ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2017 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

**14-MT-A3 Metal Extraction Processes (Procédés d'extraction des métaux)**

The exam is three pages long, including this page. Count and confirm before starting.

***Unless otherwise stated:***

- ***A tonne refers to a metric tonne;***
- ***$ refers to a Canadian dollar;***
- ***Concentrations are on a weight by weight (w/w) basis.***

Use the following molar weights (g/mol) :

| | | |
|---|---|---|
| • Aluminum : 27<br>• Nitrogen : 14<br>• Carbon : 12<br>• Chlorine : 35<br>• Copper 63.5 | • Iron : 55.8<br>• Lithium : 6.9<br>• Nickel : 58.7<br>• Niobium : 92.9<br>• Oxygen : 16 | • Lead: 207.2<br>• Silicon : 28.1<br>• Sodium : 23<br>• Sulphur : 32<br>• Zinc : 65.4 |

| | |
|---|---|
| **Units of length**<br>1 inch = 2.54 centimeters (cm)<br>1 foot = 12 inches<br>1 yard = 3 feet = 36 inches<br>1 m = 100 cm = 1 000 000 microns (μm) | **Units of weight**<br>1 kg = 2.204 lbs<br>1 short ton = 2000 lbs<br>1 pound = 16 ounces<br>1 troy ounce = 31.105 g |
| **Units of volume**<br>1 $m^3$ = 1000 litres = 1 000 000 $cm^3$<br>1 gallon (US) = 0.1336 $ft^3$<br>USGPM : US gallons per minute | **Units of temperature**<br>°C = °K - 273 = (°F-32)·5/9<br>**Units of concentration**<br>ppm = parts per million = grams per tonne (g/t) |

| | |
|---|---|
| **Other information :**<br>Scrap iron melting point : 1536°C;<br>Cp Solid scrap iron: 0.4 joule/g-°C<br>Cp Liquid iron: 0.8 joule/g-°C<br>Chaleur fusion : 13 800 joules/kg at 1536°C | Faraday's number : 96 500 coulombs/mole<br>R = 0,08206 $L•atm•K^{-1}•mol^{-1}$<br>1 mole of perfect gas at 0°C, 1atm = 22,4L |

**Question #1 (25 points): Keep answers short**

a) Which variable cost, besides alumina, is critical in aluminum production (2.5 pts) ?
b) Name **two** of the mineral properties commonly used to concentrate iron ore (2.5 pts) ?
c) Name the saleable by-product of equal or superior mass to copper resulting from the conversion of chalcopyrite ($CuFeS_2$) to unrefined copper (2.5pts)?
d) Name **two** of the roles of natural gas in the Midrex process (2.5 pts)?
e) What are the **three** components required for acid mine drainage to occur (2.5 pts)?
f) What is the difference between direct and inverse flotation (2.5 pts)?
g) Explain the operating principle of a spiral separator (2.5pts)?
h) What happens to noble metals (Au, Ag) during electrometallurgical refining (2.5 pts)?
i) Why are large amounts of silicon sold as ferro-silicon as opposed to pure silicon? (2.5 pts)
j) According to Fred Bond's third theory of comminution, which requires more energy: grinding a particle from 300 µm to 200 µm **or** taking it from 200 µm to 100 µm (2.5 pts)?

**Question #2 (25 points)**

A separating device is used in a grinding circuit, shown in Figure 1, to separate fine particles from the coarse fraction which is sent back to the grinding mill for further grinding. The device is sampled and the samples are separated by size. The results of this analysis are shown in Table 1. The average solids density is 2,7 g/cm$^3$.

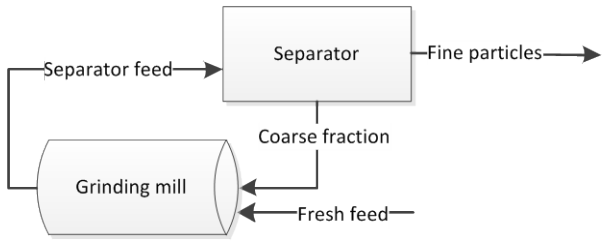


**Figure 1: Flowsheet for question #2**

**Table 1: Size analysis for each stream**

| Size fraction | Separator feed | Coarse | Fine |
|---|---|---|---|
| +212 µm | 59,8% | 68,7% | 11,7% |
| -212/+106 µm | 17,3% | 17,1% | 23,5% |
| -106/+53 µm | 9,1% | 6,6% | 21,5% |
| -53 µm | 13,8% | 7,6% | 43,3% |

a) You are required to:
   1) Calculate recovery (%) to the coarse stream for each size fraction (7 points);
   2) Calculate the solids mass flow (%) to the coarse stream for a separator feed rate of 100 m$^3$/h per hour at 30% solids by weight (7 points). Use the answers in 1). If you do not have answers in 1), use the following recoveries to the coarse fraction:
      - +212 µm: 98%
      - -212/+106 µm: 90%
      - -106/+53 µm: 60%
      - -53 µm : 42%
   3) Estimate the separator bypass fraction of fines to the coarse stream (5 points).

b) A valuable mineral has a higher density than the gangue. If the separator is a hydrocyclone, would valuable particles exit the circuit at a **finer** or **coarser** size? **Explain**. (3 points).
c) Name three factors affecting hydrocyclone cut-size (3 points).

**Question #3 (20 points)**

A zinc concentrate contains 50% Zn and 6% Fe, present as sphalerite (ZnS) and pyrite ($FeS_2$), respectively. The balance of the concentrate is quartz ($SiO_2$). The concentrate is oxidised in a fluidised bed roaster to convert the sulphides to oxides (ZnO and $Fe_2O_3$ only). Calculate:

a) The sphalerite, pyrite and quartz concentrations of the concentrate (5 points).
b) The ZnO, $FeS_2$, $Fe2O_3$ and $SiO_2$ concentration of the calcine, assuming that 100% of the sphalerite is converted to ZnO and 50% of the pyrite is converted to $Fe_2O_3$ while 50% remains as $FeS_2$ (10 points).
c) What is the minimum flow of air (20% $O_2$, 80% $N_2$ by volume) required ($m^3/h$) at 0°C, 1 atm, to roast 100 t/h of this material? Assume that air is an ideal gas mixture. (5 points).

**Question #4 (15 points)**

A rare-earth project intends to leach a concentrate containing 40% rare-earth minerals, 30% calcite ($CaCO_3$) and 30% ankerite ($CaFe(CO_3)_2$).

a) Explain one advantage and one disadvantage of using sulphuric acid ($H_2SO_4$) as opposed to hydrochloric acid (HCl) conduct this operation (5 points).
b) If ten cubic meters ($m^3$) of acidic solution are used to leach every 1 tonne of concentrate, what would be the Fe concentration in solution, in mol/L, given that all the minerals are completely leached? Assume that the solution volume remains the same after the leaching operation (5 points).
c) Explain a possible method to remove Fe from hydrometallurgical solutions such as the one generated above. (5 points).

**Question #5 (15 points)**

An aluminum plant operates 250 cells at an intensity of 250 000 amps through each cell. During a given 31-day month of continuous operation, the measured aluminum production is 14050 tonnes.

a) What is the current efficiency according to Faraday's law (5 points)?
b) Explain why this current efficiency is below 100%? (5 points)
c) Explain what the Boudouard reaction is and how it can impact anode consumption (5 points)