ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2014 SESSION

All documentation allowed
Hand calculators : Authorised models only
Duration of the test : 3 hours

14-MI-A3 Mineral processing

The test consists of 5 pages including this one. Make sure that you have the complete text prior to begin.

Unless it is specified to use another definition:

- ***A ton indicates a metric ton (1000 kg);***
- ***A $ indicates a canadian $;***
- ***Species concentrations are given in % weight (% w/w);***

If required use the data of the following tables:

Molar masses (grams)			
Antimony : 121.8	Iron : 55.8	Gold : 197	Silicon: 28.1
Arsenic : 74.9	Magnesium : 24.3	Oxygen : 16	Silver : 107.9
Carbon : 12	Manganese : 54.9	Lead : 207	Sulphur : 32
Calcium : 40.1			Titanium : 47.9
Copper : 63.5			Zinc : 65.4

Units of length 1 inch = 2.54 cm 1 foot = 12 inches 1 yard = 3 feet 1 m = 100 cm = 1,000,000 microns (μm)	Units of mass 1 kg = 2.204 pounds 1 short ton = 2000 pounds 1 pound = 16 ounces 1 ounce troy = 31.105 g
Units of volume 1 m^3 = 1000 liters 1 US gallon = 0.1336 cubic foot USGPM = US gallon per minute	Unit of temperature °C = K - 273 = (°F-32)·5/9 Unit of power: 1 kW = 0.745 HP
Density of water = 1g/cm^3	

Question 1: Processing of an iron ore (55 points)

1. Iron oxide minerals (5 points)
   a. Hematite and magnetite are the main iron carrier minerals. Give the composition of these minerals and the usual method used for their separation from gangue minerals (1 point).
   b. An iron ore contains 45%Fe_2O_3, 5% Fe_3O_4, 45% quartz (SiO_2), 2% garnet ($(Ca_{0.5}Fe_{0.5})_3(Al_{0.9}Fe_{0.1})_2(SiO_4)_3$) and 3% ilmenite ($FeO.TiO_2$). Calculate the iron (%Fe) and silica contents (%SiO_2) of the ore. (4 points)
2. Iron ore size reduction (25 points)
   a. What is the main difference between autogenous mill and conventional ball milling? (2 points)
   b. A typical iron ore grinding circuit is shown in Figure 1. The ore density is 3.4 g/cm3. The size distributions of samples collected on the main streams during steady state operation of the process are given in Table 1. Using the data of Table 1 calculate:
      i. The slurry % solids by weight of the screen underflow (fines) (4 points);
      ii. The iron content of the screen underflow (Stream #3) (4 points);
      iii. The ore flow rate (t/h) in the circulating load, i.e. stream #4 in Figure 1 (4 points)
      iv. The partition or efficiency curve of the screen, i.e. the proportions of the ore in the size intervals of the screen feed that report to the circulating load (stream #4) (8 points)
      v. The volumetric (m^3/h) flow rate of fines (Stream #3)(3 points).

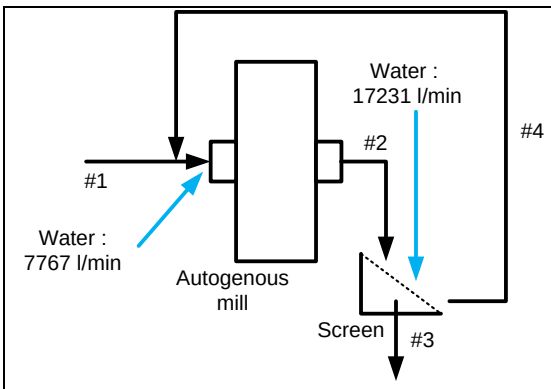

Figure 1. Grinding circuit.

Table 1. Data for the circuit of Figure 1.

	Stream			
	#1	#2	#3	#4
t/h dry	1000			
% w/w solids	100	70		95
% Fe	35,4			27,6
	% weight retained			
	#1	#2	#3	#4
+ 50 mm	55,0	0,0	0,0	0,0
50/25 mm	20,0	0,5	0,0	5,2
25/12 mm	14,0	1,4	0,4	11,9
12/6 mm	5,0	3,4	1,3	24,1
6/3mm	3,0	5,5	2,4	36,2
3/1 mm	2,0	17,7	18,0	14,9
-1 mm	1,0	71,5	77,9	7,7

3. Iron ore concentration (25 points)
   a. When it is possible, the concentration of iron ores is carried out using spirals. Describe the operation of a spiral concentrator and indicate the variables that can be manipulated to control the operation of a spiral (5 points);
   b. The feed to a rougher bank of spirals should not exceed 15% solids by volume. The slurry that comes from the grinding circuit contains 45% solids by weight and is flowing at 2500 m^3/h (see Figure 2). The ore density is 3.4 g/cm^3. Calculate the flow (m^3/h) of dilution water required to have the target slurry density at the rougher spiral feed (5 points).

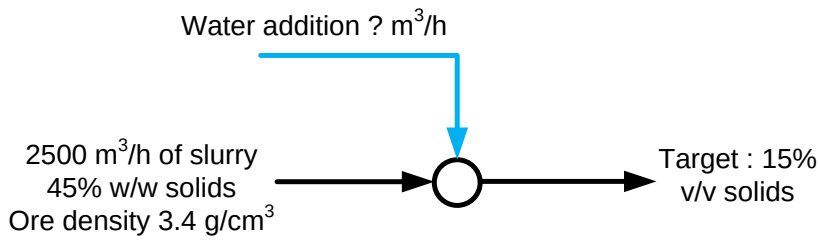

Figure 2. Rougher spiral bank dilution.

c. A spiral concentration circuit is shown in Figure 3 with some Fe and SiO_2 assays. Using the data of Figure 3 calculate:

   i. The iron recovery in the circuit (5 points)
   ii. The iron recovery in the rougher spirals (5 points);
   iii. The ore circulating load (t/h) in stream #8 (see Figure 3) (5 points).

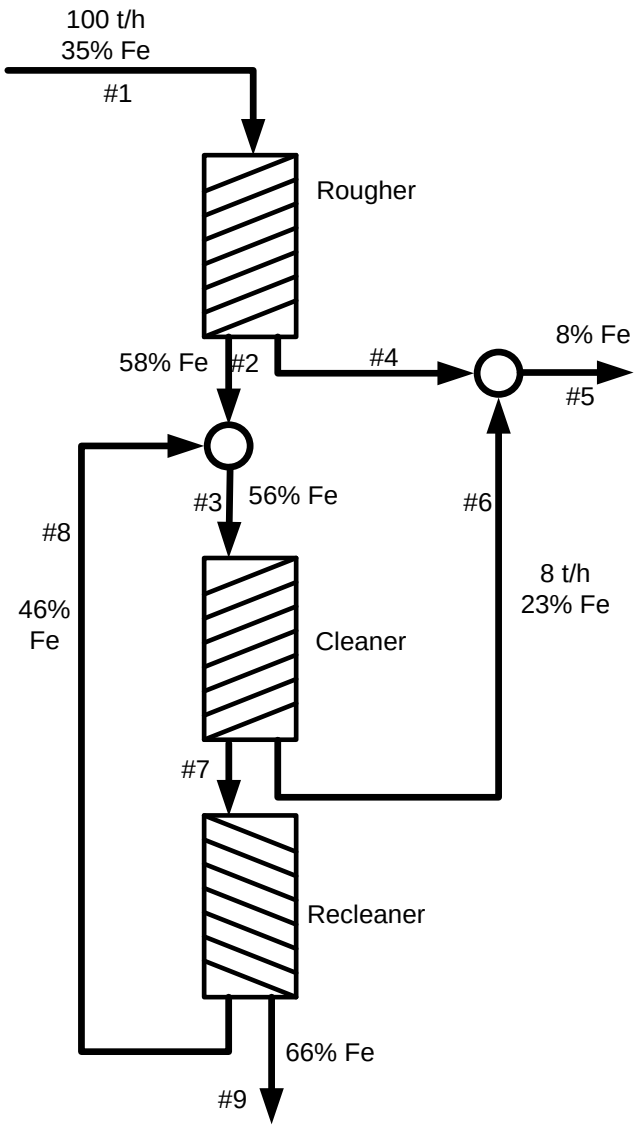

Figure 3. Spiral concentration circuit.

Question 2: Processing of a Cu-Zn ore (45 points)

1. Ore characterization (10 points)
    a. A copper-zinc ore contains 3.2% chalcopyrite and 15.2% sphalerite (ZnS). What is the copper and zinc content of the ore if all the copper is carried by chalcopyrite and all the zinc is carried by sphalerite (5 points)?
    b. A batch of 100 kg of the ore (3.2% chalcopyrite and 15.2% sphalerite) has been prepared by crushing the ore to -1.0 mm. A sample of 10 g is extracted and sent to the assay laboratory to measure the Cu and Zn contents of the ore. An engineer complains about the reproducibility of the assays and suggests pulverizing the ore to -0.053mm before sampling it to obtain the sample to be sent to the laboratory. However it is physically difficult to pulverized 100 kg of ore. Suggest a method to improve the reproducibility of the sampling procedure (5 points).
2. Size reduction of the ore (15 points)
    a. A major disturbance of the grinding circuit operation is the variation of the ore hardness. Suggest a laboratory test that can be conducted on a daily basis to control the ore hardness (2 points).
    b. The size reduction of the Cu-Zn ore is carried out by crushing and grinding in a standard rod-ball mill circuit. There is one rod mill, one ball mill and one nest of hydrocyclones in the circuit. Suggest a flow sheet for the process (3 points).
    c. The power drawn by the motor of the ball mill is 1300 kW. The F_{80} of the ore feeding the ball mill is 0.2mm and the P_{80} of the ball mill discharge is 0.06mm. Calculate the Operational Work Index of the ball mill if the mill slurry feed rate is 150 m^3/h and the slurry density is 1.9 g/cm^3. The ore density is 3.8 g/cm^3 (10 points).
3. Concentration of the copper and zinc minerals (20 points)
    a. The Cu-Zn ore is processed in a flotation circuit that firstly recovers chalcopyrite. The material that is not recovered in the copper flotation circuit is treated in a zinc flotation circuit that recovers the zinc minerals. Explain why this configuration is chosen rather than floating the zinc first followed by a copper flotation, or producing a bulk Cu-Zn concentrate that is subsequently treated to separate the copper and zinc minerals (3 points).
    b. One of the reagents used in the circuit is copper sulfate. Explain where it is used and the utility of the reagent. (2 points)
    c. The results of a semi-batch flotation test conducted with the Cu-Zn ore are given in Table 2. Calculate:
        i. The copper content of the ore (3 points);
        ii. Prepare a graph of the Cu recovery as a function of time (3 points);
        iii. Estimate a value for the rate constant and infinite recovery for the copper minerals. The flotation process is assumed to be a first order process with a non-distributed flotation rate constant and infinite recovery for the copper minerals (2 points).
        iv. Plot the grade recovery curve (as indicated in Figure 4) for the copper minerals (2 points).

Table 2. Cu semi batch flotation tests.

Flotation period		Weight	%Cu in floated
Start	End	floated (g)	materials
0	0,5	25	13,6
0,5	1,5	60	8,2
1,5	3	35	5,3
3	5	25	2,7
5	8	15	1,6
	Reject	340	0,08

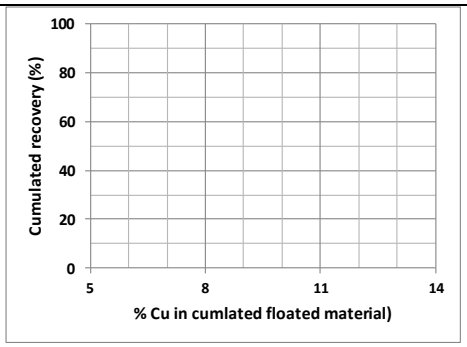

Figure 4. Grade recovery curve.

d. The rate constant for the flotation of the zinc minerals is estimated at 0.52 min^{-1} and the infinite recovery is 97%. How many flotation cells are required to achieve 95% recovery. Suppose that perfect mixing exists in the flotation cells and that the mean residence time in a cell is 2.12 minutes (5 points).