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n-heptane (C_7H_{16}) $\phi=1$

1. $C_7H_{16} + 11\,(O_2+3.76N_2) \rightarrow 7\,CO_2 + 8H_2O + 41.36N_2$
   (11 = 7+4; 41.36 = 11·3.76)

2. $\dot{m}_{fuel} = 1\ kg/s$

$$\frac{1\,kg\,fuel}{s}\cdot\frac{1\,kmol\,fuel}{12\cdot7+16\cdot1\,kg}\cdot\frac{1000\,mol\,fuel}{1\,kmol}\cdot\frac{11\cdot4.76\,mol\,air}{1\,mol\,fuel}\cdot\frac{29\,g\,air}{1\,mol\,air}\cdot\frac{1\,kg}{1000\,g}$$

$$\boxed{\dot{m}_{air} = 15.18\ \frac{kg}{s}}$$

3. LHV:

$-Q_p = H_R - H_p$

$-Q_p = \sum_i N_{iR}(\Delta \hat{h}^o_{f,iR} + \hat{h}_{s,iR}) - \sum_i N_{iP}(\Delta\hat{h}^o_{f,iP} + \hat{h}_{s,iP})$

LHV – $T_P = T_R = 25°C$ no sensible enthalpy

$LHV = \sum_i N_{iR}\Delta\hat{h}^o_{iR} - \sum_i N_{iP}\Delta\hat{h}^o_{iP}$

$LHV = 1\cdot(-224.2) + 11(0) + 41.36(0) - [7\cdot(-393.52) + 8(-241.83) + 41.36(0)]$

$LHV = 4465.08\ \frac{kJ}{mol\,fuel}$

$LHV = 4465.08\frac{kJ}{mol\,fuel}\cdot\frac{1\,mol\,fuel}{12\cdot7+16\cdot1\,g}\cdot\frac{1000\,g}{1\,kg} = 44650.8\ \frac{kJ}{kg\,fuel}$

heat loss $= 0.1\cdot4465.08\frac{kJ}{mol\,fuel} = 446.51\ \frac{kJ}{mol\,fuel}$

heat loss $= 446.51\frac{kJ}{mol\,fuel}\cdot\frac{1\,mol\,fuel}{12\cdot7+16\,g}\cdot\frac{1000\,g}{1\,kg}\cdot\frac{1\,kg}{1\,sec} = \boxed{4465.1\ \frac{kJ}{s}}$

4. Product temperature: 1st law $-Q = H_R - H_P$
   $H_P = H_R + Q$

$H_P = H_R + Q$

$\sum_i N_{iP}[\Delta\hat{h}^o_{iP} + h_{siP}] = \sum_i N_{iR}[\Delta h^o_{iR} + h_{siR}] + Q$

$\sum_i N_{iP}\Delta h^o_{iP} + \sum N_{iP}h_{siP} = \sum_i N_{iR}\Delta h^o_{iR} + \sum_i N_{iR}h_{siR} + Q$

$\sum N_{iP}h_{siP} = \underbrace{\sum N_{iR}\Delta h^o_{iR} - \sum N_{iP}\Delta h^o_{iP}}_{LHV} + \sum N_{iR}h_{siR} + Q$

$\sum N_{iP}h_{siP} = 4465.08 + 11\,h_{s,O_2}^{(T_R)} + 41.36\,h_{s,N_2}^{(T_R)} - 446.51$ ← heat losses

$7h_{sCO_2}(T_P) + 8h_{sH_2O}(T_P) + 41.36h_{N_2}(T_P) = 4465.08 + 11(12.5) + 41.36(11.94) - 446.51$

$7h_{sCO_2}(T_P) + 8h_{sH_2O}(T_P) + 41.36h_{N_2}(T_P) = 4649.92$

guess $T_P = 2000\,K$

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$7(91.45) + 8(72.69) + 41.36(56.14) \overset{?}{=} 4649.92$

$3543.62 \overset{?}{=} 4649.92$ no, temp too low

guess $T_p = 2500K$

$7(121.93) + 8(98.96) + 41.36(74.31) \overset{?}{=} 4649.92$

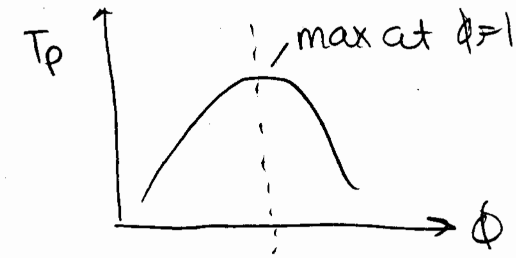
$4718.65 \overset{?}{=} 4649.92$ no, temp too high

interpolate:

$$\frac{2500 - T}{2500 - 2000} = \frac{4718.65 - 4649.92}{4718.65 - 3543.62}$$

$$T = 2470.75\ K$$

5.



6. 300 m/s

$$\tau_{chem} = \frac{[C_7H_{16}]_{init}}{-d[C_7H_{16}]/dt}$$

$$\frac{d[C_7H_{16}]}{dt} = -A_0 \exp\left(-\frac{E_a}{RT}\right)[C_7H_{16}]^a[O_2]^b$$

$$[C_7H_{16}] = \frac{P x_{C_7H_{16}}}{RT} \qquad x_{C_7H_{16}} = \frac{1}{1 + 11 \cdot 4.76} = 0.0187$$

$$[C_7H_{16}] = \frac{(101.3)(0.0187)}{(8.314)(1200K)} = 1.90 \times 10^{-4} \frac{kmol}{m^3} = 1.90 \times 10^{-7} \frac{mol}{cc}$$

$R = 1.987 \frac{cal}{mol\ K}$

$$x_{O_2} = \frac{11}{1 + 11 \cdot 4.76} = 0.206$$

$$[O_2] = \frac{(101.3)(0.206)}{(8.314)(1200K)} = 2.09 \times 10^{-3} \frac{kmol}{m^3} = 2.09 \times 10^{-6} \frac{mol}{cc}$$

$$\frac{d[C_7H_{16}]}{dt} = -5.1 \times 10^{11} \cdot \exp\left(-\frac{15101}{1200}\right)[1.90 \times 10^{-7}]^{0.25}(2.09 \times 10^{-6})^{1.5}$$

$$\frac{d[C_7H_{16}]}{dt} = -1.105 \times 10^{-4} \frac{mol}{cc \cdot s}$$

$$\tau_{chem} = \frac{1.90 \times 10^{-7}\ mol/cc}{1.105 \times 10^{-4}\ mol/cc\,s} = 1.72\ ms\ (1.72 \times 10^{-3}\ sec)$$

length of chamber must be such that

$\tau_{res} = \tau_{chem}$ $\quad \tau_{res} = L/V$

$$\frac{L}{300\ m/s} = 1.72 \times 10^{-3}\ sec \qquad L = 0.52\ m$$

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7. Pressure dependence:

$\dot{q}_{rxn} \propto p^{a+b}$

reaction rate will go up $\left(\frac{9\,atm}{1\,atm}\right)^{a+b} = (9)^{0.25+1.5} = 9^{1.75}$ or 46.7 times

and since $L \propto rr^{-1}$, the length can be ~47 times shorter.

$l \propto \frac{[\ ]_i}{d[\ ]/dt} = \frac{P}{P^{1.75}} = \frac{9}{9^{1.75}} = 0.193$

so $\frac{l_{new}}{l_{old}} = 0.193$ $l_{new} = 0.10\,m$