Example

Acetylene (C_2H_2) at a fuel flow rate of 1 kg/min is burned with dry air with an air fuel ratio of 17:1. Assuming **complete combustion** and a total pressure of 110 kPa, find

(a) the percent excess air used,
(b) the **equivalence ratio**,
(c) the percentage of CO_2 in the products by volume,
(d) the dew point temperature of the products in °C,
(e) the percentage of water vapor condensed if the products are cooled to 20°C, and
(f) the required volume flow rate of dry air if it if supplied at 22°C and 110 kPa.
(g) If the actual air supplied has a humidity ratio of 16 g H_2O per kg of dry air, find the dew point temperature of the products.

(a) COMPARE TO STOICH:

$$C_2H_2 + a(O_2 + 3.76N_2) \longrightarrow bCO_2 + cH_2O + dN_2$$

C: $2 = b$ $b=2$

H: $2 = 2c$ $c=1$

O: $2a = 2b + c$ $2a = 2\cdot 2 + 1$ $a = 2.5$

N: $(2)(3.76)a = 2d$ $d = 3.76(a) = 3.76(2.5)$

$d = 9.4$

$$C_2H_2 + 2.5O_2 + 9.4N_2 \longrightarrow 2CO_2 + H_2O + 9.4N_2$$

← THEORETICAL RXN

$$AF_{ACT} = 17 = \frac{m_{AIR}}{m_{fuel}} = \frac{n_{AIR}M_{AIR}}{n_{fuel}M_{fuel}} = \frac{n_a}{n_f}\frac{29\ kg/kmol}{26.04\ kg/kmol} \Rightarrow$$

$(n_a/n_f) = 15.26$

4.76 mol air

$$(n_a/n_{f,theo.}) = 2.5(O_2 + 3.76N_2) = 11.9$$

$$\therefore \%\ EXCESS = \frac{15.26 - 11.9}{11.9} * 100 = \boxed{28.2\%}$$

(b) $\phi = \frac{FA_{ACT}}{FA_{THEO.}} = \frac{1/17}{\frac{n_f M_f}{n_a M_a}} = \frac{1/17}{\frac{1}{11.9}\,\frac{26.04}{29}} = \boxed{0.78}$

(c) MOLE ANALYSIS → VOLUME ANALYSIS

BUT NEED ACTUAL REACTION: $\frac{AF_{ACT}}{AF_{THEO}} = \frac{1}{0.78} = 1.282$

$$C_2H_2 + (1.282)(2.5\,O_2) + (1.282)(9.4N_2) \longrightarrow 2CO_2 + H_2O + aO_2 + bN_2$$

O_2: $(1.282)(2.5)(2) = (2)(2) + 1 + 2a$

$a = 0.705$

N: $(1.282)(9.4)(2) = 2b \qquad b = 12.05$

BALANCED ACTUAL RXN:

$$C_2H_2 + 3.205\,O_2 + 12.05N_2 \rightarrow 2CO_2 + H_2O + 12.05N_2 + 0.705\,O_2$$

$$\%CO_{PRDT} = \frac{2}{2 + 1 + 12.05 + 0.705} \times 100 = \boxed{12.7\%}$$

(d) $T_{DEW} = T_{SAT}(P_v)$

$P_v = y_v P \qquad y_v = \frac{1}{2 + 1 + 12.05 + 0.705} = \underline{0.0635}$

$P_v = (0.0635)(110\text{ kPa}) = 6.98\text{ kPa}$

$T_{DEW} = T_{SAT}(6.98\text{ kPa}) = \boxed{38.8°C}$

COULD YOU HAVE USED PSYCH. CHART? NO! $P_{TOTAL} \neq 101.325$ kPa!

(e) $20°C < T_{DEW}$ ⇒ WATER WILL CONDENSE.

→ PRDTS ARE SATURATED ⇒ $P_{v,PRDTS} = P_{SAT}(20°C)$

$= 2.339$ kPa

$y_v P = P_v \Rightarrow y_v = \frac{P_v}{P}$

$= \frac{2.339\text{ kPa}}{110\text{ kPa}} = 0.02126$

$$\% \text{ CONDENSE} = \frac{n_{H_2O,\,LIQUID}}{n_{H_2O,\,TOTAL}} = \frac{n_{H_2O\,LIQUID}}{n_{H_2O,\,VAP} + n_{H_2O\,LIQUID}} \times 100\%$$

LOOK @ PRDTS:

$$2CO_2 + H_2O + 12.05\,N_2 + 0.705\,O_2$$

$H_2O \rightarrow a\,H_2O_{LIQUID} + b\,H_2O_{VAPOR}$ (ONLY VAPOR of H_2O CONTRIBUTES TO y_v.)

$$y_v = \frac{b}{2 + b + 12.05 + 0.705} = 0.02126 \Rightarrow b = 0.321$$

$\therefore a = 1 - b = 0.679$ $\quad \%\text{COND} = \frac{0.679}{1} \times 100\% = \boxed{67.9\%}$

(f)

$\dot{V} = \dot{m}_{air} v_a$ $\quad \dot{m}_{air} = (AF)\,\dot{m}_{fuel} = (17)(1\ kg/s) = 17\ kg/min$

$$v_a = \frac{R_a T}{P_a} = \frac{(0.287\ kJ/kg \cdot K)(22 + 273)K}{110\ kPa} = 0.770\ m^3/kg$$

$$\dot{V} = \left(17 \frac{kg}{min}\right)(0.770\ m^3/kg) = \boxed{13.1\ m^3/min}$$

(g) NEED A NEW RXN! AGAIN!

$$\omega_{RXT} = 0.0016 \frac{kg\ v}{kg\ air} = \frac{m_{H_2O}}{m_{AIR}} = \frac{n_{H_2O} M_{H_2O}}{n_{AIR} M_{AIR}} = 0.622 \frac{n_{H_2O}}{n_{AIR}}$$

LOOK FAMILIAR?

$$\therefore n_{H_2O,\,RXT} = \frac{(0.0016)}{(0.622)} n_{AIR} = 0.0257\, n_{AIR}$$

NEW RXN:

$$C_2H_2 + 3.205\,O_2 + 12.05\,N_2 + (0.0257)(3.205 + 12.05)\,H_2O$$

$$\longrightarrow 2CO_2 + a\,H_2O + 12.05\,N_2 + b\,O_2$$

H: $(0.0257)(3.205 + 12.05)(2) = (a)(2)$

$a = 1.392$

O: $3.205(2) + (0.0257)(3.205 + 12.05) = (2)(2) + a + b(2)$

... $b = 0.705$ ← UNCHANGED. WHY?

BALANCED RXN:

$C_2H_2 + 3.205\,O_2 + 12.05\,N_2 + 0.392\,H_2O \rightarrow 2CO_2 + 1.392\,H_2O + 12.05\,N_2 + 0.705\,O_2$

$$y_{v,PROT} = \frac{1.392}{2 + 1.392 + 12.05 + 0.705} = 0.0862$$

$$P_{v\,PROT} = y_{v\,PROT}\,P = (0.0862)(110\text{ kPa}) = 9.483\text{ kPa}$$

$$T_{DEW} = T_{SAT}(9.483\text{ kPa}) = \boxed{44.7\,°C}$$