PTC Case P-2
Mass Balance/Efficiency Error on Units Utilizing Sorbent
PTC 4 – 2008

Inquiry: Utilizing the calculation format of the Calculation Forms in Appendix A, on CFB units, we cannot seem to get a mass balance between the streams entering the steam generator and those leaving the steam generator, i.e., Fuel+Sorbent+Total Air entering should equal Total Gas+Total Residue leaving, but it does not. The error is typically between 0.3 – 0.6% by mass depending upon the conditions. This error primarily affects the efficiency loss due to Dry Flue Gas. This is not a problem on units that do not utilize sorbent.

One of our engineers believes the error is due to oxygen in captured CaSO4. In equation 5.9.20 of PTC 4, the mass increase in bottom ash includes SO_3. Equation 5.12.1 takes into account the captured S, and it is not included in the flue gas. However, there is no reduction in O_3 in air from the flue gas.

Reply: It is the opinion of the Committee that the error has been traced to not reducing the dry air flow that contributes to the flue gas mass flow rate by the mass of O_3 (ozone) required to form SO_3 in the sulfur capture process, i.e., CaO+S+O3→CaSO4 and MgO+S+O3→MgSO4, which are solids. The solids/residue was accounted for correctly; however, the reduction of the O_3 in the dry air portion of flue gas was not accounted for. Not accounting for the dry gas flow correction for the O_3 in air required to form SO_3 primarily impacts the flue gas mass flow rate (0.4 % for the case studied). However, it also impacts efficiency (<0.05 points and percent moisture in the flue gas, which affects the enthalpy of flue gas and may have a minor impact on energy-balance calculations within the steam-generator envelope. Several equations and lines on the calculation forms are affected. The following pages itemize all the necessary corrections.

Corrections for Units Utilizing Sorbent

Page #	Section #	Comment
77	5-9.7	This section has been rewritten to account for the dry gas flow correction for the O_3 in air required to form SO_3. See the revised paragraph below.

5-9.7 MFrSsb and MFrO3ACr – Mass Fraction of Spent Sorbent and Mass Fraction of O_3 from Air Correction, lbm/lbm fuel (kg/kg)

Spent sorbent is the solid residue remaining from the sorbent after evaporation of the moisture in the sorbent, calcination/dehydration and mass gain due to sulfation (formation of $CaSO_4$ from CaO and $MgSO_4$ from MgO). The O_3 from air required to form SO_3 from the fuel becomes part of the spent sorbent, a solid. Therefore, a correction to the flue gas flow rate is required due to the reduction of O_3 from the air.

MFrSsb = MFrSb – MfrCO2Sb – MFrWSb + MFrSO3, lbm/lbm fuel (kg/kg) (5-9-19)

MFrSO3 = 0.025 MFrSc MPSF, lbm/lbm fuel (kg/kg) (5-9-20)

MoO3ACr = MFrO3ACr / MwO3, moles/lbm fuel (moles/kg) (5-9-21)

MqO3ACr = MFrO3ACr / HHVF, lbm/Btu (Kg/J) (5-9-22)

MFrO3ACr =0.6 MFrSO3,lbm/lbm fuel (kg/kg) (5-9-23)

where

MFrSO3 = mass fraction of SO_3 formed in the sulfation (sulfur capture) process, lbm/lbm fuel (kg/kg). The constant 0.025 is the molecular weight of SO_3 divided by the molecular weight of sulfur and divided by 100 to convert percent to a mass to mass fraction.

MoO3ACr = dry gas flow correction for the O_3 in air required to form SO_3, moles/lbm fuel (moles/kg).

MwO3 = molecular weight of O_3, 47.9982, lbm/mole (kg/mole).

MqO3ACr = dry gas flow correction for the O_3 in air required to form SO_3, lbm/Btu (Kg/J)

MFrO3ACr = mass-fraction of O_3 from air required to form SO_3 in the sulfation process, lbm/lbm (kg/kg). The constant 0.6 is the molecular weight of O_3 divided by the molecular weight of SO_3.

77	Eq. (5-9-16)	Revise constant at the end of the equation to correct gas flow for O_3 in air that becomes a solid: K = 2.387 (0.7905 + MoWA) – 2.3
81	Eq. 5-11-18	Add '-MoO3ACr' to the equation as shown below MoDFg=MoDPc+MoThACr (0.7905+XpA/100)-MoO3ACr
81	5-11.4.2	Add following to definitions. MoO3ACr = dry gas flow correction for the O_3 in air required to form SO_3, moles/mass fuel (refer to para. 5-9.7).
82	Eq. 5-11-28	Add 'MoO3ACr' to the end of the equation as shown below $$\mathrm{MoFg} = \mathrm{MoWPc} + \mathrm{MoThACr}\left[0.7905 + \mathrm{MoWA} + \frac{\mathrm{XpA}}{100}(1 + \mathrm{MoWA})\right] - \mathrm{MoO3ACr}$$

Page #	Section #	Comment
83	5-12.9	Change the introductory paragraph to: "The total wet gas at any location z is the sum of the dry air (less the dry air flow correction for the O_3 in air required to form SO_3), moisture in air, wet gas from the fuel, gas from sorbent, water from sorbent, and any additional moisture."
83	Eq. 5-12-10	Revise equation per below. MqFgz = (MqDAz - MqO3ACr) + MqWAz + MqFgF + MqCO2Sb + MqWSb + MqWAdz, Btu/lbm (J/kg)
84	5-12.10	Change the introductory paragraph to: "The dry flue gas weight is the difference between the wet flue gas and the total moisture in flue gas at location z.
121-128	Add the following acronyms	MoO3ACr dry gas flow correction for the O_3 in air required to form SO_3, moles/mass fuel MwO3 molecular weight of O_3, 47.9982, mass/mole MqO3ACr dry gas flow correction for the O_3 in air required to form SO_3, lbm/Btu (Kg/J) MFrO3ACr mass fraction of O_3 from air required to form SO_3 in the sulfation process, mass/mass fuel MFrStCr the ratio of the design main steam flow divided by the test main steam flow, mass/mass
149-182	Appendix A Calculation Forms	The revisions to the calculation forms for the reduction in dry flue gas flow due to the dry air to gas flow correction for the O_3 in air required to form SO_3 are described below. However, revisions to the Calculation Forms are not included in this Code Case. Users that are utilizing the format of the Calculation Forms for calculations, must make corrections in accordance with the text in this Code Case.
151	A-4.1 Form EFFa, Item 11	Revise Item 11 to read as follows: *Dry Air Weight ([69]+[45]).* Enter the Gas from Dry Air weight, Item [69] from Form CMBSTNc, plus the O3 (SO3) Corr, Item [45] from Form CMBSTNb. These values should correspond to the same location as Item [10] above. This should be a mass-weighted value for units with separate air heater types.
155	A-5.2.1 Form CMBSTNb, Items [40] – [45]	Revise paragraph to read as follows: Items 40-45 The calculations are descriptive and generally self-explanatory. Item [45] is multiplied by the HHV divided by the molecular weight of O_3 to change the units to moles/100 lbm fuel, Enter zero for Items [40] through [42] and Item [45] if sorbent is not used.

Page #	Section #	Comment
160	A-8.2.1 Form SRBb Items [34] – [40]	The description of Items 34-40 were omitted from previous issues of this Code. Items 34-40 are descriptive, generally self-explanatory and arranged for convenience of hand calculations.
160	A-8.2.1 Form SRBb Item [45]	Item 45 – The mass-fraction of sulfur capture/retention ratio based on the measurement of O_2 and SO_2 in the flue gas at a single location.
166	Form EFFa Item 11	Change the equation for Item [69] on the Calculation Form from [69] to [69] + [45]
170	Form CMBSTNb Item 45	This is a new line: O3 (SO3) Corr, lb/10KBtu [23] x [30D] x 1.5 / ([1]/100)
170	Form CMBSTNb, Item [57]	The calculations have been revised as follows: Summation [54] + [55] + [56] – [45] x [1] / 4799.8
171	Form CMBSTNc Item [64]	Revise the equation to account for the O_3 (SO_3) correction: [43] + [62] – [45] x [1] / 4799.8
171	Form CMBSTNc Item [65]	Revise the equation to account for the O_3 (SO_3) correction: [44] + [63] + [55] – [45] x [1] / 4799.8
171	Form CMBSTNc Item [69]	The description was changed to “Gas from Dry Air”. The equation was revised to correct the dry air flow entering the unit to the dry air flow remaining in the flue gas after the conversion of the sulfur captured to SO_3. Refer to paragraph 5-9.7,
171	Form CMBSTNc Item [72]	Since Item [69] was revised, it was necessary to revise the equation to calculate the moisture from air based on the total air entering the unit. [7] x (1 + [60]/100) x [48]
175	Form SRBb Item [38]	Revise Item 38 to account for the O_3 (SO_3) correction. It is noted that Item 38 is Item ‘K’ in Appendix C-2, Derivation of Sulfur Capture/Retention from Measured O_2 and SO_2. (0.7905 + [30]) x 2.387 – 2.3