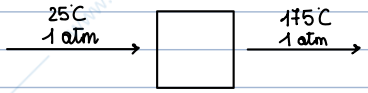
Bilancio di energia: $\frac{dE}{dt} = \sum_e \dot{E}^{(e)} - \dot{E}^{(u)} + \dot{Q} + \dot{L}_t$

BILANCI DI ENERGIA:

① Calcolo entalpia:



DATI:

- Disponibili in tabelle termodinamiche

$\dot{Q} = \dot{m}(\hat{H}(175°C, 1\,atm) - \hat{H}_L(25°C, 1\,atm))$

$\hat{H}(175°C, 1\,atm) = \frac{\hat{H}(350K, 1\,bar) - \hat{H}(400K, 1\,bar)}{450-400}(448-400) + \hat{H}(400K, 1\,bar) = 2826,3 \frac{kJ}{kg}$

$\hat{H}_L(25°C, 1\,atm) = \frac{\hat{H}(350K, 5\,bar) - \hat{H}(400K, 5\,bar)}{350-400}(298-400) + \hat{H}(400K, 5\,bar) = 103,3 \frac{kJ}{kg}$

$\frac{\dot{Q}}{\dot{m}} = 2826,3 - 103,3 = 2723,0 \frac{kJ}{kg} = 49014 \frac{kJ}{kmol}$

② Calcolo entalpia:

DATI:

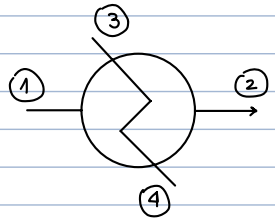
$\dot{V} = 100\ m^3/min$ (metano)

$T_i = 40°C$

$P = 1\,atm$ (metano) vap. saturo a 1,2 bar che condensa

$T_f = 80°C$

condizioni stazionarie



- 2 fluidi:

$Q_1^2 = -\dot{m}_{met}[(\hat{H}^1 - \hat{H}^{SR}) - (\hat{H}^2 - \hat{H}^{SR})]$

$Q_3^4 = -\dot{m}_{H_2O}[(\hat{H}^3 - \hat{H}^{SR}) - (\hat{H}^4 - \hat{H}^{SR})]$

$\dot{m}_{H_2O}[(\hat{H}^4 - \hat{H}^{SR}) - (\hat{H}^3 - \hat{H}^{SR})] = \dot{m}_{met}[(\hat{H}^1 - \hat{H}^{SR}) - (\hat{H}^2 - \hat{H}^{SR})]$

↳ richiesta

$\dot{m}_{met} = \dot{V} \cdot \rho_{met} = 100 \cdot 0,656 = 65,58\ kg/min$

C_p @ 40°C = 36,15 kJ/kmol K

C_p @ 80°C = 37,11 kJ/kmol K

convertiamo in kJ/kg K (massa molare metano = 16 g/mol = 0,016 kg/mol):

$C_{p,40} = 36,15/16 = 2,26\ kJ/kg\,K$

$C_{p80} = 37,11/16 = 2,32\ kJ/kg/K$

$C_{p,medio} = \frac{36,15 + 37,11}{2} = 36,63\ kJ/kmol\cdot K$

$36,63/16 \simeq 2,283\ kJ/kmol\cdot K$

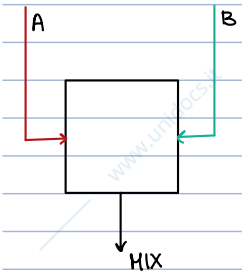
$\dot{Q} = \dot{m}_{met} \cdot C_p \cdot \Delta T = 65,58 \cdot 2,283 \cdot 40 = 6000,45\ kJ/min$

$\dot{m}_{H_2O} = \dot{m}_{met}\frac{[(\hat{H}^1 - \hat{H}^{SR}) - (\hat{H}^2 - \hat{H}^{SR})]}{[(\hat{H}^3 - \hat{H}^{SR}) - (\hat{H}^4 - \hat{H}^{SR})]} \overset{Q}{=} \dot{m}_{H_2O} = \dot{m}_{met}\frac{[C_p|_{25}^{40}(40-25) - C_p|_{25}^{80}(80-25)]}{-\Delta H_{vap}} = 2,60\ kg/min$

$H_v = 2683,615\ kJ/kg$

$H_l = 439,0308\ kJ/kg$

3) Bilancio di energia per una miscela



$\dot{n}_A = 1200$ kg/h $\quad T_A = 80°C \quad c_{pA} = 12$ kJ/kgK

$\dot{n}_B = 800$ kg/h $\quad T_B = 35°C \quad c_{pB} = 25$ kJ/kgK

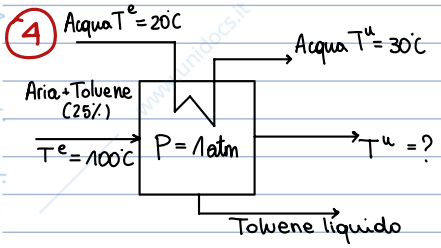
$$\frac{dU}{dt} = \sum_e \dot{n}^e \tilde{H}^e - \sum_u \dot{n}^u \tilde{H}^u + \dot{Q} + \dot{L}_m - p\frac{dV}{dt}$$

$$\dot{n}_A^e\left(\tilde{H}_A^e - \tilde{H}_A^{SR}\right) + \dot{n}_B^e\left(\tilde{H}_B^e - \tilde{H}_B^{SR}\right) - \dot{n}_{mix}^u\left[\Delta\tilde{H}_{mix}^u + x_A^u\left(\tilde{H}_A^u - \tilde{H}_A^{SR}\right) + x_B^u\left(\tilde{H}_B^u - \tilde{H}_B^{SR}\right)\right] = 0 \qquad \tilde{H}_i^u = \tilde{H}_i^{SR}$$

$$\dot{n}_A^e\left(\tilde{H}_A^e - \tilde{H}_A^u\right) + \dot{n}_B^e\left(\tilde{H}_B^e - \tilde{H}_B^u\right) = 0 \Rightarrow \dot{n}_A^e c_{pA}\left(T_A^e - T^u\right) + \dot{n}_B^e c_{pB}\left(T_B^e - T^u\right) = 0$$

$$T^u = \frac{\dot{n}_A^e \cdot c_{pA} \cdot T_A^e + \dot{n}_B^e \cdot c_{pB} \cdot T_B^e}{\dot{n}_A^e \cdot c_{pA} + \dot{n}_B^e \cdot c_{pB}} = \frac{1200 \cdot 12 \cdot 80 + 800 \cdot 25 \cdot 35}{1200 \cdot 12 + 800 \cdot 25} = 53,83°C$$

4)



DATI:

portata acqua + toluene = 100 kmol/h

frazione molare di toluene init. : 25% (0,25)

P = 1 atm

Eq. di Antoine → $\ln(P) = A - \frac{B}{T+C}$

A = 13,932

B = 3056,96

C = 217,65

? = T^u riduzione 50% toluene

? = 100°C , Q

? = $\dot{n}_{H_2O}$ $\quad T_1^e = 20°C \rightarrow T_2^u = T_1^e + 10$

1) $\dot{n}_{aria}^e = \dot{n}_{aria}^u = \dot{n}^e(1 - x_{Tol}) = 100(1 - 0,25) = 75$ kmol/h

$\dot{n}_{Tol}^e = \dot{n}^e - \dot{n}_{aria}^e = 100 - 75 = 25$ kmol/h

$\dot{n}_{Tol}^{u-vap} = \dot{n}_{Tol}^{u-liq} = \dot{n}_{Tol}^e \cdot 0,5 = 12,5$ kmol/h

$$y_{Tol}^{u-vap} = \frac{\dot{n}_{Tol}^{u-vap}}{\dot{n}_{Tol}^{u-vap} + \dot{n}_{Aria}^u} = \frac{12,5}{12,5 + 75} = 0,143$$

T uscente:

$P_{Tol}(T^u) = P\, y_{Tol}^{u-vap} = 100 \cdot 0,143 = 14,3$ kPa

$$T^u = \frac{B}{(A - \ln P_{Tol})} - C = \frac{3056,96}{13,932 - \ln(14,3)} - 217,65 = 53,5°C$$

2) $$\frac{dU}{dt} = \sum_e \dot{n}^e \tilde{H}^e - \sum_u \dot{n}^u \tilde{H}^u + \dot{Q} + \dot{L}_m - p\frac{dV}{dt}$$

$$\dot{n}_{aria}^e\left(\tilde{H}_A^e - \tilde{H}_A^{SR}\right) + \dot{n}_{Tol}^e\left(\tilde{H}_{Tol}^e - \tilde{H}_{Tol}^{SR}\right) - \dot{n}_{Tol}^{u-liq}\left(\tilde{H}_{Tol}^{u-liq} - \tilde{H}_{Tol}^{SR}\right) - \dot{n}_{aria}^u\left(\tilde{H}_A^u - \tilde{H}_A^{SR}\right) - \dot{n}_{Tol}^{u-vap}\left(\tilde{H}_{Tol}^{u-vap} - \tilde{H}_{Tol}^{SR}\right) + \dot{Q}_{aria} = 0$$

S.R. : T = 100°C, P = 100 kPa fase gas (vapore)

$$-\dot{n}_{Tol}^{u-liq}\left(\tilde{H}_{Tol}^{u-liq} - \tilde{H}_{Tol}^{SR}\right) - \dot{n}_{aria}^u\left(\tilde{H}_A^u - \tilde{H}_A^{SR}\right) - \dot{n}_{Tol}^{u-vap}\left(\tilde{H}_{Tol}^{u-vap} - \tilde{H}_{Tol}^{SR}\right) + \dot{Q} = 0$$

$$-\dot{n}_{Tol}^{u-liq}\left(c_{p,Tol}^{liq}\left(T^{u-liq} - T_{Tol}^{SR}\right) - \Delta\tilde{H}_{vap}^{Tol}\right) - \dot{n}_{aria}^u c_{aria}\left(T^u - T_A^{SR}\right) - \dot{n}_{Tol}^{u-vap} c_{p,Tol}^{vap}\left(T^{u-vap} - T_{Tol}^{SR}\right) + \dot{Q}_{aria} = 0$$

$$\dot{Q}_{aria} = 12,5\left(164 \cdot (53,5 - 100) - 33180\right) + 75 \cdot 29 \cdot (53,5 - 100) + 12,5 \cdot 113(53,5 - 100) = -676894 = -6,77 \cdot 10^5 \text{ kJ/}$$

3) corrente acqua di raffreddamento

$\dot{n}^e_{acqua} \tilde{H}^e_{acqua} - \dot{n}^u_{acqua} \tilde{H}^u_{acqua} + \dot{Q}_{acqua} = 0$

$\dot{n}^e_{acqua} - \dot{n}^u_{acqua} = 0$

$\dot{Q}_{acqua} = -\dot{Q}_{aria}$

$\dot{n}_{acqua}(H^e_{acqua} - H^u_{acqua}) - \dot{Q}_{aria} = 0$

$\dot{n}_a C_{p\text{-}a}(T^e_a - T^u_a) - \dot{Q}_{aria} = 0$

$$\dot{n}_{acqua} = \frac{\dot{Q}_{aria}}{C^e_{p\text{-}acqua}(T^e_a - T^u_a)} = \frac{-6{,}77 \cdot 10^5}{75 \cdot (20-30)} = 902 \text{ kmol/h}$$

*Passaggio 2 → da 100°C a 53,5°C

1. raffreddare l'aria

$Q_{aria} = \dot{n}_{aria} \cdot C_{p\text{-}aria} \Delta T = 75 \cdot 29 \cdot (100 - 53{,}5) = 101137{,}5 \text{ kJ/h}$

2. raffreddare toluene (vapore e liquido)

$Q_{tol,vap} = n^{vap}_{Ta} \cdot C^{vap}_{p\text{-}Ta} \cdot \Delta T = 12{,}5 \cdot 113 \cdot (100 - 53{,}5) = 65906{,}25 \text{ kJ/h}$

$Q_{tol,liq} = n^{liq}_{Ta} \cdot C^{liq}_{pTa} \cdot \Delta T = 12.5 \cdot 164 \cdot (100 - 53{,}5) = 95212.5 \text{ kJ/h}$

3. condensazione toluene

$Q_{cond} = \dot{n}_{toluene,cond} \cdot \Delta H_{vap} = 12{,}5 \cdot 33180 = 414750 \text{ kJ/h}$

↳ metà del toluene

$Q_{TOT} = -6{,}77 \cdot 10^5 \text{ kJ/h}$

(5) Entalpia di reazione e calore di reazione:

(1) 1) $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

2) $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ $\quad H_f = -241814 \text{ kJ/kmol}$

3) $C + 2H_2 \rightarrow CH_4$ $\quad H_f = -74520 \text{ kJ/kmol}$

4) $C + O_2 \rightarrow CO_2$ $\quad H_f = -393510 \text{ kJ/kmol}$

$Hf_{CO_2} + (-2 Hf_{H_2O}) + (-Hf_{CH_4}) =$

$\Delta H_R = 4Hf_{H_2} + Hf_{CO_2} - 2Hf_{H_2O} - Hf_{CH_4} = 164638 \text{ kJ/kmol}$

(2) 1) $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

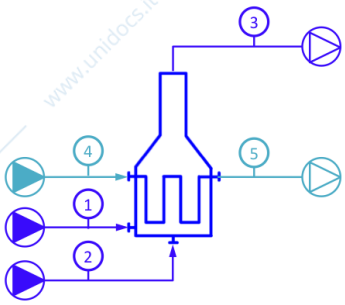
2) $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ $\quad H_c = -241814 \text{ kJ/kmol}$

3) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ $\quad H_c = -802600 \text{ kJ/kmol}$

$-4Hc_{H_2} + Hc_{CH_4} =$

$\Delta H_R = -4Hc_{H_2} + Hc_{CH_4} = 164600 \text{ kJ/kmol}$

(6) Entalpia di reazione e calore di reazione



? = T fumi ? = problemi condensa

100 kmol/h → metano

e = 0,05

1500 kmol/h → vapore

1) metano 25°C 1 atm
2) aria 50°C 1 atm
3) fumi T = ? 1 atm
4) acqua 25°C 1 atm liq.
5) acqua 100°C 1 atm vap.

		cp (kcal/kmol/K)
CO2		9.6
H2O	vap	8.17
	liq	18
O2		7
N2		7.2

$\Delta H_{c\text{-metano}}$	-802600	kJ/kmol a 25°C
$\Delta H_{vap\text{-}Acqua}$	40800	kJ/kmol a 100°C

(1) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$\dot{n}_{CH_4,1} = 100$ kmol/h

$\dot{n}^e_{O_2,2} = 2 \cdot 100 (1+e) = 210$ kmol/h (teorico)

$\dot{n}^u_{O_2,3} = \dot{n}^e_{O_2,2} - 2 \cdot 100 = 10$ kmol/h

$\dot{n}^e_{N_2,2} = \dot{n}^u_{N_2,3} = \frac{79}{21} \dot{n}^e_{O_2,2} = 790$ kmol/h

$\dot{n}^u_{H_2O,3} = 2 \cdot 100 = 200$ kmol/h

$\dot{n}_{CO_2,3} = 100$ kmol/h

$\dot{n}^e_{H_2O,4} = \dot{n}^u_{H_2O,5} = 1500$ kmol/h

S.R. = 25°C 1 atm

$\dot{n}_1(H_1 - H_1^{SR}) + \dot{n}_2(H_2 - H_2^{SR}) + \dot{n}_4(\tilde{H}_4 - H_4^{SR}) - \dot{n}_3(H_3 - \tilde{H}_3^{SR}) - \dot{n}_5(H_5 - H_5^{SR}) - \dot{n}^g_{CH_4} H^{SR}_{CH_4} = 0$ ✱ → viene bruciato tutto

bilancio di massa: $\dot{n}_2(H_2 - H_2^{SR}) + \dot{n}_4^{H_2O}(H_4 - H_5) - \dot{n}_3(H_3 - H_3^{SR}) - \dot{n}^g_{CH_4} H^{SR}_{CH_4} = 0$

$\dot{n}_3(H_3 - H_3^{SR}) = \dot{n}_3 C_{p3}(T_3 - T^{SR})$

$= \dot{n}_3(X_{N_2} C_{pN_2} + X_{O_2} C_{pO_2} + X_{H_2O} C^{vap}_{p\text{-}H_2O} + X_{CO_2} C_{p\text{-}CO_2})(T_3 - T^{SR})$

$\Rightarrow T_3 = T^{SR} + \frac{\dot{n}_2(H_2 - H_2^{SR}) + \dot{n}_4^{H_2O}(H_4 - H_5) - \dot{n}^g_{CH_4} H^{SR}_{CH_4}}{\dot{n}_3 C_{p-3}}$ ✱

(3)	ṅ	x	cp
CO_2	100	0.091	9.6
H_2O	200	0.182	8.17
O_2	10	0.009	7
N_2	790	0.718	7.2

$\dot{n}_{3\,tot} = 10 + 790 + 200 + 100 = 1100$ kmol/h fumi in uscita ($CO_2 + H_2O^{vap} + N_2 + O_2$)

$C_{p-3} = 0{,}718 \cdot 7{,}2 + 0{,}009 \cdot 7 + 0{,}182 \cdot 8{,}17 + 0{,}091 \cdot 9{,}6 = 7{,}59$ kcal/kmol K

$\left(X_i = \frac{n_i}{n_{tot}}\right)$

ARIA:

$\dot{n}_2(H_2 - H_2^{SR}) = \dot{n} C_{p-2}(T_2 - T^{SR}) = \dot{n}_2(X_{N_2} C_{p-N_2} + X_{O_2} C_{p-O_2})(T_2 - T^{SR}) = 1000 \cdot 7{,}16 \cdot (50-25) = 1{,}79 \cdot 10^5$ kcal/h

ACQUA: $\dot{n}_4(H_4 - H_5) = \dot{n}_4[C^{liq}_{p\text{-}H_2O}(T_4 - T_5) - \Delta H_{vap}] = 1500 \cdot [18 \cdot (25-100) - 40800/4{,}187] = -1{,}66 \cdot 10^7$ kcal/h

METANO: $\dot{n}^g_{CH_4} H^{SR}_{CH_4} = \frac{-100(802600)}{4{,}187} = -1{,}92 \cdot 10^7$ kcal/h $(n(-\Delta H))$

✱ $T_3 = 25 + \frac{1{,}79 \cdot 10^5 - 1{,}66 \cdot 10^7 + 1{,}92 \cdot 10^7}{1100 \cdot 7{,}59} = 358$°C

(2) VERIFICA CONDENSE:

$P^*_{H_2O}(T_u) = 10^{A - \frac{B}{T+C}} = 139{,}71$ mmHg Tensione di vapore

$P^u_{H_2O} = P x^u_{H_2O} = 760 \cdot 0{,}182 = 138{,}2$ mmHg Pressione parziale < → evapora e non condensa

Calore di reazione:

(3) $H_{f\,H_2O} = -241814$ kJ/kmol

$H_{f\text{-}CH_4} = -74520$ kJ/kmol → reagente (-)

$H_{f\text{-}CO_2} = -393510$ kJ/kmol

$\Delta \tilde{H}^R_r = +2(-241814) + 1(-393510) - 1(-74520) = -802618$ kJ/kmol

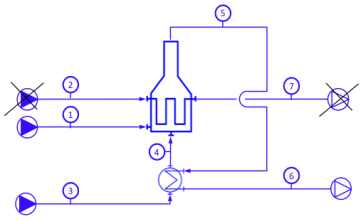
7) Temperatura adiabatica

$n\text{-}C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$

$\Delta H_r = (-44.9 + 7 \cdot 94 + 8 \cdot 57,8) = -1075,5 \text{ kcal/mol}$

$\Delta T_{ad} = \frac{\Delta H_r}{C_p N_{TOT}} = 2000K$

8) Entalpia di reazione



- n-Decano 20% in peso
- n-Esadecano 30% in peso
- n-Eicosano 50% in peso

$T = 25°C$

vapore saturo a 50 bar

$H_2O \rightarrow 50$ bar e $25°C$

3) $T = 25°C$

$e = 0,05$

6) $T = 150°C$

1) 1000 kg/h

? = portata e composizione fumi in uscita in kg/h

? = calore reso disponibile dal combustibile

Composto	Formula	Mol wt (g/mol)	$DH°_f$ (kJ/mol) (25°C)	$c_{p\text{-}vap}$ (kJ/kmol/K)
n-Decano	$C_{10}H_{22}$	142.285	-249.46	
n-Esadecano	$C_{16}H_{34}$	226.446	-374.17	
n-Eicosano	$C_{20}H_{42}$	282.553	-456.46	
Ossigeno	O_2	31.999	0	30
Azoto	N_2	28.014	0	29.3
Anidride Carbonica	CO_2	44.01	-393.51	40.6
Acqua	H_2O	18.015	-241.814	34.2

$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$

- $C_{10}H_{22} + \left(10 + \frac{22}{4}\right)O_2 \rightarrow 10CO_2 + \frac{22}{2}H_2O$
- $C_{16}H_{34} + \left(16 + \frac{34}{4}\right)O_2 \rightarrow 16CO_2 + \frac{34}{2}H_2O$
- $C_{20}H_{42} + \left(20 + \frac{42}{4}\right)O_2 \rightarrow 20CO_2 + \frac{42}{2}H_2O$

Bilanci di massa:

$\dot{m}^e_{C10} = \dot{m}_1 w_{C10} = 1000 \cdot 0,2 = 200 \text{ kg/h} \Rightarrow \dot{n}^e_{C10} = \frac{\dot{m}^e_{C10}}{M_{C10}} = \frac{200}{142,285} = 1,41 \text{ kmol/h}$

$\dot{m}^e_{C16} = \dot{m}_1 w_{C16} = 1000 \cdot 0,3 = 300 \text{ kg/h} \Rightarrow \dot{n}^e_{C16} = 1,32 \text{ kmol/h}$

$\dot{m}^e_{C20} = \dot{m}_1 w_{20} = 1000 \cdot 0,5 = 500 \text{ kg/h} \Rightarrow \dot{n}^e_{C20} = 1,77 \text{ kmol/h}$

$\dot{n}_{O2,teorico} = \dot{n}_{C10}\left(10 + \frac{22}{4}\right) + \dot{n}_{C16}\left(16 + \frac{34}{4}\right) + \dot{n}_{C20}\left(20 + \frac{42}{4}\right) = 108,2$

$\dot{n}^e_{O2} = \dot{n}_{O2,teorico}(1 + e) = 113,63 \text{ kmol/h}$

$\dot{n}^e_{N2} = \dot{n}^e_{O2} \cdot \frac{79}{21} = 427,46 \text{ kmol/h}$

Bilanci di massa-uscita

$\dot{n}^u_{C10} = \dot{n}^u_{C16} = \dot{n}^u_{C20} = 0$ → vengono eliminati

$\dot{n}_{O2,fumi} = \dot{n}^e_{O2} - \dot{n}_{O2,teorico} = 5,41 \text{ kmol/h}$

$\dot{n}_{CO2,fumi} = 10\dot{n}^e_{C10} + 16\dot{n}^e_{C16} + 20\dot{n}^e_{C20} = 70,64 \text{ kmol/h}$

$\dot{n}_{H2O,fumi} = 11\dot{n}^e_{C10} + 17\dot{n}^e_{C16} + 21\dot{n}^e_{C20} = 75,14 \text{ kmol/h}$

$\dot{n}_{N2,fumi} = \dot{n}^e_{N2} = 427,46 \text{ kmol/h}$

$\dot{n}_{fumi} = \dot{n}_{O2,fumi} + \dot{n}_{CO2,fumi} + \dot{n}_{H2O,fumi} + \dot{n}_{N2,fumi} = 578,66 \text{ kmol/h}$

Bilancio di energia:

$\dot{n}_2(\tilde{H}_1 - \tilde{H}^{SR}_1) + \dot{n}_3(\tilde{H}_3 - \tilde{H}^{SR}_3) - \dot{n}_6(\tilde{H}_6 - \tilde{H}^{SR}_6) - \sum_{r=1-3}\dot{\varepsilon}_r \sum_{i=1-8} \nu_{i-r}\tilde{H}^{SR}_i + Q = 0$

$Q = \dot{n}_6 C^6_p(T_6 - T^{SR}) + \underbrace{\dot{n}^e_{C10}\Delta\tilde{H}^R_{C10} + \dot{n}^e_{C16}\Delta\tilde{H}^R_{C16} + \dot{n}^e_{C20}\Delta\tilde{H}^R_{C20}}_{\Delta H^R_{tot}}$

$\Delta\tilde{H}^R_{CxHy} = x\Delta\tilde{H}^f_{CO2} + \frac{y}{2}\Delta\tilde{H}^f_{H2O} - \Delta\tilde{H}^f_{CxHy}$

$\Delta\tilde{H}^R_{C10} = 10\Delta\tilde{H}^f_{CO2} + 11\Delta\tilde{H}^f_{H2O} - \Delta\tilde{H}^f_{C10} = -6345594 \frac{KJ}{kmol}$

$\Delta\tilde{H}^R_{C16} = 16\Delta\tilde{H}^f_{CO2} + 17\Delta\tilde{H}^f_{H2O} - \Delta\tilde{H}^f_{C16} = -10032828 \frac{KJ}{kmol}$

$\Delta\tilde{H}^R_{C20} = 20\Delta\tilde{H}^f_{CO2} + 21\Delta\tilde{H}^f_{H2O} - \Delta\tilde{H}^f_{C20} = -12491834 \frac{KJ}{kmol}$

$\dot{n}_{C10} = 1,41 \text{ kmol/h}$
$\dot{n}_{C16} = 1,32 \text{ kmol/h}$
$\dot{n}_{C20} = 1,77 \text{ kmol/h}$
$\Rightarrow \Delta\dot{H}^R_{Tot} = -4,43 \cdot 10^7 \frac{KJ}{h}$

$\dot{Q} = \dot{n}^G C_p^G (T_G - T^{SR}) + \Delta\dot{H}^R_{Tot} = 2,26 \cdot 10^6 - 4,43 \cdot 10^7 = -4,21 \cdot 10^7 \frac{KJ}{h}$
$\dot{n}^G \sum x_{i-G} C_{pi} (T_G - T^{SR}) = 578,66 \cdot 31,32 \cdot (150 - 25) = 2,26 \cdot 10^6 \frac{KJ}{h}$

Potere calorifero:

Composto	Formula	Mol wt (g/mol)
n-Decano	$C_{10}H_{22}$	142.285
n-Esadecano	$C_{16}H_{34}$	226.446
n-Eicosano	$C_{20}H_{42}$	282.553

$PCI_c = \sum_i w_i PCI_i = -\sum_i \frac{w_i}{M_i} \Delta\tilde{H}^R_i$

$\Delta\tilde{H}^R_{C10} = -6345594 \frac{KJ}{kmol}$
$\Delta\tilde{H}^R_{C16} = -10032828 \frac{KJ}{kmol}$
$\Delta\tilde{H}^R_{C20} = -12491834 \frac{KJ}{kmol}$

$PCI_c = -\sum_i \frac{w_i}{M_i} \Delta\tilde{H}^R_i = \frac{0,2 \cdot 6,34 \cdot 10^6}{142,285} + \frac{0,3 \cdot 1,00 \cdot 10^7}{226,446} + \frac{0,5 \cdot 1,25 \cdot 10^7}{282,553} = 44316 \frac{KJ}{kg}$

$PCS = PCI + \frac{m_w}{m_{comb}} \Delta\tilde{H}^{vap}_w (298 K)$

$PCS_{tot} = \sum_i w_i PCS_i = \sum_i w_i \left[PCI_i + \frac{m_{wi}}{m_{comb-i}} \Delta\tilde{H}^{vap}_w (298 K)\right] = PCI_{tot} + \Delta\tilde{H}^{vap}_w \sum_i \frac{w_i m_{wi}}{m_{comb-i}}$
$= PCI_{tot} + \Delta\tilde{H}^{vap}_w \sum_i \frac{m_{wi}}{m_{comb-tot}} =$
$= PCI_{tot} + \frac{m_w \cdot \Delta H^{vap}_w}{m_{comb-tot}}$
$= PCI_{tot} + \frac{n_{w-tot} M_w \cdot \Delta\tilde{H}^{vap}_w}{m_{comb-tot}}$

$\dot{n}_{H2O,fumi} = 75,14 \frac{kmol}{h}$
$\Delta\tilde{H}^{vap}_w (298K) = 2441,9 \frac{KJ}{kg}$
$M_w = 18,015 \frac{kg}{kmol}$
$PCS_{tot} = 44316 + \frac{18,015 \cdot 2441,9 \cdot 75,14}{1000} = 47622 \frac{KJ}{kg}$

9) Potere calorifero

Analisi elementare	% massa
Carbonio	87.26
Idrogeno	10.84
Zolfo	0.94
Azoto	0.28
Ossigeno	0.64
Ceneri	0.04

	M_w	Cp (200-25) Cal/mol/K
CO_2	44	9.701
H_2O	18	8.177
SO_2	64	10.25
N_2	28	6.996
O_2	32	7.181

10000 kg/h olio combustibile
PCI = 42700 KJ/kg

1) PORTATA D'ARIA EFFETTIVA:

Bilanci di massa

(C): $\dot{m}^e_C = 10000 \text{ kg/h} \cdot 0,8726 = 8726 \text{ kg/h}$
$\dot{n}^e_C = 8726/12 = 727,2 \text{ kmol/h}$
(H): $\dot{m}^e_H = 10000 \cdot 0,1084 = 1084 \text{ kg/h}$
$\dot{n}^e_H = 1084/2 = 542 \text{ kmol/h}$
(S): $\dot{m}^e_S = 10000 \cdot 0,0094 = 94 \text{ kg/h}$
$\dot{n}^e_S = 94/32 = 2,9 \text{ kmol/h}$
(N): $\dot{m}^e_N = 10000 \cdot 0,0028 = 28 \text{ kg/h}$
$\dot{n}^e_N = 28/28 = 1 \text{ kmol/h}$

(0): $\dot{m}^e_{O_2} = 10000 \cdot 0{,}0064 = 64\ kg/h$

$\dot{n}^e_{O_2} = 64/32 = 2\ kmol/h$

$\dot{n}_{O_2,teorico} = \dot{n}^e_C + \frac{1}{2}\dot{n}^e_{H_2} + \dot{n}^e_S - \dot{n}^e_{O_2} = 999{,}1\ kmol/h$

$\dot{n}^{aria}_{O_2} = \dot{n}_{O_2,teorico} \cdot (1+e) = 1099{,}1\ kmol/h$

$\dot{n}^{aria}_{N_2} = \dot{n}^{aria}_{O_2} \cdot \frac{79}{21} = 4134{,}4\ kmol/h$

$\dot{n}^a_{N_2} + \dot{n}^a_{O_2} = 5233{,}4\ kmol/h$

$C + O_2 \rightarrow CO_2$

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

$S + O_2 \rightarrow SO_2$

2) PORTATA E COMPOSIZIONE FUMI:

$\dot{n}^u_C = \dot{n}^u_{H_2} = \dot{n}^u_{C_S} = 0$

$\dot{n}_{O_2,fumi} = \dot{n}^e_{O_2} + \dot{n}^{aria}_{O_2} - \dot{n}_{O_2,teorico} = 99{,}9\ \frac{kmol}{h}$

$\dot{n}_{CO_2,fumi} = \dot{n}^e_C = 727{,}2\ \frac{kmol}{h}$

$\dot{n}_{H_2O,fumi} = \dot{n}^e_{H_2} = 542\ \frac{kmol}{h}$

$\dot{n}_{SO_2,fumi} = \dot{n}^e_S = 2{,}9\ \frac{kmol}{h}$

$\dot{n}_{N_2,fumi} = \dot{n}^e_{N_2} + \dot{n}^{aria}_{N_2} = 4135{,}4\ \frac{kmol}{h}$

$\dot{n}_{fumi} = \dot{n}_{O_2,fumi} + \dot{n}_{CO_2,fumi} + \dot{n}_{H_2O,fumi} + \dot{n}_{N_2,fumi} = 5507{,}4\ \frac{kmol}{h}$

$X_{O_2,fumi} = \frac{\dot{n}_{O_2,fumi}}{\dot{n}_{fumi}} = 0{,}018$

$X_{CO_2,fumi} = 0{,}132$

$X_{H_2,fumi} = 0{,}098$

$X_{SO_2,fumi} = 0{,}0005$

$X_{N_2,fumi} = 0{,}751$

Bilanci di massa - fumi secchi

$\dot{n}_{fumi} = \dot{n}_{O_2,fumi} + \dot{n}_{CO_2,fumi} + \dot{n}_{N_2,fumi} = 4965{,}4\ \frac{kmol}{h}$

$X_{O_2,fumi} = 0{,}020$

$X_{CO_2,fumi} = 0{,}146$

$X_{H_2O,fumi} = 0$

$X_{N_2,fumi} = 0{,}833$

$X_{SO_2,fumi} = 0{,}0006$

Bilancio energia:

$\dot{n}_{fumi}(\tilde{H}_{fumi} - \tilde{H}^{SR}_{fumi}) + \dot{m}_c PCI + \dot{Q} = 0$

$\dot{Q} = \dot{n}_{fumi} C_p^{fumi} (T_{fumi} - T^{SR}) - \dot{m}_c PCI$

$C_p^{fumi} = 9{,}701 \cdot 0{,}132 + 8{,}177 \cdot 0{,}098 + 10{,}25 \cdot 5 \cdot 10^{-4} + 6{,}996 \cdot 0{,}751 + 7{,}181 \cdot 0{,}018$

$= 7{,}474\ \frac{kcal}{K \cdot kmol}$

$\dot{Q} = 5507{,}4 \cdot 7{,}474 (200-25) - \frac{10000 \cdot 42700}{4{,}1868} = -9{,}478 \cdot 10^7\ \frac{kcal}{h}$

	x	Cp (200-25) Cal/mol/K
CO_2	0.132	9.701
H_2O	0.098	8.177
SO_2	0.0005	10.25
N_2	0.751	6.996
O_2	0.018	7.181

$\dot{n}_{CO_2,fumi} = \dot{n}^e_C = 727{,}2\ \frac{kmol}{h} \Rightarrow \dot{m}_{CO_2,fumi} = \dot{n}_{CO_2,fumi} M_{CO_2} = 31995\ \frac{kg}{h}$

$\dot{n}_{SO_2,fumi} = \dot{n}^e_S = 2{,}9\ \frac{kmol}{h} \Rightarrow \dot{m}_{SO_2,fumi} = \dot{n}_{SO_2,fumi} M_{SO_2} = 188\ \frac{kg}{h}$

$EF_{CO_2-olio} = \frac{31995}{10000} = 3{,}2\ kg_{CO_2}/kg_{olio}$

$EF_{SO_2-olio} = \frac{188}{10000} = 18{,}8\ kg_{SO_2}/ton_{olio}$

$\dot{n}_{CO_2,fumi} = \dot{n}^e_C = 727{,}2\ \frac{kmol}{h} \Rightarrow \dot{m}_{CO_2,fumi} = \dot{n}_{CO_2,fumi} M_{CO_2} = 31995\ kg/h$

$\dot{n}_{SO_2,fumi} = \dot{n}^e_S = 2{,}9\ \frac{kmol}{h} \Rightarrow \dot{m}_{SO_2,fumi} = \dot{n}_{SO_2,fumi} M_{SO_2} = 188\ kg/h$

$EF_{CO_2} = \frac{31995}{9{,}478 \cdot 10^7} \cdot \frac{10^6}{4{,}1868} = 80{,}6\ kg/GJ$

$EF_{SO_2} = \frac{188}{9{,}478 \cdot 10^7} \cdot \frac{10^6}{4{,}1868} = 0{,}474\ kg/GJ$

$PN = \dot{m}_c PCI = \frac{42700 \cdot 10000}{3600 \cdot 1000} = 118{,}6\ MW$

$\dot{m}_{SO_2,fumi} = \dot{n}_{SO_2,fumi} M_{SO_2} = 188 = 1{,}88 \cdot 10^8\ \frac{mg}{h}$

$\dot{n}_{fumi} = 4965{,}4 \cdot 22{,}414 = 1{,}113 \cdot 10^5\ Nm^3/h$

$C_{Norm} = C_{misurata} \frac{0{,}21 - O_{2-rif}}{0{,}21 - O_{2-misurato}}$

$= \frac{1{,}88 \cdot 10^8}{1{,}113 \cdot 10^5} \frac{0{,}21-0{,}03}{0{,}21-0{,}02} = 1600\ mg/Nm^3$

10 Bilancio di energia

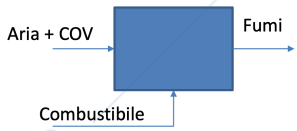
Una corrente d'aria contenente composti organici volatili assimilabili ad acetone (C3H6O) in quantità pari la 1% volumetrico viene mandata ad un combustore. Al fine di ottenere la completa distruzione dei VOC la temperatura di uscita dei fumi deve essere di almeno 900°C. Considerando che per la combustione viene utilizzato gas naturale, si chiede la quantità minima di combustibile, necessario a garantire la termodistruzione degli inquinanti.

Si consideri che il combustibile sia disponibile a 25°C, così come la corrente d'aria inquinata. La pressione di entrambe le correnti è quella atmosferica.

Nei calcoli si trascuri il calore generato dall'ossidazione degli inquinanti.

	cp (kcal/kmol/K)
CO2	9.6
H2O	8.17
O2	7
N2	7.2

$\Delta H_{c\text{-}metano}$	-802600	kJ/kmol a 25°C



$$\frac{dU}{dt} = \sum_e \dot{n}^e \tilde{H}^e - \sum_u \dot{n}^u \tilde{H}^u + \dot{Q} + \dot{L}_m - p\frac{dV}{dt}$$

$$\dot{n}^e_{aria}\left(H^e_{aria} - H^{SR}_{aria}\right) + \dot{n}^e_{CH_4}\left(H^e_{CH_4} - H^{SR}_{CH_4}\right) - \dot{n}^u_{fumi}\left(H^u_{fumi} - H^{SR}_{fumi}\right) - \dot{n}^e_{CH_4}\Delta H_R = 0$$

$$\dot{n}^u_{O_2} = \dot{n}^e_{O_2} + \dot{n}^g_{O_2} = \dot{n}^e_{O_2} - 2\dot{n}^e_{CH_4}$$

$$\dot{n}^u_{N_2} = \dot{n}^e_{N_2} + \dot{n}^g_{N_2}$$

$$\dot{n}^u_{CO_2} = \dot{n}^e_{CO_2} + \dot{n}^g_{CO_2} = \dot{n}^e_{CO_2} + \dot{n}^e_{CH_4}$$

$$\dot{n}^u_{H_2O} = \dot{n}^e_{H_2O} + \dot{n}^g_{H_2O} = \dot{n}^e_{H_2O} + 2\dot{n}^e_{CH_4}$$

$$\dot{n}^e_{N_2} C_{pN_2}\left(T_{fumi} - T^{SR}\right) + \left(\dot{n}^e_{O_2} - 2\dot{n}^e_{CH_4}\right) C_{pO_2}\left(T_{fumi} - T^{SR}\right) + \left(\dot{n}^e_{CO_2} + \dot{n}^e_{CH_4}\right) C_{pCO_2}\left(T_{fumi} - T^{SR}\right) + \left(\dot{n}^e_{H_2O} + 2\dot{n}^e_{CH_4}\right) C_{pH_2O}\left(T_{fumi} - T^{SR}\right) - \dot{n}^e_{CH_4}\Delta H_R =$$

$$\dot{n}^e_{N_2} C_{pN_2} + \dot{n}^e_{O_2} C_{pO_2} = 2\dot{n}^e_{CH_4} C_{pO_2} - 2\dot{n}^e_{CH_4} C_{pH_2O} - \dot{n}^e_{CH_4} C_{pCO_2} - \dot{n}^e_{CH_4} \frac{\Delta H_R}{\left(T_{fumi} - T_{SR}\right)}$$

$$\dot{n}^e_{CH_4} = \frac{\dot{n}^e_{N_2} C_{pN_2} + \dot{n}^e_{O_2} C_{pO_2}}{2C_{pO_2} - 2C_{pH_2O} - C_{pCO_2} - \frac{\Delta H_R}{(T_{fumi} - T_{SR})}} = \frac{79 \cdot 7{,}2 + 21 \cdot 7}{2 \cdot 7 - 2 \cdot 8{,}17 - 9{,}6 - \frac{-802600}{4{,}18(900-25)}} = 3{,}46 \text{ kmol}$$