

Common Calculations

1.0 Introduction

The following discussions are primarily for the stack emissions applications, however, the computational capability of The CPP can prove helpful in many applications. The following sections describe how to put three common types of calculations into the math template. The three types are:

-  Pounds per million Btu
-  Pounds per hour, and
-  Diluent correction.

Notice that the General Math Setup can be used to configure many different types of calculations, you are not limited to these three. However, you may want to read these sections to familiarize yourself with how equations are translated into the math template.

The CPP-3794 data acquisition system is designed to meet the requirements of data collection, data alarming, and emission calculations. Some of the terminology used in this section is defined below.

pollutant	Waste gases and/or particulates (sulfur oxides, nitrous oxides, organics, etc.) released in many cases as a by-product of incomplete combustion of a fuel (wood, natural gas, oil, etc) or of a manufacturing process.
diluent	A gas (typically oxygen or carbon dioxide) included in the pollutant gas stream that dilutes the concentrations before expulsion into the atmosphere.
dry basis	When the pollutant and diluent have had the moisture extracted before the concentration measurement is made, the measurement is said to be on a dry basis.
wet basis	When the pollutant and diluent have not had the moisture extracted before the concentration measurement is made, the measurement is said to be on a wet basis and many times a conversion from a wet to a dry basis is required.
F factor	(fuel factor) A value relating combustion gas volume to the heat content of the fuel being burned; and
FHV	Fuel heating value

If a value from a channel used in an equation (pollutant, diluent, or flow value) is invalid (downed in calibration or purge, or in bad status), the computed value is not used in forming an average.

Measured values of pollutant, diluent, and flow are used in the various calculations. Negative values of pollutant, diluent, and flow are internally forced to zero because they do not represent meaningful data in situations where this is likely to occur (such as analyzer down or malfunctioning, plant startup or shutdown), the ALARM firmware can be set to detect low (or high) values and invalidate computed data.

2.0 Pounds Per MBtu (Lbs./MBtu) Emission Calculations

The General Math Setup in the CPP firmware supports all types of Lbs/MBtu calculations. Seven common Lbs/MBtu calculations are presented below.

Equation 2.0A - Pollutant, Oxygen Diluent - Both on a Dry Basis

$$E = \frac{(Cd)(Fd)(20.9)}{(20.9 - \%O_2d)}$$

Equation 2.0B - Pollutant, Oxygen Diluent - Both on a Wet Basis

$$E = \frac{(Cw)(Fw)(20.9)}{20.9(1 - Bwa) - \%O_2w}$$

Equation 2.0C - Pollutant-Wet Basis, Oxygen Diluent-Dry Basis

$$E = \frac{(Cw)(Fd)(20.9)}{(1 - Bws)(20.9 - \%O_2d)}$$

Equation 2.0D - Pollutant-Dry Basis, Oxygen Diluent-Wet Basis

$$E = \frac{(Cd)(Fd)(20.9)}{20.9 - \%O_2w / (1 - Bws)}$$

Equation 2.0E - Pollutant, Carbon Dioxide Diluent-Both either Wet or Dry Basis

$$E = \frac{(C)(Fc)(100)}{\%CO_2}$$

Equation 2.0F - Pollutant-Wet Basis, Carbon Dioxide Diluent-Dry Basis

$$E = \frac{(C_w)(F_c)(100)}{(1 - B_{ws})(\%CO_2d)}$$

Equation 2.0G - Pollution-Dry Basis, Carbon Dioxide-Wet Basis

$$E = \frac{(C_d)(1 - B_{ws})(F_c)(100)}{\%CO_2w}$$

where:

E	= pollutant emission rate (Lbs./MBtu)
C _w	= pollutant concentration measured on wet basis (lb/wscf)
C _d	= pollutant concentration measured on dry basis (lb/dscf)
C _d , C _w	= (2.59 * 10 ⁹) x (molecular weight) x measured pollutant concentration (ppm) molecular weight - SO ₂ = 64.07 lb/lb-mole NO _x = 46.01 CO = 28.01
F _d	= dry fuel factor (dscf / 10 ⁶ Btu)
F _w	= wet fuel factor (wscf / 10 ⁶ Btu)
F _c	= carbon fuel factor (scf / 10 ⁶ Btu)
B _{wa}	= proportion by volume of H ₂ O in ambient air (.027 is the common default)
B _{ws}	= proportion by volume of H ₂ O in stack gas
%O _{2w}	= percent oxygen measured on wet basis
%O _{2d}	= percent oxygen measured on dry basis
%CO _{2w}	= percent carbon dioxide measured on wet basis
%CO _{2d}	= percent carbon dioxide measured on dry basis.

F factor values for various fuels are listed at the end of this appendix, in Table 1.0.

3.0 Example of Pounds Per MBtu (Lbs/MBtu)

In this example, the following scenario is assumed: the system must measure SO₂ with an oxygen diluent - both measured on a wet basis; the system uses bituminous coal for fuel; channel 9 will be used to calculate lbs/MBtu; SO₂ data is coming in on Channel 1; and O₂ data is coming in on Channel 4. Because both SO₂ and O₂ are being measured on a wet basis, Equation 2.0B will be used (repeating the equation)

Equation 2.0B - Pollutant with Oxygen Diluent-Both on a Wet Basis

$$E = \frac{(Cw)(Fw)(20.9)}{20.9(1 - Bwa) - \%O_2w}$$

In this equation, the variables are defined as follows.

- E = Lbs/MBtu. This will be the result of the calculation and it will be stored on channel 9.
- Cw = The product of concentration of SO₂ (ppm) measured on a wet basis and coming into the CPP on channel #1, molecular weight of SO₂, and expression (2.59 * 10⁻⁹)
- Fw = Wet fuel factor. From Table 1.0, the wet fuel factor (O₂ diluent) for bituminous coal is 10680.
- Bwa = The ambient moisture factor and accepted value is .027.
- O₂w = Concentration of oxygen measured on a wet basis and coming into the CPP on Channel 4.

Assuming these values, the equation for calculating Lbs/MBtu is

$$Lbs / MBtu = \frac{(SO_2 ppm)(64.07)(2.59 * 10^{-9})(10680)(20.9)}{20.9(1-.027) - \%O_2w}$$

:

In order to put this equation into the math template, we need to divide the equation into the template's four terms.

Term 1	Term 2	Term 3	Term 4
[(CHA)(KA) {OP#1}]	(CHB)(KB) [OP#2]	[(CHC)(K3) {OP#3}]	(CHD)(K4)

There will be more than one way to put any equation into the math template. The following is one way for it to be done. We will define the variables in the math template as follows:

Term 1 represents the measured ppm of SO₂.

- CHA = 1 This is the data channel from which the measured ppm of SO₂ will be taken to use in the calculation.
- KA= 1.000 Since Term 1 represents an actual measured value, the constant is 1 so that the result is the measured value.
- KA EXP=0 Since Term 1 represents an actual measured value, the constant should remain 1. 1*10⁰ is equal to 1. Enter 1.000E+0.

Term 2 represents all constant values in the numerator of the equation. In many equations, it is better to combine constants into one term in the template. In this case, we can combine all constants in the numerator since they will all be multiplied together. Term 2 will be the product of the items (64.07)(2.59*10⁻⁹)(106800)(20.9).

Put Term 2 into the template.

- CHB = 00 This is a null channel (sets this value to 1 internally) since we are using Term 2 for constants, not for measured values.
- KB =3.704 The product of $\{64.07 * (2.59 \times 10^{-9}) * 10680 * 20.9\}$ is .03704. Since **Kn** is a variable with a fixed format of x.xxx, we must adjust the decimal place in the value to 3.704 using the exponent (EXP) function described below.
- KB EXP =-2 The EXP function allows us to move the decimal place of a constant to fit the format of **Kn**. The variable entered for KB, 3.704, must be multiplied by 10^{-2} to result in the actual value of the constant: .03704. Enter 3.704E-2.

Term 3 also represents constants; specifically, the part of the denominator $\{20.9(1-.027)\}$.

- CHC = 00 As with Term 2, this is a null channel since we are using Term 3 for constants, not for measured values.
- KC = 2.033 The product of $(20.9 * (1-.027))$ is 20.33. Since **Kn** is a variable with a fixed format of x.xxx, we must adjust the decimal place in the value to 2.033 using the exponent (EXP) function described below.
- KC EXP =1 The EXP function allows us to move the decimal place of a constant to fit the format of **Kn**. The variable entered for KC, 2.033, must be multiplied by 10^1 to result in the actual value of the constant, 20.33. Enter 2.033E+1.

Term 4 is the measured O₂ in percent.

- CHD = 4 This is the data channel from which the measured ppm of O₂ will be taken to use in the calculation.
- KD = 1.000 We want the result of Term 4 to equal the O₂ value taken from CH #4; therefore, we will multiply it by the constant 1.000.
- KD EXP = 0 Since we don't need to move the decimal place of KD, we multiply it by 10^0 , or 1. Enter 1.000E+0.

Operators

- OP#1= * Multiply Term 1 by Term 2.
- OP#2 = / Divide the result of Operation 1 by the result of Operation 3.
- OP#3 = - Subtract Term 4 from Term 3.

Presented below in Figure 1.0 is the actual setup procedure for the Lbs/MBtu calculation.

Figure 1.0
Set Up Example Of Lbs/MBtu Calculation

- 1 Chan # = **09**
- 2 CHA = **00 1**
- 3 KA = 1.000E+0 = **1.000E+0<cr>**
- 4 OP #1 = : ***<cr>**
- 5 CHB = 00 **<cr>**
- 6 KB = 1.000E+0 = **3.704E-2<cr>**
- 7 OP #2 = : **/<cr>**
- 8 CHC = 00 **<cr>**
- 9 KC = 1.000E+0 = **2.033E+1**
- 10 OP #3 = : **-<cr>**

- 11 CHD = 00 4<cr>
- 12 KD = 1.000E+0<cr>
- 13 Enable Y/N = N Y
- 14 Chan # = <cr>
- 15 Back to Main Menu

$$\frac{[(\text{CH01})(1.000) * (1.000)(3.704)] / (1.000)(20.33) - (\text{CH04})(1.000)}{\text{SO}_2 \quad \text{KA} \quad \text{OP\#1} \quad \text{CHB} \quad \text{KB} \quad \text{OP\#2} \quad \text{CHC} \quad \text{KC} \quad \text{OP\#3} \quad \text{O}_2 \quad \text{KD}}$$

- Line 1** CHAN # = 09<cr>
The system prompts for a channel number where the result of the Lbs/MBtu calculation is to be stored.
- Line 2** CHA = 00 1<cr>
The SO₂ data to be used for variable CHAN A will be pulled from data channel 1.
- Line 3** KA = 1.000E+0<cr>
A constant entered with a fixed format of x.xxx. This constant can represent different constants depending on the type of calculation. The constant is set to 1.000 so the measured parameter is used.
- Line 4** OP#1 = : *<cr>
Select the arithmetic operator needed for this part of the algorithm. An* (asterisk) is entered which indicates that this term (#1) should be multiplied by term #2.
- Line 5** CHB= 00 <cr>
This will be read as a null channel, and set to 1.000. As a result, the term will represent the constant, KB, and its associated exponent.
- Line 6** KB = 1.000E+0 = 3.704E-2<cr>
A constant entered with a fixed format of x.xxx. This constant can represent ts depending on the type of calculation. Represents all constants in the numerator of the Lbs/MBtu calculation.
- Line 7** OP#2 = : /<cr>
Select the arithmetic operator needed for this part of the algorithm. The forward slash (/) indicates that the value rendered by operating on terms #1 and #2 are to be divided by the value rendered by operating on terms #3 and #4.
- Line 8** CHC # = 00 <Cr>
This will be read as a null channel. As a result, the value will represent the constant, KC, and its associated exponent.
- Line 9** KC = 1.000E+0 = 2.033E+1<cr>
A constant entered with a fixed format of x.xxx. This constant represents all constants in the denominator of the Lbs/MBtu calculation.

- Line 10** OP#3 = : -<cr>
Select the arithmetic operator needed for this part of the algorithm. A -(dash) is entered. This indicates that term #4 will be subtracted from term #3.
- Line 11** CHD = 00 04 <cr>
The O₂ data to be used for the CHAN D variable will be taken from data channel 4.
- Line 12** KD = 1.000E+0 <cr>
A constant entered with a fixed format of x.xxx. This constant can represent different numbers depending on the type of calculation. In this case, the use of KD's default value, 1.000, will result in the actual value of the CHAN #4, or the O₂ in percent.
- Line 13** Enable Y/N N Y<cr>
A Y response will enable the selected channel for computation. Any other response will disable the computation.
- Line 14** CHAN # = <cr>
The computed channel has now been initialized. The system prompts for another channel to initialize. A carriage return will exit the General Math Set Up, and return to the Main Menu.

4.0 Pounds Per Hour (Lbs/Hr)Emission Rate

The CPP firmware supports both common types of Lbs/Hr calculations, based either on stackflow (Q_s) or fuel flow (Q_f).

$$\text{Equation 4.0A} \quad E = (C)(Q_s)(60)(k)$$

Both C and Q_s must be either wet or dry. If C is dry and Q_s is wet, correct C by multiplying by (1-Bws), where (1-Bws) can be estimated as:

$$\frac{O_2 \text{ wet}}{O_2 \text{ dry}}$$

$$\text{Equation 4.0B} \quad E = (Lbs / MBtu)(FHV)(Q_f)(60)(k)$$

Where:

- E = Pollutant emission rate (Lbs/Hr);
- C = $(2.59 * 10^{-9}) * (\text{molecular weight}) * (\text{measured pollutant concentration})$
Molecular Weight
SO₂ = 64.07 lb/lb - mole,
NO_x = 46.01,
CO = 28.01;
- Q_s = Measured stack flow (scfm)
- k = Annubar constant (typically = 1.000) ;
- FHV = Fuel heating value (Btu/scf or Btu/gal); and

Q_f = Measured fuel flow (scfm or gpm).

5.0 Example of Lbs/Hr Calculation

Assume we want to compute the pounds per hour of NOx (based on stack flow) and store the calculated information on Channel 7. NOx raw data is coming in on Data Channel 1. The measured stack flow is stored on Channel 5. Both NOx and stack flow are based on wet measurements. Because we want to calculate pounds per hour based on stack flow, we will use the (Q_s) and equation 4.0A as shown above.

$$E = (C)(Q_s)(60)(k)$$

In this equation, the variables are defined as follows:

- E = Pounds per hour. This will be the result of our calculation; it will be stored on channel 7.
- C = The product of the following: NOx measured in ppm, coming in on channel 1 the molecular weight of NOx (46.01), and the expression (2.59×10^{-9}) .
- Q_s = Measured stack flow, coming in on Channel 5.
- k = Annubar (typically = 1.000).

$$E = (ppmNOx)(46.01)(2.59 * 10^{-9})(Flow)(60)(1.000)$$

Assuming these values, the equation for calculating Lbs/Hr is:

In order to put this equation into the math template, we need to divide the equation into the template's four terms:

$$[(CHA)(KA) OP\#1 (CHB)(KB)] OP\#2 [(CHC)(KC) OP\#3 (CHD)(KD)]$$

There will be more than one way to put any equation into the math template. In this example, we represent all constants in the equation with one term since they must all be multiplied together. Information from data channels can be represented on a one-to-one basis, *i.e.*, one term for one channel. For the example, we will define the variables in the math algorithm as follows.

Term 1 represents the measured ppm of NOx.

- CHA = 1 This is the data channel from which the measured ppm of NOx will be taken to use in the calculation.
- KA = 1.000 We want the result of Term 1 to equal the NOx value taken from CHA, so we will multiply it by the constant 1.000.
- KA EXP =0 Since we do not need to move the decimal place of KA, we can multiply it by 10^0 , or 1. Enter 1.000E+0.

Term 2 will represent all constants in the following equation, which are;

$$46.01 * (2.59 * 10^{-9}) * 60 * 1.000$$

The result of this operation is .0000071499 (we can represent this value as $7.149 * 10^{-6}$).

Put Term 2 into the template.

- CHB = 00 This is a null channel since we are using Term 2 for constants, not for measured values.
- KB = 7.149 This variable represents all constants in the equation. Since **Kn** is a variable with a fixed format of x.xxx, we must adjust the decimal place in the value to 7.149 using the exponent.
- KB EXP = -6 The EXP function allows us to move the decimal place of a constant to fit the fixed format of **Kn**. The variable entered for KB, 7.149, can be multiplied by 10^{-6} to result in the actual value of the constant, .0000071499. Enter 7.149E-6.

Term 3 represents the stack flow values coming in on Channel 5.

- CHC = 05 This is the data channel from which the measured stack flow value will be taken to use in the calculation.
- KC = 1.000 We want the result of Term 3 to equal the Stack Flow value taken from CHC, so we will multiply it by the constant 1.000.
- KC EXP = 0 Since we do not need to move the decimal place of KC, we can multiply it by 10^0 , or 1. Enter 1.000E+0.

We do not need to set up Term 4 since all constants and variables in the equation have been represented by the first three terms. Using a null operator (:) for Operator #3 tells the system that there is no Term 4.

- OP#1 = * We will multiply Term 1 by Term 2.
- OP#2 = * We will multiply the result of Operation 1 by Term 3.
- OP#3 = : Null operator. This tells the system that there is no Term 4.

An example of this math set up is presented in Figure 2.0.

Figure 2.0
Set Up Example Of Lbs/Hr Calculation

```

Chan # = 07<cr>
CHA = 00 01<cr>
KA = 1.000E+0 = <cr>
OP#1 = : *<cr>
CHB = 00 <cr>
KB = 1.000E+0 = 7.149E-6
OP#2 = : *<cr>
CHC = 00 5<cr>

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KC = 1.000E+0 = <cr>

OP#3 = : <cr>

Chan # = <cr>

Back To Main Menu

6.0 Calculating Diluent Correction

There are several types of diluent correction calculations, based either on O₂ as the diluent or on CO₂ as the diluent.

$$\text{Equation 6.0A - (corrected pollutant) = (raw pollutant) } \frac{20.9 - C.F.}{\text{DryBasis}} .$$

Both pollutant and oxygen must be on a dry basis. To correct either the pollutant and/or oxygen to a dry basis divide the wet measurement by the quantity (1-Bws).

Note: CO₂ measurements also may be used to correct pollutant measurements to a specified oxygen level. See 40 CFR Part. 60, Appendix A, Method 20 for more information.

$$\text{Equation 6.0B - (corrected pollutant) = (raw pollutant) } \frac{C.F.}{\%CO_2} .$$

The pollutant and CO₂ must be on the same basis (either wet or dry), where:

C.F. = correction factor (%),

Bws = proportion by volume of H₂O in stack gas,

%O₂ = percent oxygen, and

%CO₂ = percent carbon dioxide.

Select the equation you need and implement it using the math template. Remember to define your variables and data channels before attempting to enter information into the setup. If you need assistance, call H2NS.

7.0 F Factors For Various Fuels

Presented in Table 1.0 below are some fuel factors for various fuels.

Table 1.0
F Factors For Various Fuels^c

Fuel Type	dscm /J	dscf /10 ⁶ BtuJ	wscm 10 ⁶ BtuJ	wscf 10 ⁶ BtuJ	scm CO ₂ /J	scf CO ₂ /10 ⁶ Btu
Coal : ^a						
Anthracite ^a	2.723x10 ⁻¹⁷	(10140)	2.83x10 ⁻¹⁷	(10540)	0.532x10 ⁻¹⁷	(1980)
Bituminous ^a	2.637x10 ⁻¹⁷	(9820)	2.86x10 ⁻¹⁷	(10640)	0.486x10 ⁻¹⁷	(1810)
Lignite	2.659x10 ⁻¹⁷	(9900)	3.21x10 ⁻¹⁷	(11950)	0.516x10 ⁻¹⁷	(1920)
Oil ^b	2.476x10 ⁻¹⁷	(9220)	2.77x10 ⁻¹⁷	(10320)	0.384x10 ⁻¹⁷	(1430)
Gas :						
Natural	2.347x10 ⁻⁷	(8740)	2.85x10 ⁻⁷	(10610)	0.279x10 ⁻⁷	(1040)
Propane	2.347x10 ⁻⁷	(8740)	2.74x10 ⁻⁷	(10200)	0.322x10 ⁻⁷	(1200)
Butane	2.347x10 ⁻⁷	(8740)	2.79x10 ⁻⁷	(10390)	0.338x10 ⁻⁷	(1260)
Wood	2.492x10 ⁻⁷	(9280)			0.494x10 ⁻⁷	(1860)
Wood Bark	2.589x10 ⁻⁷	(9640)			0.500x10 ⁻⁷	(1840)

^a As classified according to ASTM D 388-66

^b Crude, residual, or distillate

^c Determined at standard conditions: 20⁰C (68⁰F) and 760mm Hg (29.92 in. Hg)

tn01