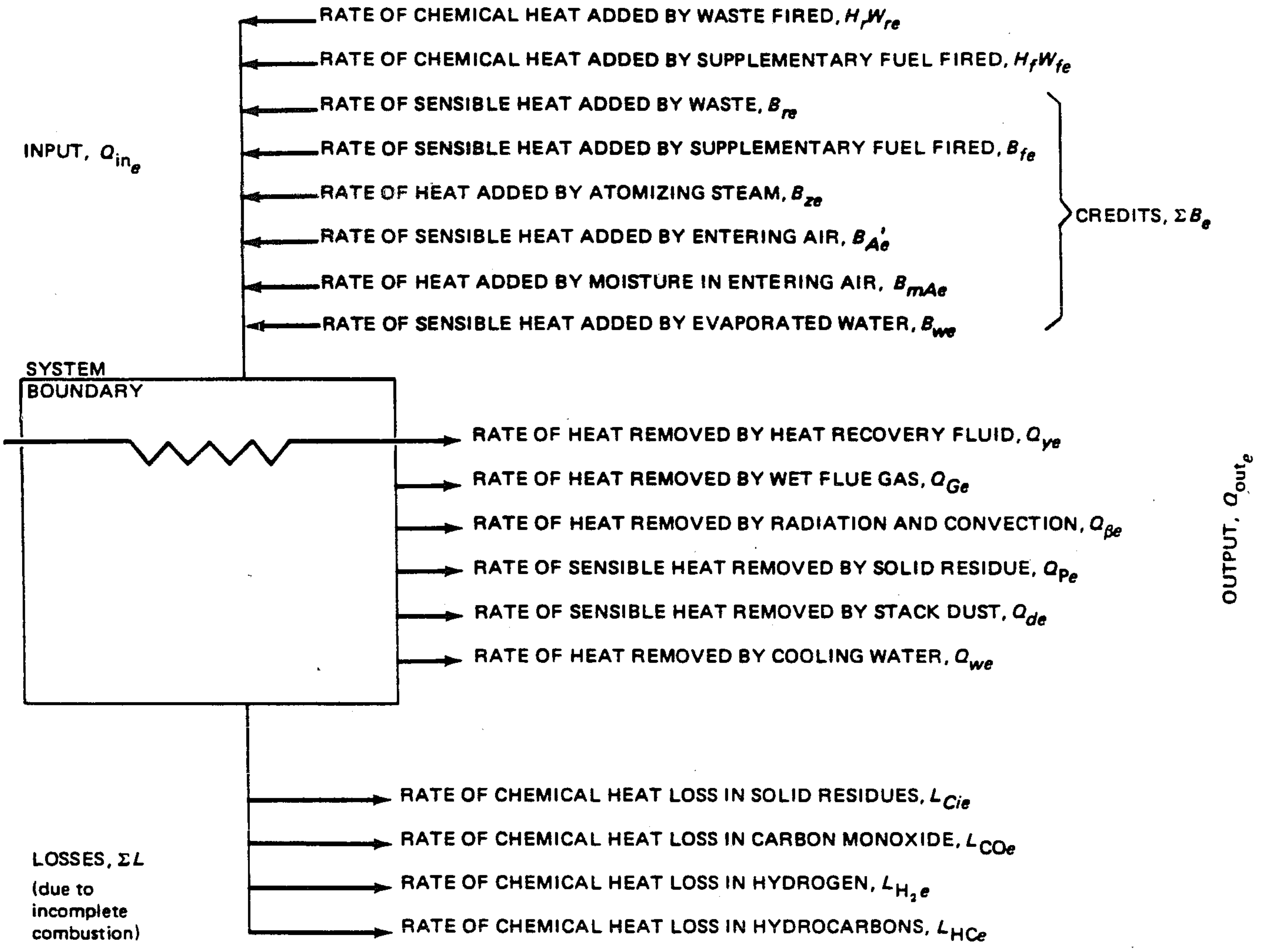


FIG. 1 TYPICAL SYSTEM BOUNDARY

*COAL COULD BE USED AS SUPPLEMENTARY FUEL.

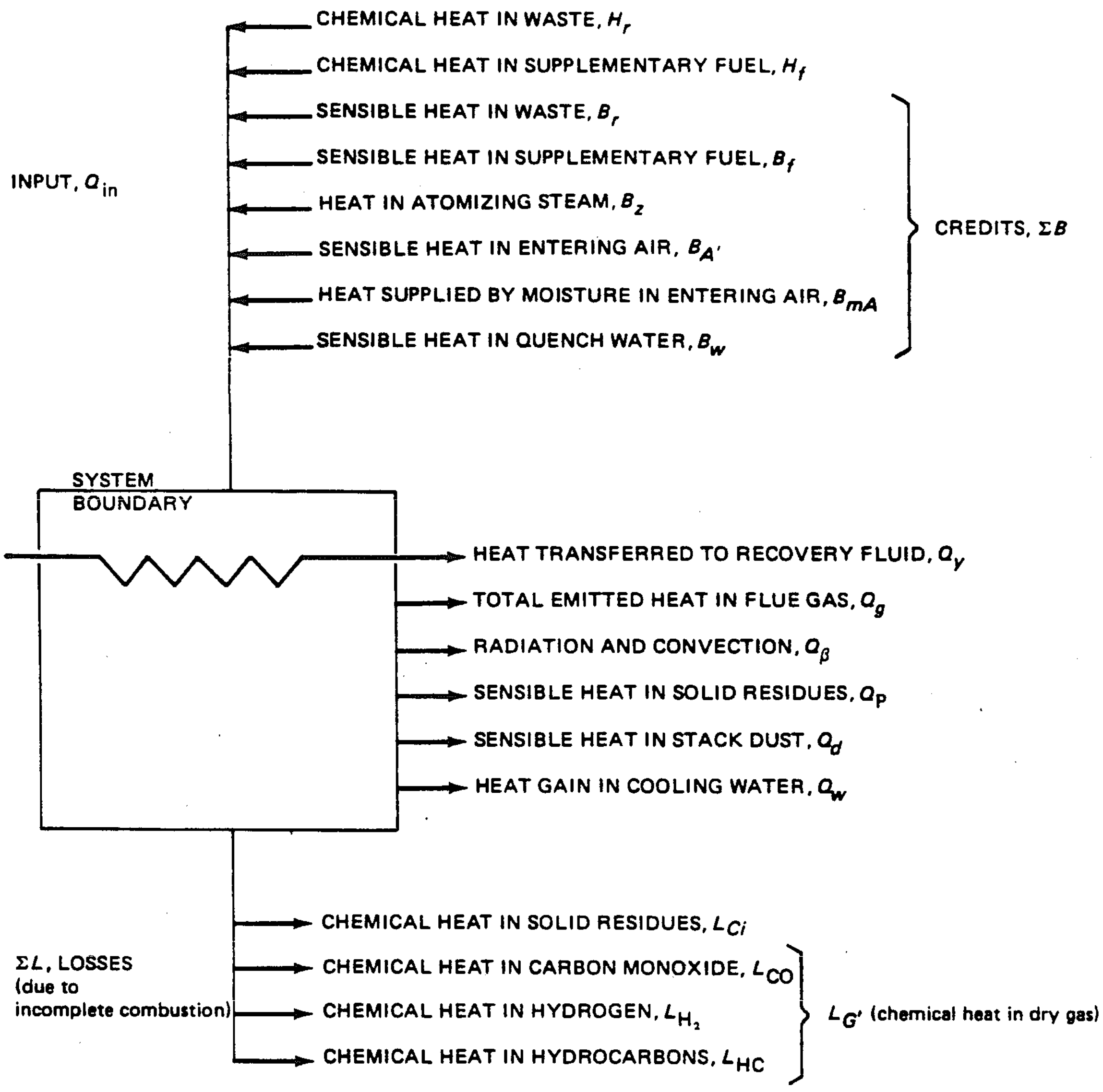


HEAT BALANCE (PER HOUR BASIS): INPUT = OUTPUT + LOSSES

DEFINITION:

$$\text{EFFICIENCY (PERCENT)} = \eta\ (\%) = \frac{Q_{out_e}}{Q_{in_e}} \times 100 = \frac{Q_{ye} + Q_{Ge} + Q_{\beta e} + Q_{Pe} + Q_{de} + Q_{we}}{H_rW_{re} + H_fW_{fe} + \Sigma B_e} \times 100$$

FIG. 2 EFFICIENCY OF INCINERATION SYSTEM BY INPUT-OUTPUT METHOD



HEAT BALANCE (PER POUND BASIS): INPUT = OUTPUT + LOSSES

DEFINITION: EFFICIENCY (PERCENT) = $\eta\,(\%) = \dfrac{Q_{out}}{Q_{in}} \times 100 = \dfrac{Q_{in} - \Sigma L}{H_r + H_f \dfrac{W_{fe}}{W_{re}} + \Sigma B} \times 100$

HEAT BALANCE: $Q_{in} = H_r + H_f \dfrac{W_{fe}}{W_{re}} + \Sigma B$ = OUTPUT + LOSSES

THEREFORE: $\eta\,(\%) = \left[1 - \dfrac{\Sigma L}{H_r + H_f \dfrac{W_{fe}}{W_{re}} + \Sigma B}\right] \times 100$

FIG. 3 EFFICIENCY OF INCINERATION SYSTEM BY HEAT BALANCE METHOD

SECTION 2, DEFINITIONS AND DESCRIPTION OF TERMS

2.1 Definitions – The following are definitions of terms used in the text of this Code:

AIR:

The natural atmospheric mixture of nitrogen, oxygen, water vapor, carbon dioxide, argon, neon and small quantities of other rare gases; standard air being at 68°F and 29.92 in. mercury absolute pressure.

AIR; EXCESS:

The air supplied to burn a fuel or waste in addition to that theoretically (stoichiometrically) necessary for complete combustion. It is usually expressed as a percent of theoretical air.

AIR; OVERFIRE:

Air controlled with respect to quantity and direction that is supplied above and does not pass through a waste/fuel bed.

AIR; PRIMARY:

Air controlled with respect to quantity and direction, supplied through or with a waste/fuel to initiate the burning of combustible material.

AIR; SECONDARY:

Air controlled with respect to quantity and direction, supplied beyond the zone where burning is initiated. This air may be used to complete the burning of combustible materials or to reduce the operating temperature within the incineration system.

AIR; THEORETICAL:

The amount of air (stoichiometric air) required to supply just that oxygen necessary for the complete combustion of a given quantity of a waste/fuel.

AIR; UNDERFIRE:

Air controlled with respect to quantity and direction, supplied beneath the grate and that passes through the waste/fuel bed.

ANALYSIS; PROXIMATE:

Laboratory analysis of a fuel sample providing the weight percentages of 1) water or moisture, 2) volatile matter, 3) fixed carbon, and 4) non-combustibles (ash).

ANALYSIS; ULTIMATE:

Laboratory analysis of a fuel sample providing the composition in weight percentages of non-combustibles (ash), moisture, carbon, hydrogen, nitrogen, sulphur, oxygen and chlorine.

ASH:

Non-combustible mineral matter that remains after complete burning of a waste/fuel sample by a prescribed method.

BAFFLE:

Any refractory or metal construction intended to change the direction of flow.

BRITISH THERMAL UNIT (Btu):

Defined as 1/180 of the quantity of heat required to raise one pound mass of water from the ice point to the steam point under a constant pressure of one atmosphere.

BURNING AREA:

The horizontal projected area of the grate, hearth, or combination thereof, within the limits of the combustion chamber.

BURNING RATE:

The amount of waste incinerated, usually expressed in mass per unit of burning area per hour.

CAPACITY; THERMAL:

The measured heat input to the system per unit time.

CHARGE:

The quantity of waste introduced to the furnace.

CHARGING CHUTE:

A passage through which waste materials are fed into an incinerator.

CHARGING RATE:

The quantity of waste fed to the system per unit of time.

CLINKER:

Hard, sintered or fused pieces formed in the fire by agglomeration of non-combustible with the possible inclusion of small amounts of combustible material.

COMBUSTION:

The rapid oxidation of combustible material with the resultant liberation of heat.

DRAFT; FORCED:

The pressure above atmospheric created by the action of the fan or blower that supplies air to the system.

DRAFT; INDUCED:

The pressure below atmospheric created by the action of a fan, or ejector.

DRAFT; NATURAL:

The pressure below atmospheric created by a stack or chimney.

DUCT:

A conduit for conveying a gaseous fluid.

EFFICIENCY; THERMAL:

The ratio of the heat output to the heat input.

EFFLUENT:

Solid, liquid or gaseous materials discharged from the system.

FIXED CARBON:

The combustible matter remaining in a sample after heating by a prescribed method.

FLY ASH:

All solids carried in the gas stream.

FLUE:

A passage for conducting gaseous combustion products.

FLUE DUST:

Any dry filterable material that is or has been airborne (particulate matter) and has been collected.

FLUE GAS:

The gaseous products of combustion.

FURNACE:

The portion of the system into which the waste is fed, ignited and burned.

FURNACE VOLUME:

The combustion space designed to promote and/or complete combustion.

GARBAGE:

Vegetable and animal wastes from the preparation, cooking and serving of food, plus wastes from handling, storage, and sale of produce.

GRATE:

A device with suitable air passages to support the burning waste.

HEAT BALANCE:

An accounting of the heat input and output of the system.

HEAT CREDITS:

Heat credits are those amounts of heat added to the envelope of the incineration system other than the HHV of the waste and supplementary fuel "As Fired."

HEAT INPUT:

Throughout this Code, heat input is based on the higher heating value (HHV) of the waste and supplementary fuel and their rates of flow, plus heat credits added by the working fluid or fluids, air, gas and other fluid circuits which cross the system boundary per unit time, as shown in Figs. 1 and 2, or per unit mass, as shown in Figs. 1 and 3. The system boundary encompasses the equipment to be included in the designated "incineration system." Heat inputs and outputs that cross the system boundary are involved in the efficiency calculations.

HEAT OUTPUT:

Heat output is based on the heat absorbed by the working fluid or fluids and total heat in the solid, liquid and gaseous effluents plus heat transferred across the system boundary per unit of time, as shown in Figs. 1 and 2.

HEAT RELEASE RATE:

The amount of heat liberated during combustion per unit of time.

HEAT RELEASE RATE, FURNACE:

Heat liberated per hour, per unit of furnace volume.

HEAT RELEASE RATE, GRATE:

Heat liberated per hour, per unit of horizontal projected burning area.

HEATING VALUE; HIGHER:

The total heat liberated per unit mass in a calorimeter corrected to the "As Fired" condition.

HEATING VALUE; LOWER:

The total heat liberated per unit mass in a calorimete minus the latent heat of vaporization of the water. (Recognized but not used in this Code.)

INCINERATION:

A controlled process for burning combustible wastes.

MATERIAL BALANCE:

An accounting of the mass of material entering and leaving the system during the test period.

METAL OXIDATION FACTOR:

This factor accounts for the metals oxidized in the furnace and the combustibles that are removed from the laboratory sample during preparation (see Par. 4.4.1).

MOISTURE:

The weight loss when a fuel sample is dried to a constant weight at a temperature from 100°C to 105°C.

MOL:

Molecular weight of a substance expressed in mass units.

PARTICULATE MATTER (DUST):

Any dry filterable material that is or has been airborne.

PUTRESCIBLE MATTER:

Organic matter that is fermentable, or capable of decaying or of assimilation by animals and micro-organisms.

PYROLYSIS:

A method of solid waste volume reduction by the use of heat to produce chemical decomposition under controlled conditions in a reducing atmosphere.

RESIDUE:

Solid materials remaining after passing through the system. This includes fly ash as well as ash and siftings from the burning system.

RUBBISH:
All solid waste having combustibles, exclusive of garbage.

RUN:
A subdivision of a test consisting of a complete set of observations made for a period of time with one or more of the independent variables maintained virtually constant.

SIFTINGS:
That solid material which falls through the grates.

SMOKE:
The visible discharge from the system to the atmosphere other than water vapor.

STACK:
A chimney or a vertical flue for discharging the gaseous products of combustion from the system to the atmosphere.

STACK DUST:
Airborne solid material that exits to the atmosphere with the flue gas.

STOKER:
A mechanically operable moving grate arrangement for supporting, burning, and transporting the waste/fuel through a furnace and discharging the residue.

SUPPLEMENTARY FUEL:
Fuel burned to supply additional heat to the system.

TEST:
The word "test" as defined in this Code applies to the entire investigation.

VOLATILE MATTER:
The weight loss of a dry sample on heating by a specified method.

WASTE:
Any solid, semi-solid, liquid or gaseous material discharged from its primary use.

2.2 Symbol and Description of Terms – The following are symbols and their descriptions used in the calculations for this test Code:

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
A	Air	lb	kilogram (kg)	4.536 E-01
A'	Dry air	lb	kilogram (kg)	4.536 E-01
AF	"As Fired"	–	–	–
API	Gravity of the fuel based on the API scale	deg API	–	–
$A_{\theta f}$	Theoretical quantity of air required for complete combustion of the AF supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
$A_{\theta r}$	Theoretical quantity of air required for complete combustion of the AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
A_X	Excess air: The actual quantity of air used minus the theoretical air required divided by the theoretical air, and expressed as a percentage	percent	percent	–
a_r	Ash content of the waste by weight	percent	percent	–
B	Sensible heat credits added to the incineration system from AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
B_{Ae}	Sensible heat credit supplied by the entering air (rate)	Btu/hr	watts (W)	2.931 E-01
$B_{A'e}$	Sensible heat credit supplied by the *dry* entering air (rate)	Btu/hr	watts (W)	2.931 E-01
B_e	Sensible heat credits added to the incineration system (rate)	Btu/hr	watts (W)	2.931 E-01
B_{re}	Sensible heat credit supplied with the waste (rate)	Btu/hr	watts (W)	2.931 E-01
B_{fe}	Sensible heat credit supplied with the supplementary fuel (rate)	Btu/hr	watts (W)	2.931 E-01
B_{mAe}	Sensible heat credit supplied from the moisture entering with the inlet air (rate)	Btu/hr	watts (W)	2.931 E-01

2.2 (Cont'd)

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
B_{we}	Sensible heat credit supplied by evaporated water (rate)	Btu/hr	watts (W)	2.931 E-01
B_{ze}	Sensible heat credit supplied by the atomizing steam (rate)	Btu/hr	watts (W)	2.931 E-01
b	Burned	–	–	–
C	Carbon	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_b	Carbon burned	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_{brf}	Carbon burned from combined waste and supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_i	Unburned carbon	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_r	Carbon in AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_f	Carbon in AF supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_{br}	Carbon burned from AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_{bf}	Carbon burned from AF supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
C_{rf}	Carbon in combined waste and supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
CO'	Carbon monoxide in dry flue gas by volume	percent	percent	–
CO_2'	Carbon dioxide in dry flue gas by volume	percent	percent	–
c	Specific heat	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pd}'	Specific heat of dry flue dust	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_p	Specific heat at constant pressure	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pA}'	Mean specific heat of dry air at constant pressure	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pf}	Mean specific heat of the inlet supplementary fuel	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pG}	Mean specific heat of the flue gas	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pG}'	Mean specific heat of the dry flue gas	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{ps}	Specific heat of steam at constant pressure	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
$c_{pP'}$	Specific heat of dry ash pit residue	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
c_{pr}	Mean specific heat of the waste	Btu/lb °F	joule/kilogram-kelvin (J/kg·K)	4.187 E+03
D	Standard or guarantee of design or performance	–	--	–
d	Flue dust	lb	kilogram (kg)	4.536 E-01
d'	Dry flue dust	lb	kilogram (kg)	4.536 E-01
E	Energy	Btu	joule (J)	1.055 E+03
E_x	Energy consumed by auxiliaries	Btu	joule (J)	1.055 E+03
e	Elapsed time	hr	seconds (s)	3.600 E+03
f	Supplementary fuel	lb	kilogram (kg)	4.536 E-01
G	Flue gas	lb	kilogram (kg)	4.536 E-01
G'	Dry flue gas	lb	kilogram (kg)	4.536 E-01
g	Gross	–	–	–
H	Higher heating value (HHV)	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
H	Hydrogen	lb/lb	kilogram/kilogram (kg/kg)	1.0
H_2g'	Hydrogen content of dry flue gas by volume	percent	percent	–
H_2r	Hydrogen exclusive of that in moisture of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
HC	Hydrocarbons in dry flue gas by volume	percent	percent	–

2.2 (Cont'd)

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
H_d	Higher heating value of flue dust	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
$H_{p'}$	Higher heating value of total dry residue	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
H_f	Higher heating value (chemical heat) of the supplementary fuel on the AF basis	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
H_f	Higher heating value (chemical heat) of the supplementary fuel on dry basis	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
H_r	Higher heating value of waste (laboratory analysis)	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h	Enthalpy	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_{Rw}	Reference enthalpy of entering moisture. It is the enthalpy of the liquid at the reference temperature.	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_{Rv}	Reference enthalpy of entering vapor. It is the enthalpy of the saturated vapor at the reference temperature.	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_s	Enthalpy of steam	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_{sx}	Enthalpy of steam supplied to any auxiliary steam drive	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_v	Enthalpy of the vapor	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
h_w	Enthalpy of the liquid	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
kWh	Electrical energy	kilowatt hour	joule (J)	3.600 E+06
L	Heat loss from the incineration system per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
L_{Ci}	Chemical heat loss in solid residues per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
L_{CO}	Heat loss due to incomplete combustion resulting in the formation of carbon monoxide per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
L_G	Chemical heat loss in flue gas per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
L_H	Chemical heat loss due to presence of hydrogen in flue gas per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
L_{HC}	Chemical heat loss due to presence of hydrocarbons in flue gas per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.326 E+03
M	Molecular weight of any substance	lb/lb mol	kilogram/kilogram mol (kg/kg mol)	4.536 E-01
m	Moisture content by weight	percent	percent	
m_A	Moisture in air	lb/lb	kilogram/kilogram (kg/kg)	1.0
m_d	Moisture in flue dust	lb/lb	kilogram/kilogram (kg/kg)	1.0
m_f	Mositure in supplementary fuel by weight	percent	percent	–
m_G	Moisture in flue gas	lb/lb	kilogram/kilogram (kg/kg)	1.0
m_r	Moisture in AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
mp	Moisture in solid residue	lb/lb	kilogram/kilogram (kg/kg)	1.0
N	Nitrogen	lb/lb	kilogram/kilogram (kg/kg)	1.0
N_2'	Nitrogen in dry flue gas	lb/lb	kilogram/kilogram (kg/kg)	1.0
n	Designated surface area	–	–	–
O	Oxygen	lb/lb	kilogram/kilogram (kg/kg)	1.0

2.2 (Cont'd)

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS)	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
O_2'	Oxygen in dry flue gas by volume	percent	percent	–
p	Pressure (absolute)	psia	pascal (Pa-a)	6.895 E+03
p_A	Atmospheric pressure	psia	pascal (Pa-a)	6.895 E+03
p_{mA}	The partial pressure or vapor pressure of the moisture in the air	psia	pascal (Pa-a)	6.895 E+03
p_{mG}	The partial pressure or vapor pressure of the moisture in the flue gas	psia	pascal (Pa-a)	6.895 E+03
p_s	Steam pressure	psia	pascal (Pa-a)	6.895 E+03
p_w	Water pressure	psia	pascal (Pa-a)	6.895 E+03
P	Solid residue	lb	kilogram (kg)	4.536 E-01
Q	Total heat	Btu	joule (J)	1.055 E+03
Q_{in}	Total heat input per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.325 E+03
Q_{out}	Total heat output per pound AF waste	Btu/lb	joule/kilogram (J/kg)	2.325 E+03
Q_{in_e}	Total heat input per unit time (capacity)	Btu/hr	watt (W)	2.931 E-01
Q_{out_e}	Total heat output per unit time	Btu/hr	watt (W)	2.931 E-01
Q_{ye}	Heat transferred to recovery fluid (e.g. steam)	Btu/hr	watt (W)	2.931 E-01
Q_{we}	Heat in water (cooling or quench)	Btu/hr	watt (W)	2.931 E-01
Q_{de}	Heat in flue dust	Btu/hr	watt (W)	2.931 E-01
Q_{Ge}	Heat in wet flue gas	Btu/hr	watt (W)	2.931 E-01
Q_{Pe}	Heat in wet residue	Btu/hr	watt (W)	2.931 E-01
$Q_{\beta e}$	Heat to radiation and convection	Btu/hr	watt (W)	2.931 E-01
R	Reference	–	–	–
R_u	Universal gas constant	ft-lb/lb mol R	J/kg mol K	5.380 E+00
r	Waste	–	–	–
S	Sulfur	lb/lb	~~kilogram/kilogram~~ (kg/kg)	1.0
SO_2'	Sulfur dioxide in dry flue gas by volume	percent	percent	–
s	Steam	–	–	–
T	Temperature (absolute)	R	kelvin (K)	5.556 E-01
t	Temperature (Fahrenheit)	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_{RA}	Reference air temperature is the base temperature to which sensible heat losses and credits are compared	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_A	Temperature of air	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_d	Temperature of dry flue dust	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_f	Temperature of supplementary fuel	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_G	Temperature of flue gas	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_n	Temperature of any surface	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_s	Temperature of steam	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$

2.2 (Cont'd)

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
t_p	Temperature of residue	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
t_w	Temperature of water	°F	kelvin (K)	$T_K = (t°_F + 459.67)\frac{1}{1.8}$
U	Velocity	ft/sec	meter/second (m/s)	3.048 E-01
u_β	Coefficient of heat transfer	Btu/ft² °F hr	watt/meter² -kelvin (W/m² ·K)	5.678 E+00
V	Volume	ft³	meter³ (m³)	2.832 E-02
V_m	Volume of moisture in flue gas	percent	percent	–
v	Vapor	–	–	–
W	Weight	lb	kilogram (kg)	4.536 E-01
WF	Weight fraction of a gas in a gas mixture	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{A'}$	Weight of dry air per pound AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{Af}	Weight of air (moist) supplied for AF supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{Ar}	Weight of air (moist) supplied for AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{A'f}$	Weight of dry air supplied for AF supplementary fuel	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{A'r}$	Weight of dry air supplied for AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{Ae}	Weight rate of air supplied	lb/hr	kilogram/second (kg/s)	1.260 E-04
$W_{A'e}$	Weight rate of dry air supplied	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_f	Weight of supplementary fuel per pound AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{G'}$	Weight of dry flue gas leaving unit on basis of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{Ge}	Weight rate of flue gas leaving unit	lb/hr	kilogram/second (kg/s)	1.260 E-04
$W_{p'}$	Weight of dry solid residue on basis of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{mAr}	Weight of moist air per pound AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{mHr}	Weight of moisture formed from burning hydrogen per pound of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{mf}	Weight of moisture in supplementary fuel per pound AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{mr}	Weight of moisture in AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{d'}$	Weight of dry flue dust on basis of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
$W_{p'e}$	Weight rate of dry residue	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_{fe}	Weight rate of supplementary fuel fired	lb/hr	kilogram/second (kg/s)	1.260 E-04
$W_{G'N_2}$	Weight of nitrogen in dry gas on basis of AF waste	lb/lb	kilogram/kilogram (kg/kg)	1.0
W_{re}	Weight rate of AF waste (charging rate)	lb/hr	kilogram/second (kg/s)	1.260 E-04
W'_{re}	Weight rate of dry waste fired	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_{se}	Weight rate of steam flow	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_{we}	Weight rate of water flow rate	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_{wve}	Weight rate of quench water vaporization	lb/hr	kilogram/second (kg/s)	1.260 E-04
W_{ze}	Weight rate of atomizing steam	lb/hr	kilogram/second (kg/s)	1.260 E-04
w	Water	–	–	–
X	Excess	–	–	–
x	Auxiliary	–	–	–
y	Heat recovery fluid	–	–	–
z	Atomizing steam	–	–	–
α	Area	ft²	meter² (m²)	9.290 E-02

2.2 (Cont'd)

SYMBOL	DESCRIPTION	U.S. CUSTOMARY UNITS	SI (METRIC) UNITS	TO CONVERT TO SI (METRIC) MULTIPLY U.S. UNITS BY
β	Radiation and convection	–	–	–
γ	Gas specific weight	lb/ft^3	kg/meter^3 (kg/m^3)	1.602 E+01
∂	Corrected	–	–	–
η	Efficiency	percent	percent	–
θ	Theoretical	–	–	–
ψ	The number of mols of any substance	lb mol	kilogram mols (kg mol)	4.536 E-01
′(prime)	Dry	–	–	–
Δ	Change	–	–	–
Σ	Summation	–	–	–

SECTION 3, GUIDING PRINCIPLES

3.1 Items on Which Agreement Shall Be Reached. In order to achieve the objectives of the test, the interested parties must reach agreement on the following pertinent items which must be recorded and disseminated to the authorized test participants.

3.1.1 Efficiency determination – defined in Par. 1.6.

3.1.1.1 General method – input-output or heat balance.

3.1.1.2 Heat credits to be measured.

3.1.1.3 Heat credits to be assigned where not measured.

3.1.1.4 Heat losses to be measured.

3.1.1.5 Heat losses to be assigned where not measured.

3.1.1.6 Permissible deviation in efficiency between duplicate runs.

3.1.2 Capacity or input – defined in Par. 1.5.

3.1.3 Establish conditions of stabilization prior to test.

3.1.4 Establish acceptable operational conditions, duration of runs, basis of rejection of runs and procedures to be followed during the test, etc.

3.1.5 Allocation of responsibility for all performance and operating conditions which affect the test.

3.1.6 Selection of test personnel to conduct the test.

3.1.7 Cleanliness of unit initially and how this is to be maintained during the test.

3.1.8 Actual air leakage to be allowed, if any, initially or during the test.

3.1.9 The source of fluid properties to be used: standard psychrometric charts, tables of thermodynamic properties of steam, and gas tables.

3.1.10 Waste and supplementary fuels to be fired.

3.1.11 Method of obtaining samples of waste, residue and supplementary fuel.

3.1.12 The laboratories to make the analyses.

3.1.13 Observations and readings to be taken to comply with the object or objectives of the test.

3.1.14 Instruments to be used, calibration of instruments, methods of measurement and equipment to be used in testing the unit. The Performance Test Code Supplements on Instruments and Apparatus should be used, when applicable.

3.1.15 Determination of residue quantities from various collection points.

3.1.16 Provisions for corrections to be made for deviations from specified operating conditions.

3.1.17 Metallic oxidation factor to be applied to the bomb calorimeter determination of higher heating value.

3.1.17.1 When applicable this factor accounts for the metals oxidized in the furnace and the combustibles that are removed from the laboratory sample during preparation.

3.2 Selection of Personnel. To ensure obtaining reliable results, all personnel participating in the test shall be fully qualified to perform their particular tasks.

3.3 Tolerances and Limits of Error. This Code does not include consideration of over-all tolerances or margins on performance guarantees. The test results shall be reported as computed from test observations, with proper corrections for calibrations.

3.3.1 Allowances for errors of measurement and sampling if used should be agreed upon in advance by the parties to the test and clearly stated in the test report. The limits of probable error on calculated gross efficiency may be taken as the square root of the sum of the squares of the individual effects on efficiency.

3.3.2 Whenever allowances for probable errors of measurement and sampling are taken into consideration, the reported test results shall be qualified by the statement that the error in the results may be considered not to exceed a given plus or minus percentage, this value having been determined in accordance with the foregoing method for computing limits of probable error.

3.4 Acceptance Test. An acceptance test shall be undertaken only when the parties to the test certify that the unit is operating to their satisfaction and is, therefore, ready for test. Especially in the case of refuse burning equipment, adjustments and changes are sometimes necessary to obtain optimum performance. The acceptance test should be started as soon as the unit is in satisfactory condition for test, provided the loading, residue removal and other governing factors are suitable.

3.4.1 Parties to the test shall designate a qualified engineer to supervise the test and to confirm the accuracy of observations, as well as the conditions and methods of operation.

3.4.2 All equipment, both internal and external, should be in normal operating cleanliness before starting the test. During the test, only the amount of cleaning shall be permitted as is necessary to maintain normal operating cleanliness.

3.4.3 After a preliminary run has been made, it may be declared an acceptance run if agreed to and provided that all the requirements of a regular run have been met.

3.4.4 At least two runs shall be made approximating the load required for acceptance. If the results exceed the previously agreed upon deviation in efficiency between runs, a third run will be required. The test efficiency at the required load will be the average of the two runs which fall within the permissible deviation in efficiency.

3.5 Preparation for All Tests

3.5.1 The entire system shall be checked and shall be corrected as required for air leakage, air distribution, spray nozzles, etc.

3.5.2 Before the test is started, it shall be agreed the waste to be fired is substantially as intended.

3.5.3 Departures from standard or previously specified conditions shall be described clearly in the report of the test.

3.5.4 Whenever possible the official stack emission test should be conducted simultaneously with the incinerator system performance test, since nearly all measurements required to meet the objectives of PTC 38 are also required for PTC 33.

3.6 Preliminary Run

3.6.1 A preliminary run shall be made for the purpose of checking the operation of all instruments, acquainting the observers and test personnel with the specific facility, and making minor adjustments, the needs for which were not evident during the preparation for the test, and establishing proper combustion conditions for the particular waste and rate of firing to be employed.

3.7 Starting and Stopping. Combustion conditions, rate of feeding waste (also quantity of waste on grate if stoker fired), excess air, air distribution and all controllable temperatures and static pressures shall be, as nearly as possible, the same at the end of the run as at the beginning. These, and any other conditions in which variations might affect the results of the test, shall essentially be reached and held as constant as possible. There must be reasonable assurance that the temperature of the setting and all other parts of the equipment have reached equilibrium before the run is started. The time required to attain stabilization or equilibrium with respect to temperatures will vary widely with the design of the unit and character of materials in the setting. This period of stabilization can vary from a minimum of three hours to more than eight hours from a cold start.

3.7.1 In some instances it may be necessary to terminate a run prematurely because of inability to maintain one or more of the operating conditions at the desired value. Any data collected shall be evaluated and if mutually agreeable, accepted as a test run.

3.7.2 In order to attain the desired operating conditions when waste is fired by stokers, it is essential that the condition of the waste bed be uniformly maintained throughout the run. Minor occasional normal manual stoking of the waste bed may be permitted during the run. Rate of burning or feeding waste shall be kept, as nearly as possible, at the rate which is to prevail during the run. The bed depth shall be the same at the beginning and end of the run. The waste charge system, stoker conveying rate and residue removal system shall be timed and residue accepted after the appropriate delay so that the weight of residue corresponds to the weight of waste burned.

3.8 Duration of Runs

3.8.1 When determining the efficiency, the runs should be preferably of not less than eight hours duration.

3.8.2 The duration of runs for tests of ancillary equipment such as heat recovery systems shall not be less than the incinerator test run.

3.8.3 The actual duration of all runs from which the final test data are derived shall be clearly stated in the test report.

3.9 Frequency and Consistency of Readings. Except for quantity measurements, the readings shall be taken at 15 minute intervals. If, however, there are fluctuations, the readings shall be taken at such frequency as may be necessary to determine the average.

3.9.1 Where quantities are determined from integrating instruments, a reading shall be taken every 15 or 30 minutes to reveal irregularities. If the quantities to be determined are weighed, the frequency of weighing is usually determined by the capacity of the scales, but the intervals shall be such that a total can be obtained for each hour of the test. When indicating flow meters or manometers are used with venturi tubes, flow nozzles or orifice plates for subsequently determining quantity measurements, the flow indicating element shall be read at five minute intervals or more frequently when deemed necessary.

3.9.1.1 Where unweighed amounts are charged (e.g. by grapple) an accurate record of the time of charge shall be kept. The amount charged shall be relatively uniform and representative sample charges weighed so that a total can be obtained for each hour of run.

3.9.2 It is suggested that, in so far as feasible, pertinent data of the run (such as flue gas flow, gas conditioning water flow, flue gas temperature and waste quantities) be plotted as the run progresses, to permit a complete review of the conduct of the run at least hourly.

3.10 Rejection of Runs. Should serious inconsistencies in the observed data be detected during a run or during the computation of the results, the run shall be rejected completely, or in part if the affected part is at the beginning or at the end of the run.

3.11 Records and Test Reports. All observations, measurements and instrument readings necessary for the objective of the test shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record.

3.12 Power for Auxiliaries. No auxiliaries are included inside the system boundary, Fig. 1, therefore no power computation is required.

3.13 Efficiency. As stated in Par. 1.6 efficiency of incineration systems determined within the scope of this Code shall be the gross efficiency only. Net efficiency, while beyond the scope of this Code, may be of interest in those incineration systems combined with waste heat recovery where the heat recovered is outside the system boundary. Such waste heat may be converted to a form of energy used within the incineration system heat cycle and/or an energy output of the incineration system. Net efficiency is the heat output of the incineration system, divided by the total of all heat in the waste plus auxiliary fuel, plus credits, plus the heat equivalent of the auxiliaries outside the system boundary.

3.13.1 All measurements and computations of heat equivalents of auxiliaries should be in accordance with methods described in Steam Generating Units PTC 4.1, Par. 6.2.

3.13.2 In the case of incineration system heat recovery by means of a waste heat boiler, the "Special Instructions for Testing a Waste Heat Boiler" described in Steam Generating Units PTC 4.1, Par. 6.3, should be used for testing such waste heat boiler.

3.13.3 In the case of incineration system heat recovery by means of other equipment, testing should be performed in accordance with applicable test codes for testing such heat recovery means.

3.14 Other Operating Characteristics. The satisfactory performance of an incineration system requires the determination of many operating characteristics. This section describes factors affecting performance and how these should be determined.

*3.14.1 **Measurement of Air Leakage or Infiltration.*** When it is desired to determine the amount of air infiltration or leakage through any portion of the enclosure of an incineration system beyond the furnace exit, it should be done by comparing excess air, as determined from flue gas analyses. The sampling locations preferably should lie in a plane normal to the flue gas flow, located as close as is practicable to the zones of comparison. The gas temperature at the sampling location will determine whether or not a water cooled sampler is required. The amount of air infiltration or leakage is normally expressed in terms of increase in O_2, in excess air, reduction in CO_2, or percent leakage.

*3.14.2 **Exit Gas Temperature.*** Operating conditions which can affect the exit gas temperature during the test such as characteristics of the material fired and excess air should be as agreed in advance. Control apparatus for maintaining and regulating furance temperatures shall be adjusted prior to the test. The period of operation prior to the test should be of sufficient duration to insure stabilization of the incineration system.

*3.14.3 **Static Pressure of Gas and Air.*** Static pressure connections shall be installed in a manner as to avoid errors due to gas velocity. Piping or tubing shall preferably be specifically installed for the test, and shall be proved tight with provisions made for cleaning and drainage. The recommendations of I&A Pressure Measurement PTC 19.2, Chapter 6, shall be followed.

*3.14.4 **Draft Loss, or Resistance to Air or Gas Flow.*** When a draft loss or resistance across an incineration system or a section of a system, is to be measured, a sensitive differential pressure measuring device should be used in preference to an absolute pressure measuring device.

*3.14.5 **Determination of Putrescible Matter.*** The putrescible matter in these test procedures is included in the combustibles, the separate determination of which is not considered to be within the scope of this test Code. Recognizing that putrescible matter is an important environmental consideration, two methods are provided for guidance in its determination in Appendix Par. 7.3.

SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

4.1 Instruments and Methods Of Measurements

The necessary instruments and procedures for making measurements are prescribed herein and should be used in conjunction with the following ASME Performance Test Codes, and their Supplements on Instruments and Apparatus, and other publications for detailed specifications on apparatus and procedures involved. In all cases, care shall be exercised to refer to the latest revision of the document concerned.

4.1.1 ASME Performance Test Codes:

General Instructions PTC 1
Definitions and Values PTC 2
Diesel and Burner Fuels PTC 3.1
Solid Fuels PTC 3.2
Gaseous Fuels PTC 3.3
Steam Generator Units PTC 4.1
Air Heaters PTC 4.3
Centrifugal, Mixed Flow and Axial Flow Compressors And Exhausters PTC 10
Fans PTC 11
Determining the Concentration of Particulate Matter in a Gas Stream PTC 38

4.1.2 Supplements on Instruments and Apparatus (I&A) PTC 19:

Part 1, General Considerations PTC 19.1
Part 2, Pressure Measurement PTC 19.2
Part 3, Temperature Measurement PTC 19.3
Part 5, Weighing Scales PTC 19.5;1
Part 6, Electrical Measurements in Power Circuits PTC 19.6
Part 10, Flue and Exhaust Gas Analyses PTC 19.10
Part 12, Measurement of Time PTC 19.12
Part 16, Density Determinations PTC 19.16
Part 17, Determination of Viscosity of Liquids PTC 19.17
Part 18, Humidity Determinations PTC 19.18

4.1.3 ASME Research Publication:

Interim Supplement 19.5 on Instruments and Apparatus
Part Two – Application of Fluid Meters (ASME Fluid Meters)

4.1.4 American Gas Association:

Orifice Metering of Natural Gas – Gas Measurement Committee Report No. 3, April 1955

4.1.5 ASTM Standard Methods:

Proximate Analysis of Coal and Coke D 3172
Ultimate Analysis of Coal and Coke, D 3176
Calculating Coal and Coke Analysis from As-Determined to Different Bases. D 3180
Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter, D 240
Test for Calorific Value of Gaseous Fuel by the Water-Flow Calorimeter, D 900
Particulate and Dissolved Matters in Industrial Water, D 1888
Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter D 2015
Refuse Sampling and Analysis E 3801

4.1.6 National Bureau of Standards:

Methods of Measuring Humidity and Testing Hydrometers, Circular 512

4.1.7 ASTM Bulletin No. 162 (TP 206)

Gauging and Sampling Water Borne Industrial Wastes

4.2 Determination of Incinerator Efficiency

4.2.1 The Input-Output Efficiency method is based on the ratio of the heat output to the sum of the combined "As Fired" waste and supplementary fuel chemical heat input plus the heat credits. It requires accurate measurement of the quantity and the higher heating value of the "As Fired" waste and supplementary fuel and the heat content of all of the materials entering and leaving the system per unit time.

$$\text{Efficiency (Input-Output Method), \%} = \left(\frac{\text{Heat Output}}{\text{Heat Input}}\right) \times 100$$

Measurements of input and output are covered in Pars. 4.3 and 4.8.

4.2.2 The heat balance efficiency method is:

$$\text{Efficiency (Heat Balance Method), \%} = \left[1 - \frac{\text{Losses}}{\text{Input}}\right] \times 100$$

Losses are defined as the amount of heat in the effluent streams resulting from incomplete combustion of the organic material per unit mass of "As Fired" waste.

Input is defined as the heat of combustion of the "As Fired" waste and supplementary fuel if required, plus heat credits contributed by the applicable influent streams per unit mass of "As Fired" waste.

The determination of the losses and input are covered in Par. 4.10.

4.3 Input Measurement

The following paragraphs describe methods of determining the incineration system heat input. Heat input is the sum of the heat of the "As Fired" waste and supplementary fuel, or fuels, and heat credits.

4.3.1 Material to Be Charged During Incinerator Test

The material charged during the test period should be representative of the material to be burned during normal operation and for which the unit was designed.

For example, in order to accomplish this for large municipal incinerators, the normal household-commercial waste collected and delivered in "packer trucks" can be used as the base material.

An incinerator is a thermal device and an incinerator test should preclude bulky waste as well as large "strapped bales" of combustible. Any such bales must be "unstrapped," broken up, and "mixed" for inclusion in the test charge.

Large bulky metal items such as appliances, 55 gal drums, etc., should be removed from the charge and disposed of separately.

Large wooden structures, tree trunks, boxes, etc., should be removed from the charge and reduced to a suitable size for the unit's feeding mechanism and normal furnace retention time to achieve acceptable burnout.

Waste should be mixed in a manner that no charge, or series of charges, should have a *predominant* component such as plastic, lacquer, paint, etc., or moisture which would tend to unbalance the over-all test data and adversely affect the test conclusions or warranties.

4.3.2 Solid Waste Quantity Measurement

The total weight of waste charged during the test period shall be determined. Any waste not charged must be weighed and accounted for. For municipal incinerators, the total weight of waste charged should be determined over the time period for the performance test. The weigh scales shall be calibrated prior to and after the test in accordance with I&A, on Weighing Scales, PTC 19.5;1. Experience indicates a range of scale error within 0.25 percent in the range of loads weighed.

4.3.2.1 Arrangements shall be made for checking the charging rate during each hour of the test as a guide. Only the totals, however, are to be used in the final calculations.

4.3.2.2 The hourly charging rate can be determined by weighing each waste charge. This can be accomplished by placing the waste into a container attached to or resting upon portable scales, or a load cell, recording the weight, and then transferring the waste to the charging hopper. The material shall not be packed or compressed to avoid changes in the normal bulk density of the waste. These scales shall be calibrated prior to and after, the test in accordance with I&A, on Weighing Scales, PTC 19.5;1.

4.3.2.3 While measuring the weight of each charge is preferable, it may be more feasible, because of the requirements of operation, to charge the incinerator at a uniform rate from a waste pit, or area, where the materials have been weighed at delivery. Care must be taken when testing that losses of material and/or moisture are accounted for. Elapsed charging time must be recorded. Refer to Pars. 3.7 and 3.9.1.

4.3.3 Solid Waste – Sampling

Incinerators usually receive a wide variety of materials, the moisture content of which are higher than the air-dried level. This heterogeneity and moisture content complicate both the size and number of increments that must be taken, as well as the reduction of the sample to representative amounts that can be analyzed.

4.3.3.1 A suggested procedure for sampling municipal, commercial and industrial waste at the receiving area follows:

In all cases the incoming waste must be adequately mixed before sampling with precautions taken to prevent density segregation.

If the waste is processed (shredded and classified), care must be taken to insure a representative sample reflecting the "As Fired" waste composition to the incineration system.

The input solid waste sample is taken hourly during the test. See ASTM E 3801 for a suggested procedure. It will be obtained by taking representative increments which are to be collected in at least two (2) equal increments at approximately 30 minute intervals. Each hourly sample which is comprised of these increments will weigh at least one percent (with a minimum of 200 lb) of the hourly charging rate for incinerators under 500 tons per 24-hour day capacity. The total hourly sample for incinerators over 500 tons per 24-hour day capacity will be at least ½ percent of the hourly charging rate. When the increments are taken, they must be weighed and piled on a large plastic sheet and covered. The hourly samples weighing more than 400 lb are quartered down to a 400 lb sample and covered with a plastic sheet to minimize moisture loss.

The eight hourly samples accumulated (1600-3200 lb) at the completion of the test must be thoroughly mixed and again quartered down to four 400 lb samples, weighed and sealed in appropriate containers. One sample will be stored for possible future arbitration. The second sample will be used for an input moisture determination. The third sample will be used for the input ultimate analysis and heat value determinations in accordance with the appropriate ASTM method. The fourth sample shall be made available to the responsible contractor.

4.3.3.2 There are two methods of sample processing for ultimate analysis and heat value determination:

(a) hand sorting before reduction

(b) bulk reduction

4.3.3.3 Where the hand sorting before reduction method is used, separate the sample into combustible and non-combustible components. The non-combustible components are represented by metals, glass, ceramics, stones, etc., larger than ½ in. in size. The combustible portion should be placed in a sealed container for transport to a reduction (shredding) station.

4.3.3.4 In the bulk reduction method, the entire sample including the combustible and non-combustible, is transported to a shredding station for reduction.

4.4 Solid Waste Analysis and Higher Heating Value (HHV)

The shredded samples should be quartered down to two samples of 10 lb each for the following analyses:

Moisture	– Standard Method ASTM D 3176, 3180
Carbon	– Standard Method ASTM D 3176, 3180
Hydrogen	– Standard Method ASTM D 3176, 3180
Oxygen	– Standard Method ASTM D 3176, 3180
Nitrogen	– Standard Method ASTM D 3176, 3180
Sulfur	– Standard Method ASTM D 3176, 3180
Chlorine	– Standard Method ASTM D 2361
Ash	– Standard Method ASTM D 3176, 3180

4.4.1 The higher heating value in Btu/lb shall be determined by the standard method of ASTM D 2015 using the oxygen bomb calorimeter. The laboratory shall make a minimum of three determinations to insure reasonable agreement before averaging. It is recognized that there is a heat contribution by the oxidation of metals during the thermal process. Based on the limited data available the metal oxidation factor has been found to range from zero to as much as 3 percent of the bomb calorimeter higher heating value. When applicable add this amount to the bomb calorimeter determination (see Par. 3.1.17). This higher heating value (HHV) is referred to as the higher heating value throughout this Code.

4.5 Liquid Waste Quantity Measurement

The use of calibrated weigh tanks is preferred for this measurement. If such facilities are not available, then calibrated volumetric tanks should be used. Experience indicates the former to have a possible measurement error within ± 0.10 percent and the latter within ± 0.25 percent. Positive displacement meters may be used if carefully calibrated under conditions simulating those existing during the test in regard to grade of material, temperature, pressure, rate of flow and meter locations. Calibrated meter accuracy must be within ± 0.50 percent.

4.5.1. Leakage of material between point of measurement and point of firing shall be measured and accounted for in the flow calibration. Branch connections on the piping shall be either blanked off or provided with double valves and suitable telltale drains for detecting leakage. Leakage from valve stuffing boxes shall be prevented. Any unavoidable leakage from pump stuffing boxes or elsewhere shall be calculated and accounted for. Where a return system from the burners is used, both supply and return flows shall be measured by calibrated meters or determined from a calibrated feed tank.

4.5.2. Liquid Waste Sampling. A representative sample of material shall be obtained in accordance with the Test Code for Diesel and Burner Fuels PTC 3.1.

4.5.3 Liquid Waste Analysis. Fuel analysis and higher heating value determinations shall be made in accordance with the Test Code for Diesel and Burner Fuels PTC 3.1, ASTM Standard Methods For Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter D 240, Density Determination PTC 19.16 and Determination of the Viscosity of Liquids PTC 19.17.

4.6 Gaseous Waste – Quantity Measurement

Measurement of the quantity of gaseous waste can be accomplished by the use of orifice flow nozzle, venturi, or dry gas meters. The measuring devices shall be calibrated prior to and after the test.

4.6.1 The recommendations of ASME Fluid Meters shall be followed with reference not only to the design, construction, calibration, and use of flow measuring elements, but also to the location and installation in the pipeline and the installation of the connecting piping system between the primary element and differential meter. All computations of flow rate from the observed differentials, pressures and temperatures shall be made in accordance with the procedures of ASME Fluid Meters.

4.6.2 If fluctuations in flow are present, due to reciprocating devices or other sources of pulsation, the difference between the indicated maximum and minimum flow rates shall be minimized and must be reduced to less than ± 5 percent of the average flow, by the introduction of a cushion chamber, surge chamber, or other means of absorbing the pulsations between the source of pulsation and the primary device, before measurement is considered acceptable. For further discussion of pulsating flow measurements, see ASME Fluid Meters.

4.6.3 Pressure of the gaseous waste at point of volume determination and at other required points shall be measured by suitable pressure measuring devices as described in Instruments and Apparatus, Pressure Measurement PTC 19.2. Temperature shall be measured with thermometers in accordance with I&A Temperature Measurements PTC 19.3, Chapter 5 on Liquid-in-Glass Thermometers.

4.6.4 Gaseous Waste Sampling. The gas shall be properly sampled in accordance with the Test Code for Gaseous Fuels PTC 3.3.

4.6.5 Gaseous Waste – Analysis. Fuel analysis and higher heating value determination shall be made in accordance with the Test Code for Gaseous Fuels PTC 3.3 and ASTM Standard Methods of Tests for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter D 900 or Method of Test for Calorific Value of Gases in Natural Gas Range by Continuous Recording Calorimeter, ASTM D 1826.

4.7 Supplementary Fuel

Supplementary fuel may be added to an incineration system during startup or when the waste is so wet that combustion is difficult or impossible to sustain, or may be added to waste in normal operations. This supplementary fuel may be solid, liquid or gaseous. The consumption rate should be measured and the time fuel is being used should be noted. If supplementary fuel firing is specified for normal operation, the incinerator efficiency shall be determined with both waste and supplementary fuel inputs.

4.7.1 Solid Fuel – Quantity Measurement. This fuel shall be weighed near the point where it is to be used. All loss of fuel between the point of weighing and charging to the incinerator shall be measured and accounted for. The weighing scale shall be calibrated prior to and after the tests in accordance with I&A, Weighing Scales, PTC 19.5;1.

4.7.1.1 Solid Fuel – Sampling. A representative sample of the fuel shall be obtained in accordance with the Test Code for Solid Fuels PTC 3.2.

4.7.1.2 Solid Fuel – Analysis. Ultimate fuel analysis and higher heating value determination shall be made in accordance with the Test Code for Solid Fuels PTC 3.2, ASTM Standard Methods of Laboratory Sampling and Ultimate Analysis of Coal and Coke, ASTM D 3176.

4.7.2 Liquid Fuel – Quantity Measurement. The use of calibrated weigh tanks is preferred for this measurement. If such facilities are not available, then calibrated volumetric tanks should be used. Experience indicates the former to have a possible measurement error within ± 0.10 percent and the latter within ± 0.25 percent. Positive displacement meters may be used if carefully calibrated under conditions simulating those existing during the test in regard to grade of fuel, temperature, pressure, rate of flow and meter location. Calibrated meter accuracy must be within ± 0.50 percent.

4.7.2.1 Leakage of fuel between point of measurement and point of firing shall be measured and accounted for in the flow calibration. Branch connections on the fuel piping shall be either blanked off or provided with double valves and suitable telltale drains for detecting leakage. Leakage from valve stuffing boxes shall be prevented. Any unavoidable leakage from pump stuffing boxes or elsewhere shall be calculated and accounted for. Where a return system from the burners is used, both supply and return flows shall be measured by calibrated meters or be determined from a calibrated feed tank.

4.7.2.2 Liquid Fuel–Sampling. A representative sample of this fuel shall be obtained in accordance with the Test Code for Diesel and Burner Fuels PTC 3.1.

4.7.2.3 Liquid Fuel – Analysis. Ultimate fuel analysis higher heating value, density and viscosity determination shall be made in accordance with the Test Code for Diesel and Burner Fuels PTC 3.1, ASTM Standard Methods for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter D 240, Density Determination PTC 19.16 and Determination of the Viscosity of Liquids PTC 19.17.

4.7.3 Gaseous Fuel – Quantity Measurement. Measurement of the quantity of gaseous fuel can be accompanied by the use of orifice, flow nozzle, venturi or dry gas meters. The measuring devices shall be calibrated prior to and after the test.

4.7.3.1 The recommendations of ASME Fluid Meters, shall be followed with reference not only to the design, construction, calibration, and use of flow measuring elements, but also to the location and installation in the pipeline and the installation of the connecting piping systems between the primary element and pressure measuring device. All computations of flow rate from the observed differentials, pressures and temperatures shall be made in accordance with the procedures of ASME Fluid Meters.

4.7.3.2 If fluctuations in flow are present, due to reciprocating devices or other source of pulsation, the difference between the indicated maximum and minimum flow rates shall be minimized and must be reduced to less than ± 5 percent of the average flow, by the introduction of a cushion chamber, surge chamber, or other means of absorbing the pulsations between the source of pulsation and the primary device, before measurement is considered acceptable. For further discussion of pulsating flow measurements see ASME Fluid Meters.

4.7.3.3 Pressure of the gaseous fuel at point of volume determination and at other required points shall be measured by suitable pressure measuring devices as described in Instruments and Apparatus, Pressure Measurement PTC 19.2. Temperature shall be measured with thermometers in accordance with I&A Temperature Measurements PTC 19.3, Chapter 5 on Liquid-in-Glass Thermometers.

4.7.3.4 Gaseous Fuel – Sampling. The gas shall be properly sampled in accordance with the Test Code for Gaseous Fuels PTC 3.3.

4.7.3.5 Gaseous Fuel – Analysis. Ultimate fuel analysis and higher heating value determination shall be made in accordance with the Test Code for Gaseous Fuels PTC 3.3 and ASTM Standard Methods of Tests for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter D 900 or Method of Test for Calorific Value of Gases in Natural Gas Range by Continuous Recording Calorimeter, ASTM D 1826.

4.7.4 Heat Credits – Determination

Heat credits, as indicated on Figs. 2 and 3, are the algebraic sum of heat differences between the input conditions and the reference conditions (see Par. 4.9). These credits are determined by the quantity measurement multiplied by the enthalpy difference between the inlet and reference conditions and must be added to the heat input (see Pars. 1.4.5, 5.2.1.2.5, and 5.3.2.4).

4.8 Output Measurements

The following paragraphs describe the methods of determining the output from the incineration system. The output from the system includes (see Figs. 1 and 2):

Heat Removed by Heat Recovery Fluid (Point 12)

Heat in Wet Flue Gas (Points 7, 8 or 10)

Heat Transferred by Radiation and Convection Across the System Boundary

Sensible Heat in Residue (Point 17)

Sensible Heat in Grate Siftings (Point 23)

Sensible Heat in Quench Water Solids (Point 16)

Sensible Heat in Flue Dust (Points 20, 21, and 22)

Sensible Heat in Emitted Stack Dust (Point 10)

Heat Transferred to Cooling Water (Points 14, 16, 18, and 19)

4.8.1 Heat Removal by Heat Recovery Fluid – Determination

The heat removed by the indirect heat exchange between the hot incinerator gases and the recovery fluid is determined by the methods and procedures of PTC 4.1, Steam Generating Units.

4.8.2 Heat in Wet Flue Gas – Determination

The output is determined by the quantity measurement multiplied by the enthalpy difference between the flue/stack conditions (Points 7, 8 or 10) and reference conditions.

4.8.2.1 Wet Flue Gases – Quantity Measurement

Determination of stack gas flow may be based on actual combustion calculations (stoichiometry) from accurate chemical analysis, measurement of velocity pressure at representative points in the duct cross-section, or by calibrated flow measuring devices.

4.8.2.1.1 The determination of a gas weight or volume for the purpose of establishing the rate of flow leaving the incineration system should utilize the most accurate method available. A full examination of the effect of the number and location of sampling connections and the frequency of sampling on the accuracy of flow measurement should determine whether these flow rates for each test situation should be established by calculation from "As Fired" waste and supplemental fuel analysis and flue gas composition or from measurements of velocity head. In many cases, due to less-than-ideal conditions for velocity head measurements, flow measurements by combustion calculations have been found to be more accurate. In such cases the flow rates as determined by velocity head measurements are usually higher than those determined by combustion calculations.

Calculation procedure for gas weight per weight unit of waste and supplementary fuel is given in

Appendix, Par. 7.4. Gas flow determination will require an accurate charging rate and chemical analysis of the charge.

If sampling connection locations indicate a reliable velocity head determination can be established, or if the system being tested does not lend itself to a calculated gas rate determination, it is recommended that the procedures in PTC 38 be followed.

4.8.2.1.2 Air Infiltration

The uncontrolled leakage and dilution air entering the system is measured by the difference between the calculated air from flue gas analysis and the measured input air.

4.8.2.1.3 Inlet Air Flow. The inlet air flow to the incineration system should be accuretely determined by the procedures of I&A, PTC 19.5 series, using either an orifice or nozzle as described in this series. If the overfire air, or other air flows, used in the incineration system are separately supplied, they must be measured. If the gas is diluted, this air should be measured and accounted for. In this way, the air entering the system may be compared with the gas flow as determined by direct measurement, or combustion calculations, as described in this section. The quantity of flue gases leaving the system should be larger than the quantity of inlet air due to the combustion of the waste. If this difference is greater than the weight of fuel burned plus quench water evaporated it is a measure of the air leakage and uncontrolled infiltration to the system. When this air leakage results in less than 3 percent CO_2 in the flue gas, the calculated results are adversely affected and retesting after reducing the uncontrolled infilitration is required.

4.8.2.2 Wet Flue Gases — Moisture Determination

The moisture in the stack gas can be calculated from the waste and supplementary fuel analysis and the moisture in the combustion air. See Par. 4.9.3 and Par. 5.2.1.1.2.1. Water vapor can also be determined by the condensation method. This method can be run in conjunction with particulate matter sampling or separately (see PTC 38). The temperature of the sampling line preceding the condenser must be kept above the water dew point to prevent condensation. The temperature of the gas at the condenser exit must be measured if no desiccant is used. Using only a condenser, the flue gas to the metering device is assumed saturated at the temperature leaving the condenser. The percent moisture in the metered flue gas should be computed using the moisture's specific volume from the tables of saturated steam properties and determining the water vapor's density.

4.8.3 Heat Transferred by Radiat n a Across the System Boundary

Unless established criteria to determine the and convection heat output are available, such a th mination of wall heat loss in steam generators (P the heat output shall be determined by field mea of the exterior skin temperatures of the incinerator after the system has arrived at wall heat transfer equili conditions. Then by computation using the form found in Par. 5.2.1.1.3 determine the total surfa transferred. This is necessary over all of the surfaces, the system boundary since they will normally be al ambient temperature and there will be heat outpu all system walls. All heat leaving the system is an in the input-output method of test. In the heat balan method of testing, this need not be computed sin output and not a loss.

The measurement of the skin temperature will be by shielded surface thermocouples in a grid pattern the shortest distance between any two points of m ment shall not exceed two meters (approximately However, closer spacing will be necessary where ther surface temperature gradient greater than 50°F be points of reading.

Special attention must be afforded doors and oth setting openings. They must be properly closed an to prevent leaks and the loss computed separately.

If the walls are air cooled as in the case of air cool furnace walls, where the air space is open to the atm the heat output shall be computed on the basis of measured volume flow and the temperature of the air ing the air space. This output would then be added to surface losses computed by the survey mentioned a and would constitute the total heat transferred fro system surfaces and will be known as the heat output fr radiation and convection.

4.8.4 Sensible Heat in Residue — Determina

The heat output of all residue that is not carried from the system with the gas is determined by mult plying the quantities by the specific heat and the ap priate measured temperature minus the reference temperature.

4.8.4.1 Residue — Quantity Measurement

The total quantity of residue for the test p shall be collected and weighed. If the residue is que in water, the residue shall be weighed wet to provide d for the determination of the quench water material bal ance.

The weigh scale should be calibrated prior and after the test in accordance with I&A PTC 19.5: 1 on Weighing Scales.

4.8.4.2 Residue Sampling

Representative samples of the residue shall be obtained in the following manner:

(a) a *shovel* sample be taken every 10 minutes with consideration for the total residue required.

(b) from units of 24 tons per day (24 hours) capacity up to 500 tons per day (24 hours), the total sample shall be approximately 1 percent of waste input to the incineration system.

(c) from units above 500 tons per day (24 hours), the total sample shall be approximately ½ of 1 percent of waste input to the incinerator.

(d) include in the total residue sample proper proportions, if applicable, of residue water trough "skimmings" and "settlement" material.

4.8.4.2.1 Residue – Sample Preparation

Shredded sample is to be quartered down to four samples of 10 pounds each. One (1) for moisture determination; one (1) stored for possible future arbitration; one (1) made available to the responsible contractor; and one (1) for laboratory processing (see Par. 4.3.3).

Dry the sample for laboratory processing and spread on a clean piece of plastic sheet. Ferrous material should be removed by passage of a strong magnet over the sample: weigh this ferrous material and set it aside. The obvious non-ferrous metal, glass, stone and ceramic should be removed from the remainder, weighed and set aside.

The prepared sample (remainder) should then be forwarded to the laboratory for the higher heating value determination (see Par. 4.4). The heating value of the sample must then be corrected to reflect the weight of non-combustibles previously removed.

4.8.4.2.2 Residue – Analysis: Moisture Determination

The moisture content of half of each sample shall be determined in accordance with the standard methods ASTM D 3176, 3180. If performance is to be determined by heat balance method, the dried sample will be used for the complete laboratory analysis in accordance with this standard. The remaining half of each sample shall be stored in sealed containers for arbitration.

4.8.4.2.3 Residue – Sensible Heat

The sensible heat in the wet residue shall be determined by the average dry residue specific heat of 0.2 Btu/lb°F (see Appendix 1, Par. 7.1) the weight of dry residue, the temperature rise of the residue above the reference temperature, plus the heat removed with the residue moisture.

4.8.4.3 Grate Siftings – Quantity Measurement

The total quantity of grate siftings shall be collected and weighed after the test period or more often if required. If grate siftings are normally discharged to the residue hopper, they may be measured with the residue. The weigh scale shall be calibrated prior to and after the test in accordance with I&A PTC 19.5;1 on Weighing Scales.

4.8.4.3.1 Grate Siftings – Sampling and Preparation

Representative samples of the grate siftings shall be taken and prepared following procedures in Par. 4.8.4.2.1. Good sampling principles should be observed and care should be exercised to prevent moisture loss or gain during sampling and shipment to the laboratory by placing the samples in air-tight, noncorrosive containers.

4.8.4.3.2 Grate Siftings – Analysis: Moisture Determination

Follow same procedure as outlined in Par. 4.8.4.2.2.

4.8.4.3.3 Grate Siftings – Sensible Heat

If siftings are not combined with residue, sensible heat of the siftings shall be accounted for by following the same procedures as outlined in Par. 4.8.4.2.3.

4.8.4.4 Quench Water Solids – Quantity Measurement

The quantity of solids in the quench water shall be determined in accordance with the ASTM D 1888, Test for Particulate and Dissolved Matter in water.

4.8.4.4.1 Quench Water Solids – Sampling

Representative samples of the quench water must be collected hourly during the test and after mixing draw off one liter sample for laboratory analysis by ASTM D 1888.

4.8.4.4.2 Quench Water Solids – Analysis

These solids must be analyzed for combustible matter and the heat loss computed for inclusion in Par. 5.3.1.1.1 (see Par. 4.4).

4.8.4.4.3 Quench Water Solids – Sensible Heat

Follow the same procedures as outlined in Par. 4.8.4.2.3.

4.8.4.5 Flue Dust – Quantity Measurement

The flue system must be clean of dust accumulations prior to the test.

The hoppers of the gas cleaning equipment shall be cleaned prior to the test. The entire quantity of dust collected by the gas cleaning equipment during the test shall be weighed. The weigh scales shall be calibrated prior to and after the test in accordance with I&A, PTC 19.5;1, on Weighing Scales.

4.8.4.5.1 Flue Dust – Sampling

Representative samples of the various flue dust collected during the test and large enough to allow laboratory analysis shall be placed in air-tight noncorrosive containers with care being exercised to avoid moisture loss or gain.

4.8.4.5.2 Flue Dust – Analysis: Moisture Determination

The moisture content of each sample shall be determined using the same procedure set forth in Par. 4.8.4.2.2.

4.8.4.5.3 Flue Dust – Sensible Heat

The sensible heat in the wet flue dust shall be determined by taking the average dry flue dust specific heat 0.2 Btu/lb°F (see Appendix Par. 7.1.) the weight of the total dry flue dust, the temperature rise of the wet flue dust above the reference temperature, plus the heat removed with the flue dust moisture.

4.8.5 Sensible Heat in Stack Dust – Determination

The heat output of stack dust that is carried from the system with the gases is determined by multiplying the dust quantity by the specific heat and the appropriate measured temperatures (at Point 7, 8 or 10), minus the reference temperature.

4.8.5.1 Stack Dust – Quantity Measurements

The quantity of stack dust emitted shall be calculated from the dust concentration sample and the total quantity of gases leaving the incineration system (see PTC 38).

4.8.5.2 Stack Dust – Sampling

The collected stack particulate sample used in Par. 4.8.5.1 above is the stack dust sample.

4.8.5.3 Stack Dust – Analysis: Moisture Determination

The moisture content of each sample shall be determined using the same procedure set forth in Par. 4.8.4.2.2.

4.8.5.4 Stack Dust – Sensible Heat

The sensible heat in the wet stack dust shall be determined by taking the average dry stack dust specific heat 0.2 Btu/lb°F (see Appendix Par. 7.1.) the weight of the total dry stack dust, the temperature rise of the wet stack dust above the reference temperature, plus the heat removed with the stack dust moisture.

4.8.6 Heat Transferred to Cooling Water – Determination

This output is determined by the flow measurement multiplied by the specific heat and the difference between the inlet and outlet water temperature.

4.8.6.1 Cooling Water – Quantity Measurement

The total quantity of water entering into and discharged from each water circuit of the incineration system boundary (Fig. 1) shall be measured. Flow rates shall be measured by calibrated volumetric tanks, weigh tanks, weirs, venturi meters, orifices or nozzles. Flow measurements should be made by personnel trained and experienced in the principles outlined in ASME Fluid Meters.

4.8.6.2 Cooling Water – Sensible Heat

This heat output is computed from cooling water quantities, the specific heat (1.0 Btu/lb°F), and the temperature rise of each flow.

4.9 Reference Conditions

4.9.1 Reference Air Temperature = t_{RA} (°F). This is the base temperature to which the sensible heat losses and credits are compared for the efficiency computations of the incinerator. If heat is added to the combustion air ahead of the forced draft fan, corrections for this heat must be made to the measured air at location 5 to obtain t_{RA}. If the temperature entering the forced draft fan, which closely approximates the ambient conditions about the unit, is not used, the base to which all computations must be related, t_{RA}, must be the measured ambient air temperature entering the system. This differs from the standard air temperature that may be used in some computations such as gas supply, standard air density, etc. The reference air temperature is actually the base temperature to which all computations must be related in the heat balance and input/output calculation in the incinerator test.

4.9.2 Reference Pressure

The reference pressure to be used in adjusting the test for variations in elevation and barometer changes will be read at least hourly during the test. This is to be from a barometer in the vicinity of the incineration system under test. It will be observed on a standard barometer in accordance with I&A, PTC 19.2 – Pressure Measurements. The measurements should be taken when possible in the vicinity of the measurement station for reference temperature and test humidity or in a reasonable proximity of Point 5 on Fig. 1.

4.9.3 Test Humidity and Moisture in Combustion Air

The moisture carried by combustion air must be taken into consideration when calculating the efficiency by the heat balance method. This moisture may be determined with the aid of a sling-type psychrometer or similar device. From the dry and wet bulb thermometer readings taken from the psychrometer at the observed barometric pressure, the absolute or specific humidity (pounds of moisture per pound of dry air) can be determined either from the chart published in I&A, PTC 19.18, Humidity Determination, or from psychrometic tables published by the U.S. Weather Bureau. The average value so determined is the test humidity. The dry and wet bulb temperatures may be determined at the atmospheric air inlet to the system, Point 5 on Fig. 1. This is possible since the desired quantity is pounds of moisture per pound of dry air for combustion. Since the specific humidity does not change with heat addition unless there is moisture addition, the air moisture crossing the envelope, Fig. 1, is the same as that measured at the air inlet.

4.10 Efficiency of Incinerator Systems by Heat Balance Method – Determination

The Heat Balance Method relates the incomplete combustion losses to the input on a pound of "As Fired" waste charged.

4.10.1 Losses

4.10.1.1 Determination of Hydrogen and Hydrocarbon Loss

A review of available methods and instrumentation as applicable to this Code, indicated that the measurement of hydrocarbons and hydrogen in incinerator flue gas cannot be accurately determined in the field. Accurate determinations of these components may be obtained by laboratory analysis of gas samples collected during the test, but it is considered adequate for this test procedure to use a value of twice the heat loss due to carbon monoxide (L_{CO}) as the chemical heat loss in the dry flue gas (L_G'), (see Par. 4.10.1.3). This is based on the fact that there are available and currently in use for flue gas analysis, accurate, continuous measuring instruments for CO in the range of 0 to 2,000 parts per million by volume. If the CO exceeds 2,000 parts per million, the operation of the system should be reviewed and optimized. This may require retesting.

4.10.1.2 Determination of Losses Due to Incomplete Combustion in Output Solids

The chemical heat in the total dry solid residue per pound must be computed by proportioning the various laboratory heating value determinations by the weight rate of pit residue, grate sifting, flue dust and stack particulates proportioned per pound of "As Fired" waste. The quantity measurement and the appropriate sample taking have been covered in Pars. 4.8.4, 4.8.4.3, 4.8.4.4 and 4.8.4.5 and will not be repeated here. Once the appropriate samples have been taken and forwarded to the laboratory, the heat content of the solids can be established by the laboratory.

4.10.1.2.1 The heat value of the output solids shall be determined by bomb calorimeter. The heat value determination should be made for each of the output samples, rather than a single composite sample. The composite loss then may be determined by multiplying the determined values by the proportional weight of each of the quantities of pit residue, grate sifting and flue dust measurements, as prescribed in Par. 5.3.1.1.1.

4.10.1.2.2 The heat-value determination of the solids shall be made in accordance with the Test Code for Solid Fuels PTC 3.2, ASTM D 3176, 3180, and D 2015. This is a heat value determination by bomb calorimeter. The laboratory shall make a minimum of three determinations to insure reasonable agreement before averaging.

4.10.1.3 Determination of Carbon Monoxide Loss

Carbon monoxide loss is determined by measuring the carbon monoxide present in the flue gas by an accurate continuous measuring instrument and multiplying the quantity per pound of "As Fired" waste (see Par. 5.3.1.2.1) by the heating value of carbon monoxide. (See PTC 19.10 on Flue and Exhaust Gas Analysis.)

4.10.2 Input

The heat input determination follows the procedures of Par. 4.3 Input Measurement and Par. 4.7.4 Heat Credits. To convert to the per pound of "As Fired" waste basis, divide these values by the rate of "As Fired" waste charged.

SECTION 5, COMPUTATION OF RESULTS

5.1 The following computation procedures are for determining the efficiency of an incinerator by both the input-output and the heat balance methods for the actual operating conditions of the tests. When a comparison is to be made between test efficiency and a standard or design efficiency, adjustments should be made in computations for deviation of test conditions from the standard or design conditions. Each computation subject to adjustments is so noted in the following section, and the procedure for adjusting is as described under "Corrections to Standard or Design Conditions," Par. 5.4.

5.2 Efficiency by Input-Output Method. (Refer Fig. 2)

$$\eta = \frac{\text{Output}}{\text{Input}} 100$$

Output is defined as the amount of heat released in the incineration process including heat absorbed by the heat recovery fluid (if used), the heat content of the effluent gas (sensible plus latent), the sensible heat content of the pit residue, grate siftings, flue dust and stack dust, and heat absorbed by the cooling water leaving the system boundary. See Figs. 1 and 2.

Input is defined as the heat of combustion based on the high heating value of the waste and supplementary fuel if required, plus heat credits contributed by the applicable influent streams.

5.2.1

$$\eta = \frac{Q_{\text{out}_e}}{Q_{\text{in}_e}} 100 = \frac{Q_{\text{out}_e}}{H_r W_{re} + H_f W_{fe} + \Sigma Be} 100$$

Where η (%) = Efficiency

Q_{out_e} (Btu/hr) = Output-Heat content of the materials leaving the system boundary.

5.2.1.1

$$Q_{\text{out}_e} = Q_{ye} + Q_{Ge} + Q_{\beta e} + Q_{P_e} + Q_{de} + Q_{we}$$

5.2.1.1.1

Q_{ye} (Btu/hr) = Rate of heat removed by the heat recovery fluid as determined by test (see PTC 4.1).

5.2.1.1.2

Q_{Ge} (Btu/hr) = Heat in the flue gas.

$$Q_{Ge} = W_{G,10e} \left[\frac{WF_{CO_2,10}}{44} (h_{CO_2,10} - h_{CO_2,R}) + \frac{WF_{O_2,10}}{32} (h_{O_2,10} - h_{O_2,R}) + \frac{WF_{CO,10}}{28} (h_{CO,10} - h_{CO,R}) + \frac{WF_{N_2,10}}{28} (h_{N_2,10} - h_{N_2,R}) + \frac{WF_{m,10}}{18} (h_{m,10} - h_{m,R}) \right]$$

Note: Sensible heat of hydrocarbons is considered negligible. For systems producing a fuel gas, the hydrocarbons sensible heat must be added.

5.2.1.1.2.1 $W_{G,10e}$ (lb/hr) = Weight rate of flue gas (Point 10).* See Par. 4.8.2.1.

The weight rate of the flue gas can be determined by either of two methods. The method selected will depend on the accuracy and availability of the various required data.

METHOD A

$W_{G,10e}$ $= 3600\, U_{G,10}\, \alpha_{10}\, \gamma_{G,10}$

3600 = Number of seconds per hour.

$U_{G,10}$ (ft/sec) = Duct velocity (Point 10) by measurement. See PTC 38.

α_{10} (ft^2) = Internal duct area (Point 10).

$\gamma_{G,10}$ (lb/ft^3) = Specific weight of flue gas (Point 10).

$$\gamma_{G,10} = \frac{M_G p_{10}}{R_u T_{10}} (144)$$

M_G (lb/lb mol) = Molecular weight of flue gas.

$$M_G = (44.01\,CO_2 + 32.00\,O_2 + 28.01\,CO + 28.02\,N_2 + 18.02\,V_m)\,\frac{1}{100}$$

$$CO_2 = CO_2'\left(1 - \frac{V_m}{100}\right);\ O_2 = O_2'\left(1 - \frac{V_m}{100}\right);\ CO = CO'\left(1 - \frac{V_m}{100}\right);\ N_2 = N_2'\left(1 - \frac{V_m}{100}\right)$$

V_m = Percent by volume of moisture in flue gas is equal to the partial pressure of the water vapor divided by the total pressure multiplied by one hundred (100). (See Section 4, Par. 4.8.2.2.)

From Orsat or equivalent analysis for CO_2', O_2', CO', N_2' in percent by volume.

Where: $N_2' = 100 - (CO_2' + O_2' + CO')$

Note: Hydrocarbons included with N_2'.

p_{10} (lb/in.^{2}) = Absolute pressure at Point 10, Fig. 1.

144 = Number to convert pressure to pounds per square foot.

R_u (ft-lb/lb mol °R) = 1545 Universal Gas Constant.

T_{10}(°R) = Absolute temperature at Point 10, Fig. 1.

METHOD B

$W_{G,10e}$ (lb/hr) = Weight rate of flue gas (Point 10).*

$$W_{G,10e} = (W_{G'rf,10} + W_{mArf} + W_{mHrf} + W_{mrf})(W_{re} + W_{fe}) + W_{ze} + W_{wve}$$

or

$$= W_{G',10}\,(W_{re} + W_{fe})\left(1 + \frac{V_m}{100}\right)$$

Where:

$W_{G'rf,10}$(lb/lb) = Pounds of dry flue gas per pound of combined "As Fired" waste and supplementary fuel.

$$W_{G'rf,10} = \left[\frac{44.01\,(CO_2{}'_{10}) + 28.01\,(CO'_{10}) + 32.00\,(O_2{}'_{10}) + 28.02\,(N_2{}'_{10})}{12.01\,(CO_2{}'_{10} + CO'_{10})}\right] \times \left[C_{brf} + \frac{12.01}{32.07}\,S_{rf}\right]$$

The derivation of this equation is presented in Appendix Par. 7.4.

Where:

$CO_2{}'_{10}$; CO'_{10}; $O_2{}'_{10}$ and $N_2{}'_{10}$ are in percent and obtained from an Orsat or equivalent analysis of the flue gas at Point 10.

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*May be Point 7, 8 or 10 – as the specific system indicates for best results.

C_{brf} (lb/lb) = Pounds of carbon burned per pound of combined "As Fired" waste and supplementary fuel.

$C_{brf} = C_{rf} - C_i$

C_{rf} (lb/lb) = Pounds of carbon per pound of combined "As Fired" waste and supplementary fuel. By laboratory analyses determine the carbon in both the waste and the supplementary fuel and combine these values in proportion to their flows.

C_i (lb/lb) = Pounds of unburned carbon in the total residue including flue dust per pound of combined "As Fired" waste and supplementary fuel.

S_{rf} (lb/lb) = Pounds of sulfur per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis (similar to C_{rf} above).

W_{mArf} (lb/lb) = Pounds of moisture in the combustion air per pound of combined "As Fired" waste and supplementary fuel.

$W_{mArf} = m_A (W_{A'rf})$

m_A (lb/lb) = Pounds of water vapor per pound of dry air from psychrometer readings at location 5 and psychrometric charts.

$W_{A'rf}$ (lb/lb) = Dry air entering the system per pound of combined "As Fired" waste and supplementary fuel.

$$W_{A'rf} = \frac{1}{0.7685}\left\{\left[\frac{28.02\,(N_2')\,(C_{brf} + \frac{12.01}{32.07}\,S_{rf})}{12.01\,(CO_2' + CO')}\right] - N_{rf}\right\}$$

This equation is based upon the derivation presented in Appendix Par. 7.4.

Where the various measurements are obtained in the same manner as indicated in the equation for $W_{G'rf,10}$ above, the only additional value required is N_{rf}:

N_{rf} (lb/lb) = Pounds of nitrogen per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis determine the nitrogen in both the waste and the supplementary fuel and combine these values in proportion to their flow rates.

$W_{mH_{rf}}$ (lb/lb) = The pounds of moisture formed by the combustion of the combined "As Fired" waste and supplementary fuel.

$$W_{mH_{rf}} = H_{rf} \times 8.9365$$

H_{rf} (lb/lb) = The pounds of hydrogen burned per pound of combined "As Fired" waste and supplementary fuel.

8.9365 = Number of pounds of moisture formed by the combustion of a pound of hydrogen.

W_{mrf} (lb/lb) = Pounds of moisture per pound of combined fuel by laboratory analysis (similar to C_{rf} above).

W_{re} (lb/hr) = Waste charging rate determined per Par. 4.3.2.

W_{fe} (lb/hr) = Supplementary fuel firing rate determined per Par. 4.7.

W_{ze} (lb/hr) = Atomizing steam flow rate determined by methods presented in ASME Research Publications: Fluid Meters – Their Theory and Application.

W_{wve} (lb/hr) = The rate of quench water evaporation determined by direct measurement of the input and output flows to the various quenching and scrubbing chambers.

5.2.1.1.2.2 WF_{CO_2} = Weight fraction of CO_2 in wet flue gas.

$WF_{CO_2} = 44\,CO_2/M_C$ (See Par. 5.2.1.1.2.1 for determination of CO_2 and M_C)

In similar manner the weight fractions of the other flue gas constituents can be computed.

5.2.1.1.2.3 $h_{CO_2,10}$ (Btu/lb mol) = Enthalpy of carbon dioxide at Point 10 on Fig. 1 (obtain from gas property tables).

5.2.1.1.2.4 $h_{CO_2,R}$ (Btu/lb mol) = Enthalpy of carbon dioxide at the reference conditions (see Par. 4.9, obtain from gas property tables).

In similar manner the enthalpies for the other flue gas constituents can be computed with the exception of water vapor which shall be determined as the enthalpy of water vapor at one (1) psia and t_{10}. The reference enthalpy of moisture (h_{mR}) is the saturated liquid enthalpy at t_{RA}.

5.2.1.1.3 $Q_{\beta e}$ (Btu/hr) = Heat output due to radiation and convection (see Par. 4.8.3.).

$Q_{\beta e} = Q_{\beta e_1} + Q_{\beta e_2} - - - Q_{\beta en}$ = The heat output due to radiation and convection is the sum of the heat transferred to the surroundings outside the system boundary from the various incinerator system surfaces.

$Q_{\beta en} = u_{\beta n} \alpha_n (t_n - t_A)$

$Q_{\beta en}$ (Btu/hr) = Heat transfer by radiation and convection to the surroundings outside the system boundary from the incinerator system surface n.

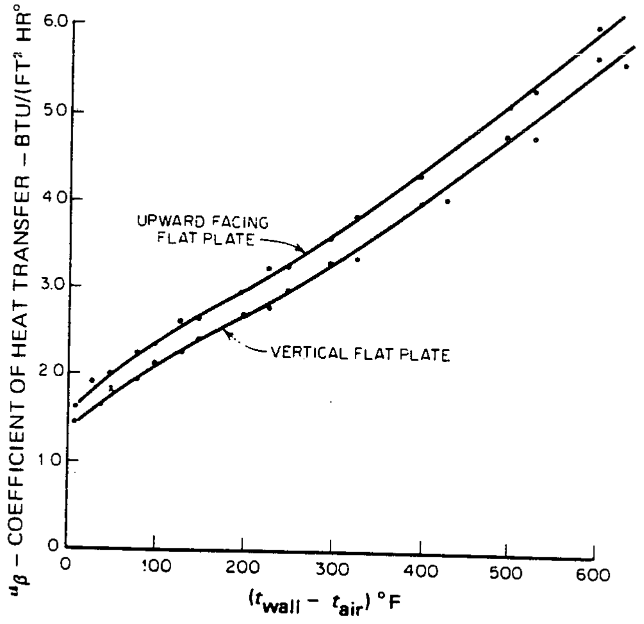
$u_{\beta n}$ (Btu/hr ft^2 °F) = Coefficient of heat transfer from incinerator system surface n. This value is determined from Fig. 4.

α_n (ft^2) = Area of incinerator system surface n.

t_n (°F) = Average temperature of surface n (see Par. 4.8.3).

t_A (°F) = Average ambient temperature to which incinerator surface heat is transferred.

COMBINED CONVECTION AND RADIATION HEAT TRANSFER COEFFICIENT



The literature of heat transfer carries many experimental correlations of heat transfer similar to that experienced by an incinerator surface. This graph is a plot of at least two of the more popular equations for this type of heat transfer. This equivalent combined radiation and convection film coefficient of heat transfer for natural convection in parallel action with radiation was calculated and plotted by assuming an ambient temperature of 70° F, an emissivity of 0.9 and that the heated surface giving up the heat is enclosed in a building. If the surface is outside and subject to varying wind velocity, these values would be modified.

FIG. 4

5.2.1.1.4 Q_{Pe} (Btu/hr) = Sensible heat output of residue and grate siftings. This calculation assumes combined grate siftings and residue; if they are not combined, use Point 23 on Fig. 1 and compute separately.

$Q_{Pe} = Q_{P'e} + Q_{mPe}$

$Q_{P'e}$ (Btu/hr) = Sensible heat output to dry residue and grate sifting.

$Q_{P'e}$ (Btu/hr) = $W_{P'e}(c_{pP'})(t_{P,17} - t_{RA})$

$W_{P'e}$ (lb/hr) = Weight rate of dry residue.

$W_{P'e} = (1 - m_P)\, W_{Pe}$

m_P (lb/hr) = Pounds of moisture per pound of wet residue from laboratory analysis.

W_{Pe} (lb/hr) = Weight rate of wet residue.

$c_{pP'}$ (Btu/lb°F) = Specific heat of dry residue, use 0.2 (see Appendix Par. 7.1).

$t_{P,17}$ (°F) = Temperature of residue after quenching.

t_{RA} (°F) = The reference temperature to which sensible heat losses and credits are compared for efficiency computations (see Par. 4.9).

Q_{mPe} (Btu/hr) = Sensible heat output of residue and grate siftings moisture.

Q_{mPe} (Btu/hr) = $W_{mPe}(c_{pm})(t_{P,17} - t_{RA})$

W_{mPe} (lb/hr) = Weight rate of residue moisture.

$W_{mPe} = W_{Pe} m_P$

W_{Pe} (lb/hr) = Weight rate of wet residue.

m_P (lb/hr) = Pounds of moisture per pound of wet residue from laboratory analysis.

c_{pm} (Btu/lb °F) = Specific heat of water; use 1.0.

$t_{P,17}$ (°F) = Temperature of residue after quenching.

t_{RA} (°F) = The reference temperature to which sensible heat losses and credits are compared for efficiency computations (see Par. 4.9).

5.2.1.1.5 Q_{de} (Btu/hr) = Sensible heat output in collected flue dust and stack exit dust.

$Q_{de} = Q_{d,20e} + Q_{d,21e} + Q_{d,22e} + Q_{d,10e}$

$Q_{d,20e}$: $Q_{d,21e}$: $Q_{d,22e}$ (Btu/hr) = Sensible heat in the collected flue dust (see Fig. 1).

5.2.1.1.5.1 $Q_{d,20e}$ (Btu/hr) = $Q_{d',20e} + Q_{md,20e}$

$Q_{d',20e}$ (Btu/hr) = Sensible heat in dry hopper dust at Point 20.

$Q_{d',20e}$ (Btu/hr) = $W_{d',20e}(c_{pd'})(t_{d,20} - t_{RA})$

$W_{d',20e}$ (lb/hr) = Weight of dry dust at Point 20.

$W_{d',20e} = (1 - m_{d,20})\, W_{d,20e}$

$m_{d,20}$ (lb/lb) = Pounds of moisture per pound of wet flue dust from laboratory analysis.

$W_{d,20e}$ (lb/hr) = Weight rate of wet flue dust.

$c_{pd'}$ (Btu/lb °F) = Specific heat of dry dust; use 0.2 (see Appendix 1 Par. 7.1).

$t_{d,20}$ (°F) = Temperature of wet dust.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

$Q_{md,20e}$ (Btu/hr) = Sensible heat of the moisture of wet hopper dust at Point 20

$Q_{md,20e}$ (Btu/hr) = $W_{md,20e}(c_{pm})(t_{d,20} - t_{RA})$

$W_{md,20e}$ (lb/hr) = Weight rate of moisture in flue dust.

$W_{md,20e} = m_{d,20} W_{d,20e}$

See above for $m_{d,20}$ and $W_{d,20e}$

c_{pm} (Btu/lb °F) = Specific heat of water; use 1.0.

See above for $t_{d,20}$ and t_{RA}

Note: Same calculation applies to $Q_{d,21e}$ and $Q_{d,22e}$

5.2.1.1.5.2 $Q_{d,10e}$ (Btu/hr) = Sensible heat in stack exit dust (see Fig. 1).

$Q_{d,10e}$ (Btu/hr) = $Q_{d'10e} + Q_{md,10e}$

Where:

$Q_{d',10e}$ (Btu/hr) = Sensible heat in dry stack dust at Point 10.

$Q_{d',10e}$ = $W_{d'10e}(c_{pd'})(t_{d10} - t_{RA})$

Where:

$W_{d',10e}$ (lb/hr) = Weight rate of dry stack dust measured at Point 10, Fig. 1 (see PTC 38).

$c_{pd'}$ (Btu/lb °F) = Specific heat of dry dust; use 0.2 (see Appendix 1 Par. 7.1).

$t_{d,10}$ (°F) = Temperature of dry stack dust at Point 10.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

$Q_{md,10e}$(Btu/hr) = Sensible heat in the stack dust moisture at Point 10, Fig. 1.

$Q_{md,10e}$(Btu/hr) = $W_{md,10e}(c_{pm})(t_{d,10} - t_{RA})$

Where:

$W_{md,10e}$ (lb/hr) = Weight rate of moisture in stack dust as determined by methods of PTC 38.

c_{pm}(Btu/lb °F) = Specific heat of water; use 1.0.

$t_{d,10}$ (°F) = Temperature at Point 10, Fig. 1.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.2.1.1.6 Q_{we} (Btu/hr) = Heat removed by cooling water.

$Q_{we} = Q_{w,14e} + Q_{w16e} + Q_{w,19e}$

Where:

$Q_{w,14e}$ (Btu/hr) = Sensible heat gain in charge chute cooling water at Point 14, Fig. 1 or a similar application.

$Q_{w,14e}$ (Btu/hr) = $W_{w,14e}(c_{pw})(t_{w,14} - t_{w,13})$

Where:

$W_{w,14e}$ (lb/hr) = Charge chute or a similar cooling water flow rate.

c_{pw} (Btu/lb °F) = Specific heat of water, use 1.0.

$t_{w,14}$ (°F) = Temperature of water at Point 14.

$t_{w,13}$ (°F) = Temperature of water at Point 13.

Note: Similar calculations apply to $Q_{w,16e}$ and $Q_{w,19e}$. Outlet water flows are used because the water evaporated is included with stack gases and a correction is required (see Par. 5.2.1.2.5.7). Where air quenching is employed, the heat absorbed is accounted for with the flue gas heat.

5.2.1.2 Q_{in_e} (Btu/hr) = Input-Heat content of material entering the system boundary. This is the thermal capacity of the incineration system.

where:

$$Q_{\text{in}_e} = H_r W_{re} + H_f W_{fe} + \Sigma B_e$$

5.2.1.2.1 H_r (Btu/lb) = Heating value of "As Fired" waste determined by a laboratory analysis following sampling and analysis procedures set forth in Pars. 4.3.3, and 4.4.

5.2.1.2.2 W_{re} (lb/hr) = "As Fired" waste charging rate; determined per Par. 4.3.2.

5.2.1.2.3 H_f (Btu/lb) = Heating value of supplementary fuel determined by laboratory analysis per ASME Performance Test Code Series on Fuels (PTC 3).

5.2.1.2.4 W_{fe} (lb/hr) = Supplementary fuel firing rate; determined per Par. 4.7.

5.2.1.2.5 ΣB_e (Btu/hr) = Heat credits to the system are those amounts of heat entering the system boundary other than the "As Fired" HHV of the waste anc supplementary fuel (see Par. 1.4.5).

Where:

$$\Sigma B_e = B_{r'e} + B_{mre} + B_{fe} + B_{ze} + B_{A'e} + B_{mAe} + B_{we}$$

5.2.1.2.5.1 $B_{r'e}$ (Btu/hr) = Dry waste sensible heat credit.

$$B_{r'e} = W_{r'e}(c_{pr'})(t_1 - t_{RA})$$

If "As Fired" waste is at the reference temperature credit is 0.

$W_{r'e}$ (lb/hr) = Weight rate of dry waste charged.

$$W_{r'e} = W_{re}(1 - m_r)$$

W_{re} (lb/hr) = Weight rate of "As Fired" waste; determined per Par. 4.3.2.

m_r (lb/lb) = Moisture in "As Fired" waste from laboratory analysis.

$c_{pr'}$ (Btu/lb °F) = Average specific heat of dry waste, use 0.3 (see Appendix Par. 7.2).

t_1 (°F) = "As Fired" waste temperature.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.2.1.2.5.2 B_{mre} (Btu/hr) = Heat credit of moisture in waste.

$$B_{mre} = m_r (W_{re})(h_{w,1} - h_{Rw})$$

If waste temperature is at the reference temperature, credit is 0.

m_r (lb/lb) = Moisture in waste from laboratory analysis.

W_{re} (lb/hr) = "As Fired" waste charging rate (see Par. 4.3.2).

$h_{w,1}$ (Btu/lb) = Enthalpy of liquid (moisture) in waste at the waste input temperature.

h_{Rw} (Btu/lb) = Enthalpy of saturated liquid (moisture) in waste at the reference temperature.

5.2.1.2.5.3 B_{fe} (Btu/hr) = Supplementary fuel sensible heat credit. Follow procedure outlined in ASME PTC 4.1, Pars. 4.02 through 4.9 and Par. 7.2.8.3.

$$B_{fe} = W_{fe}(c_{pf})(t_{f4} - t_{RA}) \text{ or } W_{fe}(c_{pf})(t_{f3} - t_{RA})$$

Where:

W_{fe} (lb/hr) = Supplementary fuel firing rate; determined as per Par. 4.7.

c_{pf} (Btu/lb °F) = Specific heat of supplementary fuel (see ASME PTC 4.1, Fig. 4 or 5).

t_{f3} or t_{f4} (°F) = Supplementary fuel inlet temperature.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.2.1.2.5.4 B_{ze} (Btu/hr) = Atomizing steam sensible heat credit.

$$B_{ze} = W_{ze}(h_{s,24} - h_{Rv})$$

Where:

W_{ze} (lb/hr) = Atomizing steam flow determined by methods presented in ASME Research Publication: Fluid Meters – Their Theory and Application.

$h_{s,24}$ (Btu/lb) = Enthalpy of inlet atomizing steam.

h_{Rv} (Btu/lb) = Enthalpy of saturated vapor at reference conditions (t_{RA} and 1 psia, see Par. 4.9).

5.2.1.2.5.5 $B_{A'e}$ (Btu/hr) = Heat credit supplied by dry entering air.

$$B_{A'e} = W_{A'e}(c_{pA'})(t_{A5} - t_{RA})$$

Note: This credit calculation may not be justified if t_{A5} is reasonably close to the reference temperature (t_{RA}) making the value of this credit negligible.

Where:

$W_{A'e}$ (lb/hr) = Dry air flow rate may be determined from the following: Par. 4.8.2.1.3; PTC 38, Par. 1.22, 3.5, 4.4 and PTC 4.1, Par. 5.10.

or

$W_{A'e} = W_{A'rf}(W_{re} + W_{fe})$

$W_{A'rf}$ (lb/lb) = Dry air entering system per pound of combined "As Fired" waste and supplementary fuel.

$$W_{A'rf} = \frac{1}{0.7685}\left\{\left[\frac{28.02\,(N_2')\left(C_{brf} + \frac{12.01}{32.07}S_{rf}\right)}{12.01\,(CO_2' + CO')}\right] - N_{rf}\right\}$$

This equation is based upon the derivation presented in Appendix Par. 7.4.

N_2' (% by volume) = Nitrogen in the dry gas.

CO_2' (% by volume) = Carbon dioxide in the dry gas.

CO' (% by volume) = Carbon monoxide in the dry gas.

See Par. 5.2.1.1.2.2 – from Orsat or equivalent analysis.

C_{brf} (lb/lb) = Pounds of carbon burned per pound of combined "As Fired" waste and supplementary fuel.

$C_{brf} = C_{rf} - C_i$

C_{rf} (lb/lb) = Pounds of carbon per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis determine the carbon in both the "As Fired" waste and the supplementary fuel and combine these values in proportion to their flows.

C_i (lb/lb) = Pounds of unburned carbon in the total residue including flue dust per pound of combined "As Fired" waste and supplementary fuel.

S_{rf} (lb/lb) = Pounds of sulfur per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis (similar to C_{rf} above).

N_{rf} (lb/lb) = Pounds of nitrogen per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis (similar to C_{rf} above).

W_{re} (lb/hr) = "As Fired" waste charging rate (see Par. 4.3.2).

W_{fe} (lb/hr) = Supplementary fuel firing rate (see Par. 4.7).

$c_{pA'}$ (Btu/lb °F) = Specific heat of dry air (see PTC 4.1, Fig. 3) or use 0.24.

t_{A5} (°F) = Temperature of dry air at Point 5.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.2.1.2.5.6 B_{mAe} (Btu/hr) = Sensible heat credit in air moisture.

$$B_{mAe} = m_A (W_{A'e})(h_{s,5} - h_{Rv})$$

Where:

m_A (lb/lb) = Pounds of water vapor per pound of dry air from psychrometer readings at location 5 and psychrometric charts.

$W_{A'e}$ (lb/hr) = Pounds of dry air supplied per hour (see Par. 5.2.1.2.5.5 above).

h_{s5} (Btu/lb) = Enthalpy of water vapor at inlet air conditions estimated as enthalpy of saturated water vapor at t_5 and 1 psia.

h_{Rv} (Btu/lb) = Enthalpy of saturated water vapor at t_{RA} and 1 psia. (See Par. 4.9.)

5.2.1.2.5.7 B_{we} (Btu/hr) = Credit for evaporated water (adjusting inlet water temperature to reference temperature).

$$B_{we} = B_{w,2e} + B_{w,13e} + B_{w,15e} + B_{w,18e}$$

To illustrate this computation the residue quench water evaporated will be used.

$B_{w,15e}$ (Btu/hr) = Sensible heat credit in water evaporated in quench tank and removed with the residue.

$$B_{w,15e} = (W_{w,15e} - W_{w,16e})(h_{w,15} - h_{Rw})$$

$(W_{w,15e} - W_{w,16e})$ = The moisture evaporated into the furnace and removed with residue when using a closed quench system. This must be modified for other systems.

$W_{w,15e}$(lb/hr) = Measured weight rate of cooling water to quench tank, Point 15.

$W_{w,16e}$ (lb/hr) = Measured weight rate of cooling water from quench tank, Point 16.

$h_{w,15}$ (Btu/lb) = Enthalpy of entering cooling water at Point 15.

h_{Rw} (Btu/lb) = Enthalpy of water at t_{RA} (see Par. 4.9).

5.3 Efficiency by Heat Balance Method (Refer Fig. 3 and Par. 4.10)

$$\eta = \left[1 - \frac{\Sigma L}{Q_{in}}\right] \times 100 = \left[1 - \frac{\Sigma L}{H_r + H_f(W_{fe}/W_{re}) + \Sigma B}\right] \times 100$$

Where

η (%) = Efficiency

5.3.1

ΣL (Btu/lb) = Total heat loss from the incinerator due to unburned organic combustibles leaving the system per pound of "As Fired" waste.

$\Sigma L = L_{Ci} + L_{G'}$

L_{Ci} (Btu/lb) = Chemical heat loss in the solid residue per pound of "As Fired" waste (see Par. 4.10.1.2).

5.3.1.1

$L_{Ci} = W_{P'} H_{P'}$

$W_{P'}$ (lb/lb) = Weight of total dry residue, including pit residue, grate siftings, flue dust and stack dust per pound of "As Fired" waste.

5.3.1.1.1 $W_{P'} = W_{P'e}/W_{re}$

$W_{P'e}$ (lb/hr) = Rate of total dry residue produced per hour.

$W_{P'e} = (1 - m_P) W_{Pe}$

m_P (lb/lb) = Moisture in total residue computed by properly proportioning and combining the various laboratory moistures determined by the weight rate of pit residue, grate siftings, flue dust and stack dust.

W_{Pe} (lb/hr) = Total rate of wet residue per hour from the residue pit, grate siftings and flue dust plus the stack dust (see Pars. 4.8.4, 4.8.4.3, 4.8.4.4, and 4.8.4.5).

W_{re} (lb/hr) = Rate of "As Fired" waste charged per hour determined per Par. 4.3.2.

$H_{P'}$ (Btu/lb) = Chemical heat in the total dry solid residue per pound computed by proportioning the various laboratory heating value determinations by the weight rate of pit residue, grate siftings, flue dust and stack dust (see Par. 4.10.1.2.1).

5.3.1.2

$L_{G'}$ (Btu/lb) = Chemical heat loss in dry flue gas.

$L_{G'} = (L_H + L_{HC})^* + L_{CO} = 2L_{CO}$

L_H (Btu/lb) = Chemical loss due to hydrogen in dry flue gas.

L_{HC} (Btu/lb) = Chemical loss due to hydrocarbons in dry flue gas.

(*See Par. 4.10.1.1)

5.3.1.2.1 L_{CO} (Btu/lb) = Chemical loss due to the formation of carbon monoxide per pound of "As Fired" waste. Where it is determined that CO is present in the flue gas and cannot be eliminated by operating adjustments, the loss is computed by either of the following procedures:

5.3.1.2.1.1

PROCEDURE I – CARBON MONOXIDE LOSS DETERMINATION

$$L_{CO} = \frac{V_{COe} \times 322}{W_{Re}}$$

Where:

$$V_{COe}\,(\text{Std ft}^3/\text{hr}) = V_{G'e}\,\frac{CO}{100}$$

$V_{G'e}$ (ft^3/hr) = The volumetric flow of the dry flue gas. This can be determined by either of two methods. The method selected will depend on the accuracy and availability of the required data.

METHOD A

$V_{G,10e}'$ (ft^3/hr) = The flow in standard cubic feet per hour of the dry flue gas at Point 10.*

$$V_{G,10e}' = W_{G,10e}'\left(\frac{R_u}{M_{G,10}'}\right)\frac{528}{(144)\,(14.7)} = W_{G,10e}'\left(\frac{385.4}{M_{G,10}'}\right)$$

$W_{G,10e}'$ (lb/hr) = Pounds of dry gas flow at Point 10 (see Par. 5.2.1.1.2.1).

R_u (ft lb/mol °R) = 1545 Universal Gas constant.

528 (°R) = Absolute temperature at which gas heating value was determined.

M_G' (lb/lb mol) = Molecular weight of the dry flue gas.

$$M_G' = (44.01\,CO_2' + 32.00\,O_2' + 28.01\,CO' + 28.02\,N_2')\,\frac{1}{100}$$

CO_2'; O_2'; CO'; and N_2' in percent by volume from Orsat or equivalent analysis of flue gas at Point 10.

144 = Square inches per square foot.

14.7 (lb/in.^{2}) = Absolute pressure at which gas heating value was determined.

METHOD B

$V_{G,10e}'$ (ft^3/hr) = Dry flue gas flow at Point 10.*

$$V_{G,10e}' = 3600\,U_{G,10}\,\alpha_{10}\left(\frac{528}{T_{10}}\right)\left(1 - \frac{V_m}{100}\right)$$

3600 = Number of seconds per hour.

$U_{G,10}$ (ft/sec) = Duct velocity (Point 10 by measurement; see Par. 4.8.2.1 and PTC 38).

α_{10} (sq ft) = Duct internal cross-sectional area at Point 10.

528 (°F) = Absolute temperature at which gas heating value was determined.

T_{10} (°F) = Absolute temperature at Point 10.

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*May be Point 7, 8 or 10 – as the specific system indicates for best results.

V_m (%) = Percent by volume of moisture in flue gas (see Pars. 4.8.2.2 and 5.2.1.1.2.1).

CO (%) = Volume of CO in the dry flue gas determination by continuous analyzer (see Par. 4.10.1.3).

322 (Btu/Std ft^3) = Approximate heat content of carbon monoxide at 68°F and 1 atm.

W_{Re} (lb/hr) = "As Fired" waste charging rate (see Par. 4.3.2).

5.3.1.2.1.2

PROCEDURE II – CARBON MONOXIDE LOSS DETERMINATION

L_{CO} (Btu/lb) = Chemical heat loss due to the formation of carbon monoxide per pound of "As Fired" waste.

Where it is determined that CO is present in the flue gas and cannot be eliminated by operating adjustments, the loss may be computed as follows:

Where:

L_{CO} = 4347 W_{CO}

4347 (Btu/lb) = Heat released when burning one pound of CO to CO_2.

W_{CO} (lb/lb) = Weight of CO in the flue gas per pound "As Fired" waste.

$$W_{CO} = \frac{28.01\,(CO')}{12.01\,(CO_2{}' + CO')}\left(C_{brf} + \frac{12.01}{32.07}\,S_{rf}\right)\left[1 + \frac{W_{fe}}{W_{re}}\right]$$

This equation involves the same assumption and follows the same derivative procedures presented in Appendix Par. 7.4.

Where:

CO' (%) = Volume of carbon monoxide in the dry gas (see Par. 4.10.1.3).

$CO_2{}'$ (%) = Volume of carbon dioxide in the dry gas by Orsat or equivalent analysis.

C_{brf} (lb/lb) = Pounds of carbon burned per pound of combined "As Fired" waste and supplementary fuel (see Par. 5.2.1.2.5.5).

C_{brf} = $C_{rf} - C_i$

C_{rf} (lb/lb) = Pounds of carbon per pound of combined "As Fired" waste and supplementary fuel. This value is computed from laboratory analysis of the carbon in both the "As Fired" waste and the supplementary fuel and combining these values in proportion to their flows.

C_i (lb/lb) = Pounds of unburned carbon in the total dry residue per pound of combined "As Fired" waste and supplementary fuel. It is computed by proportioning the various laboratory carbon determinations by the weight rate of pit residue, grate siftings, flue dust and stack dust.

S_{rf} (lb/lb) = Pounds of sulfur per pound of combined "As Fired" waste and supplementary fuel computed in a manner similar to C_{rf} above.

W_{fe}/W_{re} = Ratio of the weight rate of supplementary fuel fired to weight rate of "As Fired" waste (see Pars. 4.3.2 through 4.7).

5.3.2

Q_{in} (Btu/lb) = Input-Heat content of material entering the system boundary per pound of "As Fired" waste charged.

Q_{in} $= H_r + H_f \dfrac{W_{f_e}}{W_{r_e}} + \Sigma B$

5.3.2.1

H_r (Btu/lb) = Higher heating value of the "As Fired" waste; determined per Pars. 4.3.3, 4.4, 4.5 and 4.6.

5.3.2.2

H_f (Btu/lb) = Higher heating value of supplementary fuel; determined per ASME Performance Test Code Series on Fuels, PTC 3.

5.3.2.3

W_{fe}/W_{re} = Ratio of the weight rate of supplementary fuel fired to weight rate of "As Fired" waste (see Pars. 4.3 through 4.7).

5.3.2.4

ΣB (Btu/lb) = Total heat credits added to the incinerator system per pound of "As Fired" waste.

ΣB $= B_{r'} + B_{mr} + B_f + B_z + B_{A'} + B_{mA} + B_w$

Where:

5.3.2.4.1

B_r' (Btu/lb) = Dry waste sensible heat credit per pound of "As Fired" waste.

$B_{r'}$ $= W_{r'} (c_{pr'})(t_1 - t_{RA})$

W_r' (lb/lb) = Pounds of dry waste charged per pound of "As Fired" waste.

W_r' $= (1 - m_r)$

m_r (lb/lb) = Pounds of moisture per pound of "As Fired" waste (from laboratory analysis).

c'_{pr} (Btu/lb °F) = Average specific heat of dry waste use 0.3 (see Appendix Par. 7.2).

t_1 (°F) = Temperature of waste at Point 1.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.3.2.4.2

B_{mr} (Btu/lb) = Sensible heat credit in waste moisture per pound of moisture in "As Fired" waste.

B_{mr} $= m_r (h_{w,1} - h_{Rw})$

Where:

m_r (lb/lb) = Moisture in the "As Fired" waste from laboratory analysis.

$h_{w,1}$ (Btu/lb) = Enthalpy of water (moisture) in the "As Fired" waste.

h_{Rw} (Btu/lb) = Enthalpy of water (moisture) at the reference temperature (t_{RA}); see Par. 4.9.

5.3.2.4.3

B_f (Btu/lb) = Supplementary fuel sensible heat credit per pound of "As Fired" waste. Follow procedures outlined in ASME PTC 4.1, Sections 4.2 through 4.9.

B_f $= W_f (c_{pf}) (t_{f4} - t_{RA})$ or $W_f (c_{pf}) (t_{f3} - t_{RA})$

Where:

W_f (lb/lb) = Pounds of supplementary fuel fired per pound "As Fired" waste.

W_f = W_{fe}/W_{re}

W_{fe}/W_{re} = Ratio of the weight rate of supplementary fuel fired to the weight rate of "As Fired" waste (see Par. 5.3.1.2.1.2).

c_{pf} (Btu/lb °F) = Specific heat of supplementary fuel; see ASME PTC 4.1 Fig. 4 or 5 for oil and gas and use 0.3 for coal.

t_{f3} or t_{f4} (°F) = Supplementary fuel inlet temperatures.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

5.3.2.4.4

B_z (Btu/lb) = Atomizing steam sensible heat credit per pound of "As Fired" waste.

$$B_z = \frac{W_{ze}}{W_{re}} (h_{s,24} - h_{Rv})$$

W_{ze}/W_{re} = Ratio of the weight rate of atomizing steam to the weight rate of "As Fired" waste.

$h_{s,24}$ (Btu/lb) = Enthalpy of inlet steam.

h_{Rv} (Btu/lb) = Enthalpy of saturated vapor at t_{RA} and 1 psia (see Par. 4.9).

5.3.2.4.5

$B_{A'}$ (Btu/lb AF waste) = Heat supplied by dry entering air credit per pound of "As Fired" waste.

$$B_{A'} = W_{A'rf} (c_{pA'})(t_{A5} - t_{RA})(1 + W_f)$$

$W_{A'rf}$ (lb/lb) = Weight of dry air per pound of combined "As Fired" waste and supplementary fuel.

$$W_{A'rf} = \frac{1}{0.7685}\left\{\left[\frac{28.02 (N_2')\left(C_{brf} + \frac{12.01}{32.07} S_{rf}\right)}{12.01 (CO_2' + CO')}\right] - N_{rf}\right\}$$

N_2' (%) = Volume of nitrogen in the dry gas

CO_2' (%) = Volume of carbon dioxide in the dry gas

CO' (%) = Volume of carbon monoxide in the dry gas

} From Orsat or equivalent analysis.

C_{brf} (lb/lb) = Pounds of carbon burned per pound of combined "As Fired" waste and supplementary fuel.

C_{brf} = $C_{rf} - C_i$

C_{rf} (lb/lb) = Pounds of carbon per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis determine the carbon in both the "As Fired" waste and supplementary fuel and combine these values in proportion to their flows.

C_i (lb/lb) = Pounds of unburned carbon in the total residue including flue dust per pound of combined "As Fired" waste and supplementary fuel.

S_{rf} (lb/lb) = Pounds of sulfur per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis determine the sulfur in both the "As Fired" waste and supplementary fuel and combine these values in proportion to their flow rates.

N_{rf} (lb/lb) = Pounds of nitrogen per pound of combined "As Fired" waste and supplementary fuel. By laboratory analysis determine the nitrogen in both the "As Fired" waste and supplementary fuel and combine these values in proportion to their flow rates.

$c_{pA'}$ (Btu/lb °F) = Specific heat of the dry air (see PTC 4.1, Fig. 3 or use 0.24).

t_{A5} (°F) = Temperature of dry air at Point 5.

t_{RA} (°F) = Reference temperature (see Par. 4.9).

W_f (lb/lb) = Pounds of supplementary fuel fired per pound of "As Fired" waste (see Par. 5.3.2.4.3).

5.3.2.4.6

B_{mA} (Btu/lb) = Heat credit supplied by the moisture in entering air per pound of "As Fired" waste.

$B_{mA} = m_A\,(W_{A'rf})(h_{s5} - h_{Rv})(1 + W_f)$

Where:

m_A (lb/lb) = Pounds of water vapor per pound of dry air from psychrometer readings at location 5 and psychrometric charts.

$W_{A'rf}$ (lb/lb) = Pounds of dry air supplied per pound of combined "As Fired" waste and supplementary fuel (see Par. 5.3.2.4.5).

h_{s5} (Btu/lb) = Enthalpy of water vapor at inlet air conditions estimated as enthalpy of saturated water vapor at t_5 and 1 psia.

h_{Rv} (Btu/lb) = Enthalpy of saturated water vapor at t_{RA} and 1 psia (see Par. 4.9).

W_f (lb/lb) = Pounds of supplementary fuel fired per pound of "As Fired" waste (see Par. 5.3.2.4.3).

5.3.2.4.7

B_w (Btu/lb) = Evaporated water credit per pound of "As Fired" waste.

B_w (Btu/lb) $= B_{we}/W_{re}$

B_{we} (Btu/hr) = Credit for evaporated water per hour (adjusting inlet temperature of evaporated water to reference temperature – see Par. 5.2.1.2.5.7).

W_{re} (lb/hr) = Pounds of "As Fired" waste charged; determined per Par. 4.3.2.

5.4 Corrections to Standard or Design Conditions

Correction to heat credits and outputs.

5.4.1

Corrections to standard or design conditions are made by substituting the standard temperature, or design temperature, for the test reference temperature (t_{RA}) in all applicable equations.

Input-Output Method

The substitution is made in both the output equation (Par. 5.2.1.1) and the total heat credit equation (Par. 5.2.1.2.5). Substitute the recomputed values in the efficiency equation (Par. 5.2.1) and determine the standard or design efficiency.

Heat Balance Method

The substitution is made in the total heat credit equation (Par. 5.3.2.4). Substitute the recomputed value in the efficiency equation (Par. 5.3) and determine the standard or design efficiency. This standard, or design, efficiency allows a comparison with the test efficiency.

SECTION 6, REPORT OF RESULTS

The purpose of this section is to provide a convenient form for the reporting of test results. It is not intended to serve as a guide for determining the readings that should be taken. Some incidental readings which have no particular significance but which may be necessary for the computations, have been omitted. These data may be included, or other data added, if desired. The section is divided under headings which make it convenient for selecting those groups of items which are applicable. Standardization of forms is of great convenience to those who study or use reports. It is, therefore, recommended that this section be used with as few modifications as possible.

6.1 General Information

Date
Plant Designation and Location
Unit Designation
Owner
System Designer
Responsible Contractor
Description of Equipment (including boundary diagram)
Test Engineer (including affiliation)
Observers
Object of Test

6.2 Operating Conditions

The complete test report shall contain a general description of relative conditions at the time of the test. These conditions shall be set down in an operational log. This log shall contain data sheets plus normal and special observations with measurements taken during the test.

6.2.1 Test Log Form

The operational log shall contain, but shall not be limited to the following:

6.2.1.1 Waste characteristics and preparation, general description of the waste and special preparation necessary for this test. Record any unusual variation in waste composition and metallic oxidation factor (if used).

6.2.1.2 Ambient Conditions

(a) Temperature
(b) Relative humidity
(c) Barometric pressure
(d) General description of test conditions

6.2.1.3 Supplementary Fuel

(a) Type
(b) Method of introduction
(c) Heating value

6.2.1.4 Duration of Test

(a) Time and date of start of test
(b) Time and date of finish of test

6.2.1.5 Unusual Conditions

Any deviation or inconsistencies in the normal operating conditions should be recorded.

6.2.1.6 Stabilization Period

(a) Conditions observed – flame pattern, grate loading, gas temperatures, feed rate, steaming rate, etc.
(b) Length of time between the establishment of stabilized test conditions and start of the test.

6.2.1.7 Personnel

Record the names of key testing and operating personnel with their duties.

6.2.2 Normal Plant Operating Logs

During the normal operating periods, the plant personnel usually compiles a day-to-day log. These logs should be photocopied and added to the test log.

6.2.3 Statement on General Conditions

A statement of general over-all conditions prior to, during and after the test should be recorded. Any changes in these conditions including the recorder's own reflections of the conditions and operational status of the plant shall be detailed.

6.3 Corrections

These are detailed in Par. 5.4.

6.4 Test Methods

The purpose of this section is to list the principal measurements required for the input-output and heat balance methods for determining the incinerator system efficiency and capacity.

6.4.1 Principal measurements required for incinerator efficiency by the input-output method.

6.4.1.1 Principal Measurements for Input and Capacity

Charging rate of waste at Point 1.
Waste sample "As Fired" at Point 1.

Supplementary fuel firing rate at Points 3 and/or 4.

Supplementary fuel sample "As Fired" at Points 3 and/or 4.

Temperature of "As Fired" waste fuel at Point 1.

Temperature of supplementary fuel at Points 3 and/or 4.

Atomizing steam flow at Point 24.

Atomizing steam conditions at Point 24.

Orsat analysis of flue gas at Points 7, 8 or 10 – as the specific system may indicate for best results.

Temperature of dry air at Point 5.

Temperature to be used as reference.

Wet bulb temperature at Point 5.

Dry bulb temperature at Point 5.

Temperature of cooling water at Points 2, 13, 15 and 18.

6.4.1.2 Principal Measurements for Output

Heat recovery fluid (PTC 4.1).

Flue gas velocity at Points 7, 8 or 10 – as the specific system may indicate for best results.

Flue gas temperature at Points 7, 8 or 10 – as the specific system may indicate for best results.

Flue area at Points 7, 8 or 10 – as the specific system may indicate for best results.

Orsat analysis at Points 7, 8 or 10 – as the specific system may indicate for best results.

Moisture in flue gas (4.8.2.2) at Points 7, 8 or 10 – as the specific system may indicate for best results.

Weight rate of residue at Point 17.

Temperature of residue at Point 17.

Sample of wet residue at Point 17.

Weight rate of grate siftings if collected separately at Point 23.

Temperature of siftings if collected separately at Point 23.

Sample of siftings at Point 23 if collected separately.

Weight rate of dust at Points 20, 21, 22 and 10.

Dust temperature at Points 20, 21, 22 and 10.

Dust samples at Points 20, 21, 22 and 10.

Cooling water rate of flow at Points 2, 14, 15, 16 and 19.

Temperature of water at Points 2, 13, 14, 15, 16, 18 and 19.

6.4.2 Principal measurements required for incinerator efficiency by the heat balance method.

Weight rate of pit residue at Point 17.

Weight rate of grate siftings at Point 23 if not combined with residue.

Weight rate of flue dust at Points 20, 21, 22 and 10.

Weight rate of "As Fired" waste at Point 1.

Laboratory sample of pit residue at Point 17.

Laboratory sample of grate siftings at Point 23 if not combined with residue.

Laboratory sample of flue dust at Points 20, 21, 22 and 10.

Laboratory sample of "As Fired" waste at Point 1.

Flue gas velocity at Points 7, 8 or 10 – as specific system may indicate for best results.

Flue gas temperature at Points 7, 8 or 10 – as specific system may indicate for best results.

Flue gas Orsat analysis for O_2, CO_2 at Points 7, 8 or 10 – as specific system may indicate for best results.

Flue gas CO measurement at Points 7, 8 or 10 – as specific system may indicate for best results. See Par. 4.10.1.3.

Measurement of cross-sectional area of flue at Points 7, 8 or 10 – as specific system may indicate for best results.

Temperature of "As Fired" waste charged at Point 1.

Weight rate of supplementary fuel fired at Points 3 and/or 4.

Temperature of supplementary fuel at Points 3 and/or 4.

Atomizing media flow and conditions at Point 24.

Dry and wet bulb temperature at Point 5.

Barometric pressure.

6.5 Agreements Prior to Test

Those conditions of test allowing for options and/or deviation from specified conditions must be agreed upon and recorded prior to test; refer to Par. 3.1 for the general items requiring such agreement.

This Test Code is based on combustion processes used in mass burning or suspension fired furnaces. The following thermal processes may result in conditions which require special test procedures and additional items of agreement beyond those indicated in this Code. This list is not intended to cover all possibilities.

6.6 Test Results

	Dimensional Units	Test Results	Corrected Test
1. Test Run No.			
2. Barometric Pressure			
3. Relative Humidity			
4. Ambient Temperature			
5. *Input*			
(a) Chemical Heat in "As Fired" Waste (H_r)			
(b) Chemical Heat in Suppl. Fuel (H_f)			
(c) Sensible Heat in "As Fired" Waste (B_r)			
(d) Sensible Heat in Suppl. Fuel (B_f)			
(e) Sensible Heat in Air (B_A)			
(f) Heat in Atomizing Fluid (B_z)			
(g) Heat Supplied by Moisture in Entering Air (B_{mA})			
(h) Sensible Heat in Cooling Water (B_w)			
(i) Total Input (Q_{in})			
6. *Output*			
(a) Heat Transfer to Recovery Fluid (Q_y)			
(b) Sensible Heat to Cooling Water (Q_w)			
(c) Sensible Heat in Flue Gas (Q_G)			
(d) Sensible Heat in Solid Residues (Q_P)			
(e) Sensible Heat in Collected and Stack Exit Dust (Q_d)			
(f) Radiation and Convection (Q_β)			
(g) Total Output (Q_{out})			
7. Losses			
(a) Chemical Heat Solid Residues (L_{ci})			
(b) Chemical Heat in Hydrogen (L_{H})			
(c) Chemical Heat in CO (L_{CO})			
(d) Chemical Heat in Hydrocarbons (L_{HC})			
(e) Total Losses (L)			
8. Efficiency (%)			
9. Capacity (Q_{in_e}) (see Par. 5.2.1.2)			

6.5 *(Continued)*

1. Gasification of waste (pyrolysis).
2. Combination of solid waste with wet-sludge drying and burning.
3. Combustion of solid waste in a high temperature reactor resulting in complete slagging of inert contents.
4. Fluidized bed burning.
5. Waste processing prior to burning.

This summary should compare design criteria with test results where appropriate.

6.7 Test Conclusions

Summary statement by the responsible test engineer indicating the efficiency, capacity, validity and circumstances surrounding or bearing upon the test.

6.8 Test Log and Computations

The complete test log and computations shall be attached to this report.

SECTION 7, APPENDIX

.1 Specific Heat of the Dry Residue

he suggested value for the specific heat of the dry lue in Btu per pound symbolized as ($c_{pP'}$) is derived e following manner.

ssume all of the residue has been dried and has a n temperature somewhere between 32° and 212° F. fixes the temperature range for the temperature itive specific heat ($c_{pP'}$). The specific heat of the residue is the sum of the specific heats of the stituents proportional to the quantity of each.

he dry residue is assumed to have the following position:

Organic constituents	=	5%
Ash, glass, limestone, ceramics, etc.	=	74%
Metallics other than aluminum	=	20%
Aluminum	=	1%

t is recognized that this is at best a rough estimate of residue composition which can vary substantially.

From various handbooks, the following specific heats e estimated for the temperature range of 32° to 212°F.

Organics	=	0.4 Btu/lb °F
Ash, glass, limestone, ceramics, etc.	=	0.2 Btu/lb °F
Metallics other than aluminum	=	0.1 Btu/lb °F
Aluminum	=	0.2 Btu/lb °F

idue	Specific Heat Btu/lb		Weight Fraction		Specific Heat Fraction
ganics	0.4	x	0.05	=	0.020
h, glass, lime-one, clay, etc.	0.2	x	0.74	=	0.148
tallic other than luminum	0.1	x	0.20	=	0.020
uminum	0.2	x	0.01	=	0.002
			Total	=	0.190
SPECIFIC HEAT OF THE DRY RESIDUE					Use 0.2

Actually, these are rough handbook values for an imated composition and must be treated as such. The ove, however, is the basis for the statement in the body the Code, Par. 5.2.1.1.4, "$c_{pP'}$ (Btu/lb °F) = the specific at of the dry residue which may be estimated as 0.2". attempt has been made to more accurately determine this value since it would not be valid. Therefore, if 0.2 is used no additional precision should be indicated such as 0.19 because this is essentially an estimate from handbook data and approximate quantities. However, the possible error introduced by the use of this estimate will usually be minimal.

7.2 Specific Heat of the Dry Waste

The suggested value for the specific heat of the dry waste ($c_{pr'}$) in Btu per pound per degree Fahrenheit was derived in the following manner.

Assume all of the waste has been dried and a mean temperature established somewhere between 32°F and 212°F, which fixes the temperature range for the temperature sensitive specific heats. The specific heat of the dry waste is the sum of the specific heats of the constituents proportioned to the quantity of each. The composition of dry, municipal solid waste has been diligently studied many times over the last ten years and numerous compositions offered. The composition presented here is that published by EPA's Office of Solid Waste Management Programs in its "Second Report to Congress on Resource Recovery and Source Reduction," Environmental Protection Agency Publication SW-122, dated 1974.

TABLE 1

WASTE COMPOSITION		PERCENT BY DRY WEIGHT
Paper Products		31.3
Glass		9.7
Metals	– Ferrous 8.6%	9.5
	– Aluminum 0.6%	
	– Other Non-Ferrous 0.3%	
Plastics		3.4
Rubber and Leather		2.6
Textiles		1.4
Wood		3.7
Food Waste		17.6
Yard Waste		19.3
Sand, Stone, Clay, Ash, etc.		1.5
	Total	100.0

It is recognized that the waste composition can vary substantially with time of year, geographic location and meteorological conditions, therefore, this is only an approximation.

From various handbooks, the following specific heats were obtained for the temperature range of

32°F - 212°F and incorporated with the composition given above to produce the dry specific heat fraction which totalled to slightly over 0.29 Btu per pound degree Fahrenheit.

TABLE 2

WASTE	DRY SPECIFIC HEAT (Btu/lb° F)		WEIGHT FRACTION		DRY SPECIFIC HEAT FRACTION
Paper Products	0.33	x	0.31	=	0.102
Glass	0.18	x	0.10	=	0.018
Metallics other than Aluminum	0.12	x	0.09	=	0.011
Aluminum	0.22	x	0.01	=	0.002
Plastics	0.36	x	0.03	=	0.010
Rubber and Leather	0.42	x	0.03	=	0.013
Textiles	0.35	x	0.01	=	0.004
Wood	0.33	x	0.04	=	0.013
Food Waste	0.30	x	0.18	=	0.054
Yard Waste	0.33	x	0.19	=	0.063
Ash. Clay, Sand, etc.	0.21	x	0.02	=	0.004
				Total	0.294
				Use 0.3	

The above is the basis for the statement in the body of the Code that "c_{pr}," (Btu/lb °F) equals the specific heat of the dry waste and is estimated as 0.3 Btu per pound °F. No attempt was made or is justified to more accurately determine this value. Actually, these are very rough values from an estimated composition and an approximate specific heat and they must be treated as such. Therefore, 0.3 is used and no additional accuracy should be implied, such as the use of 0.29 and 0.30. However, the possible error introduced by the use of this estimate will usually be minimal because the "heat credits" involved are very small and normally would not justify the expenditure required to obtain a more precise value. If a more precise value is warranted, it can be computed as illustrated above using a determined composition and the handbook quantities given.

7.3 Putrescible Matter Determination

METHOD A

General

The total of putrescible materials remaining in incinerator residue may be determined in the following manner once the laboratory sample has been collected and prepared in accordance with Pars. 4.8.4.2 and 4.8.4.2.1.

Fats	– Extraction with petroleum ether.
Carbohydrates	– Hydrolysis with acid followed by an oxidation-reduction reaction with Benedict solution.
Protein	– Decomposition to ammonium sulfate followed by Kjeldahl nitrogen.

A few comments may be in order to give a better understanding and evaluation of this particular approach to measuring those components in the residue that would lend themselves to putrescibility.

Lipids

By using a solvent extraction approach for an assay of those fats, fatty acids, fatty oils, waxes, etc., in the residue that might be prone to biological decomposition and putrescibility, one has good assurance that all such organics are separated and that other more stable compounds such as paraffin waxes, saturated oils, etc., might also be extracted and reported. Therefore, lipid results reported by this method are most apt to be higher than those that are in reality prone to putrescence.

Carbohydrates

The described method of hydrolyzing carbohydrates present by boiling with acid gives assurance of making available both the mono- and di-saccharides for analysis, but there is some question as to the extent that polysaccharides (such as cellulose) would be hydrolyzed so that they could be determined. Therefore, carbohydrates as determined by this technique may not be complete. However, from the point of view of establishing putrescible potential, the more complex polysaccharides such as cellulose would appear to be susceptible to extremely slow decomposition and therefore should not be classed as creating putrescence in the decomposition process.

Proteins

Since the approach to establishing a measurement of the proteins present is to determine the total nitrogen present and relate this value to protein material, any error in this result is apt to be on the high side by virtue of interpreting non-protein nitrogen present as proteins.

TEST PROCEDURES FOR LIPIDS[1]

Lipids (ether extractable substances) is a general term including such compounds as oils, greases, fats, and waxes.

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[1] Bell, John M., "Development of a Method for Sampling and Analyzing Refuse," Purdue University – 1963.

Equipment

Soxhlet extraction apparatus with 125 milliliter flasks; water bath or low temperature heaters; extraction thimbles (Whatman, 22 by 80 millimeters, fat extracted); distillate collector; drying oven; analytical balance; desiccating jar or cabinet.

Reagent

Petroleum ether (Benzine), boiling point 65-67°C.

Procedure

Transfer about 5 grams of prepared sample to an extraction thimble, obtaining sample weight indirectly to the nearest milligram. Obtain dry tare weight of extraction flask. Add about 80 milliliters of ether to the extraction flask, place thimble into extraction tube, and extract continuously in Soxhlet extractor for 4 to 6 hours. Extraction temperature should be regulated so that extraction tube discharges approximately every 3 minutes. Make up ether loss if necessary. Disconnect and evaporate ether from flask using the distillate collector and continue drying in oven for 2 hours at 70°C. Cool flask in desiccator and weigh.

Alternate Procedure

Same procedure as above except that the flask is not weighed. Instead, the initial dry tare weight of the extraction thimble is determined as well as the thimble plus its sample contents. At the completion of the extracting process, the thimble and contents are dried at 70°C to constant weight. The amount of lipids is determined as the loss in weight of the thimble and contents rather than the gain of weight of the extraction flask. This procedure is particularly useful when a large number of samples must be analyzed, since it does not tie up the use of the extraction flasks. Neither procedure was found to be more accurate than the other.

Calculation

$$\frac{100\ (\text{weight of ether extract})}{(\text{net dry weight of sample})} = \%\ \text{lipids}$$

While the value obtained is for ether extractable matter and includes all substances soluble in ether, it represents essentially the lipids content.

TEST PROCEDURE FOR CARBOHYDRATES[2]

Carbohydrates are a class of neutral substances containing carbon, hydrogen and oxygen with the hydrogen and oxygen in a 2:1 mol ratio. Carbohydrates are a major constituent of plants and include sugars, starches, etc. Chemically they are the aldehyde or ketone derivatives of polyhydric alcohols.

Equipment

(In addition to that required for lipids determination) 50 milliliter burette, 10 milliliter pipette, 100 milliliter Erlenmeyer flask, evaporating disc.

Reagents

Sodium carbonate crystals, 10% sulfuric acid, Benedict's reagent, powdered pumice or talcum.

Procedure

Weigh and transfer approximately one-half of the thimble residue from the lipid determination to a 100 milliliter Erlenmeyer flask. Add 25 milliliters of 10% sulfuric acid and boil 5 minutes. Filter, wash residual and dilute filtrate to 50 milliliters. Transfer to a 50 milliliter burette. Pipette 10 milliliters of Benedict's reagent into a porcelain evaporating dish, add 10 grams of crystalline sodium carbonate and a small amount of powdered pumice or talcum. Heat the mixture until the carbonate is dissolved. Titrate with the solution in the burette until a chalk white precipitate forms and the blue color of the reagent begins to fade. Cautiously approach the end point which is the disappearance of the blue color. The solution must be boiled during the titration. If the mixture becomes too concentrated during the process, water may be added to replace that lost by evaporation.

Calculation

$$\frac{0.020 \times 50}{\text{weight sample} \times \text{milliliter Soln}} = \%\ \text{carbohydrates}$$

Benedicts Reagent

Copper Sulfate	18.00 grams
Sodium Carbonate	100 grams
Sodium or Potassium Citrate	200 grams
Potassium Thiocyanate	125 grams
Potassium Ferrocyanide (5% Soln)	5 milliliters

Dissolve the carbonate, citrate and thiocyanate in. 800 ± 25 milliliters of water (filter if necessary). Dissolve the copper sulfate separately in 100 milliliters of water and pour this solution slowly into the other while stirring. Add the ferrocyanide, cool and dilute to exactly 1 liter. Twenty-five milliliters of this reagent are reduced by 50 milligrams of glucose.

CARBOHYDRATES PROCEDURE

The present procedure for the analysis of carbohydrates will assist in obtaining results, but it is a general description

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[2] These analyses were adapted from "Practical Physiological Chemistry" by P. B. Hawk and O. Bergeim, Blakiston Company, Philadelphia, Pennsylvania.

and for accurate results should be outlined in a more complete manner. The following comments are presented for consideration.

The sample weight should be large enough to insure reliable results. The amount of sample can be predetermined by the analyst using what knowledge of the sample is available, but at least one gram sample should be used. Weigh and transfer the sample to a 100 milliliter beaker, add 50 milliliters H_2O and adjust pH to 3.00 with 0.1 normal sulfuric acid, boil for five minutes. Fill a 50 milliliter burette with sample solution. Now put 10 milliliters Benedict reagent into a porcelain evaporating dish, add 5-10 milliliters reagent grade H_2O, add 10 grams of sodium carbonate. Heat until carbonate is dissolved. The Benedict reagent is now ready to be titrated with the sample solution. When titrating, approach the end point very cautiously. The fading of the blue color and appearance of a chalk white precipitate prevails, this is the end point. The solution must be boiling vigorously during titration. If the mixture becomes too concentrated, water may be added before continuing the titration; again, bring solution to boiling. Since the white precipitate end point is very slow in forming, it can easily be over titrated. It is suggested that duplicate samples be processed; this permits the first sample to establish the end point and the second to confirm the exact end point. If after titrating the total 100 milliliters of sample solution and no end point is reached, add a few crystals of dextrose to the boiling solution. If a white precipitate slowly forms with a fading disappearance of the blue color, this will insure the analyst that the Benedict reagent is working.

If the total 100 milliliters of the sample solution is used in titrating 10 milliliters of Benedict reagent and no end point is reached, it can be assumed that there is less than 0.02% carbohydrates in the residue sample.

TEST PROCEDURES FOR PROTEINS[2]

Proteins are an essential part of living protoplasm and together with fats and carbohydrates are the principal classes of organic foodstuffs. In addition to carbon, hydrogen and oxygen, proteins always contain nitrogen and frequently sulfur.

Equipment

500 milliliter Kjeldahl flask and a 2 liter wash bottle.

Reagents

Concentrated sulfuric acid, copper sulfate crystals, concentrated sodium hydroxide, 0.1 normal sodium hydroxide, 0.1 normal sulfuric acid.

Procedure

Place the remaining weighed half of the thimble residue from the lipid determination into a 500 milliliter long-necked Kjeldahl flask, add 20 milliliters concentrated sulfuric acid and about 0.2 grams of copper sulfate and digest the mixture for sometime after it is colorless (one hour). *Note:* Carry out in hood or fume absorber.

Allow flask to cool and dilute with 200 milliliters of ammonia-free water. Add a little more concentrated sodium hydroxide than is necessary to neutralize the excess sulfuric acid (check with litmus paper or phenolpthalein). Add a small amount of pumice to prevent bumping. By means of a safety-tube connect the flask to a measured volume of 0.1 normal sulfuric acid. The end of the delivery tube must be beneath the surface of the fluid.

Mix the contents of the distillation flask thoroughly and distill until its volume is diminished about one-half. Titrate the partly neutralized 0.1 normal sulfuric acid with 0.1 normal sodium hydroxide and calculate the nitrogen content.

Calculation

Subtract the number of milliliters of 0.1 normal sodium hydroxide in the titration from the volume of 0.1 normal sulfuric acid originally added. The remainder is equivalent to the number of milliliters of 0.1 normal sulfuric acid neutralized by the ammonia generated from the sample. One milliliter of 0.1 normal sulfuric acid is equivalent to 0.0014 grams of nitrogen. Therefore:

$$\% N_2 = \frac{(0.0014\epsilon) \times 100}{\text{weight sample}}$$

Where ϵ = milliliters of 0.1 normal sulfuric acid neutralized by the generated ammonia

and: % protein = 6.25 ($\%N_2$)

METHOD B

General

Method A, a chemical procedure, introduces certain difficulties, is time consuming and expensive, so a purely optical-manual method is also presented.

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[2] These analyses were adapted from "Practical Physiological Chemistry" by P. B. Hawk and O. Bergeim, Blakiston Company, Philadelphia, Pennsylvania.

Procedure

Weigh out two 50 gram samples of the prepared, dried residue and place them in separate porcelain or enamel dishes for the determination of the putrescible matter.

From each of the weighed samples all putrescible, or organic particles, shall be removed by means of tweezers using a magnifying glass with a magnification factor of at least two. The putrescible particles are readily recognized as they have a fibrous appearance. Black particles such as paper, char or charcoal are not putrescible. Treat each sample and its putrescible material separately.

The removed particles shall be free of iron, slag, steel or any other non-putrescible materials. The selected putrescible particles shall be dried for about 10 minutes at 218°F (103°C), since they are quite hydroscopic, and the determination is on a dry weight basis. All removed particles shall be carefully weighed on a precise scale. It is important to accomplish this work quickly because of the above mentioned hydroscopic sensitivity.

Calculation

The original sample weight was 50 grams, and the selected organic fraction (putrescible material) has now been removed, dried and weighed. The ratio of these two values times 100 determines the percent putresible organic matter in the residue, that is:

$$\frac{\text{putrescible matter in grams}}{\text{original 50 gram weight}} \times 100 = \%\ \text{putrescible in the residue}$$

It should be remembered that this is a dry weight and must be handled in that manner.

THIS APPENDIX IS BASED ON
SECTION 9, APPENDIX PTC 4.1

7.4 Derivation of the Weight of Dry Air. The following is the derivation of the equation for computing the weight of dry air per pound of combined "As Fired" waste and supplementary fuel. In this derivation the assumption is made that whatever sulfur is present in the waste or fuel is burned to sulfur dioxide. This is not entirely true, a fraction may be burned to sulfur trioxide and another fraction could form oxides with the ash. In addition some of the sulfur may be in the form of sulfides or sulfates and unavailable for combustion. However, the treatment presented here appears to be the best for general usage. An additional minor assumption made is that all the sulfur dioxide sampled is removed in the Orsat by the carbon dioxide reagent.

Pounds of dry gas per mol of dry gas =

$$44.01\,\frac{(CO_2')}{100} + 28.01\,\frac{(CO')}{100} + 32.00\,\frac{(O_2')}{100} + 28.02\,\frac{(N_2')}{100}$$

Pounds of equivalent carbon burned per mol of dry gas =

$$12.01\,\frac{(CO_2' + CO')}{100}$$

In order to use this equation the pounds of carbon burned per pound of combined "As Fired" waste and supplementary fuel must be adjusted for the sulfur dioxide absorbed in the Orsat as carbon dioxide.

To reduce the sulfur in the combined "As Fired" waste and supplementary fuel to its carbon equivalent, multiply the sulfur in the combined "As Fired" waste and supplementary fuel by:

$$\frac{12.01}{32.07}$$

Molecular weight:

$C = 12.01$
$S = 32.07$

Then the equivalent carbon burned is:

$$C_{brf} + \frac{12.01}{32.07}\,S_{rf}$$

The pounds of dry gas per pound of combined "As Fired" waste and supplementary fuel is obtained as follows:

$$W_{G'} = \frac{\text{lb dry gas}}{\text{mol dry gas}} \times \frac{1}{\left(\dfrac{\text{lb carbon}}{\text{mol dry gas}}\right)} \times \frac{\text{lb carbon}}{\begin{array}{c}\text{lb AF waste and}\\ \text{supplementary fuel}\end{array}} = \frac{\text{lb dry gas}}{\begin{array}{c}\text{lb AF waste and}\\ \text{supplementary fuel}\end{array}}$$

$$W_{G'} = \frac{44.01\,(CO_2') + 28.01\,(CO') + 32.00\,(O_2') + 28.02\,(N_2')}{12.01\,(CO_2' + CO')} \left(C_{brf} + \frac{12.01}{32.07}\,S_{rf}\right)$$

Pounds of nitrogen per mol of dry flue gas =

$$28.02\,\frac{(N_2')}{100}$$

$$W_{G'N_2} = \frac{1}{\left(\dfrac{\text{lb dry gas}}{\text{mol dry gas}}\right)} \times \frac{\text{lb nitrogen}}{\text{mol dry gas}} = \text{pounds of nitrogen in the dry flue gas per pound of dry flue gas}$$

$$W_{G'N_2} = \frac{28.02\,(N_2')}{44.01\,(CO_2') + 28.01\,(CO') + 32.00\,(O_2') + 28.02\,(N_2')}.$$

Pounds of nitrogen in the dry flue gas per pound of the dry flue gas multiplied by pounds of dry flue gas per pound of combined "As Fired" waste and supplementary fuel = $W_{NC'} \times W_{G'}$ = Pounds of nitrogen in the dry flue gas per pound of combined "As Fired" waste and supplementary fuel = $W_{G'N_2'}$.

Therefore:

$$W_{G'N_2} = \frac{28.02\,(N_2')}{44.01\,(CO_2') + 28.01\,(CO') + 32.00\,(O_2') + 28.02\,(N_2')} \times \frac{44.01\,(CO_2') + 28.01\,(CO') + 32.00\,(O_2') + 28.02\,(N_2')}{12.01\,(CO_2' + CO')} \left(C_{brf} + \frac{12.01}{32.07}\,S_{rf}\right)$$

$$W_{G'N_2} = \frac{28.02\,(N_2')}{12.01\,(CO_2' + CO')} \left(C_{brf} + \frac{12.01}{32.07}\,S_{rf}\right)$$

$W_{A'rf}$ = lb of dry air per lb of combined "As Fired" waste and supplementary fuel

$W_{A'rf} = \dfrac{W_{G'N_2} - N_{rf}}{0.7685}$ = weight of dry air per pound of combined "As Fired" waste and supplementary fuel

N_{rf} = lb of nitrogen per lb of combined "As Fired" waste and supplementary fuel (from laboratory analysis of the "As Fired" waste and supplementary fuel proportioned to their flow rate)

0.7685 = the pounds of nitrogen per pound of standard air (see International Critical Tables – Vol. 1)

The complete equation for the weight of dry air per pound of combined "As Fired" waste and supplementary fuel is equal to:

$$W_{A'rf} = \frac{1}{0.7685}\left\{\left[\frac{28.02\,(N_2')\left(C_{brf} + \dfrac{12.01}{32.07}\,S_{rf}\right)}{12.01\,(CO_2' + CO')}\right] - N_{rf}\right\}$$

7.5

SELECTED LIST OF UNITS FOR CONVERSION FROM U.S. CUSTOMARY UNITS TO SI (METRIC) UNITS (1)

TO CONVERT FROM U.S. CUSTOMARY UNITS	TO SI (METRIC)	MULTIPLY BY	CALCULATION BASES
Std. Grav. Ft/Sec^2	meter/sec^2 m/s^2	9.807 E+00	$32.174 \times 3.048000 \times 10^{-1}$ = 9.8066352 = 9.807
Calorie	joule (J)	4.187 E+00	4.186800 = 4.187
Foot-Pound	joule (J)	1.356 E+00	1.355818 = 1.356
Btu	joule (J)	1.055 E+03	1.055056×10^{3} $= 1.055 \times 10^{3}$
Pound	kilogram (kg)	4.536 E-01	4.535924×10^{-1} $= 4.536 \times 10^{-1}$
Btu/Pound	joule/kilogram (J/kg)	2.326 E+03	$\frac{1.055056 \times 10^{3}}{4.535924 \times 10^{-1}}$ $= 2.326000171 \times 10^{3}$ $= 2.326 \times 10^{3}$
Cubic Foot	cubic meter (m^3)	2.832 E-02	2.831685×10^{-2} $= 2.832 \times 10^{-2}$
Btu/Ft^3	joule/cubic meter (J/m^3)	3.726 E+04	$\frac{1.055056 \times 10^{3}}{2.831685 \times 10^{-2}}$ $= 3.725894653 \times 10^{4}$ $= 3.726 \times 10^{4}$
°F*	K		$\frac{t_f + 459.67}{1.8}$
Btu/Pound °F	joule/kilogram K (J/kg K)	4.187 E+03	$\frac{2.326000171 \times 10^{3}}{5.555556 \times 10^{-1}}$ $= 4.186799973 \times 10^{3}$ $= 4.187 \times 10^{3}$
Pound/Ft^3	kilogram/cubic meter (kg/m^3)	1.602 E+01	$\frac{4.535924 \times 10^{-1}}{2.831685 \times 10^{-2}}$ $= 1.601846251 \times 10$ $= 1.602 \times 10$
Ton (Short, 2000 lb)	kilogram (kg)	9.072 E+02	9.071847×10^{2} $= 9.072 \times 10^{2}$
Btu/Hour	watt (W)	2.931 E-01	2.930711×10^{-1} $= 2.931 \times 10^{-1}$
Horsepower	watt (W)	7.460 E+02	7.460000×10^{2}
Pound/Sq Inch	pascal (Pa)	6.895 E+03	6.894757×10^{3} $= 6.895 \times 10^{3}$

* °F Temperature difference divided by 1.8 equals K temperature difference.

[1] Source: ASME Orientation and Guide for Use of SI (Metric) Units (Publication E00058).