Excess Air = Excess Oxygen

The equation for percent excess air is as follows: (see F&R, 3rd Ed., p. 145)

\[
\% \text{ excess air} = \frac{(\text{moles of air})_{\text{fed}} - (\text{moles of air})_{\text{theoretical}}}{(\text{moles of air})_{\text{theoretical}}} \times 100
\]

If you multiple the fractional term in the above equation by \((0.21 / 0.21)\) and remember that \((0.21 \text{ moles of air})\) equals \((\text{moles of oxygen})\), you can write the following expression for "percent excess oxygen":

\[
\% \text{ excess } \text{O}_2 = \frac{0.21 \times (\text{moles of air})_{\text{fed}} - (\text{moles of } \text{O}_2)_{\text{theoretical}}}{(\text{moles of } \text{O}_2)_{\text{theoretical}}} \times 100
\]

\[0.21 \times (\text{moles of air})_{\text{fed}} = (1.0 + \text{excess}) \times (\text{moles of } \text{O}_2)_{\text{theoretical}} \quad (\text{Eq. 1})\]

where \(\text{excess} = \% \text{ excess } \text{O}_2/100\). Thus, "\% excess air" and "\% excess \text{O}_2" have the same value.

Theoretical oxygen is the moles (for a batch system) or molar flow rate (for a continuous system) of \(\text{O}_2\) needed for complete combustion of all fuel fed to the reactor, assuming that all carbon in the fuel is oxidized to \(\text{CO}_2\), all of the hydrogen is oxidized to \(\text{H}_2\text{O}\), and any sulfur is oxidized to \(\text{SO}_2\).

For example, 75 mol\% \(\text{C}_3\text{H}_8\) (propane) and 25 mole\% \(\text{H}_2\) are fed in Stream F to a reactor. An air stream (21 mol\% \(\text{O}_2\) and 79 mol\% \(\text{N}_2\)) is fed to the same reactor as Stream A. This stream contains twenty-five percent excess air. The following chemical reactions are actually what occur in the reactor:

\[
\begin{align*}
\text{C}_3\text{H}_8 + 5 \text{ O}_2 & \rightarrow 3 \text{ CO}_2 + 4 \text{ H}_2\text{O} \\
2 \text{ C}_3\text{H}_8 + 7 \text{ O}_2 & \rightarrow 6 \text{ CO} + 8 \text{ H}_2\text{O} \\
2 \text{ H}_2 + \text{ O}_2 & \rightarrow 2 \text{ H}_2\text{O}
\end{align*}
\]

In the theoretical case which is not associated with the actual case above, all of the propane must be oxidized to \(\text{CO}_2\) and \(\text{H}_2\text{O}\), and all of the hydrogen must be oxidized to \(\text{H}_2\text{O}\) by the following reactions:

\[
\begin{align*}
\text{C}_3\text{H}_8 + 5 \text{ O}_2 & \rightarrow 3 \text{ CO}_2 + 4 \text{ H}_2\text{O} \\
2 \text{ H}_2 + \text{ O}_2 & \rightarrow 2 \text{ H}_2\text{O}
\end{align*}
\]

For 25\% excess air in the example, we can write the following equation in a mathematical model:

\[
0.21 \cdot \dot{n}_A = (1 + 0.25) \left( 0.75 \cdot \dot{n}_F \cdot \frac{5 \text{ mol } \text{O}_2}{1 \text{ mol } \text{C}_3\text{H}_8} + 0.25 \cdot \dot{n}_F \cdot \frac{1 \text{ mol } \text{O}_2}{2 \text{ mol } \text{H}_2} \right)
\]

\[
\begin{align*}
\text{mol } \text{O}_2 & \cdot \text{mol } \text{A} \\
\text{mol } \text{A} & \cdot \text{time} \\
\text{mol } \text{C}_3\text{H}_8 & \cdot \text{mol } \text{F} \cdot \text{mol } \text{O}_2 \\
\text{mol } \text{F} & \cdot \text{time} \cdot \text{mol } \text{C}_3\text{H}_8 \\
\text{mol } \text{H}_2 & \cdot \text{mol } \text{F} \cdot \text{mol } \text{O}_2 \\
\text{mol } \text{F} & \cdot \text{time} \cdot \text{mol } \text{H}_2
\end{align*}
\]

This example equation for \% excess oxygen is \textbf{Equation 1} above, since \% excess air and \% excess oxygen are numerically equivalent. \textbf{Equation 1} is what you are to write in a mathematical model when a problem statement contains \% excess air.