Materials Production Homework 2.83 and 2.813
2011

1. Estimate the efficiency for the Roasting and Smelting of copper sulfide ore in US Industry using the data of Ayres and Masini.

Efficiency Equation – Degree of Perfection**:**

$$\eta_P = \left(\frac{exergy\ of\ useful\ outputs}{exergy\ of\ inputs} \right)$$

Calculation of Exergy of Useful Outputs:

Output	**Exergy**
Refined Copper	1573
	1573 MJ/tonne = *1.57 MJ/kg*

Calculation of Exergy Inputs: (Masini & Ayres Figure 12)

Look at the Roasting and Smelting Box:

Input	**Exergy**
Air	248
SiO2	10
Limestone	104
Sulfide Ore	25,201
Electricity	22,454 * 3 (to account for the efficiency of the grid)
	92,925 MJ/tonne = *93 MJ/kg*

Therefore,

$$\boxed{\eta_p = \frac{1.57}{93} = 1.69\%}$$

2. Estimate the efficiency for the final refining step for copper in US Industry.

Degree of Perfection

$$\eta_P = \left(\frac{exergy\ of\ useful\ outputs}{exergy\ of\ inputs}\right)$$

1. Calculation of Exergy of Useful Outputs:

Output	**Exergy**
Refined Copper	2112
	2112 MJ/tonne = *2.1 MJ/kg*

2. Calculation of Exergy of Inputs:

Input	Exergy
Anode Copper	2155
Utilities	2376 (792 x 3 – grid efficiency)
Total Exergy	4531 MJ/tonne = *4.531 MJ/kg*

Degree of Perfection:

$$\eta_P = \left(\frac{2.1}{4.531}\right) = 46.3\%$$

3. Please do an exergy analysis for $2Cu_2S + 3O_{2(g)} \rightarrow 2Cu_2O + 2SO_2$
(An important reaction in copper smelting) Determine B_{in}, B_{out} and B_{lost} How much energy is needed to drive this reaction?

$$2Cu_2S + 3O_{2(g)} \rightarrow 2Cu_2O + 2SO_2$$

$$B_{in} = 2(791.8) + 3(3.97) = 1595.51$$

$$B_{out} = 2(124.4) + 2(313.4) = 875.6$$

$$\Delta B = B_{in} - B_{out}$$

$$\Delta B = 1595.51 - 875.6 = 719.91 \textit{ kJ/mol} \quad \text{(Exothermic)}$$

$$\text{Energy Produced} = \frac{719.91 kJ/mol}{2*[(2*65.55+32.06)g/mol} = 2.2\frac{MJ}{kg} \text{ of ore processed}$$

This reaction <u>does not</u> require energy input to proceed! This is a highly exothermic reaction. One way to control the temperature of this reaction is to put in some scrap copper. Thus secondary copper is melted "for free", and the temperature of the reaction is controlled.

4. Estimate the exergy required to process recycled copper if you can skip the roasting and smelting process.

For refining copper from ore you need 45.3 GJ/t total utility input (see Masini & Ayres Figure 13) which when adjusted for the efficiency of the grid leads to 136 GJ/t of energy inputs

<u>From Ore = 136 MJ/kg</u>

Recycled Material only needs the last step: Electrolytic Refining = 792 MJ/t * 3 =

<u>Recycled Material = 2.4 MJ/kg</u>

There is a big savings when copper is recycled! (May not quite be as much as this since the copper that is recycled is not usually anode grade)

5. For the ideal reduction of hematite to iron with carbon, what is the degree of perfection? (see class slides)

The inputs are 3 moles of carbon, 2 moles of hematite, and the required 301.4 kJ of work. The output is 4 moles of iron:

η_P **= 1505.6/1565.3 = 0.96**

6. From the data given in the class slides, estimate the efficiency of the mining and milling process as the ore grade goes to zero.

See class notes: energy goes like E ~ K/g, where K is a constant (slide from Chapman and Roberts p 113 & 116). We also know from exergy analysis that the minimum work goes like W ~ ln(1/g). So the efficiency goes like W/E ~ -g ln g. This goes to zero in the limit when ore grade "g" goes to zero. (Use L'Hospital's Rule).

7. Using the Ellingham diagram, estimate the temperature required to use the reaction 2C + O2 = 2CO to reduce Cr_2O_3 to Cr.

Ans. about 1500°K

8. Using the CMU I/O model compare primary and secondary production of 1) aluminum and 2) copper in terms of energy use per dollar of output. Can you also do energy use per kg of output? How do these results compare with Masini and Ayres?

CMU EIO (1997)	Aluminum	Copper
Primary Production	47.6 TJ/ million dollars	16.2 TJ/million dollars
Secondary Production	9.16 TJ/ million dollars	6.94 TJ/million dollars

(TJ/million $ = MJ/$)

For current metals prices try www.metalprices.com (try the free preview)
For metals prices from 1997 (the year for the CMU tables) go to the USGS website: http://minerals.usgs.gov/minerals/pubs/commodity/ Look at the 1998 publications

In 1997:
Aluminum = $0.75/lb = $1653/metric t
Copper = $1.08/lb = $2380/metric t

Therefore according to the CMU website the energy use in each is :

	Aluminum	Copper
Primary Production	78,683 MJ/t	38,556 MJ/t
Secondary Production	15,141 MJ/t	16,517 MJ/t

While, according to Masini & Ayres:

	Aluminum	Copper
Primary Production	316,929 MJ/t	136,000 MJ/t
Secondary Production	N/A	N/A

And, according to Ashby:

	Aluminum	Copper
Primary Production	200,000-240,000 MJ/t	68,000 – 74,000 MJ/t
Secondary Production	18,000-21,000 MJ/t	17,000 – 18,500 MJ/t

Comments:
1)There is a big difference between primary and secondary process energy!
2)The CMU I/O model agrees roughly with Ashby for the secondary process energy use for both aluminum and copper.
3) However the CMU I/O model for primary is quite low. It is very likely that these primary sectors have lower than average per unit energy prices which make them appear as using less energy than they really do. I would not trust the CMU model here.
4) It also seems that Ayres might be high, but this needs further investigation. Keep in mind his model is for the US and Ashby's model would apply more broadly, though I am not sure if he states where.