Hydrocarbon Fuel Gas [insert into Title-V Permits]

Calculate \( \text{SO}_2 \) concentration using the equations below:

\[
A = \left[ \text{H}_2 \text{S concentration} \right] \div 1,000,000 = \text{ppmv} \div 1,000,000 = \\
B = 6.64 \times A = 6.64 \times \text{_____} = \\
C = \left[ \text{vol\% inertgas}_{\text{fuel}} \right] \div 100\% = \text{_____ \%} \div 100\% = \\
D = \left[ \text{wt\% HC}_{\text{fuel}} \right] \div 100\% = \text{_____ \%} \div 100\% = \\
E = \left[ \text{wt\% C}_{\text{HC}} \right] \div 100\% = \text{_____ \%} \div 100\% = \\
F = 0.396 \times E = 0.396 \times \text{_____} = \\
G = \left[ \text{wt\% HC}_{\text{fuel}} \right] \div 100\% = \text{_____ \%} \div 100\% = \\
H = 0.933 \times G = 0.933 \times \text{_____} = \\
I = F + H = \text{_____} + \text{_____} = \\
J = D \times I \times \left[ \text{MW}_{\text{HC}} \right] = \text{_____} \times \text{_____} \times \text{_____} = \\
K = B + C + J = \text{_____} + \text{_____} + \text{_____} = \\
L = 21\% - \left[ \text{vol\% dry O}_2, \text{exhaust} \right] = 21\% - \text{_____ \%} = \text{_____ \%} \\
M = \left[ \text{vol\% dry O}_2, \text{exhaust} \right] \div L = \text{_____ \%} \div \text{_____ \%} = \\
N = 1 + M = 1 + \text{_____} = \\
O = K \times N = \text{_____} \times \text{_____} = \\
\text{SO}_2 \text{ concentration} = \left[ \text{H}_2 \text{S concentration} \right] \div O = \text{_____ ppmv} \div \text{_____} = \text{_____ ppmv}
\]

List of Abbreviations Used in this Permit [insert into Section 1 of Title-V Permits]

\( \text{H}_2 \text{S concentration} \) is the volumetric \( \text{H}_2 \text{S} \) concentration of a fuel gas on a dry or wet basis, \( 10^6 \times \text{gmole-} \text{H}_2 \text{S/gmole-fuel} \) (i.e. ppmv)

\( \text{MW}_{\text{HC}} \) is the molecular weight of the hydrocarbon portion of the fuel gas, \( \text{g/gmole-HC} \)

\( \text{SO}_2 \text{ concentration} \) is the volumetric \( \text{SO}_2 \) concentration of the exhaust gas on a dry basis, \( 10^6 \times \text{gmole-} \text{SO}_2/\text{gmole-air,exhaust,dry} \) (i.e. ppmv)

\( \text{vol\% dry O}_2, \text{exhaust} \) is the volume percent \( \text{O}_2 \) of the exhaust gas on a dry basis, \( 100\\% \times \text{gmole-} \text{O}_2/\text{gmole-dry exhaust} \)

\( \text{vol\% HC}_{\text{fuel}} \) is the volume percent hydrocarbons of a fuel gas, \( 100\\% \times \text{gmole-} \text{HC/gmole-fuel} \)

\( \text{vol\% H}_2 \text{O}_{\text{fuel}} \) is the volume percent water vapor of a fuel gas (equals zero if on a dry basis), \( 100\\% \times \text{gmole-} \text{H}_2 \text{O/gmole-fuel} \)

\( \text{vol\% inertgas}_{\text{fuel}} \) is the volume percent inert gas (e.g. \( \text{N}_2 \) and \( \text{CO}_2 \)) of a fuel gas, excluding water vapor, \( 100\\% \times \text{gmole-} \text{inertgas/gmole-fuel} \)

\( \text{wt\% C}_{\text{HC}} \) is the weight-percent carbon of the hydrocarbon portion of a fuel gas, \( 100\\% \times \text{g-C/g-HC} \)

\( \text{wt\% H}_{\text{HC}} \) is the weight-percent hydrogen of the hydrocarbon portion of a fuel gas, \( 100\\% \times \text{g-H/g-HC} \)
For example, a fuel gas on a dry basis is 50-ppm H₂S, 2% CO₂, 3% N₂, and 95% CH₄ (i.e. methane) with vol% dry O₂ exhaust = 15%. The inputs are:

\[ \text{H}_2\text{S concentration} = 50 \text{ ppm}; \quad \text{MW}_{\text{HC}} = 16; \quad \text{vol}\%_{\text{inertgas}_\text{fuel}} = 2 + 3 = 5\%; \]
\[ \text{vol}\%_{\text{HC}_\text{fuel}} = 95\%; \quad \text{wt}\%_{\text{C}_{\text{HC}}} = 75\%; \quad \text{and} \quad \text{wt}\%_{\text{H}_{\text{HC}}} = 25\%. \quad \text{(Note that vol}\%_{\text{H}_2\text{S}_\text{fuel}} = 50 / 10,000 = 0.005\%, \quad \text{that vol}\%_{\text{H}_2\text{O}_\text{fuel}} = 0\%). \quad \text{SO}_2\text{concentration} = 1.8 \text{ ppmv.} \]

Note that the sum of the following four terms must total 100%:
1) \( \text{H}_2\text{S concentration} \) converted to a percent by dividing by 10,000 (i.e. vol% H₂S fuel);
2) vol% inertgas_fuel;
3) vol% HC_fuel; and
4) vol% H₂O_fuel. Note that the sum of wt% C_{HC} and wt% H_{HC} must total 100%.
ATTACHMENT 1 [insert into Title-V Statements of Bases]

Computational Basis is 1 \textit{gmole} hydrocarbon fuel gas

NOMENCLATURE (in alphabetical order):

- $C_{\text{fuel}}$ = number of gram-moles of the carbon part of a fuel gas, \textit{gmole-C}
- $H_{2,\text{fuel}}$ = number of gram-moles of the "equivalent H$_2$" part of a fuel gas, \textit{gmole-H$_2$}
- $H_2S_{\text{concent}}$ = volumetric H$_2$S concentration of a fuel gas on a dry or wet basis, $10^6 \times \frac{\text{gmole-H}_2S}{\text{gmole-fuel}}$ (i.e. ppmv)
- $\text{mol-CO}_2$ = amount of CO$_2$ in the exhaust gas, \textit{gmole-CO}_2
- $\text{mol-H}_2O$ = amount of H$_2$O in the exhaust gas supplied by the free hydrogen in the fuel gas, excluding water vapor from the fuel gas and excluding water vapor from the ambient air, \textit{gmole-H}_2O
- $\text{mol-O}_2$ = amount of O$_2$ in the exhaust gas, \textit{gmole-O}_2
- $\text{mol-N}_2$ = amount of N$_2$ in the exhaust gas, excluding N$_2$ from the fuel gas, \textit{gmole-N}_2
- $\text{mol-SO}_2$ = amount of SO$_2$ in the exhaust gas, \textit{gmole-SO}_2
- $\text{MW}_{\text{HC}}$ = molecular weight of the hydrocarbon part of a fuel gas, g-\textit{HC/gmole-HC}
- $N_{2,C}$ = ambient N$_2$ accompanying O$_2,C$ for combustion, \textit{gmole-N}_2
- $N_{2,H_2}$ = ambient N$_2$ accompanying O$_2,H_2$ for combustion, \textit{gmole-N}_2
- $N_{2,S}$ = ambient N$_2$ accompanying O$_2,S$ for combustion, \textit{gmole-N}_2
- $O_{2,C}$ = ambient O$_2$ used to combust the carbon part of a fuel gas, \textit{gmole-O}_2
- $O_{2,H_2}$ = ambient O$_2$ used to combust the H$_2$ part of a fuel gas, \textit{gmole-O}_2
- $O_{2,S}$ = ambient O$_2$ used to combust the sulfur part of a fuel gas, \textit{gmole-O}_2
- $\text{part-H}_2S$ = fraction of hydrogen-sulfide of a fuel gas, $\frac{\text{gmole- H}_2S}{\text{gmole-fuel}}$
- $\text{part-HC}$ = fraction hydrocarbon of a fuel gas, $\frac{\text{gmole- HC}}{\text{gmole-fuel}}$
- $\text{part-inertgas}$ = fraction inert gas (e.g. N$_2$ and CO$_2$) of a fuel gas, \textit{gmole-inertgas/gmole-fuel}
- $S_{\text{fuel}}$ = number of gram-moles of the sulfur part of a fuel gas, \textit{gmole-S}
- $\text{SO}_2_{\text{concent}}$ = volumetric SO$_2$ concentration of the exhaust gas on a dry basis, $10^6 \times \frac{\text{gmole-SO}_2}{\text{gmole-dryexhaust}}$ (i.e. ppmv)
- $\text{total-N}_2$ = amount of ambient N$_2$ accompanying \textit{total-O}_2 for combustion, \textit{gmole-N}_2
- $\text{total-O}_2$ = total amount of ambient O$_2$ for combustion plus the excess O$_2$, \textit{gmole-O}_2
- $\text{vol\% dryO}_2,ex$ = volume percent O$_2$ of the exhaust gas on a dry basis, 100\% \times $\frac{\text{gmole-O}_2}{\text{gmole-dryexhaust}}$
- $\text{vol\% H}_2O_{\text{fuel}}$ = volume percent water vapor of a fuel gas (equals zero if on a dry basis), 100\% \times $\frac{\text{gmole-H}_2O}{\text{gmole-fuel}}$
\[ \text{vol}\%\text{HC}_{\text{fuel}} = \text{volume percent hydrocarbons of a fuel gas, } 100\% \times \frac{\text{g mole-HC}}{\text{g mole-fuel}} \]

\[ \text{vol}\%\text{inertgas}_{\text{fuel}} = \text{volume percent inert gas (e.g. N}_2\text{ and CO}_2\text{) of a fuel gas, excluding water vapor, } 100\% \times \frac{\text{g mole-inertgas}}{\text{g mole-fuel}} \]

\[ \text{wt}\%\text{C}_{\text{HC}} = \text{dry weight-percent carbon of the hydrocarbon part of a fuel gas (not weight percent carbon of the total fuel gas), } 100\% \times \frac{\text{g-C}}{\text{g-HC}} \]

\[ \text{wt}\%\text{H}_{\text{HC}} = \text{dry weight-percent hydrogen of hydrocarbon part of a fuel gas (not weight percent carbon of the total fuel gas), } 100\% \times \frac{\text{g-H}}{\text{g-HC}} \]

**Note 1:** Volume percent and mole percent are equivalent, but neither volume percent nor mole percent are equivalent to weight percent.

**Note 2:** \text{wt}\%\text{H}_{\text{HC}} is equivalent to (defined by analogy) \text{wt}\%\text{H}_{2,HC}. \text{part-inertgas} is equivalent to both (defined by analogy) inertgas_{fuel} and to mol-inertgas.

**OUTPUT:**

1. \text{SO}_2\text{concentration} on a dry basis for the combustion of a fuel gas

**Note 3:** Although \text{SO}_2\text{concentration} is on a dry basis, \text{mol-H}_2\text{O} is still an important dummy variable that needed to be calculated because \text{N}_{2,H_2} that accompanies \text{O}_2,H_2 dilutes \text{SO}_2\text{concentration}.

**INPUTS:**

1. \text{H}_2\text{Sconcentration}
2. \text{vol}\%\text{H}_2\text{O}_{\text{fuel}}
3. \text{vol}\%\text{HC}_{\text{fuel}}
4. \text{vol}\%\text{inertgas}_{\text{fuel}}
5. \text{MW}_{\text{HC}}
6. \text{wt}\%\text{C}_{\text{HC}}
7. \text{wt}\%\text{H}_{\text{HC}}
8. \text{vol}\%\text{dry}\text{O}_2,\text{exhaust}

**Note 4:** The sum of the following four terms must total 100%: 1) \text{H}_2\text{Sconcentration} converted to a percent by dividing by 10,000 (i.e. \text{vol}\%\text{H}_2\text{S}_{\text{fuel}} by analogy); 2) \text{vol}\%\text{inertgas}_{\text{fuel}}; 3) \text{vol}\%\text{HC}_{\text{fuel}}; and 4) \text{vol}\%\text{H}_2\text{O}_{\text{fuel}}. \text{wt}\%\text{C}_{\text{HC}} and \text{wt}\%\text{H}_{\text{HC}} must total 100% by the definition of hydrocarbon. The sum of \text{wt}\%\text{C}_{\text{HC}} and \text{wt}\%\text{H}_{\text{HC}} must total 100%. For example, a fuel gas on a dry basis is 50-ppm \text{H}_2\text{S}, 2\% \text{CO}_2, 3\% \text{N}_2, and 95\% methane: 1) \text{vol}\%\text{H}_2\text{S}_{\text{fuel}} = 50 / 10,000 = 0.0\%; 2) \text{vol}\%\text{inertgas}_{\text{fuel}} = 2 + 3 = 5\%; 3) \text{vol}\%\text{HC}_{\text{fuel}} = 95\%; 4) \text{vol}\%\text{H}_2\text{O}_{\text{fuel}} = 0\%; 5) \text{wt}\%\text{C}_{\text{HC}} = 75\%; and 6) \text{wt}\%\text{H}_{\text{HC}} = 25\%. 
ASSUMPTIONS:

1. Any and all water in the fuel gas and/or in the ambient air is inert during combustion of the fuel gas.
2. All fuel gas consists of inert gas (e.g. N$_2$ and CO$_2$), gaseous hydrocarbons, hydrogen sulfide, and water vapor. Note 4 is the only reason why the water vapor in the fuel may not be negligible.
3. Ambient air— only O$_2$ and N$_2$—has 3.76 moles of N$_2$ per mole of O$_2$. Therefore, there are 4.76 moles of air per mole of O$_2$. Any and all water vapor in the ambient air is negligible because the output is on a dry basis and because of assumption 1.
4. The only source of O$_2$ for combustion is from the ambient air.
5. Perfect combustion is combustion that is complete and clean with no soot, PM, HC, VOC, CO, and NO$_x$ in the exhaust gas. Therefore, vol$\%_{\text{dry O}_2, \text{exhaust}}$ must be greater than or equal to zero while all part-inertgas, all N$_2$, and all excess O$_2$ is inert in the combustion process.
6. For regulatory purposes (i.e. the purpose of developing this output), all of the sulfur in the fuel gas forms SO$_2$ in the exhaust gas and none of the sulfur is removed by from the exhaust gas.

Note 5: Assumptions 1 – 5 are commonly accepted assumptions for combustion analysis. Assumption 6 is based on 18 AAC 50.055(c), which states, “sulfur-compound emissions expressed as sulfur dioxide.”

SOLUTION:

Note 6: Eqs. (1-1) – (1-6) are definitions of variables as functions of inputs, constants, and other variables on a computational basis of 1 gmole hydrocarbon fuel gas (including hydrogen sulfide and inert gas).

Eq. (1-1) \( \text{part-H}_2\text{S} = \frac{\text{H}_2\text{S concentration}}{10^6} \)

Eq. (1-2) \( \text{part-inertgas} = \frac{\text{vol}\%_{\text{dry inertgas}}}{100\%} \)

Eq. (1-3) \( \text{part-HC} = \frac{\text{vol}\%_{\text{dry HC}}}{100\%} \)

Eq. (1-4) \( S_{\text{fuel}} = \text{part-H}_2\text{S} \)

Eq. (1-5) \( C_{\text{fuel}} = \text{part-HC} \times \left( \frac{\text{wt}\%_{\text{HC}}}{100\%} \right) \times \left( \frac{\text{MW}_{\text{HC}}}{12.01} \right) \)

Eq. (1-6) \( H_{2,\text{fuel}} = \text{part-H}_2\text{S} + \left( \text{part-HC} \times \left( \frac{\text{wt}\%_{\text{H}_2,\text{HC}}}{100\%} \right) \times \left( \frac{\text{MW}_{\text{HC}}}{2.016} \right) \right) \)
Note 7: Eqs. (2-1) – (2-3) are the stoichiometric combustion equations for sulfur, carbon, and hydrogen, whereas the right arrows show exothermic chemical reactions. The inert water vapor from the fuel gas and from the ambient air was not shown in eq. (2-3); see assumptions 2 – 3. Eq. (2-4) shows that the O\textsubscript{2} supplied by the ambient air minus the O\textsubscript{2} consumed in eqs. (2-1) – (2-3) is the O\textsubscript{2} in the exhaust gas. Eq. (2-5) shows that the N\textsubscript{2} supplied by the ambient air is the N\textsubscript{2} in the exhaust gas without any chemical change (e.g. zero NO\textsubscript{x} from assumption 4). Eq. (2-6) shows that like the N\textsubscript{2}, the inert gas in the fuel is the same in the exhaust gas. The double arrows in eqs. (2-4) – (2-6) show no chemical reactions (i.e. inert from assumption 5).

Eq. (2-1) \[ S\textsubscript{fuel} + O\textsubscript{2,S} + N\textsubscript{2,S} \iff \text{mol-SO}_{2} + N\textsubscript{2,S} \]

Eq. (2-2) \[ C\textsubscript{fuel} + O\textsubscript{2,C} + N\textsubscript{2,C} \iff \text{mol-CO}_{2} + N\textsubscript{2,C} \]

Eq. (2-3) \[ H\textsubscript{2,\text{fuel}} + O\textsubscript{2,H2} + N\textsubscript{2,H2} \iff \text{mol-H}_{2}O + N\textsubscript{2,H2} \]

Eq. (2-4) \[ \text{total-O}_2 \cdot O\textsubscript{2,S} \cdot O\textsubscript{2,C} \cdot O\textsubscript{2,H2} \iff \text{mol-O}_2 \]

Eq. (2-5) \[ \text{total-N}_2 \iff \text{mol-N}_2 \]

Eq. (2-6) \[ \text{part-inertgas} \iff \text{part-inertgas} \]

Note 8: Eqs. (3-1) – (3-3) are corollaries of eqs. (2-1) – (2-3), respectively. Eq. (3-4) is a corollary of eq. (2-4) and of eqs. (3-1) – (3-3). Eq. (3-5) is a corollary of eq. (2-5), of assumption 3, and of eq. (3-4).

Eq. (3-1) \[ \text{mol-SO}_2 = S\textsubscript{fuel} = O\textsubscript{2,S} \]

Eq. (3-2) \[ \text{mol-CO}_2 = C\textsubscript{fuel} = O\textsubscript{2,C} \]

Eq. (3-3) \[ \text{mol-H}_{2}O = H\textsubscript{2,\text{fuel}} = 2 \times O\textsubscript{2,H2} \]

Eq. (3-4) \[ \text{mol-O}_2 = \text{total-O}_2 \cdot O\textsubscript{2,S} \cdot O\textsubscript{2,C} \cdot O\textsubscript{2,H2} = \text{total-O}_2 \cdot \text{mol-SO}_2 \cdot \text{mol-CO}_2 \cdot (0.5 \times \text{mol-H}_{2}O) \]

Eq. (3-5) \[ \text{mol-N}_2 = \text{total-N}_2 = 3.76 \times \text{total-O}_2 = 3.76 \times (\text{mol-SO}_2 + \text{mol-CO}_2 + (0.5 \times \text{mol-H}_{2}O) + \text{mol-O}_2) = (3.76 \times \text{mol-SO}_2) + (3.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_{2}O) + (3.76 \times \text{mol-O}_2) \]

Note 9: Eq. (4-1) is the definition of vol\%\textsubscript{dry}O\textsubscript{2,exhaust}. Eq. (4-2) is the solution of eq. (4-1) as a function of mol-O\textsubscript{2}. Eq. (4-3) is the result of substituting mol-N\textsubscript{2} from eq. (3-5) into eq. (4-2). Eq. (4-4) is the result of combining terms on the right side of eq. (4-3). Eq. (4-5) is
the result of moving the \( \text{mol-O}_2 \) term on the right side of eq. (4-4) to the left side and then factoring out \( \text{mol-O}_2 \). Eq. (4-6) is the result of multiplying both sides of eq. (4-5) by “100% - \( \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \).” Eq. (4-7) is the result of combining the two \( \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \) terms on the left side of eq. (4-6) and isolating the \( \text{mol-O}_2 \) term on the left side by division. Eq. (4-8) is the result of factoring out a constant in the denominator of eq. (4-7).

**Eq. (4-1)** \[ \text{vol\%}_{\text{dryO}_2,\text{exhaust}} = 100\% \times \frac{\text{mol-O}_2}{(\text{part-inertgas} + \text{mol-SO}_2 + \text{mol-CO}_2 + \text{mol-O}_2 + \text{mol-N}_2)} \]

**Eq. (4-2)** \[ \text{mol-O}_2 = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + \text{mol-SO}_2 + \text{mol-CO}_2 + \text{mol-N}_2)}{(100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}})} \]

**Eq. (4-3)** \[ \text{mol-O}_2 = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + \text{mol-SO}_2 + \text{mol-CO}_2 + ((3.76 \times \text{mol-SO}_2) + (3.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (3.76 \times \text{mol-O}_2)))}{(100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}})} \]

**Eq. (4-4)** \[ \text{mol-O}_2 = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (3.76 \times \text{mol-O}_2))}{(100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}})} \]

**Eq. (4-5)** \[ \text{mol-O}_2 \times \left(1 - (3.76 \times \frac{\text{vol\%}_{\text{dryO}_2,\text{exhaust}}}{(100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}})})\right) = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}))}{(100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}})} \]

**Eq. (4-6)** \[ \text{mol-O}_2 \times \left((100\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}}) - (3.76 \times \text{vol\%}_{\text{dryO}_2,\text{exhaust}})\right) = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}))}{(100\% - (4.76 \times \text{vol\%}_{\text{dryO}_2,\text{exhaust}}))} \]

**Eq. (4-7)** \[ \text{mol-O}_2 = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}))}{(100\% - (4.76 \times \text{vol\%}_{\text{dryO}_2,\text{exhaust}}))} \]

**Eq. (4-8)** \[ \text{mol-O}_2 = \text{vol\%}_{\text{dryO}_2,\text{exhaust}} \times \frac{(\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}))}{(4.76 \times (21\% - \text{vol\%}_{\text{dryO}_2,\text{exhaust}}))} \]

**Note 10:** Eq. (5-1) is the definition of \( \text{SO}_2 \) concentration. Eq. (5-2) is the result of substituting \( \text{mol-N}_2 \) from eq. (3-5) into eq. (5-1). Eq. (5-3) is the result of combining terms on the right side of eq. (5-2). Eq. (5-4) is the result of substituting \( \text{mol-O}_2 \) from eq. (4-8) into eq. (5-3). Eq. (5-5) is the result of combining terms in eq. (5-4).

**Eq. (5-1)** \[ \text{SO}_2 \text{concentration} = 10^6 \times \frac{\text{mol-SO}_2}{(\text{part-inertgas} + \text{mol-SO}_2 + \text{mol-CO}_2 + \text{mol-O}_2 + \text{mol-N}_2)} \]
\textbf{Eq. (5-2)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{mol-SO}_2 / (\text{part-inertgas} + \text{mol-SO}_2 + \text{mol-CO}_2 + \text{mol-O}_2 + (3.76 \times \text{mol-SO}_2) + (3.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (3.76 \times \text{mol-O}_2))

\textbf{Eq. (5-3)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{mol-SO}_2 / (\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (4.76 \times \text{mol-O}_2))

\textbf{Eq. (5-4)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{mol-SO}_2 / (\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))

\textbf{Eq. (5-5)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{mol-SO}_2 / ((1 + (\text{vol}\% \text{dry O}_2, \text{exhaust} / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))) \times (\text{part-inertgas} + (4.76 \times \text{mol-SO}_2) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O}) + (4.76 \times \text{mol-CO}_2) + (1.88 \times \text{mol-H}_2\text{O})))

\textbf{Note 11:} \quad \text{Eqs. (6-1)} – (6-4) were derived such that the eq. (6-4) depends on only constants and inputs. Eq. (6-1) is the result of substituting \text{mol-SO}_2, \text{mol-CO}_2, and \text{mol-H}_2\text{O} from eq. (5-5) into eqs. (3-1) – (3-3) and then substituting \text{S}_\text{fuel}, \text{C}_\text{fuel}, and \text{H}_2\text{fuel} into eqs. (1-4) – (1-6). Eq. (6-2) is the result of combining the two part-H\_2S terms in the denominator and combining the two part-HC terms in eq. (6-1). Eq. (6-3) is the result of combining the two MW\_CH terms, moving part-inertgas, and combining some constants in eq. (6-2). Eq. (6-4) is the result of substituting part-H\_2S, part-inertgas, and part-HC from eq. (6-3) into eqs. (1-1) – (1-3), respectively.

\textbf{Eq. (6-1)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{part-H}_2\text{S} / ((1 + (\text{vol}\% \text{dry O}_2, \text{exhaust} / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))) \times (\text{part-inertgas} + (4.76 \times \text{part-H}_2\text{S}) + (4.76 \times \text{part-HC} \times (\text{wt}\% \text{C}_\text{HC} / 100\%) \times (\text{MW}_\text{HC} / 12.01)) + (1.88 \times (\text{part-H}_2\text{S} + (\text{part-HC} \times (\text{wt}\% \text{H}_2\text{HC} / 100\%) \times (\text{MW}_\text{HC} / 2.016)))))

\textbf{Eq. (6-2)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{part-H}_2\text{S} / ((1 + (\text{vol}\% \text{dry O}_2, \text{exhaust} / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))) \times (\text{part-inertgas} + (6.64 \times \text{part-H}_2\text{S}) + (\text{part-HC} \times (4.76 \times (\text{wt}\% \text{C}_\text{HC} / 100\%) \times (\text{MW}_\text{HC} / 12.01)) + (1.88 \times (\text{wt}\% \text{H}_2\text{HC} / 100\%) \times (\text{MW}_\text{HC} / 2.016))))

\textbf{Eq. (6-3)} \quad \text{SO}_2 \text{concentration} = 10^6 \times \text{part-H}_2\text{S} / ((1 + (\text{vol}\% \text{dry O}_2, \text{exhaust} / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))) \times ((6.64 \times \text{part-H}_2\text{S}) + \text{part-inertgas} + (\text{MW}_\text{HC} \times \text{part-HC} \times (0.396 \times \text{wt}\% \text{C}_\text{HC} / 100\%) + (0.933 \times \text{wt}\% \text{H}_2\text{HC} / 100\%)))

\textbf{Eq. (6-4)} \quad \text{SO}_2 \text{concentration} = \text{H}_2\text{Sconcentration} / ((1 + (\text{vol}\% \text{dry O}_2, \text{exhaust} / (21\% - \text{vol}\% \text{dry O}_2, \text{exhaust}))) \times ((6.64 \times \text{H}_2\text{Sconcentration} / 10^6) +}
(vol\textsubscript{dry inert gas\textsubscript{fuel}} / 100\%) + (MW_{HC} \times (\text{vol\textsubscript{dry HC\textsubscript{fuel}} / 100\%}) \times ((0.396 \times \text{wt\%C}_{HC} / 100\%) + (0.933 \times \text{wt\%H}_{HC} / 100\%))))

Note 12: **Eq. (6-4)** is relatively long and could confuse some people needing to use this equation. To resolve this potential problem, **eq. (6-4)** was simplified in the permit by breaking it into sixteen simple steps.