15-80 Propane is burned with stoichiometric and 50 percent excess air. The adiabatic flame temperature is to be determined for both cases.

Assumptions **1** Steady operating conditions exist. **2** Air and combustion gases are ideal gases. **3** Kinetic and potential energies are negligible. **4** There are no work interactions. **5** The combustion chamber is adiabatic.

Analysis Under steady-flow conditions the energy balance $E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$ applied on the combustion chamber with $Q = W = 0$ reduces to

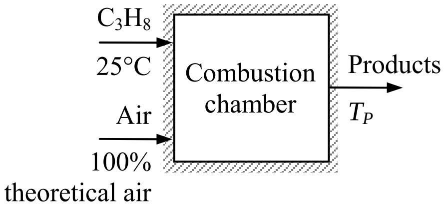
$$\sum N_P\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_P = \sum N_R\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_R \longrightarrow \sum N_P\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_P = \sum N_R \bar{h}_{f,R}^\circ$$

since all the reactants are at the standard reference temperature of 25°C. Then, for the stoicihiometric air

$$C_3H_8 + a_{\text{th}}(O_2 + 3.76\,N_2) \longrightarrow 3\,CO_2 + 4\,H_2O + a_{\text{th}} \times 3.76\,N_2$$

where a_{th} is the stoichiometric coefficient and is determined from the O_2 balance,

$$a_{\text{th}} = 3 + 2 = 5$$



Thus,

$$C_3H_8 + 5\,(O_2 + 3.76\,N_2) \longrightarrow 3\,CO_2 + 4\,H_2O + 18.8\,N_2$$

From the tables,

Substance	$\bar{\mathbf{h}}_\mathbf{f}^\circ$ **kJ/kmol**	$\bar{\mathbf{h}}_{\mathbf{298K}}$ **kJ/kmol**
C_3H_8 (*g*)	-103,850	---
O_2	0	8682
N_2	0	8669
H_2O (*g*)	-241,820	9904
CO_2	-393,520	9364

Thus,

$$(3)\left(-393{,}520 + \bar{h}_{\text{CO2}} - 9364\right) + (4)\left(-241{,}820 + \bar{h}_{\text{H2O}} - 9904\right) + (18.8)\left(0 + \bar{h}_{\text{N2}} - 8669\right) = (1)\left(-103{,}850\right) + 0 + 0$$

It yields $\quad 3\bar{h}_{\text{CO2}} + 4\bar{h}_{\text{H2O}} + 18.8\bar{h}_{\text{N2}} = 2{,}274{,}680 \text{ kJ}$

The adiabatic flame temperature is obtained from a trial and error solution. A first guess is obtained by dividing the right-hand side of the equation by the total number of moles, which yields 2,274,680/(3 + 4 + 18.8) = 88,166 kJ/kmol. This enthalpy value corresponds to about 2650 K for N_2. Noting that the majority of the moles are N_2, T_P will be close to 2650 K, but somewhat under it because of the higher specific heat of H_2O.

At 2500 K:

$$\begin{aligned} 3\bar{h}_{\text{CO2}} + 4\bar{h}_{\text{H2O}} + 18.8\bar{h}_{\text{N2}} &= 3 \times 131{,}290 + 4 \times 108{,}868 + 18.8 \times 82{,}981 \\ &= 2{,}389{,}380 \text{ kJ} \;\; \text{(Higher than 2,274,680 kJ)} \end{aligned}$$

At 2450 K:

$$\begin{aligned} 3\bar{h}_{\text{CO2}} + 4\bar{h}_{\text{H2O}} + 18.8\bar{h}_{\text{N2}} &= 3 \times 128{,}219 + 4 \times 106{,}183 + 18.8 \times 81{,}149 \\ &= 2{,}334{,}990 \text{ kJ} \;\; \text{(Higher than 2,274,680 kJ)} \end{aligned}$$

At 2400 K:

$$\begin{aligned} 3\bar{h}_{\text{CO2}} + 4\bar{h}_{\text{H2O}} + 18.8\bar{h}_{\text{N2}} &= 3 \times 125{,}152 + 4 \times 103{,}508 + 18.8 \times 79{,}320 \\ &= 2{,}280{,}704 \text{ kJ} \;\; \text{(Higher than 2,274,680 kJ)} \end{aligned}$$

At 2350 K:

$$3\bar{h}_{CO2} + 4\bar{h}_{H2O} + 18.8\bar{h}_{N2} = 3 \times 122{,}091 + 4 \times 100{,}846 + 18.8 \times 77{,}496$$
$$= 2{,}226{,}580 \text{ kJ (Lower than } 2{,}274{,}680 \text{ kJ)}$$

By interpolation of the two results,

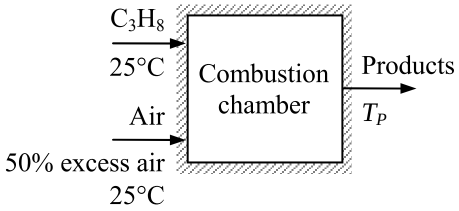
T_P = **2394 K = 2121°C**

When propane is burned with 50% excess air, the reaction equation may be written as

$$C_3H_8 + 1.5 \times a_{th}(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 0.5 \times a_{th}O_2 + 1.5 \times a_{th} \times 3.76N_2$$

where a_{th} is the stoichiometric coefficient and is determined from the O_2 balance,

$$1.5a_{th} = 3 + 2 + 0.5a_{th} \longrightarrow a_{th} = 5$$



Thus,

$$C_3H_8 + 7.5(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 2.5O_2 + 28.2N_2$$

Using the values in the table,

$$(3)\left(-393{,}520 + \bar{h}_{CO2} - 9364\right) + (4)\left(-241{,}820 + \bar{h}_{H2O} - 9904\right) + (2.5)\left(0 + \bar{h}_{O2} - 8682\right)$$
$$+ (28.2)\left(0 + \bar{h}_{N2} - 8669\right) = (1)(-103{,}850) + 0 + 0$$

It yields $3\bar{h}_{CO2} + 4\bar{h}_{H2O} + 2.5\bar{h}_{O2} + 28.2\bar{h}_{N2} = 2{,}377{,}870 \text{ kJ}$

The adiabatic flame temperature is obtained from a trial and error solution. A first guess is obtained by dividing the right-hand side of the equation by the total number of moles, which yields 2,377,870/(3+4+2.5+28.2) = 63,073 kJ/kmol. This enthalpy value corresponds to about 1960 K for N_2. Noting that the majority of the moles are N_2, T_P will be close to 1960 K, but somewhat under it because of the higher specific heat of H_2O.

At 1800 K:

$$3\bar{h}_{CO2} + 4\bar{h}_{H2O} + 2.5\bar{h}_{O2} + 28.2\bar{h}_{N2} = 3 \times 88{,}806 + 4 \times 72{,}513 + 2.5 \times 60{,}371 + 28.2 \times 57{,}651$$
$$= 2{,}333{,}160 \text{ kJ (Lower than } 2{,}377{,}870 \text{ kJ)}$$

At 1840 K:

$$3\bar{h}_{CO2} + 4\bar{h}_{H2O} + 2.5\bar{h}_{O2} + 28.2\bar{h}_{N2} = 3 \times 91{,}196 + 4 \times 74{,}506 + 2.5 \times 61{,}866 + 28.2 \times 59{,}075$$
$$= 2{,}392{,}190 \text{ kJ (Higher than } 2{,}377{,}870 \text{ kJ)}$$

By interpolation,

T_P = **1830 K = 1557°C**