South Dakota School of Mines and Technology
Department of Materials and Metallurgical Engineering

Met 426/526 Homework 17b

1. In the design of a high-temperature calorimeter employing molten iron at 1600°C the feasibility of using a quartz crucible has been considered. However, the extent of the solution of the crucible into the iron must be ascertained in as much as contamination of the molten iron by silicon cannot be tolerated to an extent greater than 0.5%. To prevent oxidation of the iron melt the calorimeter is filled with purified argon for which $P_{O2} = 10^{-10}$ atm. Calculate the %Si in the iron, resulting from solution of the crucible, under the conditions outlined above.

   $Si_{(l)} + 0_{2(g)} = Si0_{2\ (B\text{-quartz})}$ $\Delta G^o_R = -227{,}700 + 48.70\ T$

   $Si_{(l)}$ in iron; $\gamma^{\circ}_{Si}\ _{1873°K} = 0.00132$* $\log f_{Si} = 0.07\ [\%\ Si]$* MW Si = 28.09

   *Hultgren et al.

2. Compare the effectiveness of the following deoxidation methods for 100 ton steel at 1600°C, containing, initially 0.3% C and 0.006% 0.
   (a) Adding 1000 lb. of ferrosilicon (80% Si).
   (b)Vacuum degassing at 50 mm. Hg pressure.

   $\underline{C} + \underline{0} = C0_{(g)}$ $K_{1600} = 500$

   $Si + 20 = Si02_{(c)}$ $K_{1600} = 3.5 \times 10^4$

   Activities of <u>Si</u>, <u>0</u>, and <u>C</u> in wt% (f_C, f_O, f_{Si} all unity).

3. One hundred tons of steel at 1550°C is to be treated to remove oxygen. The oxygen content goes from 0.008 to 0.002. The carbon content is 0.3 percent. Try the following treatment.
   (a) Vacuum treatment. Effective pressure 500 microns. Cost of treatment $30 per ton.
   (b) Argon flushing. Cost of argon 30 cents per cubic foot. Cost of treatment $3.00 per ton.
   Which is the most economical method and can the desired result be obtained by either method?

4. A rimming steel, poured at 1600°C, contains 0.1% carbon, 0.017% oxygen, and an unknown quantity of hydrogen. The steel starts to solidify at 1500°C and to evolve a gaseous mixture of C0 and H_2 at 1 ATM. total pressure.
   (a) The composition of the gas evolved
   (b) The % Hn in the steel when poured.

   $\underline{C} + \underline{0} = CO_{(g)}$ $K_{1500\ C} = 438$

   $0.5\ H_{2(g)} = \underline{H}$ $K_{1500\ C} = 24$

Where the concentration of the dissolved carbon and oxygen is expressed in wt.%, the hydrogen in parts per million, and the concentration of the $C0_{(g)}$ and $H_{2}(g)$ is expressed in atmospheres.

5. Determine $\Delta G°$ at 1600°C for the

   $Si + O_2 = SiO_2$

   For the following combinations of standard states:

Combination	Si	O_2	SiO_2
1	pure l	1 atm	pure l
2	"	"	pure s
3	"	1 torr	pure l
4	"	"	pure s
5	1wt %	1 atm	pure l
6	"	"	pure s
7	"	1 torr	pure l
8	"	"	pure s

   $Si_{(l)} + 0_{2(g)} = Si0_{2\ (B\text{-quartz})}$ $\Delta G^{o}_{R} = -218{,}600 + 47.40\,T$

   $Si_{(l)}$ in iron; $\gamma^{o}_{Si\ \ 1873°K} = 0.00132$* $\log f_{Si} = 0.07\,[\%\,Si]$*   MW Si = 28.09   * Hultgren et al.

6. A steel melt contains 0.4 wt% C at 1600°C.
   (a). Estimate the wt% O dissolved in it
   (b) What is the maximum wt% Mn that could exist in the above steel melt?

7. Find the final wt% 0 remaining in a steel melt produced in an acid open hearth furnace lined with $Si0_2$ after the below treatments. The activity of the Fe0 in the slag before its removal from the melt was 0.5 relative to pure liquid Fe0. T = 1600°C.
   (a) Addition of 10 pounds of ferrosilicon per ton of steel. The ferrosilicon is 80 wt%Si.
   (b) vacuum degassing at a pressure of 10^{-3} atm.
   (c) sparging with 10 cubic feet of argon at STP per ton of steel.

8. A mass balance on the blast furnace shows that if all the sulphur entering the blast furnace in the burden and fuel became dissolved in the hot metal that the hot metal would contain 1.0 wt% S. If the temperature of the blast furnace hearth is 1500°C, how much sulphur would be expected in the hot metal if
   (a) 500 pounds of slag are produced per 2000 pounds of hot metal, and the slag's composition is 5wt% $A1_20_3$, 40 wt% $Si0_2$, and 55wt% Ca0 and Mg0. Assume equilibrium.
   (b) Approximately what %S in the hot metal would be expected under actural non-equilibrium conditions?

9. Compare the effectiveness of the following deoxidation methods for 100 ton steel at 1600°C, containing, initially 0.3% C and 0.008% 0.
   (a) Adding 1000 lb. of ferrosilicon (80% Si).
   (b) Vacuum degassing at 50 mm. Hg pressure.
   (c) Flushing with argon - total volume 100 ft^3

   $\underline{C} + \underline{0} = C0_{(g)}$ $K_{1600} = 500$
   $\underline{Si} + 2\underline{0} = Si0_{2(c)}$ $K_{1600} = 3.5 \times 10^4$
   Activities of Si, 0, and C, in %, fc, fo, fSi all unity.

10. The Dortmund Horder degassing process employs a degassing vesseland action as shown in the diagram.
   (a) If the vessel holds 1/5 of the total quantity of steel, develop an equation relating the lowering of the hydrogen content to the number of times the vessel is raised and lowered. Assume that the steel in the vessel reaches equilibrium with the vacuum and that it is perfectly mixed with the remainder each time the vessel is raised.
   (b) For the following gas contents:
   Initial %H = 6×10^{-4}
   Final % H = 1×10^{-4}

   and for a vessel holding 1/5 the total steel quantity estimate the minimum number of times the vessel must be raised. Solubility of hydrogen in steel at 1600°C = 27 parts per million. Available vacuum 100 microns.

11. Determine by calculation the maximum wt % 0 possible in steel at 1600°C containing
   a) no carbon
   b) 0.20 wt % carbon

12. A steel heat at 1600°C is in equilibrium with a slag containing SiO_2 with an activity of 0.2, relative to pure solid silica. How much Si is in the steel if the steel contains 0.2 wt % $\underline{C}$ and is in equilibrium with C0 gas at1 atm.

13. A steel heat at 1600°C contains 0.1 wt % $\underline{0}$ and 0.05 wt % $\underline{Si}$. What will the final wt % Si be if 10 lbs FeSi (80% Si) are added per ton?

14. How much argon per ton would be required to deoxidize a steel heat by sparging containing 0.2 wt % C to the same oxygen content achieved by vacuum degassing at 0.001 atm? The initial heat is in equilibrium with CO gas at 1 atm.

15. A 100-ton heat of steel at 1873°K containing 0.20 wt % $\underline{C}$ is in equilibrium with $C0_{(g)}$ at 1 atm. What is the wt % $\underline{0}$ dissolved in the steel?

16. How many pounds of ferrosilicon (50 wt % Si) are required to remove 80% of the oxygen in 100 tons of steel containing 0.01 wt % $\underline{0}$ at 1873°K?

17. How many cubic feet of argon would be required to remove 90% of the hydrogen in steel containing 0.0008 wt % $\underline{H}$ at 1873°K?

18. A basic open hearth furnace with a pure, solid Mn0 hearth is charged with hot metal containing 0.2 wt % $\underline{Mn}$. No scrap is added to the furnace. After the refining period, the steel contains 0.10 wt % $\underline{Mn}$ and the activity of $Si0_2$ in the slag is 0.1 relative to pure, solid $Si0_2$. What is the final wt % $\underline{Si}$?

19. A 100-ton heat of steel at 1873°K containing 0.005 wt % $\underline{0}$ and 0.20 wt % C is to be deoxidized to 0.001 wt % $\underline{0}$.
    (a) Can this level be achieved by vacuum degassing at 0.01 atm?
    (b) How many pounds of ferrosilicon (50 wt % Si) are required to achieve this oxygen concentration?
    (c) How many cubic feet of argon at 298°K and 1 atm would be needed to achieve this concentration?

20. What is the Si distribution in the BF at 1500 °C if the slag contains 45 % CaO, 10 % Al_2O_3, 10 % MgO, 35 % SiO_2.

21. Calculate the activity, relative to pure liquid, of FeO in the blast furnace at 1550 °C. What wt % FeO does this correspond to if the slag basicity, V, is 1.5?

22. Redraw Figure 2.90 in the text using a coordinate of Log {[%Mn]/(%Mn)} and comment on the relative change in the Mn distribution with T.

23. What does Figure 2.89 reveal concerning the relative stability of Mn silicates vs MnO-CaO compounds?

24. A BF slag contains 50 % CaO and MgO, 10 % Al_2O_3, 1 % MnO, and 40% SiO_2. What [%Mn] is expected in the 1500 °C hot metal containing [%Si] of 0.2?

25. Estimate the (%S) in a BF slag at 1600 °C with a basicity (B) of 1.0 if the hot metal is running 0.04% S.

26. In essentially all slag-metal pseudo-equilibrium constants a conversion has been made to convert a slag component's mole fraction to its weight fraction. This would require knowing the moles of slag per unit weight of slag. A typical BOF slag contains 50 % CaO, 25% SiO_2, 16% FeO, 6% MnO, and 3% MgO. Compute the gram moles in 100 grams of this slag. How does your result compare to the number of gram moles are typically assumed in the steelmaking industry? (See text.)

27. Layout the computations and assumptions needed to find [ppm O]/(% FeO) from thermodynamic data and an Fe-O phase diagram (or data for the solubility of O in Fe vs T: see p 684 in Hansen, ***Constitution of Binary Alloys*** , McGraw Hill Book Co, New York, 1958. (Ref section Devereaux Library)

28. What would be the expected partition ratio, [%Mn]/(%Mn), in a steelmaking operation at 1600 °C if the slag composition is 50 % CaO, 25% SiO_2, 16% FeO, 6% MnO, and 3% MgO. What is the expected [%Mn]?

29. What would be the expected partition ratio, [%Cr]/(%Cr), in a steelmaking operation at 1600 °C if the slag composition is 50 % CaO, 25% SiO_2, 16% FeO, 6% MnO, and 3% MgO.

30. What would be the expected partition ratio, [%P]/(%P), in a steelmaking operation at 1600 °C if the slag composition is 50 % CaO, 25% SiO_2, 16% FeO, 6% MnO, and 3% MgO if a 1040 steel is produced.

31. One hundred tons of steel at 1600 °C containing 0.04% S are to be desulfurized by the addition of 75 lbs Al of which 1/3 reacts with dissolved O leaving 2/3 in solution. What slag weight is needed to reduce the final % S to 0.001 %? The slag composition is 56% CaO, 4% SiO_2, and 40% Al_2O_3.

32. A steel heat at 1600 °C containing 0.6% Mn and 0.02% Si is deoxidized by adding 2 lbs of FeSi (80% Si) per ton.
    a) What is the final expected [%O]?
    b) What is the final expected [%O] if so much Si, say 0.5%, were addedso as to saturate the system with silica?

33. A steel melt at 1600 °C containing 0.2 % Si is to be continuously cast. What is the maximum [%Al] that could be tolerated in the melt without risking nozzle plugging via $3MnO \bullet Al_2O_3 \bullet 3SiO_2$

34. Describe how a Cr/Cr_2O_3 oxygen potential probe is constructed and operates.

35. What happens to Si and Ti oxides in steel slag with the addition of Al?

36. A 200 ton Al-deoxidized steel melt covered with 10 tons of slag, contains 0.04 % Al. What fraction of total
    a) Si
    b) Ti

    is in the slag? Assume the slag is a lime saturated calcium aluminate melt containing very low silica (<5 %).