A ROUTINE OR DAILY TEST PROCEDURE FOR THE PERFORMANCE OF A HEAT RECOVERY INCINERATOR

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ABSTRACT

This technical paper presents an outline of a simplified test procedure and associated instrumentation requirements that can be incorporated into a resource recovery incineration system to facilitate daily evaluation of the unit's performance. This abbreviated test procedure is based upon the principles of ASME Test Codes PTC 4.1 on Steam Generators and PTC 33 on Large Incinerators. The procedure is presented as an aid to monitor overall performance under the now commonly accepted long term continuous operations contracts for resource recovery projects.

INTRODUCTION

A heat recovery incinerator by definition is a controlled process for burning combustible waste and producing a heated fluid. Its efficiency is related to how effectively it burns the combustible material to gaseous products of combustion and transfers the heat released to a working fluid.

As noted, this abbreviated test follows the guiding principles of PTC 4.1 on Steam Generators and PTC 33 on Large Incinerators. The user should read and understand these Codes to better understand the basis of the test, the means of actually conducting the test, and to realize this test's variances from the standard test including effects on the level of engineering accuracy and its relation to monitoring long term contract performance.

MEASUREMENTS

This abbreviated test incorporates the methodology of the indirect or boiler/calorimeter method of testing the incinerator boiler. It requires that a number of parameters be measured on a daily basis and be made a part of the facility's daily log. The facility should be designed to allow these measurements to be taken routinely at the locations shown in Fig. 1. The measurements include:

Waste Firing Rate

The rate at which refuse is fed (W_{re}) to the incinerator shall be measured in several ways.

First, in the instance where a pit and crane operation is employed, the load cells on the cranes shall be used as the primary means of determining waste feed rates. The load cells should be recalibrated weekly by using the cranes to lift a concrete or similar block of a known weight of approximately the crane's normal working load. The load cell design should facilitate easy replacement when necessary. If a pit and crane is not employed, then the station's scale house records along

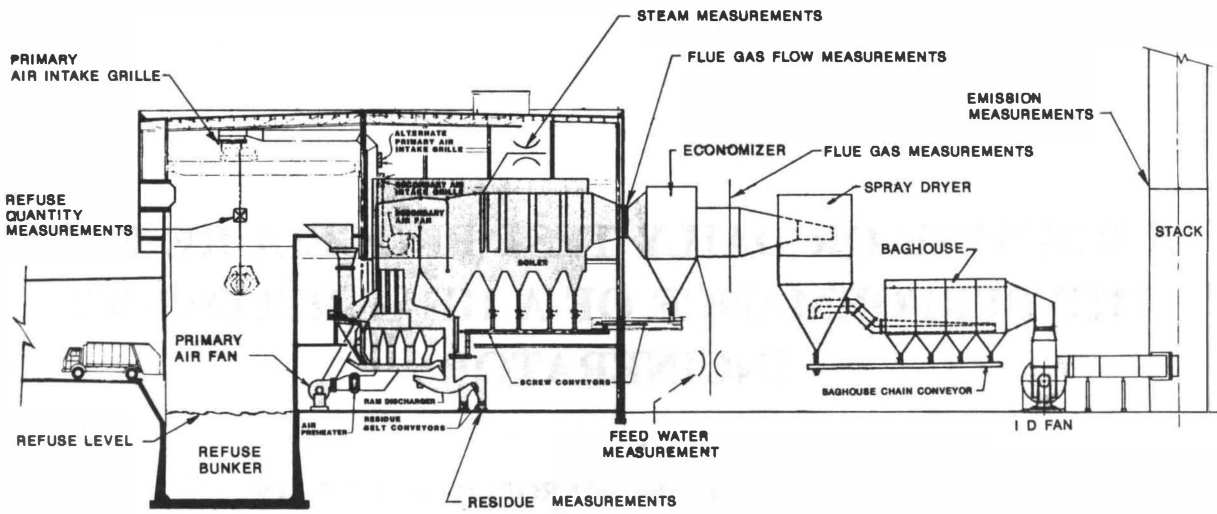

FIGURE 1 HEAT RECOVERY INCINERATOR

with the change in tonnage as stored on the receiving floor will have to serve as a best estimate of waste fired.

Second, the pit should be observed daily to gage the level of acceptable waste in the pit each morning at a convenient time before receiving the day's waste. A fixed time for the leveling and gaging of the waste in the pit each day must be established. All acceptable waste received must pass over the receiving scale and be recorded, and this waste corrected for pit level to determine weight of waste fired. This should be compared against the load cell weight data.

Flue Gas Temperature

The temperature of the flue gas (T_G) leaving the economizer and ahead of the scrubber should be measured. It should be measured continuously by a thermocouple array in the duct ahead of the scrubber where other flue gas parameters are measured. Refer to ANSI/ASME PTC 38, PTC 19.3 and PTC 19.10.

Flue Gas Flow

The weight rate of wet flue gas flow (W_{G_e}) can be measured in several different manners.

(a) The preferred method is to measure pressure drop (ΔP) across a venturi section in the duct between the economizer and the scrubber. This method may be somewhat more expensive than the other methods suggested, but can provide the highest accuracy.

(b) The second method is to install a permanent pitot tube array that is cleanable between the economizer and the scrubber.

(c) The third method is to permanently install a perforated plate ahead of the scrubber with a sufficient number of holes to distribute the flow evenly to the scrubber and produce a pressure drop of at least 4 in. W. C. at unit's maximum steaming capacity after soot blowing.

With the data thus obtained the weight rate of wet flue gas flow may be calculated by:

$$W_{Ge} = (K)\sqrt{\frac{P_G\,\Delta P}{T_G}}$$

where

ΔP = the pressure drop across the measuring element

T_G = the flue gas temperature

P_G = the flue gas pressure

(K) = a constant to be obtained during calibration and adjusted at subsequent checks. This equation should be built into the measurement system and should read the flow directly. It should be calibrated [correcting the constant (K)] during the Acceptance Test, and whenever the flue gas flow is accurately determined.

Flue Gas Humidity

The specific humidity of the wet flue gas must be obtained from the duct gas sampling manifold. This sample point is the same one used to obtain the other flue gas parameters noted above. The system to be used is described in ANSI/ASME PTC 19.18, Humidity Determinations or PTC 38, Section 5 and PTC 19.10, Section 3 Fig. 5. The reading should be taken every four (4) hours, twice a shift on the average, to produce a daily average. The specific humidity can then be obtained from Fig. K-2 of PTC 38, Psychrometric Chart — Medium Temperatures. There are new instruments available today that directly read this value with accuracy, if the sample is properly taken they should be given consideration.

Steam Flow Rate

The steam mass flow rate (W_{se}) should be determined from a calibrated flow nozzle system in the feedwater line to the boiler after the high pressure heater. This value should be corrected for any boiler blow down, soot blowing, or steam uses other than the steam supplied to the turbine. If the plant steam measuring and recording system is used for this value, the system must be purged and calibrated against the feedwater nozzle flow measurement without blow down or other non-turbine uses during an hour of stable operation. The steam chart can be calibrated during the Acceptance Test and should be rechecked at least monthly, unless the corrections are found to be less than $\pm\frac{1}{4}\%$. Refer to ANSI/ASME PTC 6S, Paragraphs 4.19 through 4.55.

Steam Temperature and Pressure

The measurement of the steam temperature (t_s) and pressure (P_s) must be accurately determined. See ANSI/ASME PTC 19.2 and 19.3 for instrument selection and installation. Also, see PTC 6S Paragraph 4.64 to 4.106. These measuring systems must be kept in proper repair to insure correct operation and recalibrated when needed.

Feedwater Temperature and Pressure

The measurement of feedwater temperature (t_w) and pressure (P_w) must be accurately determined. Refer to paragraph F above for references and precautions.

Ambient Conditions

Ambient conditions about the unit should be measured every four (4) hours or twice a shift. The measurements should include ambient temperature (t_a) and barometric pressure (P_a). The temperature at the inlet to the forced draft fan should be measured to establish the test reference temperature (t_R). The plant barometric pressure may be used as the test reference pressure (P_R). The daily average of these readings should be used to compute daily results.

Flue Gas Composition

The flue gas composition should be determined by drawing from a permanently installed sampling array located in the flue gas duct between the economizer and the scrubber. The samples should be taken into a manifold; analyzed for O_2, CO, CO_2 and combustibles; and continuously recorded by a calibrated recording system.

There are measuring systems on the market today that read these parameters to an acceptable level of accuracy. These should be installed and read hourly as part of the station log. The average of each of these readings for each twenty-four hour period should be used to determine the particular day's performance. Of the utmost importance, is the proper sampling of the flue gas. This should be given considerable attention at the design stage of the facility as it cannot be properly adapted to the system later. The manifold and measuring array should be back blown regularly to insure they are clear and receiving a proper sample.

COMPILATION OF RESULTS

Principle of Efficiency Determination

This simplified test procedure is based upon the Heat Balance Method of efficiency determination as follows

$$\eta_{HRI} = \frac{\text{Heat Output}}{\text{Heat Input}} \times 100$$

where

η_{HRI} = efficiency of a heat recovery incinerator

and

Heat Input = Heat Output + Losses − Credits

It should be noted that if the "as fired" waste temperature, entering air temperature, and quench inlet water temperature are not substantially different (±20°F) from the reference temperature, the heat credits can be ignored and the equation reduces to

$$\eta_{HRI} = \frac{\text{Heat Output } (Q_{out_e})}{\text{Heat Output } (Q_{out_e}) + \text{Losses } (L_e)} \times 100$$

$$\eta_{HRI} = \frac{1}{1 + L_e/Q_{out_e}} \times 100$$

$$Q_{out_e} = W_{se}\,(h_s - h_w) + \text{blowdown, etc.}$$

where
- W_{se} = weight rate of steam flow
- h_s = steam enthalpy
- h_w = feedwater enthalpy

$$\text{HRI} = \frac{100}{1 + L_e/[W_{se} \times (h_s - h_w)]}$$

Heat Losses

The heat losses which must be considered for incorporation into the efficiency equation are summarized by:

$$L_e = L_{Cie} + L_{Ge'} + L_{mre} + L_{He} + L_{COe} + L_{HCe} + L_{\beta e} + L_{mAe} + L_{ze} + L_{we} + L_{Pe}$$

where
- L_{Cie} = unburned carbon in total residue
- $L_{Ge'}$ = heat in the dry flue gas
- L_{mre} = moisture in the "as fired" waste
- L_{He} = moisture from burning hydrogen
- L_{COe} = the formation of carbon monoxide
- L_{HCe} = unburned hydrogen and hydrocarbons
- $L_{\beta e}$ = surface radiation and convection
- *L_{mAe} = moisture in the combustion air
- *L_{ze} = atomizing steam, if used
- *L_{Pe} = radiation to ashpit, sensible heat in residue
- *L_{we} = heat pickup by cooling water
- *LNM_e = losses not measured but by agreement included as 1½% of input

thereby reducing to

$$L_e = L_{Cie} + L_{Ge'} + L_{mre} + L_{He} + L_{COe} + L_{HCe} + L_{\beta e} + LNM_e$$

Heat Losses Determination

Each of the heat losses should periodically be firmly established and then may be used routinely in this simplified procedure.

Carbon Loss in the Process Residue

The unburned carbon loss in the process residue (L_{Cie}) is determined from the total quantity of bottom ash and fly ash less any spent reagent from the flue gas scrubbers. The mixture, which will be quite wet, should be corrected for moisture content. The moisture content should be determined by laboratory test during the Acceptance Test to obtain a representative average and then periodically re-established thereafter.

Once a baseline is established, variations in the carbon loss in the dry process residue may be estimated by monitoring flue gas carbon monoxide and combustible contents. These readings may be compared against similar readings taken during the acceptance test along with the process residue carbon content (and higher heating value) taken at that time. If the gas readings remain within a range of approximately ±25%, then the process residue carbon content can be adjusted proportionately. Should readings go beyond this range, then the relationship between the flue gas readings and the process residue carbon content should be re-established.

The carbon loss may be calculated by:

$$L_{Cie} = W_{Pe'} \times H_p$$

where
- $W_{Pe'}$ = weight rate of dry process residue
- H_P = higher heating value of total dry process residue

Heat Loss With the Dry Flue Gas

The heat lost with the dry flue gas is normally the largest loss and therefore particular attention must be paid to its determination. The loss may be calculated by correcting the wet flue gas flow rate (W_{Ge}) for humidity and multiplying times the flue gas specific heat (assumed to be 0.245 Btu/lb-°F) and the difference in temperature between the flue gas (t_G) and the reference temperature (t_R).

$$L_{GE} = W_{Ge} \times (\text{1-Sp. Humidity}) \times (C_p) \times (t_G - t_R)$$

Heat Loss Due to Moisture

The heat loss due to moisture from burning hydrogen (L_{He}) and the heat loss due to moisture in the "as fired" waste (L_{mre}) may be combined into a total loss due to heat in the moisture in the flue gas (L_{Gme}). This loss may be determined by using the wet flue gas flow rate (W_{Ge}) and flue gas specific humidity to determine the flue gas moisture flow rate. This is multiplied times the difference in enthalpy of the flue gas moisture (at the flue gas temperature, t_G, and assuming a partial pressure of 1 psia) and the enthalpy of water at the reference temperature (t_R).

$$L_{Gme} = W_{Ge} \times (\text{Sp. Humidity}) \times (h_{Gm} - h_{Rw})$$

Heat Losses Due to Carbon Monoxide and Hydrocarbons

The heat losses due to carbon monoxide and unburned hydrogen and hydrocarbons in the flue gas may each be determined from the sampling array in the duct between the economizer and the scrubber. The losses may be calculated by

$$L_{COe} = W_{Ge} \times (1 - \text{Sp. Humidity}) \times (\%\ \text{CO}) \times (4347\ \text{Btu/lb})$$

$$L_{HCe} = W_{Ge} \times (1 - \text{Sp. Humidity}) \times (\%\ \text{HC}) \times (23{,}861\ \text{Btu/lb})$$

Radiation and Convection Losses

Radiation and convection losses from the boiler may be calculated using the American Boiler Manufacturer's Association (AMBA) standard radiation loss chart, Fig. 8, ANSI/ASME PTC 4.1, or as presented in paragraph 4.8.3 of ANSI/ASME PTC 33.

SUMMARY

The key to success and the acceptability of this abbreviated test is the measuring systems employed. They must be rugged, reliable and able to produce accurate reproducible results. In addition, they must be properly operated and kept in proper calibration and repair.

The greatest opportunity for error lies in the daily measurement of waste throughput and in the measurement of bottom ash and fly ash produced. Methods to more accurately determine these items need further attention to improve the consistent accuracy of the results.

It is intended that the daily average of the various parameters will be computed by and processed in a small plant computer. This computer will contain all the memory routines necessary to produce the daily results. On-line data reduction is necessary, and when coupled with reasonably frequent calibration of the various sensing systems, is an acceptable and convenient method of routinely establishing the performance of a heat recovery incinerator.

SYMBOLS DEFINITIONS

Symbol	Description	Units
CO	Percent carbon monoxide per volume dry flue gas.	%
CO_2	Percent carbon dioxide per volume dry flue gas.	%
C_p	Specific heat at constant pressure (the reference pressure (P_R) of the dry flue gas.	Btu/lb-F°
H_P	Higher heating value of total dry process residue.	Btu/lb
H_{re}	Higher heating value of the refuse as fired.	Btu/lb
h_{Gm}	Enthalpy of moisture in the flue gas.	Btu/lb
h_{Rw}	Enthalpy of water in the reference temperature (T_R) and pressure (P_R).	Btu/lb
h_s	Enthalpy of steam in the boiler outlet header.	Btu/lb
h_w	Enthalpy of water at the boiler inlet header.	Btu/lb
(K)	Calibration constant for dry flue gas flow established by calibration and testing.	
LNM_e	Losses per unit time which are not measured, but assumed to be 1½% of total heat input (Q_{in_e}) and agreed to before the test.	Btu/hr
$L_{\beta e}$	Losses per unit time due to radiation and convection.	Btu/hr
L_{Cie}	Losses per unit time due to unburned carbon and other chemicals in the process residue.	Btu/hr

Symbol	Description	Units
L_{COe}	Losses per unit time due to incomplete combustion resulting in the formation of carbon monoxide.	Btu/hr
L_e	Total losses per unit time.	Btu/hr
$L_{Ge'}$	Losses per unit time due to heat in the dry flue gas.	Btu/hr
L_{Gme}	Losses per unit time due to moisture in the flue gas.	Btu/hr
L_{HCe}	Losses per unit time due to unburned hydrocarbons in the flue gas.	Btu/hr
L_{He}	Losses per unit time due to moisture from burning hydrogen in the flue gas.	Btu/hr
L_{mAe}	Losses per unit time due to moisture in the combustion air.	Btu/hr
L_{Pe}	Losses per unit time due to radiation to the ashpit and sensible heat loss in the process residue.	Btu/hr
L_{we}	Losses per unit time due to heat rejected to cooling water within the steam generating unit envelope.	Btu/hr
L_{ze}	Losses per unit time due to atomizing steam (if any).	Btu/hr
O_2	Percent oxygen per volume of dry flue gas.	%
P_A	Barometric or atmospheric pressure.	psia
P_R	Test reference pressure.	psia
P_s	Pressure of steam in the boiler outlet header.	psia
P_w	Pressure of feedwater in the boiler inlet header.	psia
Q_{in_e}	Heat input per unit time.	Btu/hr
Q_{out_e}	Heat output per unit time.	Btu/hr
t_A	Ambient temperature.	°F
t_G	Temperature of flue gas.	°F
T_G	Temperature of flue gas.	°R
t_R	Test reference temperature.	°F
t_s	Temperature of steam in boiler outlet header.	°F
t_w	Temperature of feedwater after the last heater.	°F
W_{Ge}	Weight rate per unit time of flue gas.	lb/hr
$W_{Pe'}$	Weight rate per unit time of dry process residue production.	lb/hr
W_{re}	Weight rate per unit time of acceptable waste feed to the furnace.	lb/hr
W_{se}	Weight rate per unit time of steam in the boiler outlet header.	lb/hr
ΔP	Change in pressure.	psi
η_{HRI}	Efficiency of heat recovery incinerator.	%
ρ_G	Density of flue gas.	lb/ft^3

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