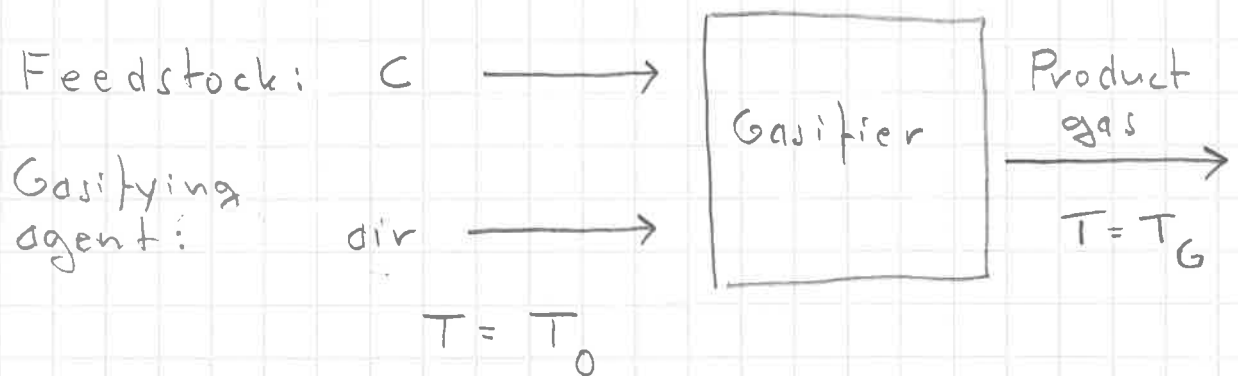


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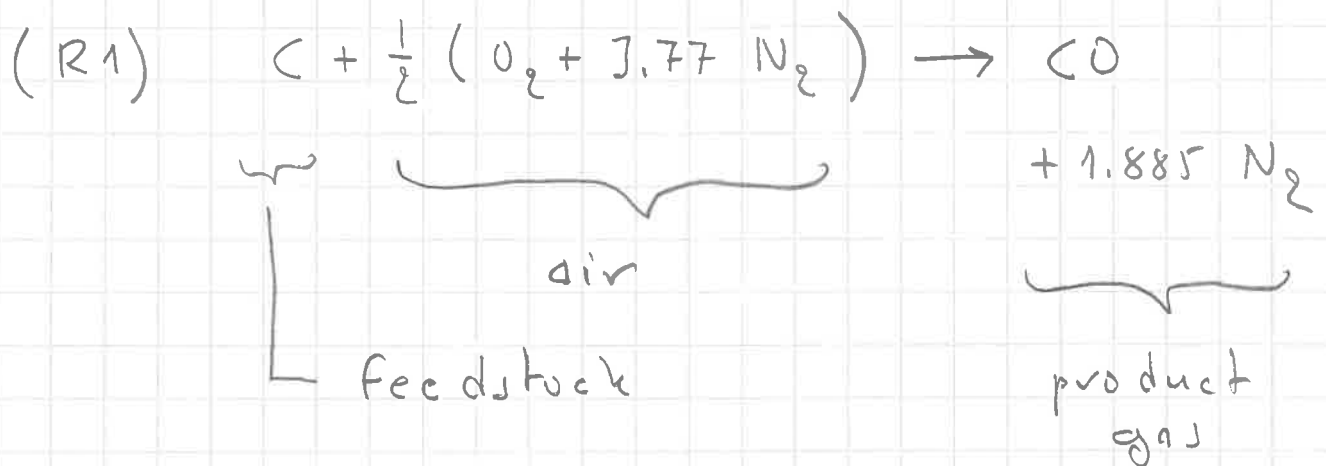
Gasification

Consider the gasification of carbon (C) with air.

Assume the following system:



Gasifying reaction:



Define cold gas efficiency:

$$\eta_{CG} = \frac{\text{chemical energy in product gas}}{\text{chemical energy in feedstock}}$$

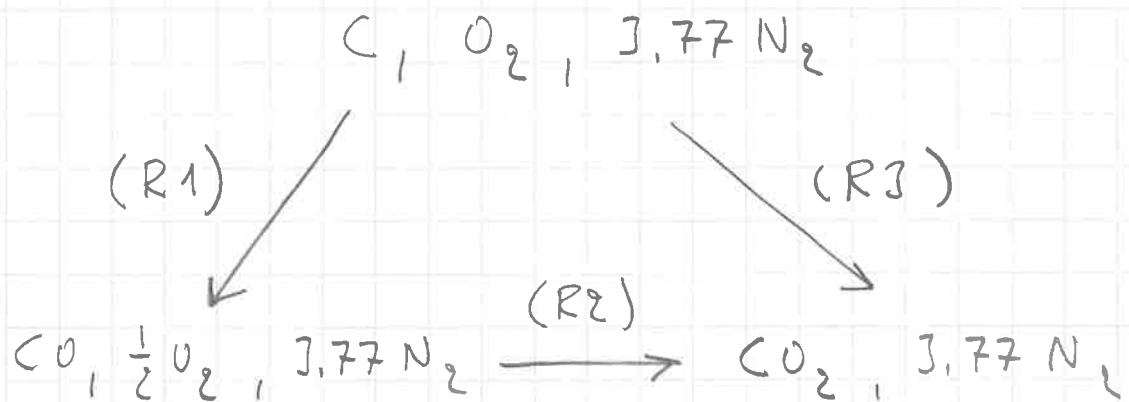
In this case:

$$\eta_{CG} = \frac{\sum Y_{i,PG} Q_{m,i,PG}}{\sum Y_{i,F} Q_{m,i,F}}$$

$$= \frac{1 \cdot Q_{m,CO}}{1 \cdot Q_{m,C}} = \frac{Q_{m,CO}}{Q_{m,C}}$$

What are the values of $Q_{m,CO}$ and $Q_{m,C}$?

Consider the following reaction system:



The law of Hess:

$$\Delta H_{m,(R3)} = \Delta H_{m,(R1)} + \Delta H_{m,(R2)}$$

$$\Rightarrow \Delta H_{m,(R2)} = \Delta H_{m,(R3)} - \Delta H_{m,(R1)}$$

$$\Delta H_{m,(R3)} = \Delta H_{m,f,\text{CO}_2} = -394 \frac{\text{MJ}}{\text{kmol}}$$

$$\Delta H_{m,(R1)} = \Delta H_{m,f,\text{CO}} = -111 \frac{\text{MJ}}{\text{kmol}}$$

since (R3) is the formation reaction of CO_2 etc.

Numerical values from BR pr. 574, 576 (3)

$$\begin{aligned}\Rightarrow \Delta H_{m, (R2)} &= -394 \frac{\text{MJ}}{\text{kmol}} - \left(-111 \frac{\text{MJ}}{\text{kmol}} \right) \\ &= -283 \frac{\text{MJ}}{\text{kmol}}\end{aligned}$$

$$\begin{aligned}Q_{m, \text{CO}} &= -\Delta H_{(R2)} = - \left(-283 \frac{\text{MJ}}{\text{kmol}} \right) \\ &= 283 \frac{\text{MJ}}{\text{kmol}}\end{aligned}$$

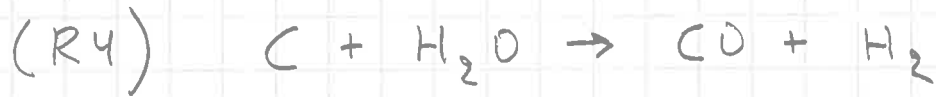
$$\begin{aligned}Q_{m, \text{C}} &= -\Delta H_{(R3)} = - \left(-394 \frac{\text{MJ}}{\text{kmol}} \right) \\ &= 394 \frac{\text{MJ}}{\text{kmol}}\end{aligned}$$

$$\Rightarrow \eta_{\text{CG}} = \frac{283 \frac{\text{MJ}}{\text{kmol}}}{394 \frac{\text{MJ}}{\text{kmol}}} = 0,72$$

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What if we consider
steam gasification of carbon?

Assume:



$$\begin{aligned} \Rightarrow \eta_{CG} &= \frac{\sum v_{i,PG} Q_{m,i,PG}}{\sum v_{i,F} Q_{m,i,F}} \\ &= \frac{1 \cdot Q_{m,CO} + 1 \cdot Q_{m,H_2}}{1 \cdot Q_{m,C}} \\ &= \frac{Q_{m,CO} + Q_{m,H_2}}{Q_{m,C}} \end{aligned}$$

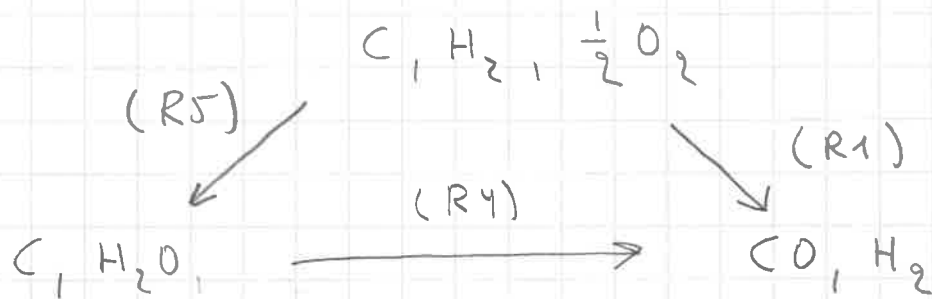
$$\begin{aligned} Q_{m,H_2} &= -\Delta H_{m,F,H_2O} = -(-242 \frac{MJ}{kmol}) \\ &= 242 \frac{MJ}{kmol} \end{aligned}$$

$$\Rightarrow \eta_{CG} = \frac{283 \frac{\text{MJ}}{\text{kmol}} + 242 \frac{\text{MJ}}{\text{kmol}}}{394 \frac{\text{MJ}}{\text{kmol}}} = 1.33$$

What does it mean that $\eta_{CG} > 1$?

Reaction (R4) is an endothermic reaction (an energy-consuming reaction). We cannot make (R4) happen unless extra energy is supplied from outside.

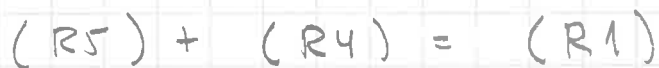
To find out the reaction enthalpy for (R4), consider the following scheme :



where



and



$$\Rightarrow \text{(R4)} = \text{(R1)} - \text{(R5)}$$

$$\begin{aligned} \Rightarrow \Delta H_{m, \text{(R4)}} &= \Delta H_{m, \text{(R1)}} - \Delta H_{m, \text{(R5)}} \\ &= \Delta H_{m, f, \text{CO}} - \Delta H_{m, f, \text{H}_2\text{O}} \end{aligned}$$

$$\begin{aligned}\Rightarrow \Delta H_{m,R} &= -111 \frac{\text{MJ}}{\text{kmol}} - \left(-242 \frac{\text{MJ}}{\text{kmol}} \right) \\ &= 131 \frac{\text{MJ}}{\text{kmol}}\end{aligned}$$

(cf. HB Eqn (2.5) p. 12)

Generally :

$$\begin{aligned}\Delta H_{m,R} &= \sum \Delta H_{m,f, \text{products}} \\ &\quad - \sum \Delta H_{m,f, \text{reactants}}\end{aligned}$$

What would be the adiabatic operating temperature of the gasifier?

Follow the procedure of Ex. J.12 in BR pp. 90-91 (with slightly different symbols)

For adiabatic operation,

$$\text{Enthalpy of reactants} = \text{Enthalpy of products}$$

includes all enthalpy terms (chemical, sensible, latent)

$$\begin{aligned} \Rightarrow \underbrace{\sum H_{i,\text{reactants}}(T=T_0)} &= \underbrace{\sum H_{i,\text{products}}(T=T_G)} \\ &= H_C(T=T_0) + H_{O_2}(T=T_0) + H_{N_2}(T=T_0) \\ &= H_{CO}(T=T_G) + H_{N_2}(T=T_G) \text{ (g)} \end{aligned}$$

$$\Rightarrow n_C H_{m,C}(T=T_0) + n_{O_2} H_{m,O_2}(T=T_0) \\ + n_{N_2} H_{m,N_2}(T=T_0) =$$

$$= n_{CO} H_{m,CO}(T=T_0) + n_{N_2} H_{m,N_2}(T=T_0)$$

$$H_{m,C}(T=T_0) = \underbrace{\Delta H_{m,f,C}}_{\text{enthalpy of formation}} + \underbrace{\Delta H_{m,s,C}(T=T_0)}_{\text{sensible enthalpy}}$$

enthalpy of formation
= 0 since
C is an element

sensible enthalpy
= 0
since $T=T_0$

similarly:

$$H_{m,O_2}(T=T_0) = H_{m,N_2}(T=T_0) = 0$$

$$H_{m,CO}(T=T_G) = \Delta H_{m,f,CO} + \Delta H_{m,s,CO}(T=T_G)$$

$$\Delta H_{m,N_2}(T=T_G) = \underbrace{\Delta H_{m,f,N_2}}_{=0} + \Delta H_{m,s,N_2}(T=T_G)$$

Thus, the energy balance becomes

$$1 \cdot 0 + \frac{1}{2} \cdot 0 + 1.885 \cdot 0 =$$

$$= 1 \cdot \left[\Delta H_{m,f,CO} + \Delta H_{m,s,CO}(T=T_G) \right] +$$
$$+ 1.885 \cdot \Delta H_{m,s,N_2}(T=T_G)$$

$$\Rightarrow -\Delta H_{m,f,CO} = \Delta H_{m,s,CO}(T=T_G)$$

$$+ 1.885 \Delta H_{m,s,N_2}(T=T_G)$$

Assume: $\Delta H_{m,s,CO}(T) \approx \Delta H_{m,s,N_2}$

since both are gases with

two atoms in the molecule

$$\Rightarrow -\Delta H_{m,f,CO} \approx 2.885 \Delta H_{m,s,CO} (T=T_G)$$

$$\Rightarrow \Delta H_{m,s,CO} (T=T_G) \approx \frac{-\Delta H_{m,f,CO}}{2.885}$$

$$\approx \frac{-(-111 \frac{\text{MJ}}{\text{kmol}})}{2.885} \approx 38.5 \frac{\text{MJ}}{\text{kmol}}$$

BR App. C p. 576:

$$\Delta H_{m,s,CO} = 38.85 \frac{\text{MJ}}{\text{kmol}} \Rightarrow T = 1500 \text{ K}$$

(at this temperature,

$$\Delta H_{m,s,N_2} = 38.40 \frac{\text{MJ}}{\text{kmol}} \approx \Delta H_{m,s,CO})$$

↑ BR App. C p. 575

$$\Rightarrow \underline{T_G} \approx 1500 \text{ K} \approx \underline{1230 \text{ } ^\circ\text{C}}$$