Here, \( \Delta H_f^{\circ} \text{CH}_4 = -78431 \text{ kJ/kmol} \) at 298 K.
\( \Delta H_f^{\circ} \text{CO}_2 = -393546 \text{ kJ/kmol} \).
\( \Delta H_f^{\circ} \text{H}_2\text{O} = -241845 \text{ kJ/kmol} \).

Now the problem is to guess \( T_{\text{prod}} \) such that eqn (1) is satisfied.

Iteration 1:
Let us guess \( T_{\text{prod}} = 2200 \text{ K} \).

\( \Delta h_{\text{S}, \text{CO}_2}(2200 \text{ K}) = 103562 \text{ kJ/kmol} \).
\( \Delta h_{\text{H}_2\text{O}}(2200 \text{ K}) = 83160 \text{ kJ/kmol} \).
\( \Delta h_{\text{N}_2}(2200 \text{ K}) = 63360 \text{ kJ/kmol} \).

Now, LHS of eqn (1) = \( 1 \times \left[-78431 + 0\right] + 2 \times \left[0 + 0\right] + 7.52 \times \left[0 + 0\right] \).
= \( -78431 \).

RHS = \( 1 \times \left[-393546 + 103562\right] + 2 \times \left[-241845 + 83160\right] + 7.52 \times \left[0 + 63360\right] \).
\( = -130886.8 \)
Notice that RHS is more negative than LHS.
In order to increase RHS & make it equal to LHS, the only variable that can be altered is $T_{prod}$.

Note that if $T_{prod}$ is assumed to be a high value, the sensible enthalpy changes become more positive, thus increasing RHS.

So let us have $T_{prod} = 2300 \, K$.

For this case, only the sensible enthalpy changes of the products are going to be different.

Hence, at $T_{prod} = 2300 \, K$,

$\Delta h_{S, CO_2}(2300K) = 109670 \, kJ/kmol.$

$\Delta h_{S, H_2O}(2300K) = 88426 \, kJ/kmol.$

$\Delta h_{S, N_2}(2300K) = 66997 \, kJ/kmol.$

Note that LHS is not changed by any of these above changes. $\Rightarrow$ LHS $= -78431$

If we substitute the above values of $\Delta h_{S,i}$ in RHS, we get,

$RHS = 1 \times [-303546 + 109670] + 2 \times [-241845 + 88426] + 7.52 \times [0 + 66997] = -86896.56$

(again less than LHS)
**Iteration #3**

Now RHS is close to LHS but not quite.
Let us have $T_{prod} = 2400 K$.
Repeating the above calculations with product specific enthalpies evaluated at 2400 K, we get:

\[
\Delta h_{S, CO_2} = 115728 \text{ kJ/kmol}, \quad \Delta h_{S, H_2O} = 93744 \text{ kJ/kmol}, \quad \Delta h_{S, N_2} = 70645 \text{ kJ/kmol}
\]

\[
\text{RHS} = -42699.6 \quad \text{(Greater than LHS!)}
\]

The guessed $T_{prod} (2400 K)$ must be too high!

The next guess would logically be between 2300 K & 2400 K.

However, in most thermodynamic tables, enthalpy values are given in multiples of 100 K. So linearly interpolate to get approx. values.

Thus if we assume $T_{prod} = 2350 K$,
\[
\Delta h_{S, CO_2} = 112734 \text{ kJ/kmol}, \quad \Delta h_{S, H_2O} = 91085 \text{ kJ/kmol}, \quad \Delta h_{S, N_2} = 66821 \text{ kJ/kmol}
\]

By substituting the above values in RHS, we get
\[
\text{RHS} = -64798 \quad \text{(Closer to LHS)}
\]

Notice that RHS is closer to LHS for $T_{prod} = 2300 K$ than for $T_{prod} = 2350 K$. 
Thus, we can conclude that the adiabatic flame temperature for stoichiometric combustion of methane in air with \( T_{\text{react}} = 298 \text{ K} \) and \( P = 1 \text{ atm (const.)} \) is approximately \( 2300 \text{ K} \).

* Now, we can write a computer program to automate this iteration process to get a much closer estimate if necessary.

* **Dissociation:** We have assumed complete combustion products which is may not really be the case at high temperatures such as 2300 K. In such cases, dissociation of products occurs and this reduces the adiabatic flame temperature.
Combustion efficiency of an I.C. Engine

- Typically, complete combustion products are not the only constituents of any engine exhaust.
  - Incomplete combustion products include:
    1. CO
    2. H₂
    3. Unburned hydrocarbons (HC)
    4. Particulates or soot (solid carbon particles)

- Under lean conditions, incomplete combustion products are small.

- Under rich conditions, combustion is incomplete.
  - Only a fraction of fuel's chemical energy is released.

- If the engine is an open system exchanging heat & work with the surroundings and a mass flow through the control volume, then the net chemical energy released due to