Lecture 30: Exercise in ladle metallurgy

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1) **Problem of desulphurization**

   (A) Calculate K_s for a synthetic slag composed of $X_{caO} = 0.65$ and $X_{Al_2O_3} = 0.35$. The slag is contact with molten steel at temperature T. with dissolved aluminum $0.01\text{wt}\ \%$. In slag activity of alumina is 0.38. use $T = 1773\text{K}$ and $1850\ \text{K}$ and interpret the results.

$\log C_s$ by equation 4 of lecture 22 = - 1.96.

$$\log K_s = \log C_s + \frac{20397}{1773} + \frac{2}{3}\log 0.01 + \frac{1}{3}\log 0.38 - 5.482$$

$$= -1.96 + 11.50 - 1.33 - 0.14 - 5.482$$

$$= 2.588$$

$K_s = 387$ at $T = 1773\text{K}$

$K_s = 130$ at $T = 1850\text{K}$

We note the partition coefficient is higher at 1773K as compared with that at 1850K. Ws can conclude that lower tempearure favours desulphurization.

   (B) Discuss the transitory and permanent contact mode of desulphurization based on the following calculations: Molten steel is desulphurised by injecting powder at the rate of 4 kg/ton. The partition coefficient of sulphur is 50. Now we select a slag whose partition coefficient is 400. We also increase the powder injection rate in one case to 4kg/ton and in other case to 6kg/ton. What will be the effect of a) sulphur partition coefficient and b) powder injection rate on desulphurization modes

   Note a Similar problem is solved in lecture 23.

2) Problem on degassing

(A) In RH degassing, liquid steel is circulated through the vacuum chamber in order to lower the hydrogen content from 6ppm to 3ppm in 15 minutes. Molten steel attains equilibrium with to hydrogen.

Given: $\text{temperature} = 1600°\text{C}$

Molten steel in $\text{ladle} = 60 \text{ tons.}$

Pressure inside vacuum $\text{chamber} = 0.2 \text{ tor r}$

The molten steel analyzes $\text{C} = 0.06\%, \text{Cr} = 6\%, \text{Ti} = 0.5\%, \text{Ni } 2\%$ and rest iron.

Interaction parameter $e_H^C = 0.045, e_H^{Cr} = 0.005$ and $e_H^{Ti} = -0.22$

Calculate rate of circulation of molten steel.

Solution

$$R = \frac{m}{t} \ln \frac{[\text{PPmH}]_1 - [\text{PPmH}]^*}{[\text{PPmH}]_2 - [\text{PPmH}]^*}$$

$$\log f_H = 0.045 \times 0.06 + 0.005 \times 6 - 0.22 \times 0.5$$

$$= 0.0027 + 0.03 - 0.11$$

$$f_H = 0.837\ .$$

$$[\text{PPmH}^*] = k_H \sqrt{pH_2}$$

$$\log k_H = -\frac{1905}{T} + 2.409$$

$$k_H = 24.65$$

$$[\text{PPmH}^*] = \frac{24.65}{f_H} \sqrt{0.2 \times 1.315 \times 10^{-3}}$$

$$= 0.465$$

$$R = \frac{60}{15} \ln \frac{6 - 0.465}{3 - 0.465}$$

$= 3.12 \text{tonnes/min}$ Ans.

(B) Repeat the above calculations when $T = 1650°\text{C}$ and When pressure inside the chamber $= 0.1 \text{Tor r}$

Discuss the results in terms of technology development and requirements (refer lecture 25,26)

3) Problems on deoxidation (Refer lecture 24)

(A) Calculate the time required to float Al_2O_3 deoxidation product through a 2 meters steel bath height from the following data:

Density of liquid steel and $Al_2O_3 = 7 \times 10^3$ and $4 \times 10^3 \mathrm{kg/m^3}$ viscosity of liquid steel $= 6 \times 10^{-3}\ \mathrm{kg\ m^{-1} s^{-1}}$

Size of deoxidation product = 10micron 50 micron and 100 micron

Repeat the calculation when de oxidation product is silica and its density is $2.3 \times 10^3\ \mathrm{kg/m^3}$

Interpret the result and get a feel about the importance of size of de oxidation products on velocity.

(B) Aluminum, titanium and zirconium are the strongest deoxidizers compared with manganese. Deoxidation with either aluminium or zirconium or titanium shows a minimum solubility of oxygen in steel. Determine the expression to calculate the value of Al in weight percent at minimum oxygen content in Fe-Al-O system

Given: $\mathrm{log f_{Al}} = \mathrm{e_{Al}^{Al} W_{Al}} + \mathrm{e_{Al}^{O} W_{O}}$ and $\mathrm{log f_{O}} = \mathrm{e_{O}^{Al} W_{Al}} + \mathrm{e_{O}^{O} W_{O}}$

Let us consider the following reaction;

$$\mathrm{Al_2O_3(S) = 2[Al] + 3[O]} \qquad 1)$$

Assume activity of alumina, $\mathrm{a_{Al2O3}} = 1$, since it is pure,

$$\mathrm{log K_{Al} = 2 log h_{Al} + 3 log h_{O}} \qquad 2)$$

Substitute $h_{Al} = f_{Al} W_{Al}$ and $h_O = f_O W_O$ and expression for f_{Al} and f_O in equation 2. Differentiate the expression 2 with respect W_{Al} to get

$$\frac{\mathrm{dW_O}}{\mathrm{dW_{Al}}} = -\frac{0.868\frac{1}{\mathrm{W_{Al}}} + 2\mathrm{e_{Al}^{Al}} + 3\mathrm{e_{O}^{Al}}}{1.30\frac{1}{\mathrm{W_o}} + 2\mathrm{e_{Al}^{O}} + 3\mathrm{e_{O}^{O}}}$$

For the minima $\frac{\mathrm{dW_O}}{\mathrm{dW_{Al}}} = \text{zero}$ and $\mathrm{W_{Al}} = \mathrm{W_{Al}^{e}}$ we get

$$\mathrm{W_{Al}^{e}} = \frac{0.434}{\mathrm{e_{Al}^{Al}} + 1.5\mathrm{e_{O}^{Al}}}$$

The readers may substitute the values of the interaction parameters to get a feel of the value of Al and to understand the role of interaction parameters in calculations.

4) Problems on gas stirring (Reference lectures 21,22)

(A) Calculate the recirculation rate of molten steel due to injection of gas in a ladle containing 250 tons of steel for the following conditions:

Gas flow rate: $400 \mathrm{m}^3/\mathrm{s}, 600\mathrm{m}^3/\mathrm{s}$ and $800\mathrm{m}^3/\mathrm{s}$. (Volume is expressed at 1 atmospheric pressure and 273 K). **Bath height**: 3 meter and **temperature** $1200°\mathrm{C}$

Discuss the result in terms of effect of gas rate on recirculation and the benefits accrued.

(B) Calculate stirring energy produced in a bath by injection of gas through the bottom of the vessel for the following conditions:

Argon flow rate: $500\ \mathrm{Nl/min}$ in 100 ton ladle. Bath height is 1.2m. Density of steel is $7000\mathrm{kg/m^3}$. Temperature of steel bath $1600°\mathrm{C}$. Pressure above the surface =1bar. Temperature of argon 25°C.

Stirring power (W)

$$\mathrm{W} = 6.18 \times 10^{-3} \mathrm{Q\,T}\left[\left(1 - \frac{273}{\mathrm{T}}\right) + \ln\frac{\mathrm{P_1}}{\mathrm{P_2}}\right]$$

$$6.18\ 10^{-3} \times 500 \times 1873\left[\left(1 - \frac{273}{1873}\right) - \ln\frac{1.013\times10^5+7000\times981\times1.2}{1.013\times10^5}\right]$$

$$= 5787.6[0.85 + 0.595]$$

$$= 8364\mathrm{W}$$

$= 83.64\mathrm{W/ton}$ of steel

$= 585.48\mathrm{W/m^3}$ of steel melt.

Repeat the above calculations for gas flow rates $400\mathrm{Nl/min}$ and $600\mathrm{Nl/min}$ in a ladle of 150 ton capacity. Bath height is 1.5m. Discuss the results of calculations.

5) Problem on momentum flow rate (reference lecture for the problem is 13)

Calculate the momentum flow rate produced by passing oxygen gas through a lance fitted with four convergent-divergent nozzles in a 300 ton converter. The diameter of each nozzle is 45mm.

Hint: Calculate P_O by equation 6 and use equation 5 to calculate momentum flow rate. Use surrounding pressure 1.013×10^5 N/m^2

The lance distance to start the blow is 3m upto 25% of the blow time which is then decreased to 2m for 25% to 75% of the blow time. Between 75% and upto the end the lance distance id decreased further to 1.5m. Calculate the depth of penetration of gas jet and discuss the nature of blow and the associated physico-chemical reactions as a function of lance distance. Include in your calculation the depth of penetration of gas jet.

Hint Calculate dimensionless momentum flow rate from equation 8 and depth of gas jet penetration from equation9