An Evaluation of Current Incinerator Emission Standards

JOHN R. DERVAY, II
HAN LIU
GREGORY THEOCLITUS

The Air Preheater Company, Inc.
Wellsville, New York

ABSTRACT

There are a number of different bases currently being used to evaluate the emission levels of incinerators. These criteria and their limitations are discussed in detail with the purpose of proposing a fair and impartial basis for the determination of incinerator emissions.

INTRODUCTION

There presently exists a number of stack emission standards all with the purpose of defining the pollution contribution of an incinerator against some criteria. Any analysis of an incinerator is complicated due not only to the many different designs on the market, but also due to the nonhomogeneity of the waste consumed. Hence, an emission standard should take these differences into account so that no incinerator has an inherent advantage over another due solely to the method of implementation of the standard.

The three most widely used criteria of incinerator evaluation are:

1. Grains particulate per cubic foot of dry flue gas (at 70°F and 29.92 in. Hg) corrected to 12 percent CO₂;
2. Grains particulate per cubic foot of dry flue gas (at 70°F and 29.92 in. Hg) corrected to 50 percent excess air; and
3. Pounds of particulate per hundred pounds (or ton) of waste charged.

This paper will discuss the above three criteria with the purpose of determining which of these provide an impartial basis for the evaluation of an incinerator’s emission level. In addition, a discussion is presented on the determination of an incinerator’s burning rate which is implicit to an incinerator’s emission level.

INCINERATOR EMISSION STANDARDS

Any emission standard should prescribe to the following set of criteria:

1. Provide a consistent basis for evaluating the emission level of an incinerator regardless of incinerator design and/or composition of waste consumed;
2. Reflect proper operation of equipment;
3. Be readily and accurately measured with a straightforward application; and
4. Test equipment utilized should be generally available at a reasonable cost.

The most important criterion is that of establishing a consistent basis for determining the absolute value of the total emission discharged from an incinerator. This value of emission should not be influenced in any way by dilution of some manner. By correcting the emission level to 12 percent CO₂ or 50 percent excess air or some other component of the flue gas, the emission level will be unaffected by dilution.

Inherently, an emission standard based on total mass of particulate emitted per unit quantity of waste charged precludes lowering of the stack emission level through dilution of the flue gas. However, it does not take into account “dilution” of the waste itself. This can be accomplished by simply adding water to the waste, thereby increasing the mass charged with no increase in combustible or ash content. Generally, this can be circumvented by fixing the composition of the waste used during an emission test. Examples are the standard PHS [1]
or II A [2] test charges. However, for large incinerators, the cost involved in the preparation of the standardized test charges can be prohibitive. For this reason, the use of standardized waste charges cannot be considered as a reasonable approach.

The correction of the emission to either 12 percent CO$_2$ or 50 percent excess air is on a dry basis, hence, any dilution of the waste will not affect the resultant loadings. From this one might then erroneously conclude that the emission standards based on either 12 percent CO$_2$ or 50 percent excess air would provide a consistent basis for evaluation. In the following section it will be shown that the 12 percent CO$_2$ correction method does not provide a consistent basis.

The equivalent allowable emission as calculated by the three criteria for incinerator emissions are shown in the following table. Three different types of materials were chosen for illustration.

In Table 1, for each type of waste, a specific emission level was chosen and the equivalent allowable emission level was calculated for the other two standards. For example, using cellulose as the waste, 0.1 grains/scf corrected to 12 percent CO$_2$ is equivalent to 0.086 grains/scf corrected to 50 percent excess air and 0.126 lb particulate per 100 lb of cellulose burned. Similarly, 0.1 grains/scf corrected to 50 percent excess air is equivalent to 0.116 grains/scf corrected to 12 percent CO$_2$.

As an alternate method of comparison, Fig. 1 is presented. The left side of Fig. 1 shows the relationship between percent excess air and percent CO$_2$ (dry basis) for the combustion of the three types of materials indicated. The right hand side relates percent CO$_2$ and the uncorrected incinerator emission level through an iso-emission line representing 0.1 grains/scf corrected to

![Graph](image-url)

Table 1

<table>
<thead>
<tr>
<th>Material Burned</th>
<th>Grains/scf corrected to 12% CO$_2$</th>
<th>Grains/scf corrected to 50% Excess Air</th>
<th>Pounds Particulate per 100 lb Material Charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (C$<em>6$H$</em>{10}$O$_5$)</td>
<td>0.10</td>
<td>0.086</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>0.116</td>
<td>0.10</td>
<td>0.147</td>
</tr>
<tr>
<td></td>
<td>0.079</td>
<td>0.068</td>
<td>0.10</td>
</tr>
<tr>
<td>Polyethylene ([CH$_2$]$_n$)</td>
<td>0.10</td>
<td>0.123</td>
<td>0.497</td>
</tr>
<tr>
<td></td>
<td>0.081</td>
<td>0.10</td>
<td>0.405</td>
</tr>
<tr>
<td></td>
<td>0.020</td>
<td>0.025</td>
<td>0.10</td>
</tr>
<tr>
<td>Methane (CH$_4$)</td>
<td>0.10</td>
<td>0.159</td>
<td>0.725</td>
</tr>
<tr>
<td></td>
<td>0.063</td>
<td>0.10</td>
<td>0.456</td>
</tr>
<tr>
<td></td>
<td>0.014</td>
<td>0.022</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fig. 1 Relationship between percent excess air and percent CO$_2$ for various materials.

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12 percent CO₂. In actuality, the right hand side of Fig. 1 indicates that given the measured percentage CO₂ in the incinerator stack gas (dry basis), one can readily determine the maximum uncorrected emission level the particular incinerator may attain and still meet a regulatory code based on 0.1 grains/scf corrected to 12 percent CO₂.

As Fig. 1 indicates, at a fixed percentage of excess air, the percent CO₂ will vary with chemical composition of the material and will result in a wide variation in uncorrected emission levels.

For example, if one were to burn cellulose at 75 percent excess air and meet an emission of 0.1 grains/scf corrected to 12 percent CO₂, the measured incinerator loading could not exceed 0.10 grains/scf. On the other hand, if one was burning polyethylene at 75 percent excess air, the measured incinerator emission could not exceed 0.069 grains/scf. It should be noted, in Fig. 1, that a regulatory emission limit of 0.1 grains/scf corrected to 12 percent CO₂ is used for illustrative purposes only, here and subsequently.

The conclusion is that any emission standard based on a fixed percent CO₂ in the stack gas does not provide a consistent basis since the corrected emission will vary with waste composition. It would, then, be desirable to eliminate this variation. Let us consider the oxidation of cellulose and methane. The combustion reaction can be expressed as follows:

- Cellulose: C₆H₁₀O₅ + 6 O₂ = 6 CO₂ + 5 H₂O
- Methane: CH₄ + 2 O₂ = CO₂ + 2 H₂O

For cellulose, the only oxidizable component is carbon, while in the case of methane, both carbon and hydrogen will oxidize. Hence, emission standards correcting to only carbon dioxide completely disregard any other combustible component of the waste, while on the other hand, a correction to an excess air standard will account for all combustible portions of the waste including uncombined hydrogen. This would more reflect the purpose of an incinerator; namely, to achieve a reduction in volume and mass of the waste through the oxidation of all combustible portions of that waste.

It would be a simple matter of promulgating an emission standard based solely on excess air at this point. However, it would be desirable to show that this method provides a consistent basis for determining the emission level of an incinerator regardless of the waste consumed. Let us consider the oxidation of cellulose. One finds that the moles of CO₂ produced in the combustion process are numerically equal to the moles of stoichiometric oxygen used. In this case, the percent CO₂ scale in Fig. 1 can be simply changed to percent O₂,s where percent O₂,s is the ratio of the oxygen used in the combustion process to the total air supplied, in terms of a percentage. The cellulose curve in Fig. 1, then, remains unaltered.

Now, consider the complete oxidation of one mole of methane in stoichiometric air. The resultant products of combustion would be:

1 Mole CO₂
2 Moles H₂O
7.57 Moles N₂

The total oxygen used in the combustion reaction can be expressed as:

\[ O₂,s = \text{Moles of O₂ in CO₂} + \text{Moles of O₂ in H₂O} \]
\[ = \text{Moles of CO₂} + 1/2 (2 \text{ Moles H₂O}) \]
\[ = 2 \text{ Moles O₂} \]

One should particularly note that in the case of methane, the oxygen associated with the water in the products of combustion is included in the stoichiometric oxygen, since methane does not contain combined oxygen. This is not the case with cellulose where there is combined oxygen which is in the form of [H₂O]ₙ.

Therefore, for methane, the total stoichiometric air is 9.57 moles. The quantity, percent O₂,s, for methane is then:

\[ \% O₂,s = \left[ \frac{2}{9.57} \right] \times 100 = 20.9\% \]

Referring back to Fig. 1, we see that if we burn cellulose in stoichiometric air, the resultant percent CO₂ would also be 20.9 percent. Noting the aforementioned equivalency between percent CO₂ and percent O₂,s for cellulose, we may find that regardless of the material oxidized, the ratio of the oxygen used for combustion to the total air supplied is a constant at a given percentage of excess air. In general, this relation can be expressed as:

\[ \% O₂,s = \left[ \frac{20.9\%}{1 + \% \text{ Excess Air}} \right] \]

Appendix I contains a detailed derivation of percent O₂,s in terms of readily measured incinerator variables, i.e., orsat analysis of the flue gas. The resultant expression is:

\[ \% O₂,s = \left[ \frac{K(%N₂) - (%O₂) - 1/2(%CO)}{(1+K)(%N₂)} \right] (100) \]

where

- K = volumetric ratio of oxygen to nitrogen in ambient air
  \[ = (.209/.791) = 0.264 \]

and percent N₂, percent O₂ and percent CO are the volumetric components in the stack flue gas determined by an orsat analysis (dry basis).
Fig. 2 Relationship between percent excess air and percent $O_2$, $S$ for all materials.

Fig. 3 Relationship between percent excess air and uncorrected emission level.
Fig. 2 shows a plot of percent excess air versus percent $O_2$, along with an isoemission curve based on 0.1 grains/scf corrected to 12 percent $O_2$. As was previously indicated, only a single curve is required to relate percent excess air and percent $O_2$, regardless of waste composition. In fact, this is identically the same curve as shown in Fig. 1 for cellulose.

Appendix I also includes a derivation of percent excess air in terms of the measured incinerator variables. The resultant expression is:

$$\% \text{ Excess Air} = \left[ \frac{0.209(1+K)(%N_2)}{K(%N_2) - (%O_2) - 1/2(%CO) - 1.0} \right]$$

We can now conclude that:

1. The “percent excess air” and “percent $O_2$” calculations can be determined from the measured values of the incinerator stack gas through an Orsat Analysis on a dry basis.

2. The “percent excess air” base point reflects the oxidation of both carbon and unoxidized hydrogen contained in the waste.

3. The use of “percent excess air” as a standard for the evaluation of incinerator emission levels provides for a consistent basis which accounts for all combustible material in the waste including unoxidized hydrogen. This is especially important since in common waste the amount of plastics which contains a large portion of free hydrogen is increasing rapidly.

In addition to the above, the following points should be noted:

1. The relationship between the percent excess air, percent $O_2$, and the uncorrected emission level, as shown in Fig. 2, may be simplified by cross plotting the data contained in Fig. 2. Fig. 3 shows the direct relationship between percent excess air and the uncorrected emission level. It should be noted that the iso-emission curve, 0.086 grains/scf corrected to 50 percent excess air (equivalent to 0.10 grains/scf corrected to 12 percent $O_2$), was used for illustration purposes only and can be redesignated at will.

2. The fundamental assumption for the development of the percent excess air calculation was that carbon and hydrogen are the only oxidizable components of the waste. Other combustible components may be included, if desired, by measuring their contribution to the flue gas and appropriately changing the percent excess air derivation.

**BURNING RATE DETERMINATION**

Most emission codes require that a given incinerator’s emission level be determined at the manufacturer’s established burning rate. This is derived from the fact that an incinerator’s emission level is implicit to its burning rate. In other words, as the burning rate of an incinerator increases, in general, the emission level increases.

For clarification purposes, the following defines three bases for the evaluation of the waste throughput of an incinerator.

* **Burning Rate**: Quantity of waste oxidized and vaporized in the incinerator per unit time. This would include all free and combined water in the waste plus any component oxidized (carbon, hydrogen, etc.).

* **Charging Rate**: Sum of combustible and incombustible portions of the waste incinerated. Charging rate would then be the burning rate plus the ash component.

* **Loading Rate**: Quantity of waste loaded into the incinerator per unit time.

The significant point of these definitions is that while a certain amount of waste can be loaded into an incinerator, it is possible to have a burning or charging rate less than the loading rate. For a given incinerator of sufficiently large volume, it would be possible to load the waste at a greater rate than the actual charging rate for a period of time, thereby achieving an apparent inflated charging rate for the 1-2-h emission test.

With the traveling grate type of incinerator, material buildup is not actually possible. However, the throughput or loading rate can be influenced by the percent weight and volume reduction. For example, by decreasing the weight reduction from 90 percent to 80 percent, the loading rate can be increased by 12 percent. Thus, unless the ash leaving this type of incinerator is analyzed for combustibles, loading rate (throughput) is not a valid measure of charging rate.

The most straightforward method of determining an incinerator’s burning or charging rate is a system mass balance. During an emission test, the total stack flow, its water content and the various percentages of gaseous constituents of the flow are generally determined. By suitable analysis of these parameters, the incinerator’s burning rate can be readily determined.

Appendix II contains a detailed derivation for the determination of burning rate based on these accurately measured parameters. The burning rate on an ash free basis, RAF, can be determined by:

$$\text{RAF} = \frac{Q_s \left[ \rho_H g - (1 + Ha) \left( \frac{\%N_2}{100} \right) \left( \rho_{ng}/\rho_{n2} \right) \right]}{Q_b \rho_{ng} \left[ 1 - (1 + Ha) \left( X_{ng}/\rho_{n2} \right) \right]}$$

where, the variables are defined in Appendix II.

If the ash content of the waste is known or can be determined, the charging rate, $RT$, can be expressed as:
RT = \frac{\text{RAF}}{1 - \left(\frac{\% \text{Ash}}{100}\right)}

where percent Ash is the percent by weight of ash in refuse charged.

The basis for this derivation of incinerator burning rate is the use of nitrogen as a tie element to establish the quantity of combustion air introduced to the system. It is the authors' experience that this method is quite reliable if all the variables have been accurately measured. The following table compares the calculated burning rate, charging rate and the actual loading rates for three incinerator tests.

From Table 2 we can see that valid burning and charging rates can be determined through proper analysis of the flue gas. The authors have only shown three tests for illustration purposes. The above conclusion has, in actuality, been verified by more than 50 incinerator performance tests.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of Burning Rate Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Test 2 IIA</td>
</tr>
<tr>
<td>PHS Type</td>
<td>Test Charge</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Stack Flow – scfm</td>
<td>1228</td>
</tr>
<tr>
<td>Orsat Analysis (dry) %CO₂</td>
<td>11.9</td>
</tr>
<tr>
<td>%CO</td>
<td>0.0</td>
</tr>
<tr>
<td>%O₂</td>
<td>7.9</td>
</tr>
<tr>
<td>%N₂</td>
<td>80.2</td>
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<tr>
<td>Water Content (% of total flue gas)</td>
<td>18.69</td>
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<tr>
<td>Burner Gas (scfh)</td>
<td>0.0</td>
</tr>
<tr>
<td>Ambient Air Humidity (#H₂O/# Air)</td>
<td>0.0115</td>
</tr>
<tr>
<td>% Ash in Waste (by weight)</td>
<td>4.0</td>
</tr>
<tr>
<td>Calculated Burning Rate (#/hr)</td>
<td>728</td>
</tr>
<tr>
<td>Calculated Charging Rate (#/hr)</td>
<td>758</td>
</tr>
<tr>
<td>Actual Loading Rate (#/hr)</td>
<td>795</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The analysis contained in this paper shows that incinerator emission codes utilizing the measured emission corrected to percent CO₂ or those based on quantity of waste loaded into the system, do not provide for an im-

partial evaluation of an incinerator's emission level. An analytical approach is presented which clearly indicates that correcting the emission to 50 percent excess air will result in a consistent, representative evaluation of any incinerator regardless of the composition of the waste consumed.

An accurate burning rate or charging rate of an incinerator can be determined through suitable analysis of the stack flue gas. The data presented indicates that based on a knowledge of the total system flow, water content and orsat analysis of the flue gas, valid burning rates can be calculated without an analysis of the chemical composition of the waste.

REFERENCES


APPENDIX I: DERIVATION OF RELATIONSHIP OF PERCENT O₂, S AND PERCENT EXCESS AIR

Assumptions

(1) Any CO₂, N₂, and H₂O contributed by an auxiliary fuel, such as natural gas, has been removed from the wet basis Orsat measurement.
(2) The waste incinerated does not contain appreciable amounts of N₂, sulfur or other combustible inorganics.
(3) For each mole of oxygen in the waste, there exists at least 2 moles of hydrogen.

Procedure

(1) Measured Quantities

a) Orsat Analysis (wet basis) of stack gas:
   \[ \% \text{CO}_2 + \% \text{CO} + \% \text{O}_2 + \% \text{N}_2 + \% \text{H}_2\text{O} = 100\% \]
   (I-1)

b) Total stack flow, Qs, in scfm (at 70 F and 29.92 in. Hg)
c) Total molar volume of stack gas:
   \[ \text{Msf} = (Qs/386.7) \text{ where 386.7 is a molar volume in cubic feet at 70 F and 29.92 in. Hg} \]
d) Absolute humidity of combustion air, Hₐ, in
   \[ \text{water/dry air} \]

(2) Molar composition of flue gas may be expressed as:
   \[ \text{Mco}_2 + \text{Mco} + \text{Mo}_2 + \text{Mn}_2 + \text{Mw} = \text{Msf} \text{(Moles/Min.)} \]
   (I-2)

where the molar volume of each constituent is cal-
culated by $M_{CO_2} = (Msf)\ (%CO_2)/(100)$ and similarly for the other components.

3) Moles of combustion air, $Mca$, may be expressed as:

$$Mca = \left(\frac{1}{.791}\right) Mn_2 \tag{I-3}$$

where molar volume of nitrogen in air is 79.1 percent.

4) Moles of water contained in combustion air, $Mwca$, is found as:

$$Mwca = A Mca Ha = \left(\frac{A}{.791}\right) Mn_2 Ha \tag{I-4}$$

where $A = \left(\frac{29.00}{18.016}\right) = \text{Conversion for Ha from #H}_2O/#\text{Air to moles H}_2O/mol\text{e air}$.

5) System Oxygen Balance

(Moles O$_2$ in waste) – (Moles O$_2$ in flue gas) – (Moles of O$_2$ in combustion air)

since (Moles O$_2$ in flue gas) = $M_{CO_2} + M_{O_2} + 1/2 M_w + 1/2 M_{CO}$

then: (Moles O$_2$ in waste) = $M_{CO_2} + M_{O_2} + 1/2 M_{CO} - 1/2 Mn_2 - 1/2 (A/.791) Ha Mn_2 \tag{I-5}$

where $K = \left(\frac{.209}{.791}\right) = \text{molar volume of oxygen to nitrogen in air}$.

6) Total moles of combined hydrogen (in form of H$_2O$) in the waste, $Mfw$, is then (from assumption No. 3):

$$Mfw = 2 \text{ (Moles of O}_2\text{ in waste) = } 2 \left[ M_{CO_2} + M_{O_2} + 1/2 M_w + 1/2 M_{CO} - 1/2 Mn_2 \left(2 K + \frac{A}{.791} Ha\right)\right] \tag{I-6}$$

7) The total moles of uncombined hydrogen in the waste, $Muhw$, is therefore:

$$Muhw = Mw - Mfw - Mwca$$

$$= Mw - 2 \left[ M_{CO_2} + M_{O_2} + 1/2 M_w + 1/2 M_{CO} - 1/2 Mn_2 \left(2 K + \frac{A}{.791} Ha\right)\right] - \left[\frac{A}{.791} Ha Mn_2\right] \tag{I-7}$$

therefore, $Muhw = 2 \left[ KMn_2 - M_{CO_2} - M_{O_2} - 1/2 M_{CO}\right] \tag{I-8}$

8) The total moles of water formed due to the oxidation of the uncombined hydrogen in the waste is:

$$M_{H_2O} = Muhw = 2 \left[ KMn_2 - M_{CO_2} - M_{O_2} - 1/2 M_{CO}\right] \tag{I-9}$$

9) We can now define the corrected flue gas composition, $Mcfg$, which includes the water formed from the oxidation of the uncombined hydrogen in the waste and no other water, namely:

$$Mcfg = M_{CO_2} + M_{O_2} + Mn_2 + M_{H_2O} + M_{CO} \tag{I-10}$$

10) The total moles of oxygen used to completely oxidize the combustible portion of the waste (stoichiometric oxygen) is:

$$O_{2,s} = M_{CO_2} + 1/2 M_{H_2O}$$

where the oxygen associated with $M_{CO}$ is not accounted for. This penalizes an incinerator for the formation of carbon monoxide.

Combining Equation I-8 and the above, we have:

$$O_{2,s} = KMn_2 - M_{O_2} - 1/2 M_{CO} \tag{I-11}$$

11) The total moles of oxygen in the corrected flue gas, $Mcfg$, from Equation I-9, is:

$$(\text{Moles of O}_2 \text{ in Mcfg}) = M_{CO_2} + M_{O_2} + M_{H_2O} + 1/2 M_{CO}$$

$$= M_{CO_2} + M_{O_2} + M_{H_2O} + 1/2 \left[ 2(KMn_2 - M_{CO_2} - M_{O_2} - 1/2 M_{CO})\right]$$

$$= KMn_2 \tag{I-12}$$

12) We may now represent the oxygen used to oxidize the combustible material on a percentage basis, namely:

$$\%O_{2,s} = \frac{\text{Moles of Stoichiometric Oxygen}}{\text{Moles of O}_2 \text{ in Mcfg} + \text{Moles of Nitrogen}} \times 100 \tag{I-13}$$

$$= \left[\frac{O_{2,s}}{Mn_2 (1+K)}\right] \times 100 \tag{I-14}$$

Therefore, by substituting Equation I-10 and I-11,

$$\%O_{2,s} = \left[\frac{K \%N_2 - \%O_2 - 1/2 \%CO}{\%N_2 (1+K)}\right] \times 100 \tag{I-15}$$

13) Originally, it was assumed that the orsat analysis was on a wet basis, or:

$$\%CO_2 (\text{wet basis}) = \%CO_2 (\text{dry basis}) \times \left[1 - \frac{\%H_2O}{100}\right]$$

For Equation I-14, the water correction factor can be removed such that percent $N_2$, percent $O_2$ and percent $CO$ represent the orsat analysis on a dry basis.

14) The percent excess air in the flue gas can be determined by:
% Excess Air = \left[ \frac{O_2, \text{Total} - O_2, \text{Theoretical}}{O_2 \text{Theoretical}} \right] \quad (100)

(15) The theoretical oxygen required is:

\[ O_2, \text{Theo.} = \frac{M_{CO_2} + 1/2 M_{CO} + 1/2 M_{H_2O}}{K_{Mn_2} - (K_{Mn_2} + 1/2 M_{CO} - M_{O_2})} \quad (I-15) \]

(16) By substituting Equations 1-5 and 1-16 into Equation 1-15, we find:

\[ \% \text{Excess Air} = \frac{\%O_2 - 1/2 \%CO}{K \%N_2 + 1/2 \%CO - \%O_2} \quad (100) \]

\[ \% \text{Excess Air} = \frac{\%O_2 - 1/2 \%CO}{K \%N_2 + 1/2 \%CO - \%O_2} \quad (100) \]

**APPENDIX II: BURNING RATE DETERMINATION**

**Assumptions**

1. There are negligible amounts of Nitrogen, Sulfur and other inorganic combustibles in the waste.

**Procedure**

1. Measure Parameters:
   a) Orsat Analysis (wet basis)
   \[ \%CO_2 \]
   \[ \%CO \]
   \[ \%O_2 \]
   \[ \%N_2 \]
   \[ \%H_2O \]
   b) Total Stack Flow Rate, \( Q_s \), in standard cubic feet per hour.
   c) Auxiliary fuel flow rate, \( Q_b \), in standard cubic feet per hour.

2. The specific gravity of the flue (stack) gas referred to air, can be determined by the following:

   \[ \text{Sp. Gr.} = \frac{M_{CO_2} + M_{CO} + M_{O_2} + M_{N_2} + M_{H_2O}}{29.0} \quad (II-1) \]

   where:
   \[ M_{CO_2} = \left( \frac{\%CO_2}{100} \right) \times 44.011 \]
   \[ M_{CO} = \left( \frac{\%CO}{100} \right) \times 28.011 \]
   \[ M_{O_2} = \left( \frac{\%O_2}{100} \right) \times 32.000 \]
   \[ M_{H_2O} = \left( \frac{\%H_2O}{100} \right) \times 18.016 \]
   \[ M_{N_2} = \left( \frac{\%N_2}{100} \right) \times 28.20 \]

Molecular Weight of Dry Air = 29.00

3. The density of the flue gas at standard conditions is then:

   \[ \rho_{fg} = \text{Sp. Gr.} \times \rho_a \quad (II-2) \]

   where: \( \rho_a \) = density of dry air at standard conditions = 0.075 lb/ft\(^3\)

4. The total mass of flue gas leaving the system is:

   \[ M_o = \rho_{fg} Q_s, \quad (lb/hr) \quad (II-3) \]

5. The nitrogen in the flue gas can be used as a tie element to determine the quantity of dry combustion air introduced to the incinerator.

   \[ M_a = Q_s \left( \frac{\%N_2}{100} \right) \left( \rho_{N_2} / \rho_{N_2} \right), \quad (lb/hr) \quad (II-4) \]

   where: \( \rho_{N_2} \) = density of Nitrogen in lb/ft\(^3\) at standard conditions
   \( \rho_{N_2} = \text{weight fraction of Nitrogen in air} = .7683 \)

6. Equation (II-4) can be corrected for Nitrogen contained in any auxiliary fuel utilized in the incineration process.

   \[ M_{cca} = \left[ Q_s \left( \frac{\%N_2}{100} \right) \rho_{N_2} - Q_b \rho_{ng} \rho_{ng} \right] / \rho_{N_2}, \quad (lb/hr) \quad (II-5) \]

   where: \( \rho_{ng} = \text{density of auxiliary fuel, lb/ft}^3 \text{ at standard conditions} \)

7. By determining the absolute humidity (\( H_a \)) of the combustion air at the time of the test, the water contained in the combustion air can be accounted for.

   \[ M_{ca} = \left[ 1 + H_a \right] \left[ Q_s \left( \frac{\%N_2}{100} \right) \rho_{N_2} - Q_b \rho_{ng} \rho_{ng} \right] / \rho_{N_2}, \quad (lb/hr) \quad (II-6) \]

   where: \( H_a = \text{absolute humidity; lb water/lb dry air} \)

8. The burning rate of an incinerator can now be determined on an ash free basis.

   \[ \text{RAF} = \frac{M_o - M_{ca} - M_b}{M_b} \quad (lb/hr) \quad (II-7) \]

   where: \( M_b = \text{Auxiliary fuel flow rate, (lb/hr)} \)
   \( M_b = Q_b \rho_{ng} \)

9. Substituting Equations (II-3) and (II-6) into Equation (II-7), the burning rate equation can be expressed as:

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RAF = Q_s \left[ \rho_{fg} - (1 + H_a) \left( \frac{\%N_2}{100} \right) \left( \frac{\rho_{n_2}}{\rho_{n_2}} \right) \right] - 
Q_b \, \rho_{ng} \left[ 1 - \left( \frac{X_{ng}}{\rho_{n_2}} \right) (1 + H_a) \right]

in lb/hr of ash free waste burned.

If the ash content of the waste is known or can be determined, the charging rate can be expressed as:

(10) \quad RT = RA F \left[ \frac{1}{1 - \left( \frac{\% Ash}{100} \right)} \right], \quad (\text{lb/hr}) \quad (11.9)

where: \% Ash = weight percentage of incombustibles in the waste.