Examination Extractive Metallurgy and Physical Processing – AESB3342

15 April 2016

Time: 9:00 – 12:00

Location:

This examination contains 12 questions.

There is a total of 50 points for the Extractive Metallurgy part of the exam. These 50 points are sub-dived in two parts: 40 points from this written exam and the rest of 10 points is accounted for by the excursion to and guest lectures at Tata Steel in IJmuiden.

There is also a total of 50 point for the Physical Processing part of the exam.

Everywhere, points per (sub)question are indicated.

NB: Please answer the questions of Mr. Yang EM(1-1) to EM(3-1) on separate sheet(s).

NB: Please answer question EM(3-2) (phase diagrams – Mr. Voncken) on a separate sheet(s).

NB: Please answer the questions of Mr. Voncken PP(1-1) to PP (1-5) on a separate sheet(s).

NB: Please answer question of Mr. Chaigneau PP(2-1) on a separate sheet(s

Please write down your answers clearly to assist the reading and evaluatio

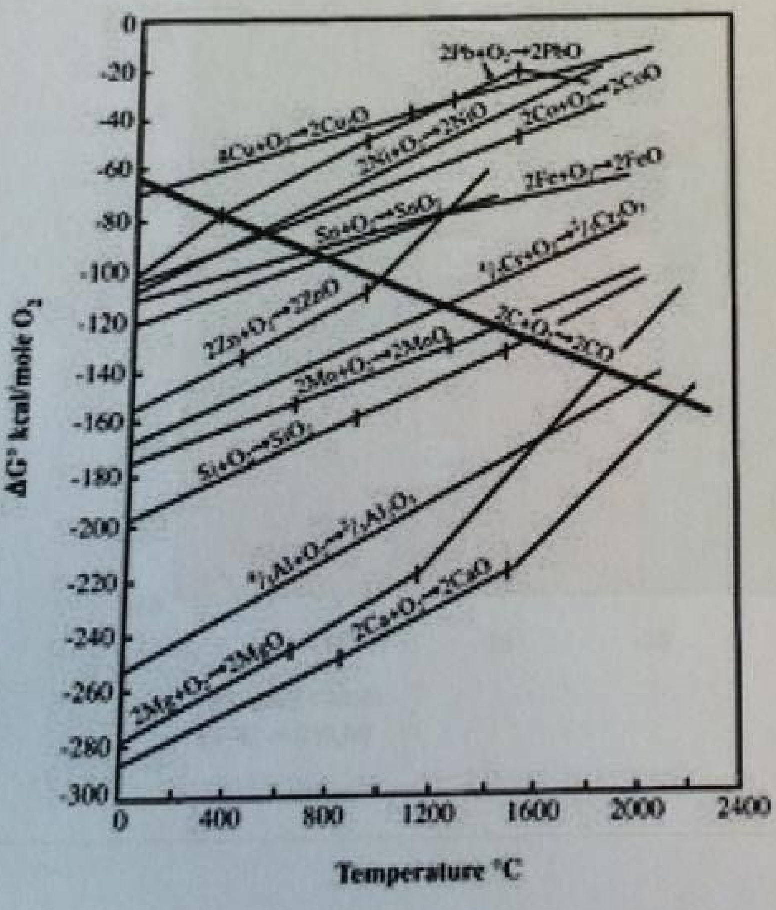
Illegible answers are considered wrong answers!

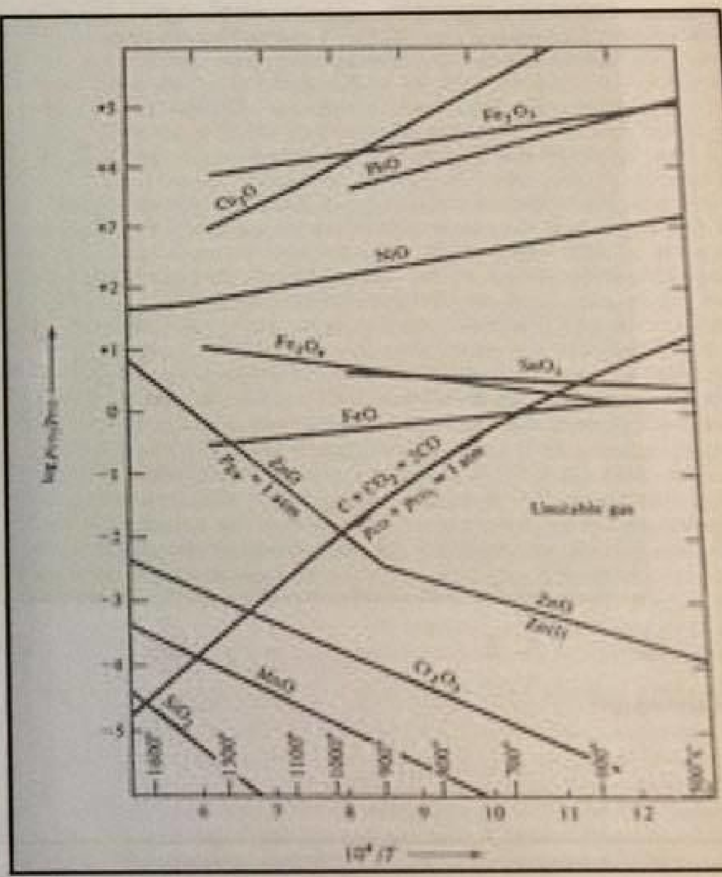
EM1: General questions *(10 points)*

(5 points for each sub-question)

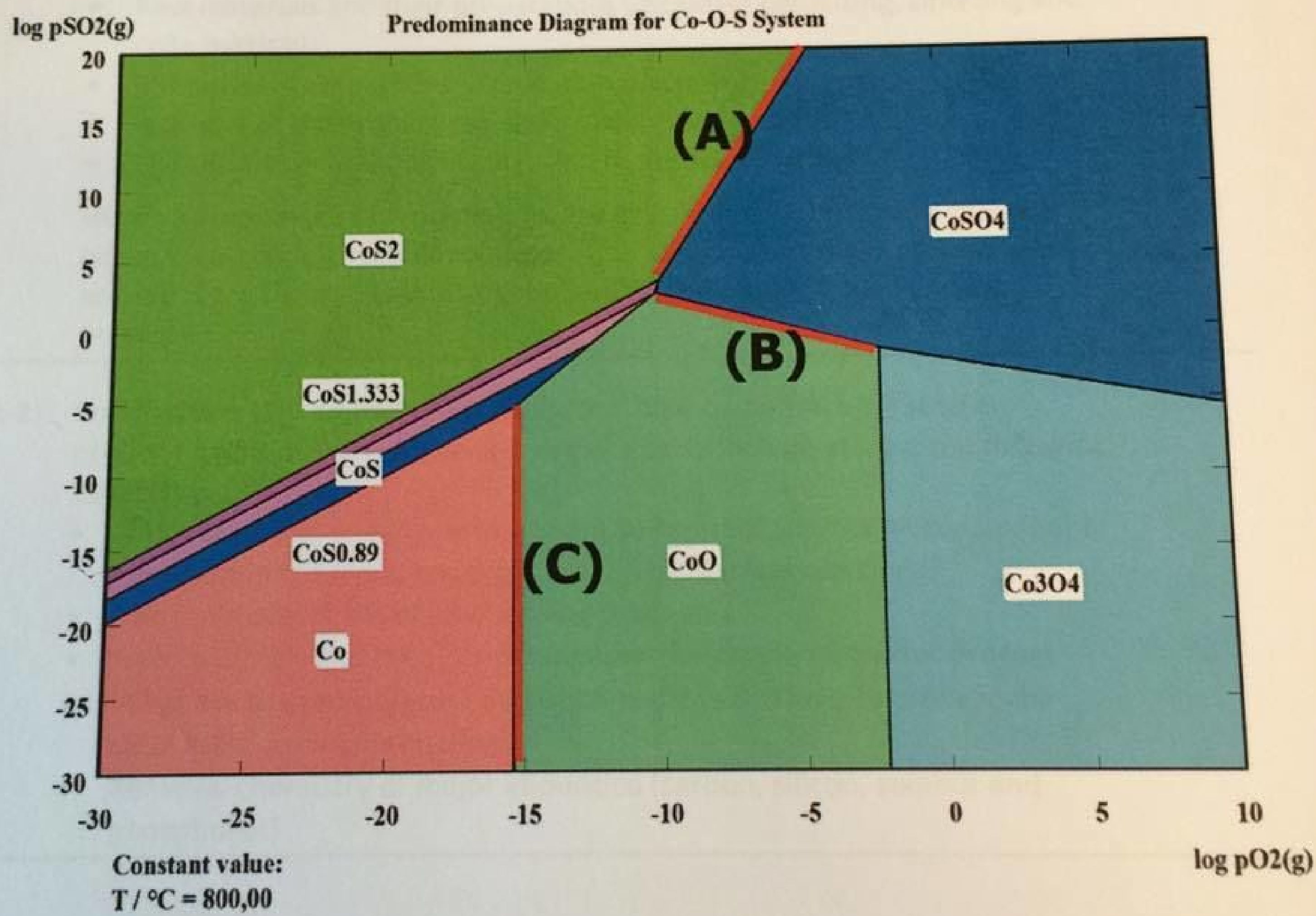
EM (1-1) Please write down the reduction reactions of metal oxides MnO and SiO_2 by using carbon. What role plays the Boudouard in the carbothermic reduction of these metal oxides? Use the Ellingham diagrams below (two forms) to determine the minimum reduction temperature of MnO and SiO_2 and the approximate equilibrium partial pressure ratio of $\log(pCO_2/pCO)$.

N.B.: See also extra sheet.





EM (1-2) What is the Kellogg diagram? Where and how it is used in the evaluation of metallurgical processes. Please write down the chemical reactions along the border lines (A), (B), and (C) shown below:



Kellogg diagram of Co-S-O system at 800°C
(calculated with HSC Chemistry 6.0)

EM2: Metal production processes *(20 points)*

EM (2-1) Ironmaking (7.5 points)

Blast furnace process (5 points): Please describe the working principles of ironmaking blast furnaces. Please include at least the following aspects:

- Raw materials and their preparations (including pelletizing, sintering and coke making)
- Main chemical reactions (all possible reactions)
- Products of the process and their major compositions
- The roles of metallurgical coke, and how coke is made

HIsarna ironmaking (2.5 points): Please describe one of the most promising alternative ironmaking technologies "HIsarna". How does the process work and what are the main advantages over the dominating Blast Furnace process?

EM (2-2) **Steelmaking (7.5 points):** Please describe how crude (carbon) steel is produced with BOF steelmaking process. Please include at least the following aspects:

- Why hot-metal needs pre-treatment to removal Sulphur? How Sulphur is removed in the ladle, and what are main chemical reactions?
- The main objectives of steelmaking processes
- Raw materials and their roles/functions during the converter process
- What are the temperature evolution profiles and how to prevent the steel melt from overheating?
- Removal chemistry of major impurities (carbon, silicon, sulphur and phosphorus)

EM (2-3) **Zinc production (5 points):** Please describe the complete flowsheet of hydrometallurgical zinc production from zinc sulphide concentrates to pure zinc metal. Please explain the metallurgical principles and the main chemical reactions for each main steps (roasting, leaching, solution purification, electrowinning)?

EM 3: Metallurgical thermodynamics *(10 points)*

EM (3-1) Thermodynamic evaluation of copper converting process (5 points)

- What are the objectives of copper converting? *(1 point)*
- Copper converting is carried out at about 1200°C. The standard Gibbs energy change for reactions (1) and (2) are given below.

$$\tfrac{2}{3} Cu_2S_{(l)} + O_2 = \tfrac{2}{3} Cu_2O_{(l)} + \tfrac{2}{3} SO_2 \qquad (1)$$

$$\Delta G^o_{(1)} = -256898 + 81.17T \qquad (J/mole\ O_2)$$

$$\tfrac{2}{3} FeS_{(l)} + O_2 = \tfrac{2}{3} FeO_{(l)} + \tfrac{2}{3} SO_2 \qquad (2)$$

$$\Delta G^o_{(2)} = -303340 + 52.68T \qquad (J/mole\ O_2)$$

$$Cu_2O_{(l)} + FeS_{(l)} = FeO_{(l)} + Cu_2S_{(l)} \qquad (3)$$

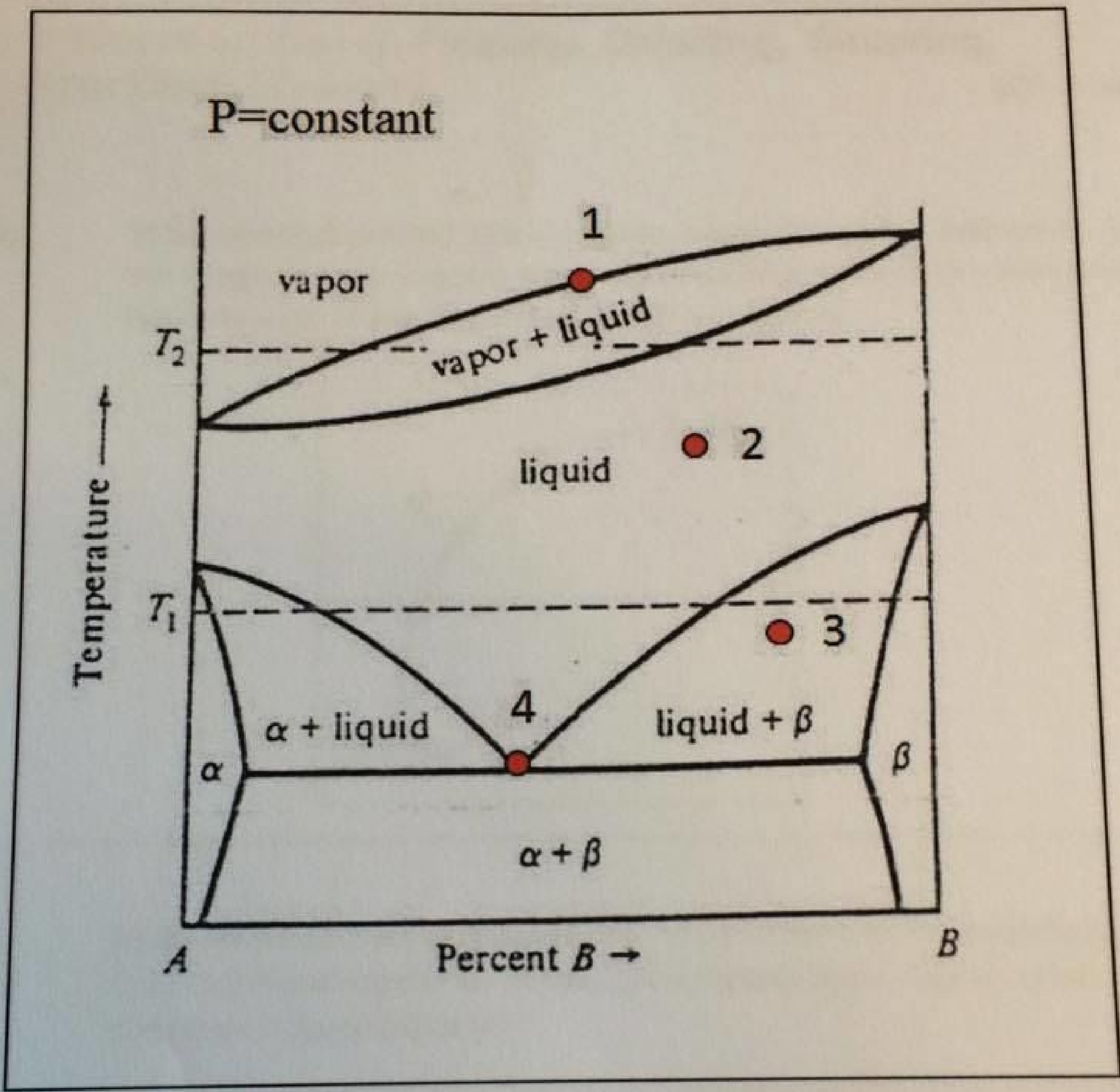
Please derivate the standard Gibbs energy as function of temperature for reaction (3) using reaction (1) and (2). Please explain why any locally formed Cu_2O in the copper matte will be converted back to Cu_2S by FeS if FeS is still available in the matte at about 1200°C (Hint: using the standard Gibbs energy value of reaction (3)). *(4 points)*

EM (3-2) Phase Diagrams (5 points)

Below is given the binary phase diagram for the system A-B. Give for every point (1 – 4) the number of degrees of freedom according to the phase rule, and explain what can be varied, and what cannot be varied.

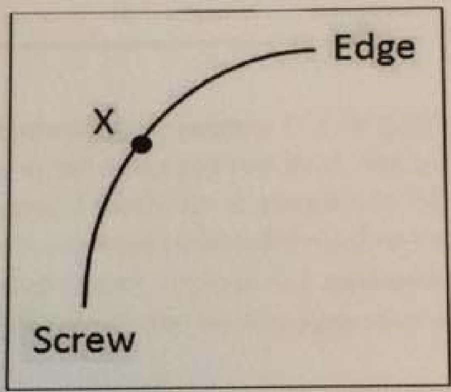
The phase rule for a diagram where P = constant is given as: $F = N + 1 - \pi$

(F = Degrees of freedom. N = Number of components, π = number of phases).

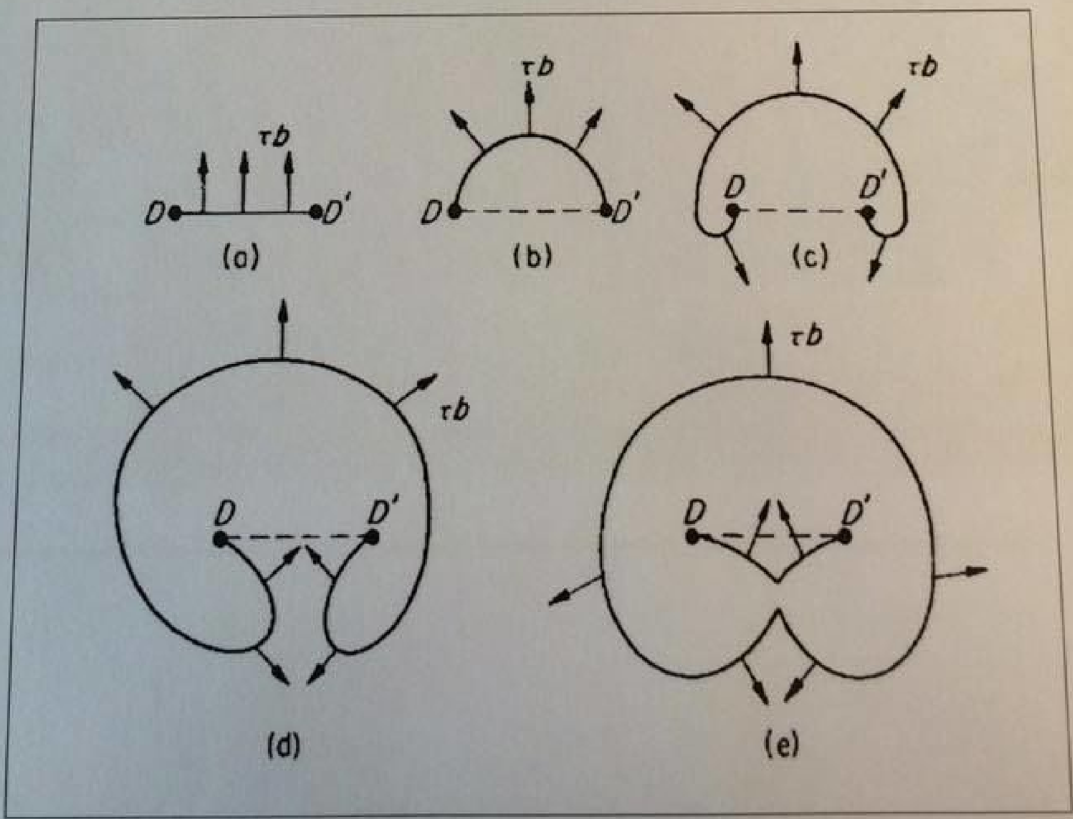

P=constant
1
vapor
vapor + liquid
T_2
liquid
2
Temperature →
T_1
3
4
α + liquid
liquid + β
α
β
α + β
A
Percent B →
B

PP1: Dislocation theory, Factures, Grinding, Sintering, Rare Earth Elements *(25 points)*

PP(1-1) **Dislocations (5 points)** Below is given a part of a ***mixed*** dislocation. Draw the ***Burgersvector*** in point X and at the positions where the dislocation has only edge character, and only screw character.



PP(1-2) **Dislocations (7.5 points)** Below you see a schematic representation of the Frank-Read model for dislocation multiplication. Explain what happens in figure (a) to (e).

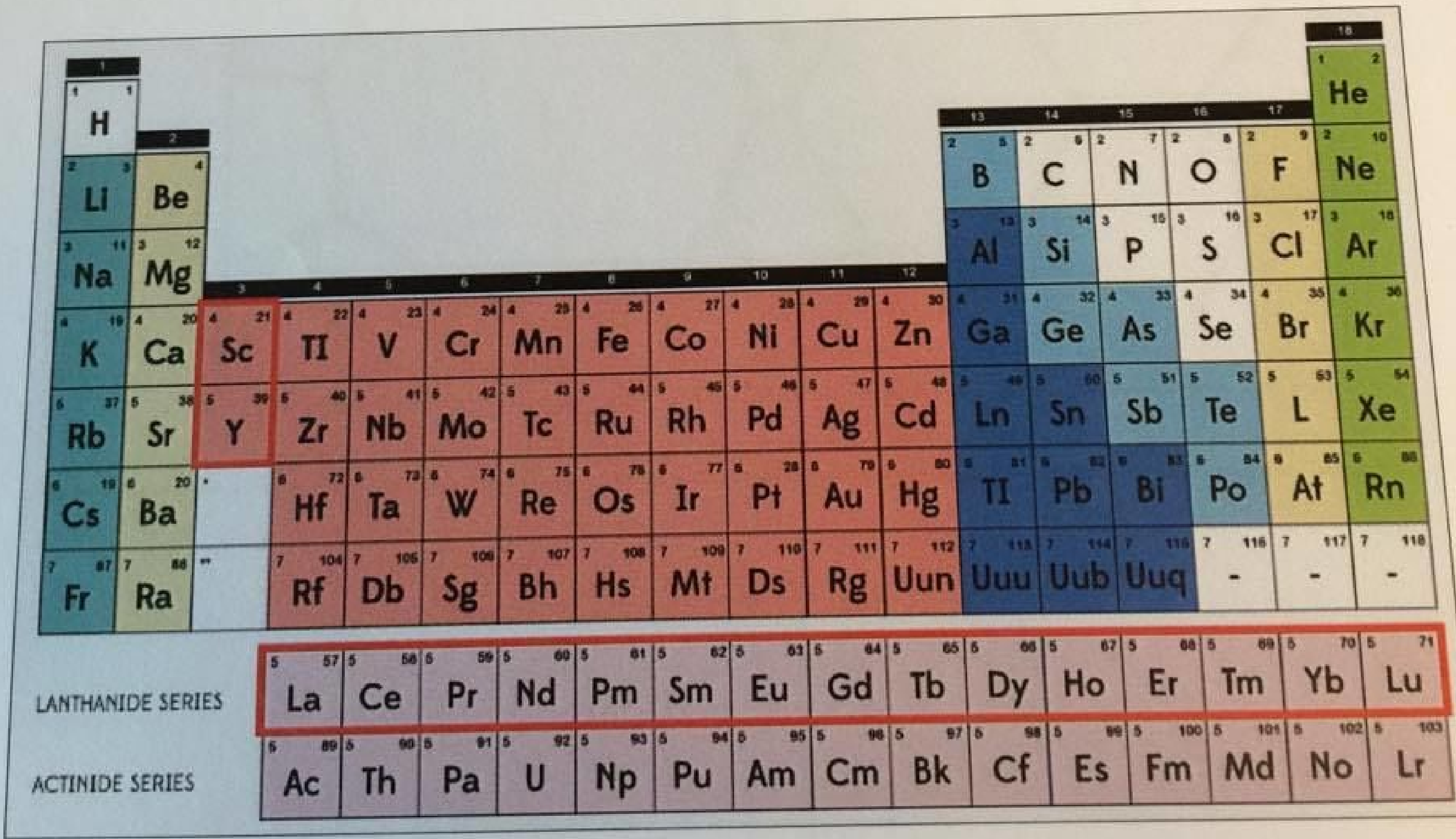


PP(1-3) **Grinding (2.5 points)** During grinding particles will be subject to all three modes of fracture toughness (listed below).

1) Tensile Mode, K_{Ic} ("Extension")
2) Sliding Mode, K_{IIc} ("Scraping/Scouring")
3) Tearing Mode K_{IIIc} ("Tear")

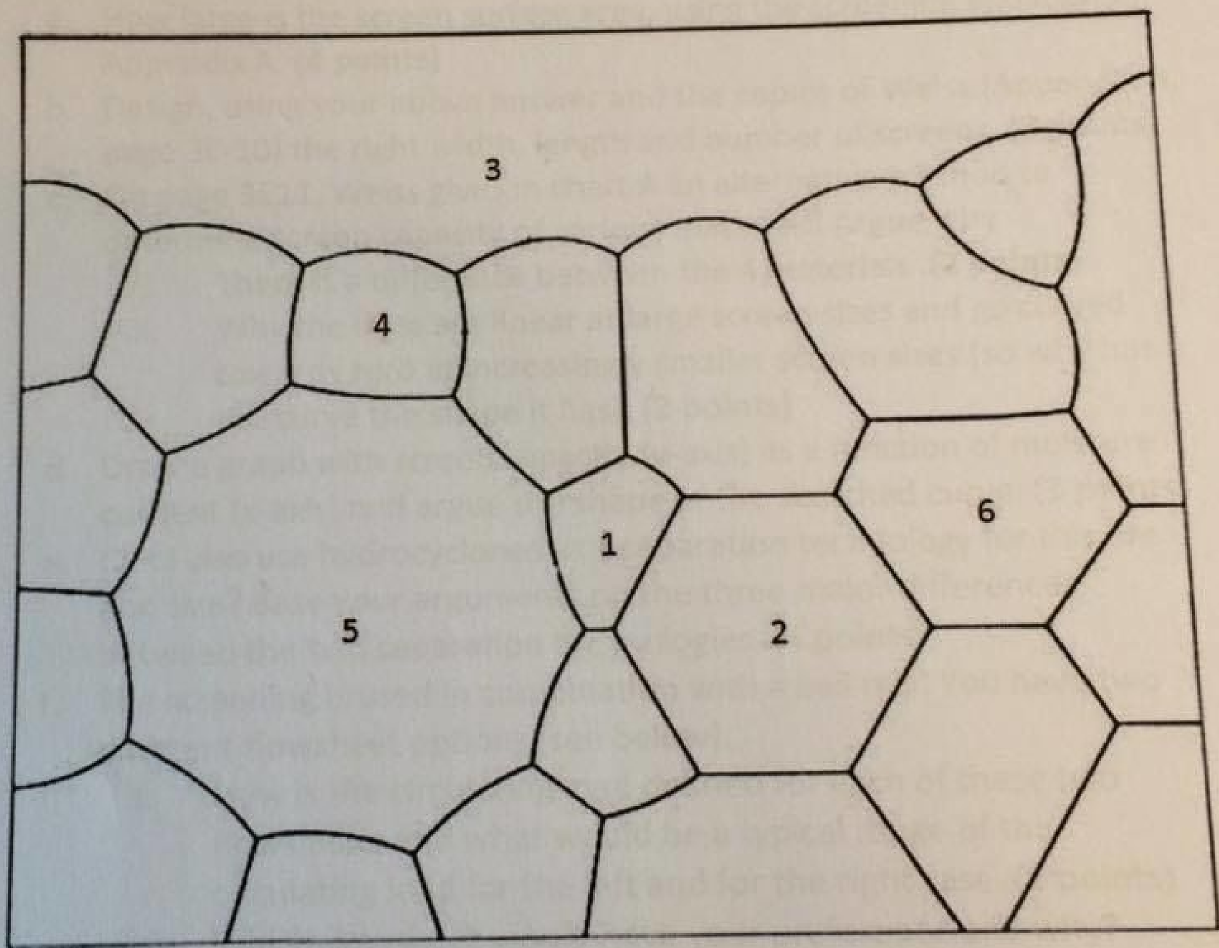
Which mode of fracture toughness do you expect to be dominant in the final stages of grinding? Explain your answer.

PP (1-4) **Rare Earth Elements (2.5 points)** The so-called Rare Earth Elements (REE), shown below in between the red lines, are extracted preferentially by hydrometallurgical methods. It appears to be very complicated to extract pure rare earth elements with chemical methods (it took about 150 years to discover all of them). Explain in a qualitative way why it is so complicated to extract chemically pure rare earth elements.



PP(1-5) **Sintering (7.5 Points)** Below you see a schematic picture of a **partially** sintered grain compact. During further sintering, some grains will grow, others will disappear, and some grains will not change. Indicate for grain 1 – 6 what you think what will happen with that grain, and why.

N.B.: grain 3 is shown only for a small part. It should be considered to continue over a large area above and outside the image.



PP2: Mineral Processing *(25 points)*

PP(2-1) Ore has a density of 2200 kg/m3. It requires sieving at 4 mm at a throughput rate of 500 t/hr. 25% of the material is within the difficult to sieve class (between 0.5*D and 1.5*D)

a. How large is the screen surface area, using the screening equation in Appendix A. **(4 points)**

b. Design, using your above answer and the copies of Weiss (Appendix A, page 3E-10) the right width, length and number of screens. **(3 points)**

c. On page 3E11, Weiss gives in chart A an alternative method to determine screen capacity of various materials. Argue why

   i. There is a difference between the 4 materials **.(2 points)**

   ii. Why the lines are linear at large screen sizes and go curved towards zero at increasingly smaller screen sizes (so why has the curve the shape it has). **(2 points)**

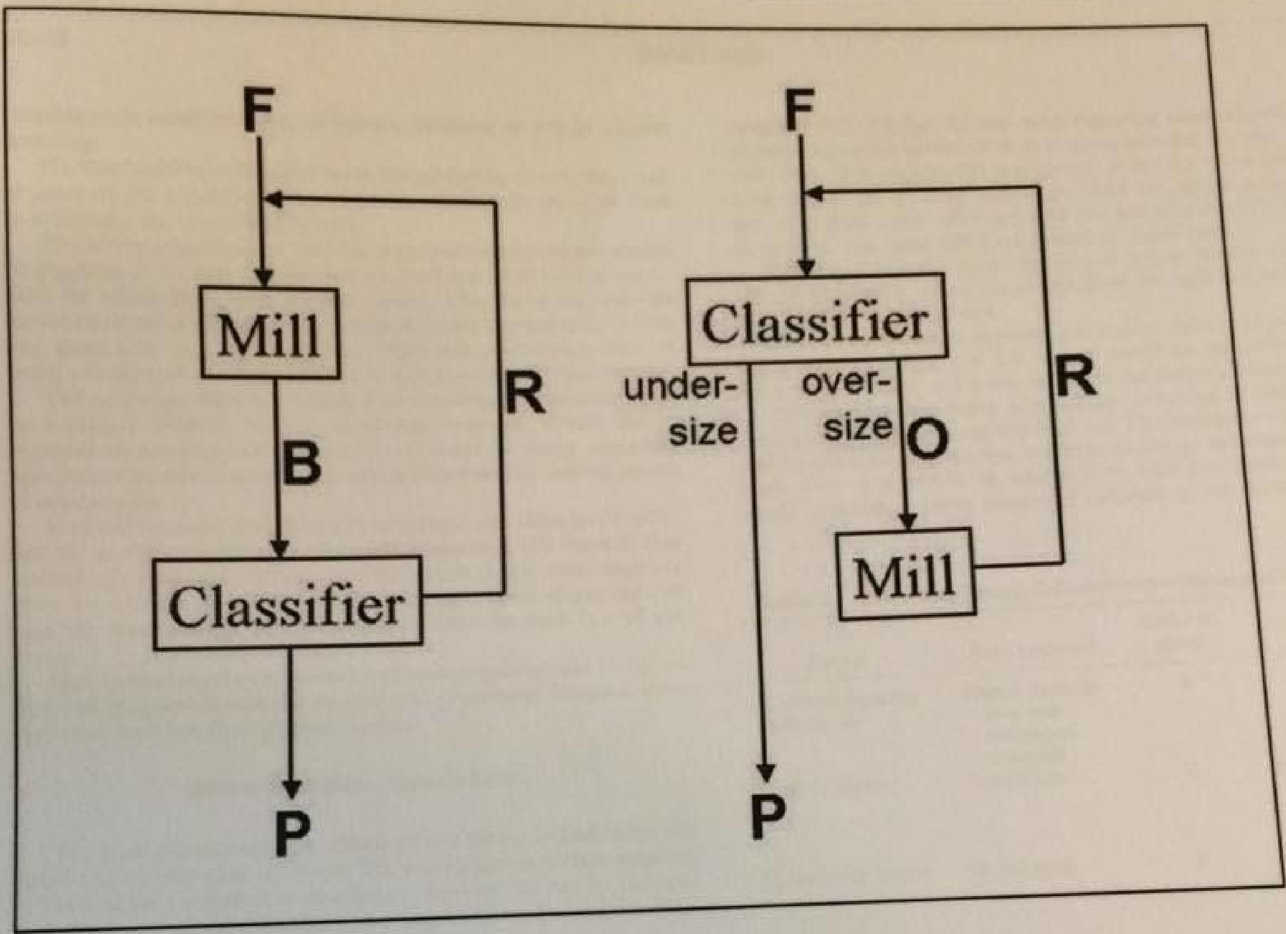
d. Draw a graph with screen capacity (y-axis) as a function of moisture content (x-axis) and argue the shape of the sketched curve. **(3 points)**

e. Can I also use hydrocyclones as a separation technology for this ore and size? Base your arguments on the three major differences between the two separation technologies. **(4 points)**

f. The screening is used in combination with a ball mill. You have two different flowsheet options (see below).

   i. How is the circulating load defined for each of these two flowsheets and what would be a typical range of this circulating load for the left and for the right case. **(4 points)**

   ii. Which flowsheet would have your preference and why? **(3 points)**



Appendix A (for Question 2-1)

$$C = 1.4\frac{\rho}{\gamma}D^{0.6}$$

C= Screen capacity in $t/m^2 \cdot hr$; D = mesh size in mm.
1 foot = 12 inch = 0.3048 m.

SME Mineral processing handbook (Weiss et al.).
See next pages.

contains such small amounts of surface moisture as not to impede screening.

10) Combination—In many cases, the operation may involve two or more of the preceding. If so, attention should be given to each to determine the controlling factors.

The screen manufacturer and his technical representative should be prepared to provide specific data on the types of screening operations for which their units are best suited. They must also provide some indication of the range of product sizes and capacities for which any given unit may be considered. With this preliminary data at hand, the field of available choices is narrowed down considerably.

The next step, then, is to make a screen sizing calculation based on a rational method. Such a calculation, however, should not be regarded as providing an exact solution, since the many constants have been determined empirically and have somewhat limited ranges of applicability.

It should be noted that there are, in current use, three basic methods for capacity calculation: (1) overflow method, (2) through-flow method, (3) total feed method. As their names imply, these methods differ in the flow of material that is used as a basis of calculation; tons per hour passing over, through, or into the feed box of the screen.

Each method has its proponents, and each proponent has his favorite set of empirical factors and variations in procedure. The procedure presented here is a through-flow method.

Screen Selection Calculations

The basic relationship on which screen sizing calculations are based may be expressed as follows: The area of screen surface required is equal to the through-flow tonnage or capacity divided by the corrected unit capacity for the material being handled. In mathematical terms, this may be expressed as follows:

$$A = C_t/C_u \times F$$

where A is area of screen surface in square feet; C_t is through-flow capacity, or tonnage of undersize in the feed to the screen; C_u is unit capacity or basic tons per hour per square foot through the screen, for the size separation and material being handled; F is the product of the various corrective factors.

Table 5 presents a summary and description of these various factors, and provides an index to the tables in which their numerical values may be found.

The typical problem requires entering chart A with the size of separation desired and type of material handled. Moving horizontally across the graph, read out the unit capacity.

For example, assuming sand and gravel at a 2-in. separation, a unit capacity of 4.85 tph per sq ft is obtained. This value of C_v must now be corrected for the various conditions represented by the factors.

Previously, the many variables that affect screening performance were discussed briefly and their interrelatedness noted.

Now, having described the use of a rational screen sizing procedure by which the required screen area may be approximated, it seems appropriate to return to these many variables and illustrate their influence on the final selection of a screen.

It should be noted that for a multi-product screen, it is necessary to calculate the area of each deck separately for the size of separation desired.

Having determined the approximate area that must be provided, the determination of the proper length to width ratio must be resolved. As a general rule, the largest ratio that should be considered is about 2:1. However, 1.5:1 provides a somewhat better ratio.

Within limits, the wider screen delivers a greater capacity at a higher efficiency. It follows then, that the widest units practical should be used for greatest efficiency.

S. A. Stone, vice president-engineering, Deister Concentrator Co., speaking for the clay products industry, recommends a maximum length of 7 to 8 ft for the fine mesh screening encountered there. A corresponding maximum of 5 ft is recommended for the width of such units. It is suggested that a battery of smaller screens be considered as a more effective alternative than the larger screen. There are, of course, other advantages to the use of a battery of screens in parallel, and these will be discussed in detail later.

One down-to-earth guide for proper screen width says that it should be possible to see the screen deck through the bed within 1 to 2 ft of the discharge end.

Assume that the area required was approximately 32 sq ft. Applying a ratio of 2:1, a 4 x 8-ft screen would be indicated; whereas, for a ratio of 1.5:1, a 5 x 8-ft screen is the better choice.

One method of arriving at a rational selection of width involves determining the theoretical depth of bed. The importance of bed depth and its effect on stratification has been discussed previously. The formula $C = 3\ d\ W/20$, in which C = tons per hour per inch of depth, provides a simple means for calculating bed depth or tonnage

Table 5. Screening Sizing Calculations—Through-Flow Method

Factor	Data required	Refer to chart	Comments
C_u screen capacity per sq. ft.	Name, description and weight of material	A	
F_f, fines factor	% half-size	B	Provides comparison of the difficulty of separation
F_o, oversize factor	% oversize	B	Allows for stratification. May use 0.80-in. range 70 to 95% if screen is wide enough
F_e, efficiency	% efficiency desired	B	Scalping efficiency usually taken as 85%. Separation range 80 to 95%
F_d, decks	Number of separations	C	Allows for area lost on lower decks
F_w, wet screening	Size of opening	D	When water/feed ratio is 3 to 5 gpm per cycle per hr, use F_w. If not certain of water use adjusted factor, F_{wa}
F_{oa}, open area	% open area of medium to be used	E	Assume capacity varies directly with the change in open area
F_s, slotted opening	Shape of opening and length/width ratio	F	Assumes long dimension of opening is parallel to material flow and in line with screen motion
40% rule: area equals $\dfrac{\text{Tph (feed)} \times 0.40}{C_u \times F_w \times F_{oa} \times F_s}$	% of feed less than opening size		Use when 40% or less of feed is smaller than openings, or for rescreening where little or nothing is screened out

Adapted from Hewitt-Robins, Inc.

GENERAL CLASSES OF SCREENS

Chart A—Screen capacity per square foot

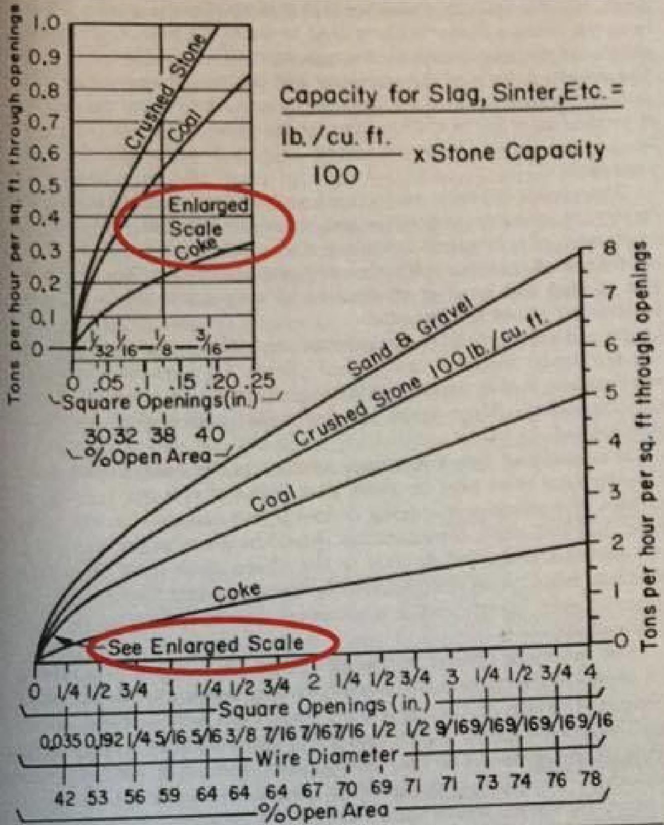


Chart B

%	Factor: Fines, F_f	Oversize, F_o	Efficiency, F_e
0	0.44		
10	0.55	1.05	
20	0.70	1.01	
30	0.80	0.98	
40	1.00	0.95	
50	1.20	0.90	
60	1.40	0.86	
70	1.80	0.80	
80	2.20	0.70	1.75
85	2.50	0.64	1.50
90	3.00	0.55	1.25
95	3.75	0.40	1.00

Chart C

Decks	Deck factor, F_d
Top	1.00
2nd	0.90
3rd	0.75

Chart D

Opening size (square), in.	Wet screening factors: Limiting moisture*	F_w	F_{we}†
1/32 or less	0%	1.25	1.10
1/16	1%	3.00	2.00
1/8	1%	3.50	2.50
3/16	2%	3.50	2.50
5/16	4%	3.00	2.00
3/8	4%	2.50	1.50
1/2	6%	1.75	1.30
3/4	6%	1.35	1.20
1 to 2	6%	1.25	1.10
1-1/2	No limit	1.25	1.10
+2	No limit	1.0	1.0

* When screening dry: If moisture exceeds this limit, must consider special aperture constructions

† Use F_{we} when uncertain about maximum spray water being available, or being used efficiently

Chart E

Open area factor – % Open area = P
For the more common apertures

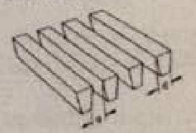
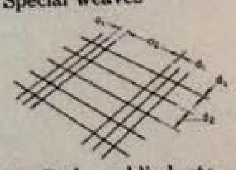
Type of aperture	Formula for % open area, P
Rectangular opening 	P = % Open area; d = diam of wire, or horizontal width of bar (for plate); a = clear opening dimension; $P = \frac{\text{Open area} \times 100}{\text{Total area}} = \frac{100\,(a_1)(a_2)}{(a_1+d_1)(a_2+d_2)}$
Square openings Specified by opening size.	$P = \frac{100\,a^2}{(a+d)^2} = 100\left(\frac{a}{a+d}\right)^2$ $a_1 = a_2 = a$, $d_1 = d_2 = d$
Square openings Specified in mesh (m).	$P = 100\,a^2 m^2$ $m = \frac{1}{a+d}$
Parallel rod decks 	$P = \frac{100\,a}{(a+d)}$
Special weaves  Ty-Rod, nonblind, etc.	Assuming $a_3 = a_1$: $P = 100\left[\frac{a_1(a_2+2a_1)}{(a_2+2a_1+3d_2)(a_1+d_1)}\right]$

Chart F—Slotted opening factor

Typical screen media	Length/width ratio [(a_2/a_1), Chart E]	Slotted opening factor, F_s
Square and slightly rectangular openings	less than 2	1.0
Rectangular openings, Ton-Cap	Equal to or greater than 2, but less than 4	1.1
Slotted openings, Ty-Rod, nonblind	Equal to or greater than 4, but less than 25	1.2
Parallel rod decks	Equal to or greater than 25	1.4