Examination Extractive Metallurgy and Physical Processing AESB3342

July 03, 2015

Time: 9:00 – 12:00 h
Location: CITG - 2.02

- *This examination contains **8 questions in total** (3 for Extract. Metal., and 5 for Physical Processing) counting in total for 90 points: Physical processing 40, extractive metallurgy 50, and the rest of 10 points is accounted for by the excursion to Nyrstar Budel.*
- *Please write down your answers clearly to assist the reading and evaluation.*
  N.B.: Illegible answers are considered wrong answers!
- *Please write the questions for Part I and II on separate sheets, and follow the instructions to write other particular questions on again separate sheets. This is because the answers have to be marked by three different lecturers.*

Part I: Extractive Metallurgy

EM-Q1: General questions *(15 points)*

(3 points for each sub-question)

(1) What are the pyrometallurgical, hydrometallurgial and electro-metallurgical processes? What metals are mainly produced through the above 3 types of metallurgical processes or in the combination of different types of processes (with at least 1 example for each type)?

(2) What is Ellingham diagram? What are the two important parameters in the diagram? How is it used in carbothermic reduction of metal oxides and metal refining processes?

(3) What is the Kellogg diagram? Where and how it is used in the evaluation of metallurgical processes, please give one example

with a sketch of the diagram, indicating the key parameters (along X- and Y-axes) at a fixed temperature.

(4) What are the objectives and the main reactions of roasting zinc sulphide concentrates? What are sintering and pelletising? For Ironmaking, why do we need sinter and pellets in blast furnace process?

(5) What are the principles of electrowinning and electro-refining? Please describe briefly electrochemical reactions on cathode, anode and overall reactions for: electrowinning of zinc; electro-refining of copper; molten salt electrolysis of aluminium.

EM-Q2: Metals production processes *(20 points)*

(1) Ironmaking (5 points):

Please describe the working principles of ironmaking blast furnaces. Please include at least the following aspects:

- Raw materials and their preparation
- Main chemical reactions
- Products of the process and their major compositions
- The roles of metallurgical coke

(2) Steelmaking (5 points):

Please describe how crude (carbon) steel is produced with BOF steelmaking process. Please include at least the following aspects:

- The main objectives of steelmaking processes
- Raw materials and their roles/function, and the main products
- Removal chemistry of major impurities (carbon, silicon, sulphur and phosphorus)

(3) Copper production (5 points):

Copper occurs in majority as sulphide ores in the earth. Please describe the main extraction and refining steps and the main chemical reactions from copper sulphide concentrates to refined copper as final metal product. What is the average Cu content in the concentrates and final purity of copper?

(4) Aluminium production (5 points):

How many steps are needed to produce Al metal from bauxite ore? Please explain the technologies used currently in industry (Bayer process and Hall-Héroult-process with key chemical reactions)? Please explain why we DO NOT use carbothermic reduction to produce Al metal from bauxite ore?

EM-Q3: Metallurgical thermodynamics *(15 points)*

(1) Thermodynamic evaluation of copper converting process (7.5 points)

Copper converting is carried out at about 1200°C in two steps: slag-making and copper-making. Oxidations of FeS and Cu_2S are two major competing reactions (see below). The standard Gibbs energy change for reactions (1) and (2) are given below.

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

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

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

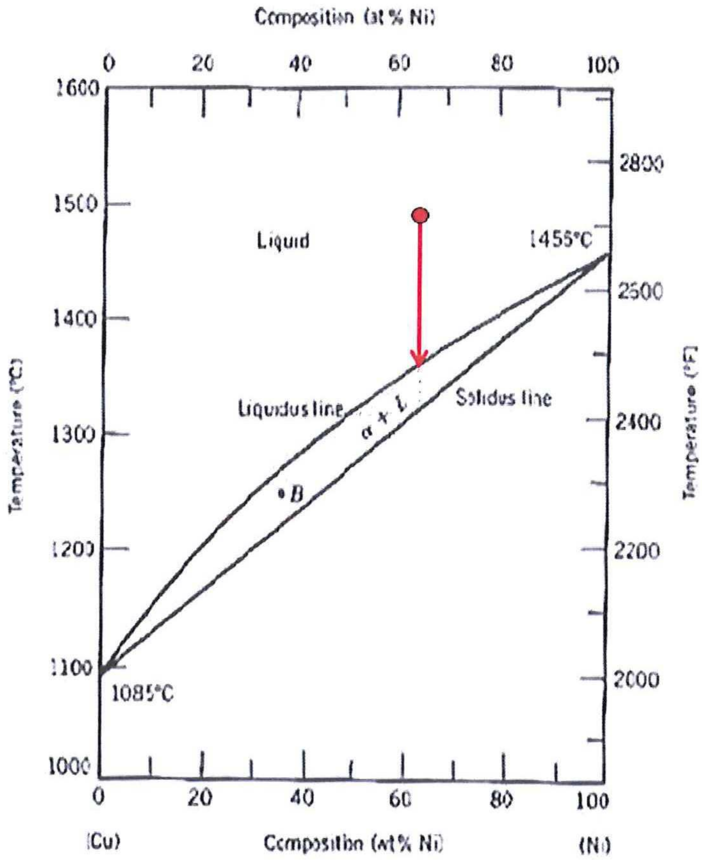
$$\Delta G^o_{(2)} = -303340 + 52.68T \qquad (J/mole\ O_2)$$

a. Please write down the <u>equilibrium constants</u> for both reactions as the function of activity and/or partial pressure of chemical species in the system, and calculate the equilibrium constants for both reactions at 1200°C. *(5 points)*

b. Please use the values from the calculated standard Gibbs energy change to explain the oxidation order of the 2 sulphide compounds (Cu_2S and FeS) in the matte: which oxide is oxidized first, and WHY? *(2.5 points)*

(2) **Phase diagrams** **(7.5 points)**

<u>*Please answer this question on (a) separate sheet(s).*</u>



Above is shown the phase diagram of the binary system Cu - Ni. A certain liquid composition (given by the red dot), starts cooling, and the liquid composition reaches the liquidus. The liquid starts crystallising.

Answer the following questions:

a) Draw on a separate sheet (provided) the crystallization path of the liquid. **(5 points)**

b) What is the composition of the final liquid that will crystallise? **(1.5 points)**

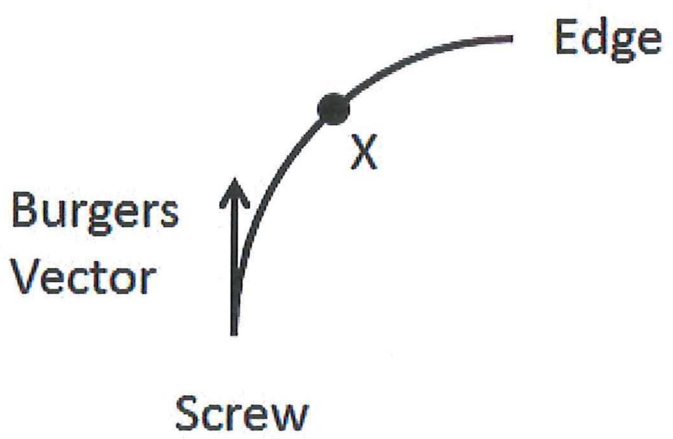
c) What is the exact name of this kind of phase relationship between Cu and Ni? **(1 point)**

Part II: Physical Processing

Please answer this part of the exam on separate sheets

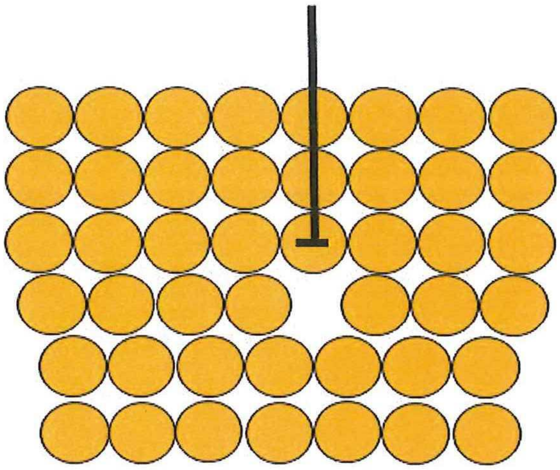
PP-Q1: Physical Processing – Plastic Deformation (5 points).

Consider the curved dislocation of ***mixed type*** drawn below. Indicate in ***point X*** the position of the Burgers vector, and explain your answer. (Redraw the image on your answer-sheet).



PP-Q2: Physical Processing – Plastic Deformation (Total 5 points).

Below you see a schematic picture of an Edge Dislocation. De ***dislocation line*** is situated ***perpendicular to the plain of the drawing.***



Suppose the dislocation would climb out of its slip plane.

a) What process has to take place for this to happen? **(1.5 points)**

b) What physical quantity (Dutch: fysische grootheid) is of fundamental importance for this process to take place, and is controlling the rate of this process? Explain your answer. **(3.5 points)**

PP-03: Physical Processing – Comminution (2.5 points)

When heterogeneous material is ground, one may expect with respect to the grain sizes that each of the different minerals in the mixed and comminuted material will have its own grain size distribution. Explain this using the Hall-Petch Law.

You may assume that none of the minerals has cleavage.

Hall-Petch Law:

$$\sigma = \sigma_0 + \frac{K_y}{\sqrt{d}}$$

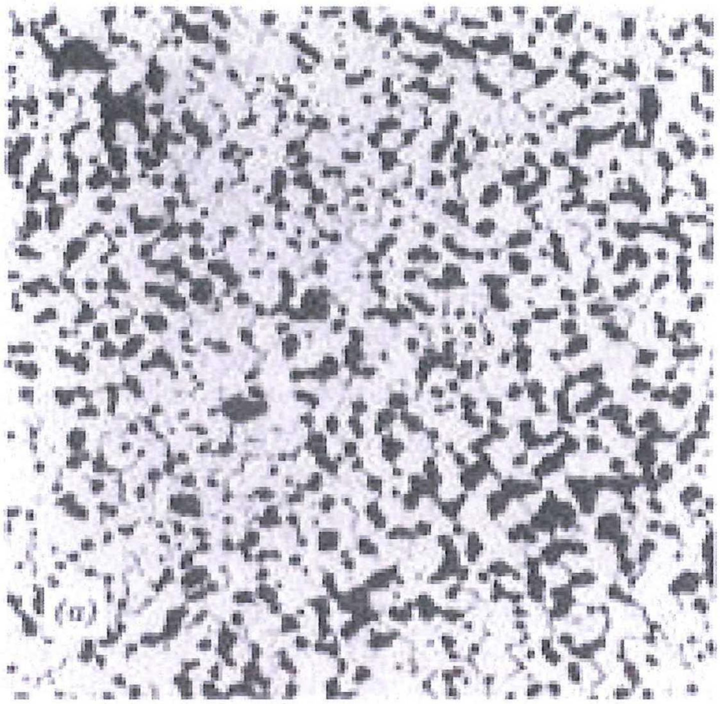
Here: σ_0 *and* K_y = constant, d = (average) grain diameter.

PP-04: Physical Processing - Sintering (7.5 points)

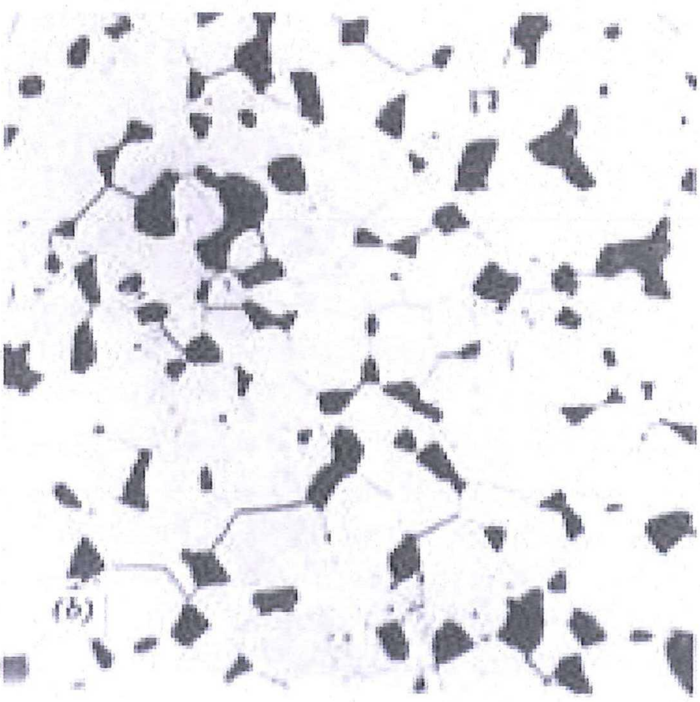
Consider the sintered compact depicted below. The upper picture shows the compact after 2 minutes of sintering, the lower picture (same magnification !!) after 5 hours.

The number of pores (black areas) has significantly decreased after 5 hours, but the size of individual pores is considerably larger. This is called pore coarsening.

Explain the mechanism for pore coarsening. Use sketch drawings to illustrate the process.



Compact after 2 minutes of sintering.



Compact after 5 hours of sintering.

PP-Q5: Physical Processing – Separation and Screening (Total 20 Points)

Please answer this question on (a) separate sheet(s).

Ore has a density of 2200 kg/m^3. It requires sieving at 3 mm at a throughput rate of 600 t/hr. 20% of the material is within the difficult to sieve class (between 1.5 mm and 4.5 mm).

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

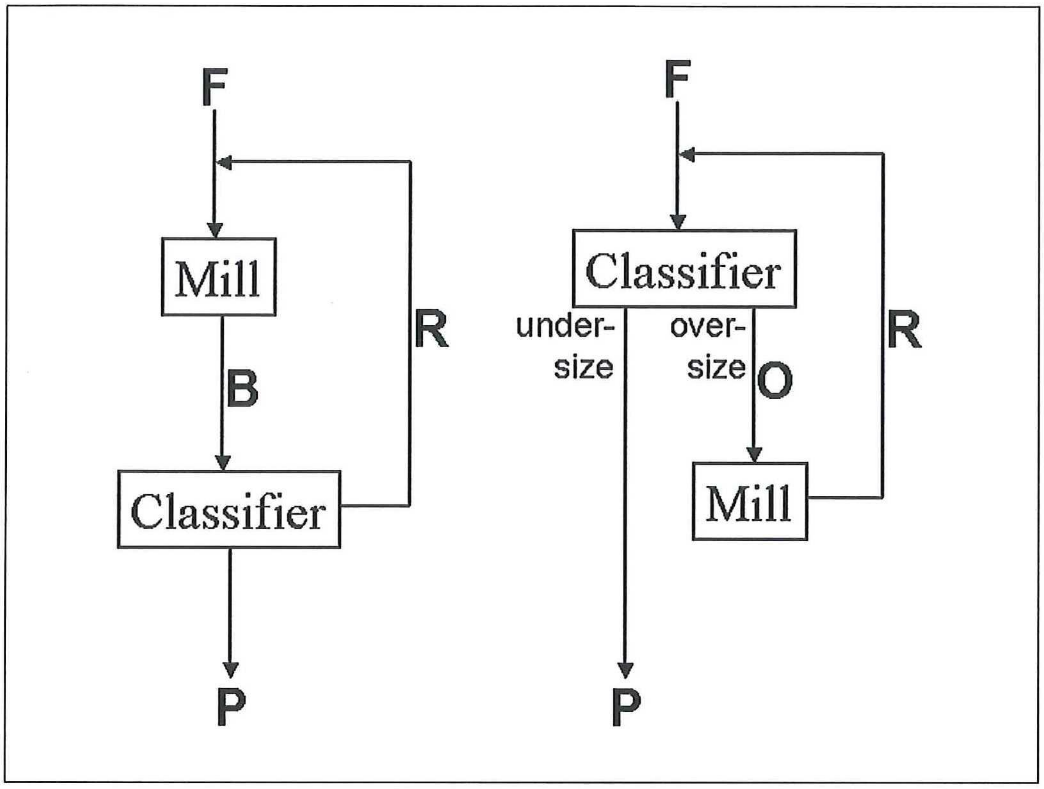
b. Design, using your above answer and the copies of Weiss (Appendix A, page 3E-10) the right width, length and number of screens. **(3 points)**

c. On page 3E-11, Weiss gives in chart A an alternative method to determine screen capacity of various materials. Argue why
   1. There is a difference between the 4 materials, **(2 points)**
   2. 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. **(3 points)**

f. The screening is used in combination with a ball mill. You have two different flow sheet options (see below). Which one would have your preference and why? **(3 points)**



Appendix (for PP-Q5)

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

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

Page 3E-10 and 3E-11 are from:
SME Mineral Processing Handbook, (Weiss et al.)

See next pages for Page 3E-10 and page 3E-11

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 $\frac{\text{Tph (feed)} \times 0.40}{C_u \times F_w \times F_{oa} \times F_s}$	% 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.

Chart A—Screen capacity per square foot

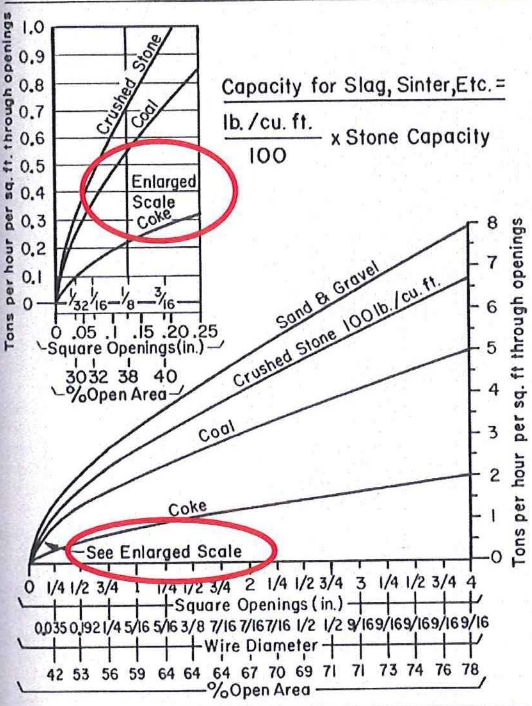


Chart B

%	Fines, F_f	Oversize, F_o	Efficiency, F_e
	Factor		
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_{wa}†
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

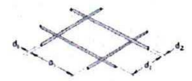
* When screening dry: If moisture exceeds this limit, must consider special aperture constructions

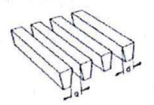
† Use F_{wa} when uncertain about maximum spray water being available, or being used efficiently

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.	$P = \frac{100\,a^2}{(a+d)^2} = 100\left(\frac{a}{a+d}\right)^2$ $\quad a_1 = a_2 = a$, $d_1 = d_2 = d$
Square openings Specified in mesh (m).	$P = 100\,a^2 m^2$ $\quad m = \frac{1}{a+d}$
Parallel rod decks	$P = \frac{100\,a}{(a+d)}$
Special weaves Ty-Rod, nonblind, etc.	Assuming $a_3 = a_1$: $P = 100\left[\frac{a_1(a_3+2a_1)}{(a_2+2a_1+3d_2)(a_1+d_1)}\right]$





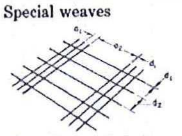


Chart F—Slotted opening factor

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