EngrD 2190 – Lecture 17

Concept: Process Analysis by Mathematical Modeling

Context: Process Economics Examples.

1. Recycle or Two Reactors? (exercise 3.89)
2. When to Replace a Key Part? (exercise 3.111)
3. Order of Separations? (exercise 3.108)

Solutions are posted.

Read Chapter 4, pp. 243-253:

Graphical Modeling for Mass & Energy Balances.

Lecture 18 (Wednesday after Fall Break) will follow the textbook.

Bring a Straightedge or a Ruler.

Prelim 1

- Prelim 1: **Tomorrow**, 7:30-9:30 p.m. 245 and 128 Olin Hall

  Covers Chapter 2 and mass balances (formal and informal).

  Covers through Lecture 10, Homework 4, Calculation Session 5.

  Open notes and open exercise solutions.

  Bring a calculator. Graphing calculators are allowed.

  No Laptops and no iPads.

- Practice Exercises for Prelim 1. *Optional - do not submit solutions.*

  Process Design with real chemicals: **2.18**

  Process Design with qualitative, informal mass balances: **3.123 and 3.132**

  Formal Mass Balances: **3.20, 3.25, and 3.45**

  Informal Mass Balances: **3.41**

  Solutions are posted.

Spreadsheets for Mass Balances with Economic Analysis.

Wednesday Lecture and Calculation Session this week

Bring a ***charged*** laptop with Excel installed ***and the Solver routine installed*** and ***the spreadsheet template for Exercise 3.112 downloaded.*** See today's Handout for basic Excel functions and instructions to install Solver.

Bring a mouse for your laptop. Much better for spreadsheets than a touchpad.

Try the Mass Balance tutorial on pp. 182-186 of the textbook. If you can complete the tutorial independently, *you need not attend lecture Wednesday*.

Try Exercise 3.112 before Calculation Session. Start with the downloaded template, enter formulae for mass flow rates in the process flowsheet and enter formulae for economic parameters. If you can complete Exercise 3.112 independently, *you need not attend lecture Wednesday*.

You will need the Excel skills to be taught in Wednesday's lecture and Wednesday's calculation session for the Spreadsheet Assignment, *to be done independently*. The tutorials are the most efficient means to learn these skills.

Spreadsheets for Mass Balances with Economic Analysis.

Wednesday Lecture and Calculation Session this week

If you can independently complete the Mass Balance tutorial on pp. 182-186 of the textbook and/or Exercise 3.112, Professor Kowal is offering a special opportunity.

Professor Kowal will conduct a tutorial on Advanced Excel Techniques during Wednesday's calculation session, in 128 Olin.

Spreadsheets: Excel and Circular References

	A	B	C
1	reactants	7,365	k$/year
2	labor	1,749	k$/year
3	utilities	857	k$/year
4	depreciation	2,892	k$/year
5	TOTAL		k$/year
6			

Should enter “= sum(B1:B4)”

Instead, incorrectly enter “= sum(B1:B5)”

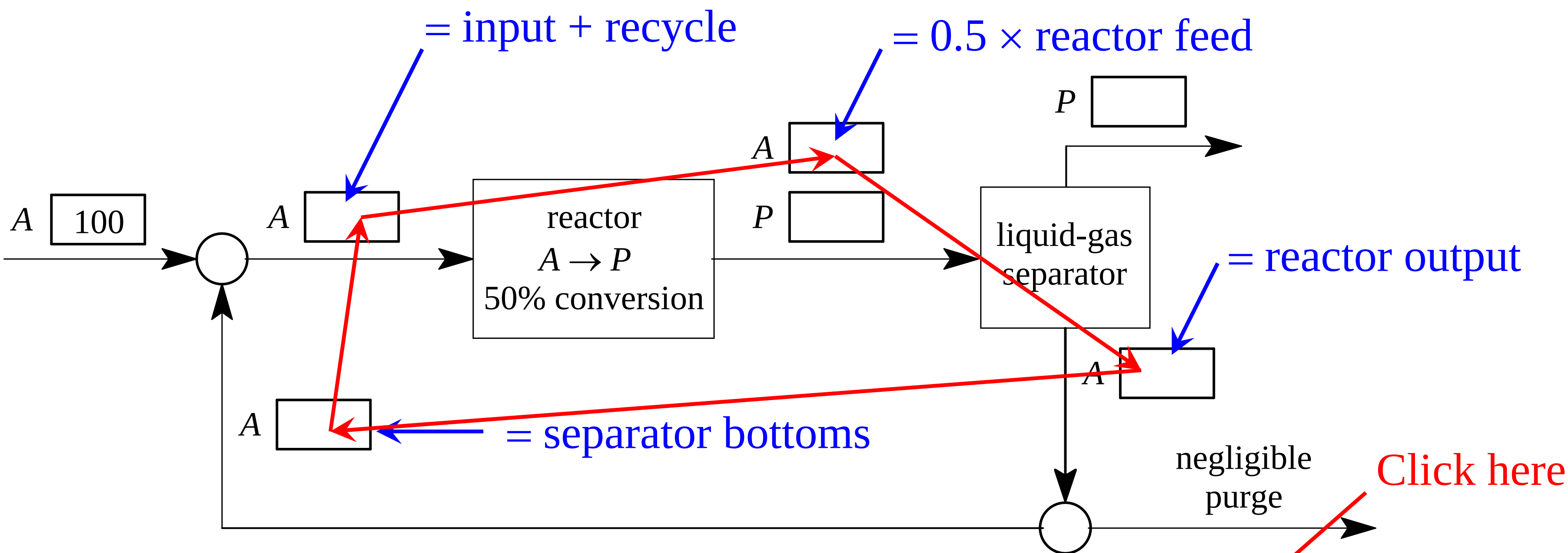
Microsoft Excel

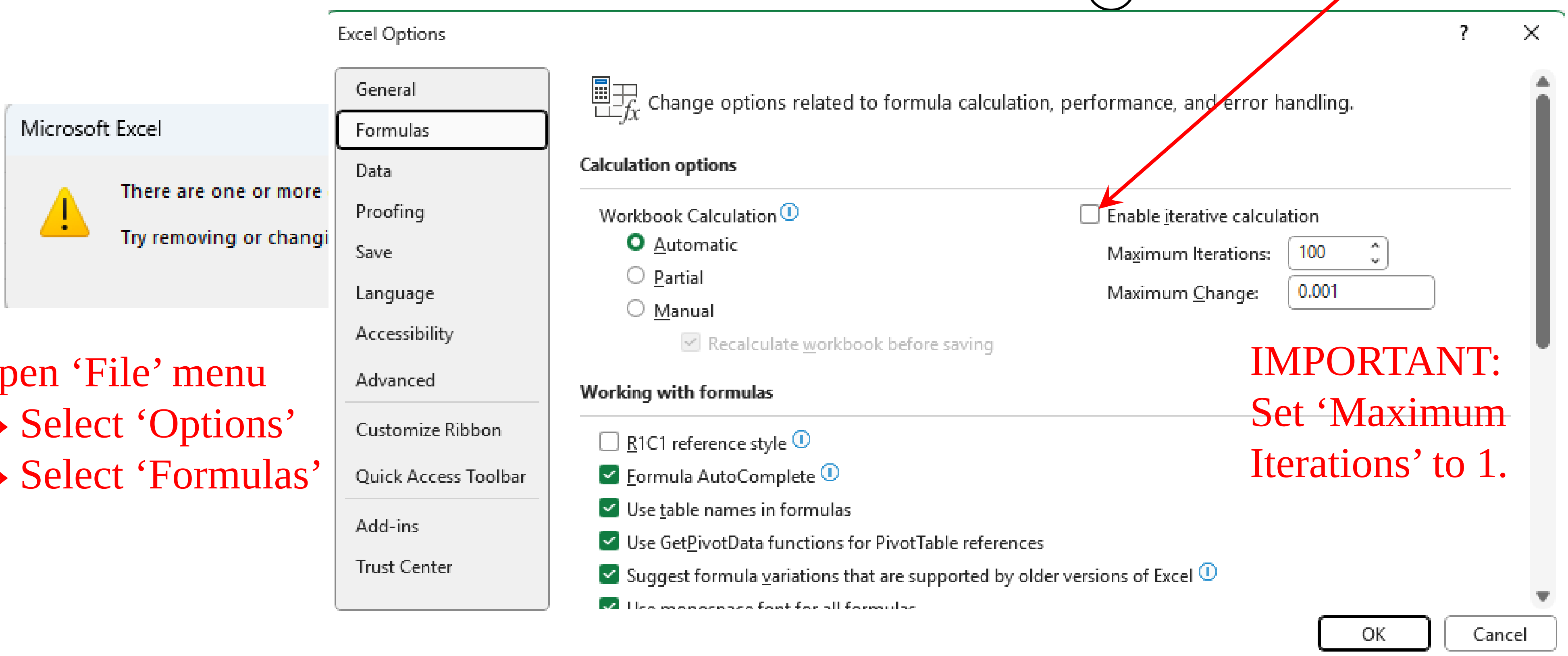
There are one or more circular references where a formula refers to its own cell either directly or indirectly. This might cause them to calculate incorrectly.

Try removing or changing these references, or moving the formulas to different cells.

OK   Help

Spreadsheets: Excel and Circular References, cont'd





Open 'File' menu
→ Select 'Options'
→ Select 'Formulas'

IMPORTANT: Set 'Maximum Iterations' to 1.

New Homework Teams

Peer Evaluations and New Team Questionnaires Due Friday 10/10.
May be submitted in Calculation Sessions.
New Teams to be announced Friday 10/17.

Want to remain with your present team? If so **EVERY** team member must use the Google form Lara created by Friday 10/10 at noon.

Want to request a team? If so **EVERY** team member must use the Google form Lara created by Friday 10/10 at noon.

Economics of Lake Source Cooling

Lake Source Cooling (LSC) is one of the most significant environmental initiatives ever undertaken by an American university to promote a sustainable future. With its startup in July 2000, LSC upgraded the central campus chilled water system to a more environmentally sound design that utilizes a renewable resource, the deep cold waters of nearby Cayuga Lake. With a price tag of $58.5 million, a higher cost than simply replacing the existing chillers with new, LSC was a significant project.

The renewable resource tapped by LSC has reduced Cornell's reliance on fossil fuels. LSC saves over 20 million kWh per year versus previous cooling methods which represents about an 85% reduction in energy use for campus cooling.

In 2000, the average price of a kWh in New York was 15¢.

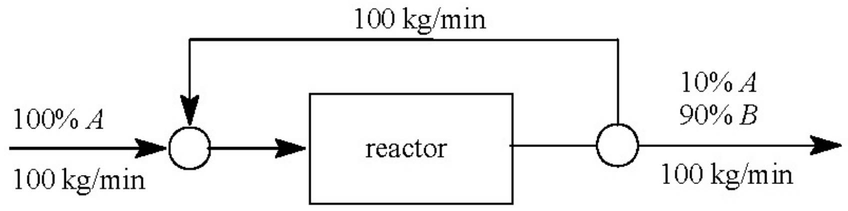
$$\frac{20\times10^6\ \text{kWh}}{\text{year}} \times \frac{0.15\,\$}{\text{kWh}} = 20\times10^6\ \$/\text{year}$$

$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{3.0\times10^6\ \$/\text{year}}{58.5\times10^6\ \$} = 5\%/\text{year}$$

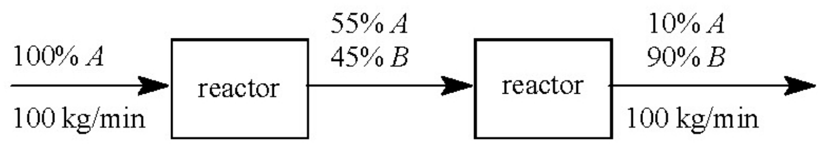
Exercise 3.98 – Consider two options for producing *B* from *A*.

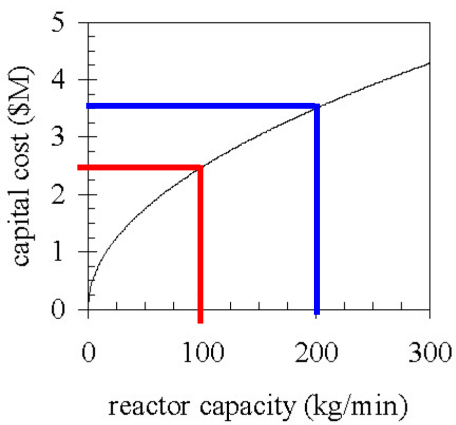
Solution is posted.

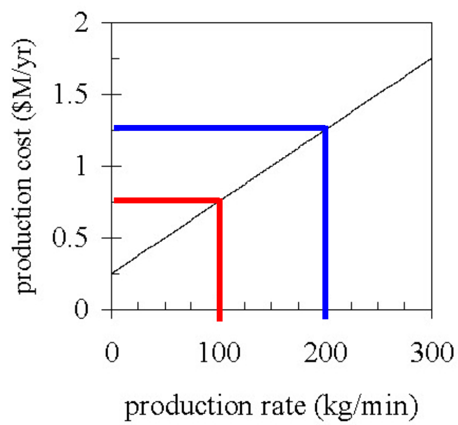
Option I.



Option II.







The revenue from 100 kg/min of 90% *B* is 2700 K$/year. Which option should we build?

$$\text{operating cost} = \text{production costs} + \text{depreciation}$$

$$= 1.25\times10^6 \text{ \$/ year} + \frac{3.5\times10^6 \text{ \$}}{10 \text{ years}} = 1.60\times10^6 \text{ \$/ year}$$

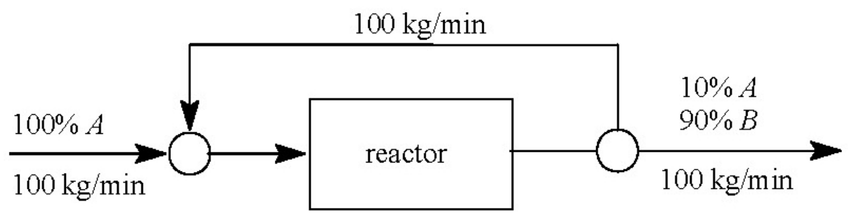
$$\text{operating cost} = \text{production costs} + \text{depreciation}$$

$$= 2\times\left[0.75\times10^6 \text{ \$/ year} + \frac{2.5\times10^6 \text{ \$}}{10 \text{ years}}\right] = 2.0\times10^6 \text{ \$/ year}$$

Exercise 3.98 – Consider two options for producing *B* from *A*.

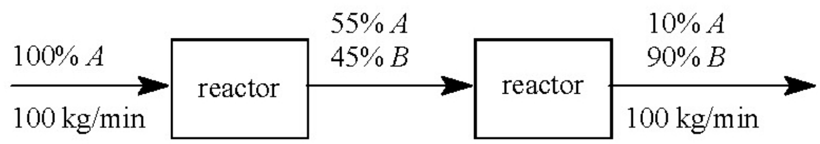
Solution is posted.

Option I.

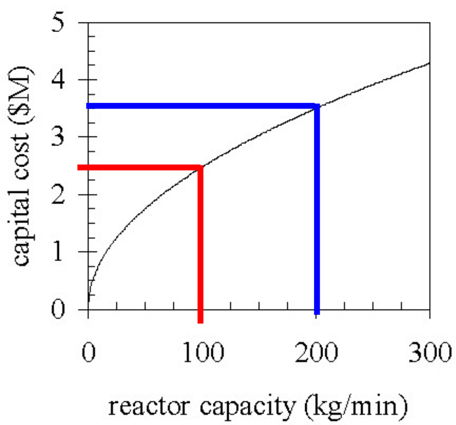


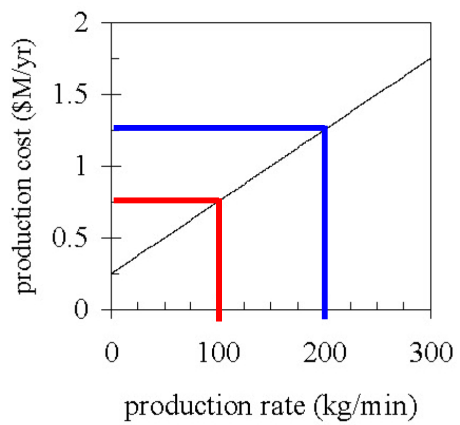
operating cost = 1.60 M$/year

Option II.



operating cost = 2.00 M$/year





The revenue from 100 kg/min of 90% *B* is 2700 K$/year. Which option should we build?

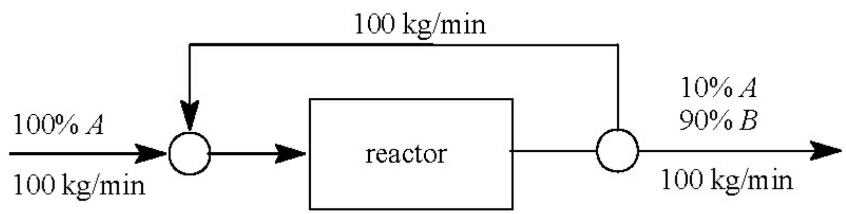
$$\text{profit} = \text{revenue} - \text{operating cost}$$
$$= 2.70\times10^6 \text{ \$/year} - 1.60\times10^6 \text{ \$/year} = 1.10\times10^6 \text{ \$/year}$$

$$\text{profit} = \text{revenue} - \text{operating cost}$$
$$= 2.70\times10^6 \text{ \$/year} - 2.00\times10^6 \text{ \$/year} = 0.70\times10^6 \text{ \$/year}$$

Exercise 3.98 – Consider two options for producing *B* from *A*.

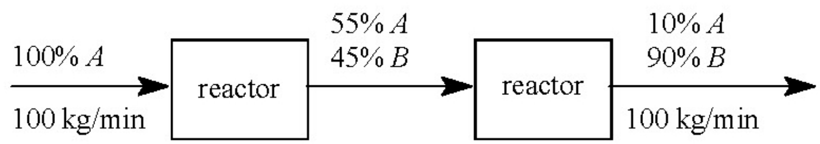
Solution is posted.

Option I.

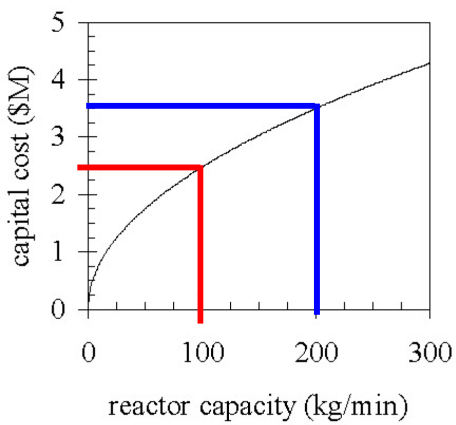


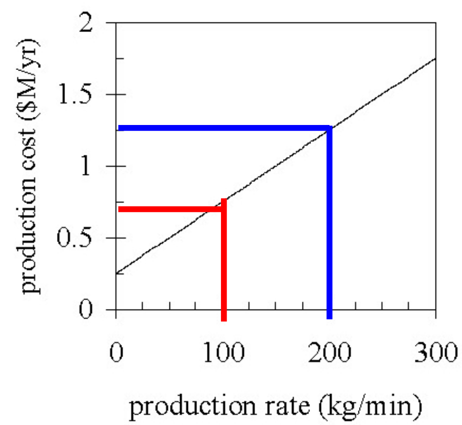
operating cost = 1.60 M$/year
profit = 1.10 M$/year

Option II.



operating cost = 2.00 M$/year
profit = 0.70 M$/year





The revenue from 100 kg/min of 90% *B* is 2700 K$/year. Which option should we build?

$$\mathrm{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{1.10\times10^{6}\ \$/\text{year}}{3.5\times10^{6}\ \$} = 0.31/\text{year}$$

$$\mathrm{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{0.70\times10^{6}\ \$/\text{year}}{2\times2.5\times10^{6}\ \$} = 0.14/\text{year}$$

Build Option I.

Exercise 3.111: Part (A)

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(A) Calculate the profit and return on investment (ROI). Assume a straight-line depreciation with a lifetime of 10 years.

$$\text{annual production of X} = \left(\frac{340\text{ kg X}}{\text{production week}}\right)\left(\frac{50\text{ production weeks}}{\text{year}}\right) = 17{,}000\text{ kg X / year}$$

$$\text{profit} = \text{revenue} - \text{operating costs}$$

$$\text{profit} = \text{revenue} - (\text{production costs} + \text{depreciation})$$

$$= \left(\frac{17{,}000\text{ kg X}}{\text{year}}\right)\left(\frac{28.7\$}{\text{kg X}}\right) - \left[\left(\frac{17{,}000\text{ kg X}}{\text{year}}\right)\left(\frac{11.4\$}{\text{kg X}}\right) + \frac{62{,}500\$}{\text{year}} + \frac{523{,}000\$}{10\text{ years}}\right]$$

$$= \frac{487{,}900\$}{\text{year}} - \left[\frac{193{,}800\$}{\text{year}} + \frac{62{,}500\$}{\text{year}} + \frac{52{,}300\$}{\text{year}}\right]$$

$$\text{profit} = 179{,}300\ \$/\text{year}$$

$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{179{,}300\ \$/\text{year}}{523{,}000\ \$} = \frac{0.34}{\text{year}} = 34\%\ /\ \text{year}$$

Exercise 3.111: Part (B)

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(B) A key part on your equipment breaks once a year, on average. When you purchased the equipment for \$523,000 you also purchased a spare part for \$24,900 (total price = \$547,900.). It takes one week to replace the part, during which no formula X is produced. The additional costs for each repair are \$31,200 (\$6,300 for labor plus \$24,900 for a new spare part to replace the part in inventory.) Calculate the profit and ROI during a year in which the part is replaced once.

$$\text{annual production of } X = \left(\frac{340\text{ kg } X}{\text{production week}}\right)\left(\frac{49\text{ production weeks}}{\text{year}}\right) = 16{,}660\text{ kg } X\text{ / year}$$

$$\text{profit} = \text{revenue} - \text{operating costs}$$

$$= \text{revenue} - (\text{production costs} + \text{depreciation})$$

$$= \left(\frac{16{,}660\text{ kg } X}{\text{year}}\right)\left(\frac{28.7\$}{\text{kg } X}\right) - \left[\left(\frac{16{,}660\text{ kg } X}{\text{year}}\right)\left(\frac{11.4\$}{\text{kg } X}\right) + \frac{62{,}500\$}{\text{year}} + \frac{31{,}200\$}{\text{year}} + \frac{547{,}900\$}{10\text{ years}}\right]$$

$$= \frac{478{,}142\$}{\text{year}} - \left[\frac{189{,}924\$}{\text{year}} + \frac{62{,}500\$}{\text{year}} + \frac{31{,}200\$}{\text{year}} + \frac{54{,}790\$}{\text{year}}\right]$$

$$\text{profit} = 139{,}700\text{ \$/year}$$

$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{139{,}700\text{ \$/ year}}{547{,}900\text{ \$}} = \frac{0.255}{\text{year}} = 26\%\text{ / year}$$

Exercise 3.111: Part (B) – Alternate Solution

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(B) A key part on your equipment breaks once a year, on average. When you purchased the equipment for \$523,000 you also purchased a spare part for \$24,900 (total price = \$547,900.). It takes one week to replace the part, during which no formula *X* is produced. The additional costs for each repair are \$31,200 (\$6,300 for labor plus \$24,900 for a new spare part to replace the part in inventory.) Calculate the profit and ROI during a year in which the part is replaced once.

Alternate solution: regard the part as capital, but with a lifetime of one year. As such, the cost of the replacement part is not an operating cost.

$$\text{depreciation} = \frac{523{,}000\,\$}{10\text{ years}} + \frac{24{,}900\,\$}{1\text{ year}} = 77{,}200\,\$/\text{year}$$

$$\text{cost of repair} = \text{labor cost only} = 31{,}200 - 24{,}900 = 6{,}300\,\$$$

$$\text{profit} = \text{revenue} - \text{operating costs}$$

$$= \text{revenue} - (\text{production costs} + \text{depreciation})$$

$$= \left(\frac{16{,}660\text{ kg }X}{\text{year}}\right)\left(\frac{28.7\$}{\text{kg }X}\right) - \left[\left(\frac{16{,}660\text{ kg }X}{\text{year}}\right)\left(\frac{11.4\$}{\text{kg }X}\right) + \frac{62{,}500\$}{\text{year}} + \frac{6{,}300\$}{\text{year}} + \frac{77{,}200\$}{\text{year}}\right]$$

$$= \frac{478{,}142\$}{\text{year}} - \left[\frac{189{,}924\$}{\text{year}} + \frac{62{,}500\$}{\text{year}} + \frac{6{,}300\$}{\text{year}} + \frac{77{,}200\$}{\text{year}}\right] = 142{,}200\,\$/\text{year}$$

Exercise 3.111: Part (B) – Alternate Solution, cont'd

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(B) A key part on your equipment breaks once a year, on average. When you purchased the equipment for \$523,000 you also purchased a spare part for \$24,900 (total price = \$547,900.). It takes one week to replace the part, during which no formula *X* is produced. The additional costs for each repair are \$31,200 (\$6,300 for labor plus \$24,900 for a new spare part to replace the part in inventory.) Calculate the profit and ROI during a year in which the part is replaced once.

Alternate solution, continued. Regard the replacement part as capital, but with a lifetime of one year.

profit = 142,200 \$/year

$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{142{,}200\ \$/\text{year}}{547{,}900\ \$} = \frac{0.260}{\text{year}} = 26\ \%/\text{year}$$

Compare to first solution to part (B): Replacement part is capital equipment, with a lifetime of 10 years.

profit = 139,700 \$/year

ROI = 26 %/year

Exercise 3.111: Part (C)

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(C) Because you know the key part will fail every year or so, you decide to avoid any production interruptions by replacing the part during the biannual one-week maintenance periods. Because the equipment is disassembled for maintenance, there is no additional labor to replace the part. The cost of replacing the part is only the price of the part, \$24,900. Calculate the profit and ROI for replacing the part twice a year during the normal maintenance periods.

Capital cost is again \$523,000.

Operating cost has the additional expense of two replacement parts. These parts are treated as consumable, like reactants or a toner cartridge in a printer. These parts are not capital investments; these parts are operating costs.

$$\text{profit} = \text{revenue} - (\text{production costs} + \text{depreciation})$$

$$= \left(\frac{17{,}000 \text{ kg X}}{\text{year}}\right)\left(\frac{28.7\ \$}{\text{kg X}}\right) - \left[\left(\frac{17{,}000 \text{ kg X}}{\text{year}}\right)\left(\frac{11.4\ \$}{\text{kg X}}\right) + \frac{62{,}500\ \$}{\text{year}} + \frac{2 \times 24{,}900\ \$}{\text{year}} + \frac{523{,}000\ \$}{10 \text{ years}}\right]$$

$$= \frac{487{,}900\ \$}{\text{year}} - \left[\frac{193{,}800\ \$}{\text{year}} + \frac{62{,}500\ \$}{\text{year}} + \frac{49{,}800\ \$}{\text{year}} + \frac{52{,}300\ \$}{\text{year}}\right] = 129{,}500\ \$/\text{year}$$

$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{129{,}500\ \$/\text{year}}{523{,}000\ \$} = \frac{0.248}{\text{year}} = 25\ \%/\text{year}$$

Exercise 3.111: Part (D)

3.111 You buy equipment for \$523,000 that has a capacity of 340. kg/week of formula X. The equipment operates 50. weeks per year; there are one-week maintenance periods every 6.0 months. Formula X sells for \$28.7/kg. The production costs (reactants, labor, electricity, maintenance, repairs, etc.) are \$11.4/kg. Rent, insurance, and miscellaneous fees are \$62,500./year.

(D) You decide to replace the part only after it fails, but with a different strategy. When the equipment fails, the first two days of the repair are spent disassembling the equipment and removing the broken part. Instead of having a spare part on hand, you decide to rush-order the part when it fails. The rush order costs \$24,900 for the part plus \$1000 for special rush delivery. Calculate the profit and ROI for this *just-in-time* strategy during a year when the part is replaced once.

Capital cost is again \$523,000.

Operating cost has the additional expense of the labor to replace the part, the cost of one replacement part, plus the rush-order delivery fee of \$1000.

Like part (B), we produce *X* for only 49 weeks per year.

$$\text{profit} = \text{revenue} - (\text{production costs} + \text{depreciation})$$

$$= \left(\frac{16{,}660 \text{ kg } X}{\text{year}}\right)\left(\frac{28.7\$}{\text{kg } X}\right) - \left[\left(\frac{16{,}660 \text{ kg } X}{\text{year}}\right)\left(\frac{11.4\$}{\text{kg } X}\right) + \frac{62{,}500\$}{\text{year}} + \frac{32{,}200\$}{\text{year}} + \frac{523{,}000\$}{10 \text{ years}}\right]$$

$$= \frac{478{,}142\$}{\text{year}} - \left[\frac{189{,}924\$}{\text{year}} + \frac{62{,}500\$}{\text{year}} + \frac{32{,}200\$}{\text{year}} + \frac{52{,}300\$}{\text{year}}\right] = 141{,}200 \text{ \$/year}$$

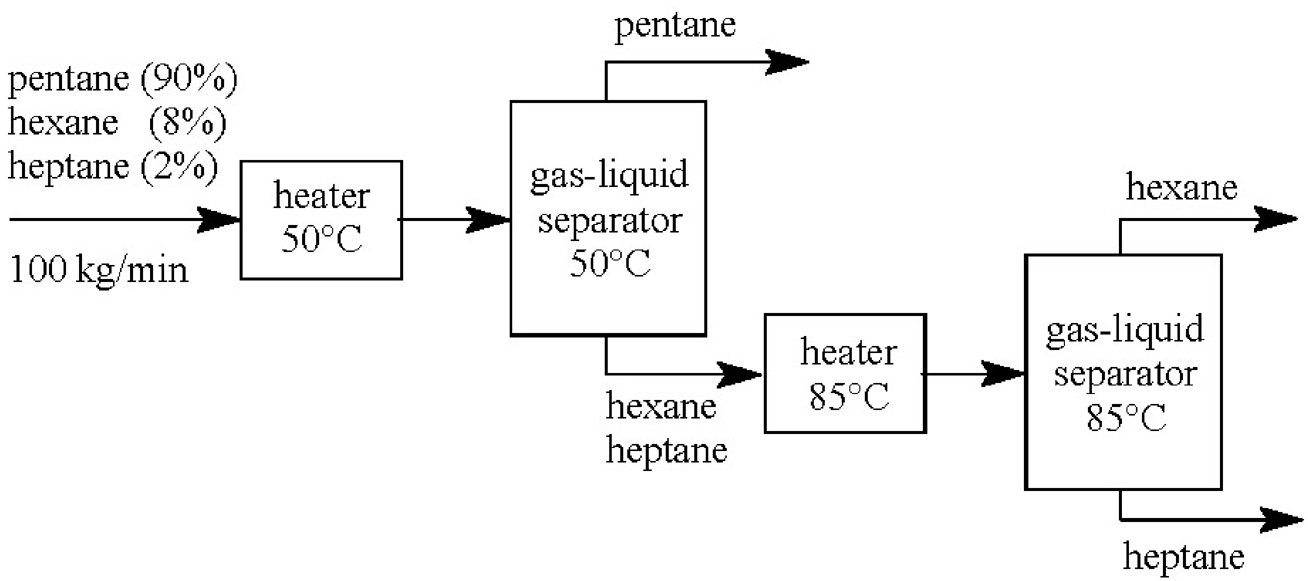
$$\text{ROI} = \frac{\text{profit}}{\text{capital cost}} = \frac{141{,}200 \text{ \$/ year}}{523{,}000 \text{ \$}} = \frac{0.270}{\text{year}} = 27 \text{ \%/year}$$

Exercise 3.108

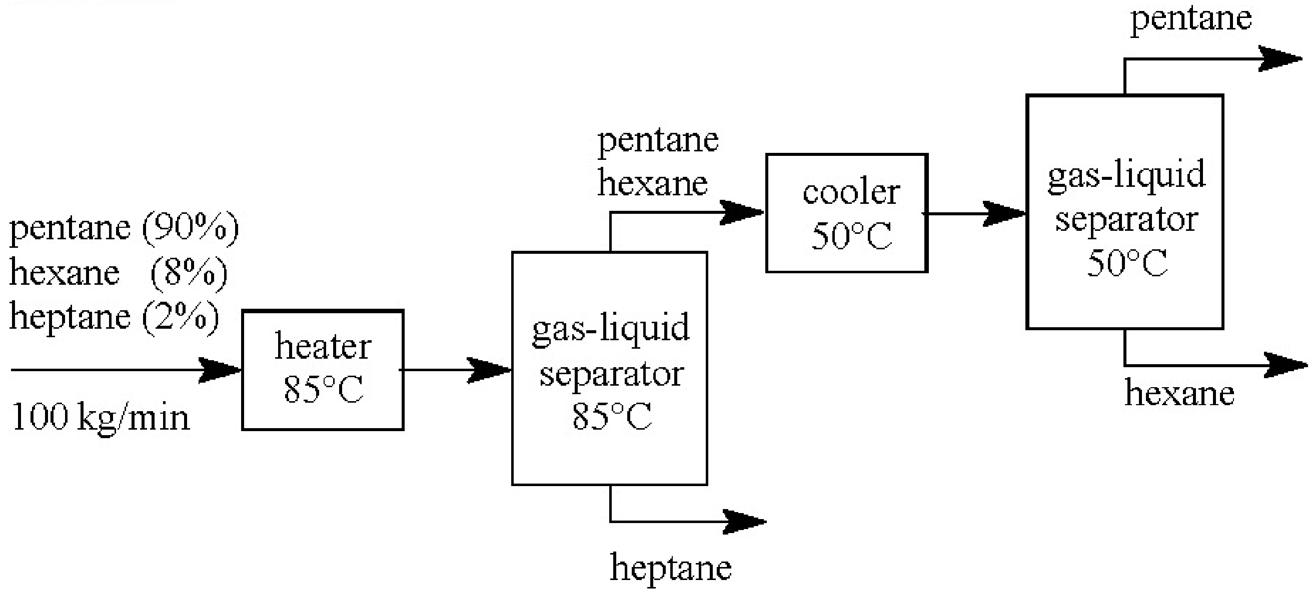
Consider the two schemes below for separating a mixture of pentane, hexane, and heptane.

Solution is posted.

Scheme I



Scheme II

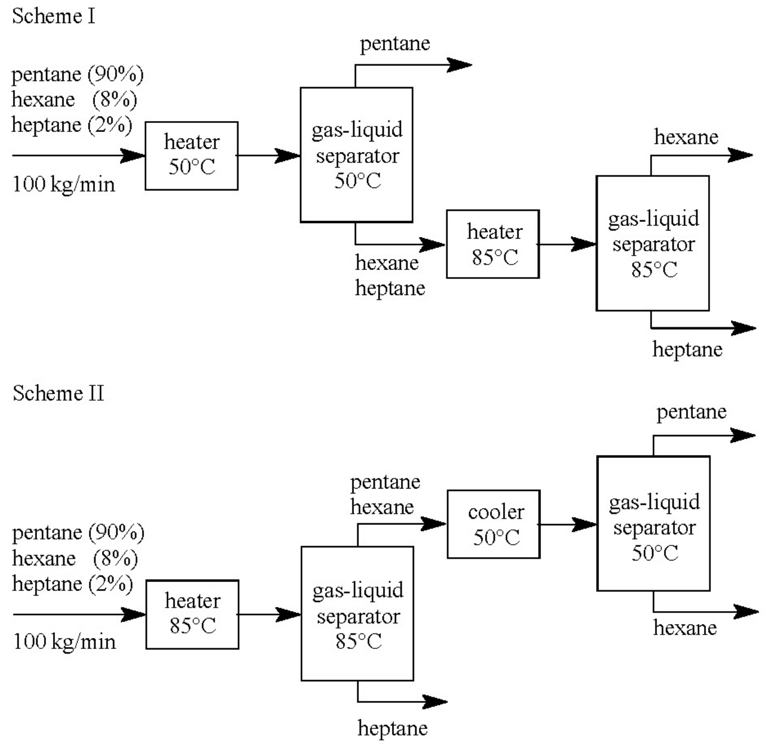


Which scheme is should we build?

Exercise 3.108 - Summary

Consider the two schemes below for separating a mixture of pentane, hexane, and heptane.

Solution is posted.



Which scheme is should we build?

capital cost in scheme I < capital cost in scheme II

depreciation cost in scheme I < depreciation cost in scheme II

energy cost in scheme I < energy cost in scheme II

Assume energy cost, material cost, and depreciation are the chief operating costs. Therefore operating cost in scheme I < operating cost in scheme II

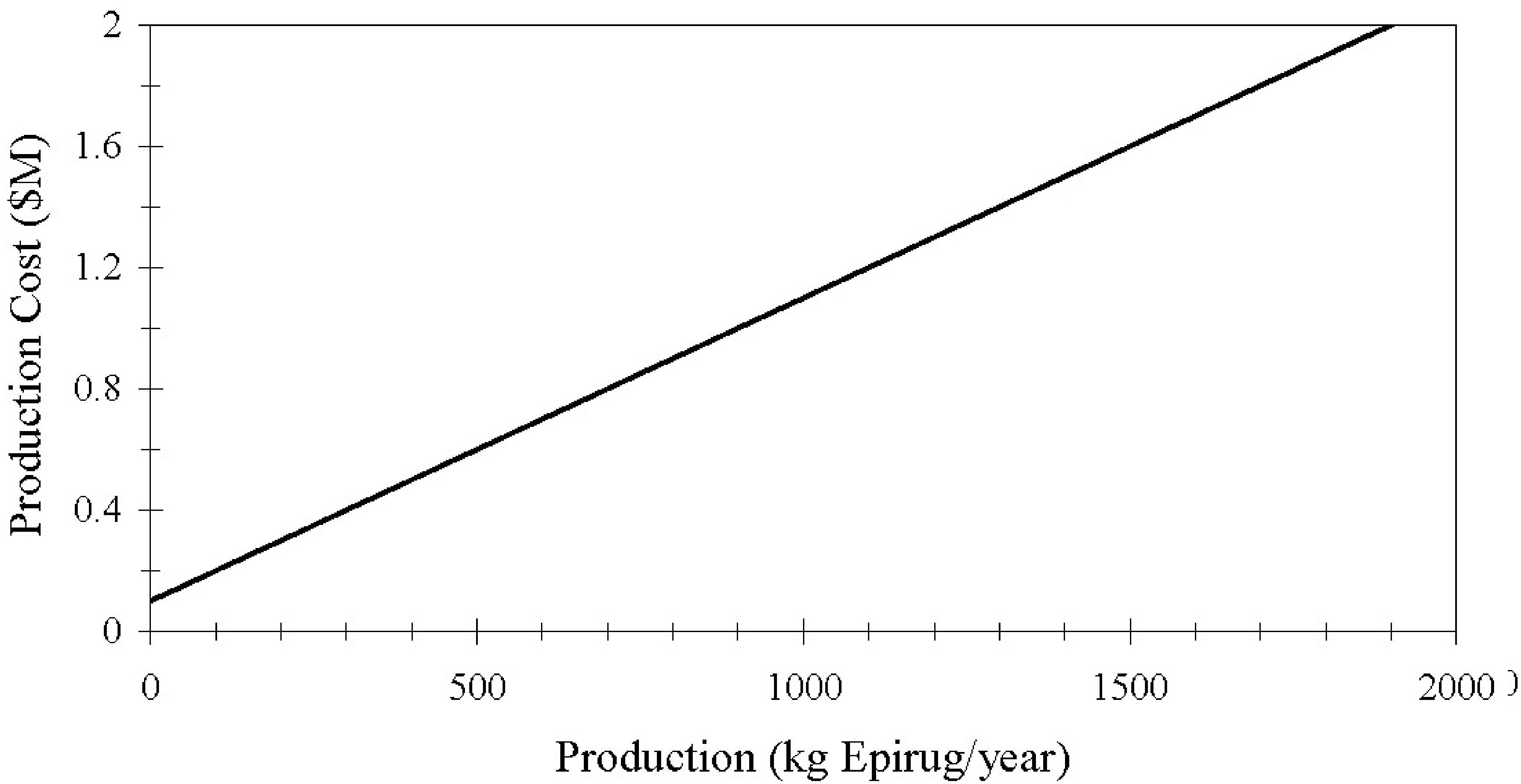
Because profit = revenue – operating costs, and revenue is the same for both schemes, profit from scheme I > profit from in scheme II

And finally, because ROI = profit/(capital cost) we conclude that ROI for scheme I > ROI for scheme II

Experiential Module 2 – An Economics Tournament

This experiential module concerns process economics. Homework teams will compete to amass the highest Net Value after several years of manufacturing a new drug. The drug, Epirug®, is a hundred-fold more effective than any existing drug for treating male pattern baldness.

Your assignment: Your company has $1M initially and must decide how much equipment to purchase and how much Epirug® to produce the first year. The graphs on the other side of this page will guide your decisions.



Experiential Module 2 – An Economics Tournament

To compensate for the time spent in the Economics Tournament, lecture Friday 10/10 is cancelled.

Instead, I will offer an optional lecture Friday 10/10.

Tips on the "Mass Balances with Process Economics" Assignment.

To be assigned Wednesday 10/8, Due Monday 10/20.

Strategies for the Economics Tournament.

Slides for the optional lecture will not be posted.