Materials and Energy Balance

Term Project Questions

1- Vanadium is produced from its ore by reducing the oxide, V_2O_5 with Ca metal in a "bomb" reactor according to the following reaction

$5Ca + V_2O_5 = 5CaO + 2V$

In order to absorb some of the excess heat evolved in this reaction, SiO_2 is added to the stoichiometric reactant mixture. This SiO_2 combines with CaO to form a silicate:

$CaO + SiO_2 = CaO.SiO_2$

If 5 moles of SiO_2 are added to the original stoichiometric mix of Ca and V_2O_5 per mole of V_2O_5, calculate the adiabatic flame temperature of the products. The initial temperature of all reactants is 298 K.

Data

Materials	Cp Cal/mol.K	Tm C	Delt aH fusion Cal/mol	Delta H formation cal/mol
V2O5	46.5			-371800
V(s)	5.2			
V(l)	6.5	1860	3500	
CaO(s)	11.8			-151900
CaO(l)	12.0	2600	19000	
SiO2(s)	11.2			-203400
SiO2(l)	13.4	1713	3600	
CaO.SiO2(s)	26.4			-378600
CaO.SiO2(l)	27.0	1540	13400	
Ca(s)	5.3			

2- In iron foundry cupola 14 tons of pig iron are melted in one hour, using 1.5 tons of coke (90% C). The flue gases contain by volume 13% CO, 13% CO_2, 74%N_2 and leave the cupola at 500 C. One ton of slag is formed and tapped. The analyses of the slag and pig iron are as follows:

Slag: 53.4% $CaO.SiO_2$, 28.1% $2CaO.SiO_2$, 13.4% $2CaO.Al_2O_3.SiO_2$, 3% $2MgO.SiO_2$, 2% MnO_2

Pig iron: 93.72% Fe, 4.6% C, 0.8% Si, 0.8% Mn, 0.8% S

Calculate the net melting efficiency of the cupola

Heats of solution of elements in pig iron (per 1wt% concentration at 1600 C):

Heats of Solution of Elements in Molten Iron
at 1 wt.% Concentration and 1600°C (1873 K)

Reaction:			$\bar{H}_i^m$ cal/g mol
C (gr)	→	$\underline{C}$ (1% in Fe)	+ 5,100
Si(ℓ)	→	$\overline{Si}$ (1% in Fe)	- 31,100
Mn(ℓ)	→	Mn (1% in Fe)	0
Cr(s)	→	$\underline{Cr}$ (1% in Fe)	+ 5,000
Al(ℓ)	→	$\overline{\underline{Al}}$ (1% in Fe)	- 10,300
$1/2\ O_2(g)$	→	$\underline{O}$ (1% in Fe)	- 28,000
$1/2\ S_2(g)$	→	$\underline{S}$ (1% in Fe)	- 31,500
Co(ℓ)	→	$\overline{\underline{Co}}$ (1% in Fe)	0
Cu(ℓ)	→	$\overline{\underline{Cu}}$ (1% in Fe)	+ 8,000
Ni(ℓ)	→	$\overline{\underline{Ni}}$ (1% in Fe)	- 5,000

3- Write an Excel sheet to find the adiabatic flame temperature for the combustion of a gas containing 96% CH4, 1.8% CO, 2.2% N2. The gas and air enter at 298 K. Calculate the flame temperature when a) theoretical air is used, b) when air is enriched with 30% oxygen, c) when pure oxygen is used d)when excess air is used in a range between 1-100%.

4- Some processes operate only if the temperature at certain locations in the furnace is maintained at a particular temperature. One such process is iron ore reduction in the iron blast furnace. The maximum possible temperature is reached at the tuyere, where a blast of air at some temperature is forced into the bosh zone of the furnace. This blast may be modified by the addition or injection of O2, CH4, fuel oil, powdered coal or other supplementary fuel. The blast will contain some moisture either from atmospheric humidity or due to steam injection. The blast reacts with coke which continually enters the tuyere zone from above at a temperature approximating the gas and solid temperatures in the zone through which the gaseous reaction reaction products move. The temperature of the flame produced by reaction at elevated temperatures between the coke, the supplementary fuels, and oxygen controls the rate of

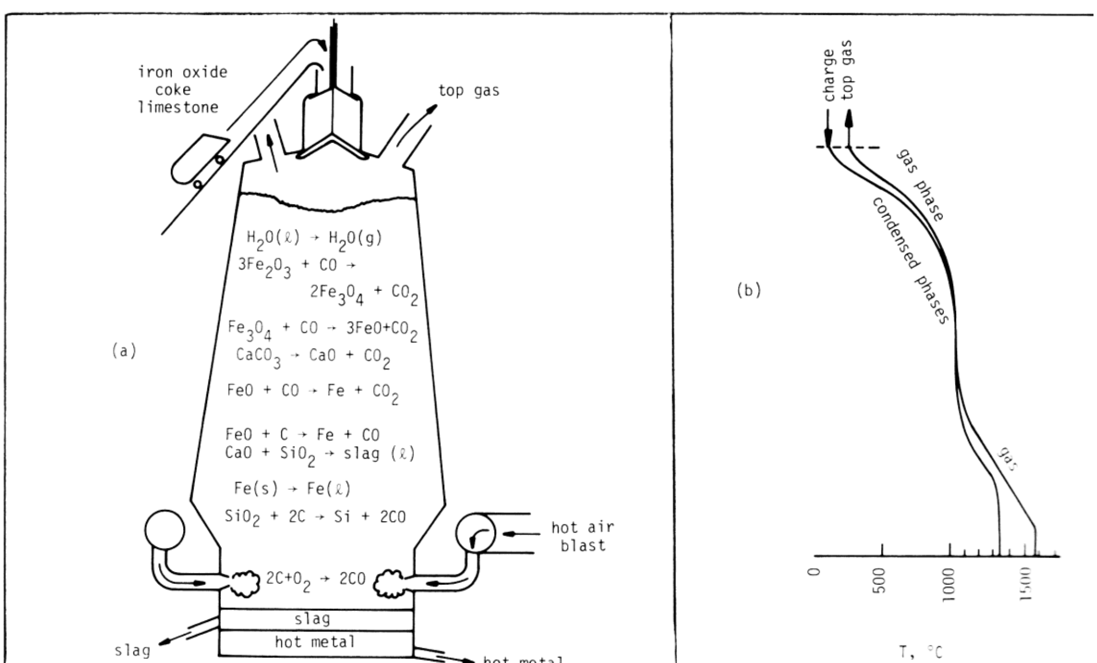
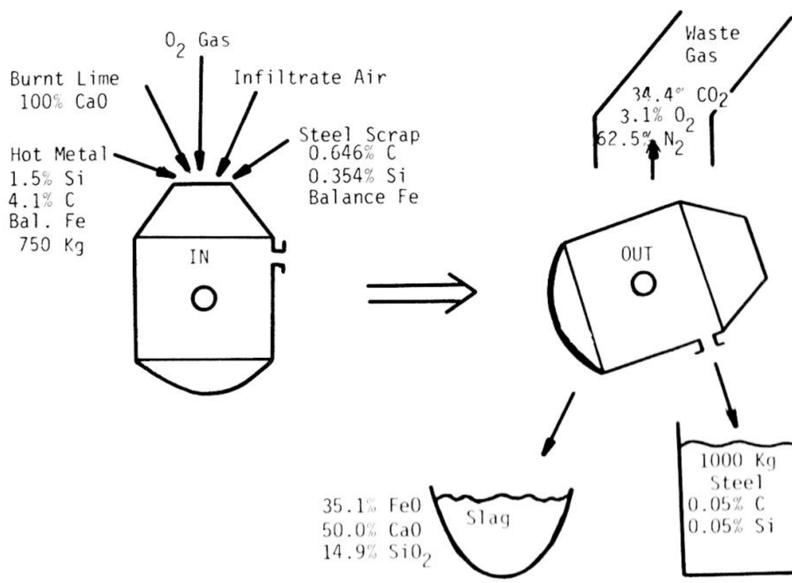


Fig. 6.2-3 (a) Principle reactions and input and output streams of the iron blast furnace.
(b) Typical temperature profile (vertical) in the blast furnace.

heating and melting of the products of reduction in the shaft of the furnace, and thus indirectly controls the overall production rate. Develop an Excel sheet to calculate the adiabatic flame temperature for various blast conditions using the reactions and temperature profile in the iron

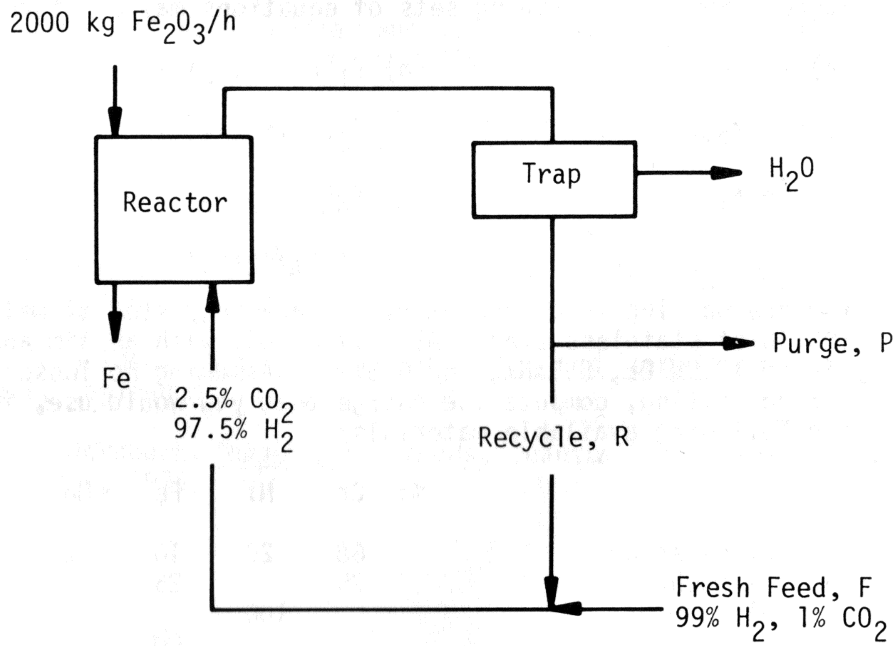
5- The basic oxygen steelmaking process is possible because the heat liberated in the refining process is enough to melt the scrap and lime and end up with steel at a satisfactory temperature for producing ingots. Information available for the production of 1 ton of steel is shown in the diagram. The gas analysis is reported as the average during the blow. Calculate the complete material and heat balances to produce 1000 kg steel.



6- The plant shown in the figure employs H_2 to reduce 2000 kg/h of Fe_2O_3 according to the following reaction:

$Fe_2O_3 + 3H_2 = 3H_2O + 2Fe$

The hydrogen in the recycle is mixed with the H_2 in the fresh feed before entering the reactor. The purge stream takes away excess CO_2 buildup above 2.5%. The ratio of R to fresh feed gas is 4:1. Calculate the material and energy balance for 24 hours of operation and find the thermal efficiency. What is the improvement in thermal efficiency due to recycling.



7- Calculate the material and energy balance for the reduction of a chromium ore to produce 1 ton of ferro-chromium using an ore with the analysis 54% Cr_2O_3, 15.5% FeO, 13.5% MgO, 10% Al_2O_3, 7% SiO_2. Quartz (97% SiO_2) is used as flux and 25% excess coke with the analysis 87% C. Assume 90% of Cr_2O_3 and 95% of FeO are reduced by carbon, 7% C in alloy, 1.5% Si in alloy (reduced by C), and 30% SiO_2 in slag.

8- A furnace calcining $CaCO_3$ is burning coal (89% carbon, 3% hydrogen, 1% oxygen and 7% ash) with air and the airflow is controlled and metered so that air enters the furnace at 100 m3/min. The flue gas analysis is 55% N_2. Calculate a) the theoretical coal requirement per minute, b) the amount of coal that would be consumed if the off-gas were recycled back to the furnace, c) the amount of coal that would be consumed if the off-gas were recycled and carbon in coal was burned partially to CO.

9- 100 tons of hard lead (98% Pb, 2% Sb) are melted in a steel kettle and then treated with 2 tons of PbO. The products are a slag consisting of PbO and Sb_2O_3, analyzing 20% Sb and a Pb-Sb alloy of lowered Sb content and negligible oxygen content. What is the heat given to the kettle for 100% efficiency.

$3PbO + 2Sb(\text{in } Pb) = Sb_2O_3 + 3Pb$

10- A furnace for reheating billets, priorto their being rolled uses fuel oil and air to produce hot gases which pass over the billets, transferring heat to both the billets and the furnace walls. Some of the heat in the walls is re-radiated to the billets and some travels through the walls and is lost to the surroundings. The gases finally exit from the furnace at a reduced temperature. The net calorific value of the fuel oil is 40000 kJ/kg. 25% excess air is supplied and the waste gases analyze 4.6% O2. The billets enter the furnace at 298 K and leave at 1400 K at a rate of 130000 kg/hour/ The waste gases leave at 1500 K. The oil is supplied at a rate of 100 kg/hour and analyzes 85% C, 14% H and 1% S. Calculate the heat losses and the thermal efficiency.