ABE 55800: Biological and Food Process Design II

Martin Okos, Alyssa Christoffer, Troy Tonner, Colleen Riley

T/R 2:30 pm – 5:20 pm

Hicks Undergraduate Library G980D

okos@purdue.edu

christ65@purdue.edu

tonner@purdue.edu

riley21@purdue.edu

Syllabus: <syllabus-spring19.docx>

Homework submission example: [Homework\HWK\_Submission\_Example.pdf](Homework/HWK_Submission_Example.pdf)

Textbooks:

Peters, M. Timerhaus, K., West, R. 2003. *Plant Design and Economics for Chemical Engineers.* 5th Edition. McGraw Hill, New York, NY.

Geankoplis, C. 2003. *Transport Processes and Separation Process Principles.* Prentice-Hall, Inc., Upper Saddle River, NJ.

Contents

[January 8, 2019 3](#_Toc536609037)

[Membrane Separation Literature 3](#_Toc536609038)

[Membrane Filtration 3](#_Toc536609039)

[Design Problem 3](#_Toc536609040)

[Homework for Thursday 3](#_Toc536609041)

[Homework for Monday 4](#_Toc536609042)

[January 10, 2019 4](#_Toc536609043)

[Pre-Quiz 1: Membrane Separation 4](#_Toc536609044)

[Given Equations: 4](#_Toc536609045)

[Solution: 4](#_Toc536609046)

[January 15, 2019 5](#_Toc536609047)

[Quiz 1: Membrane Separation 5](#_Toc536609048)

[Design Problem: Evaluate the Cost of the Process 5](#_Toc536609049)

[Chapter 6 of plant design book: cost estimation (starting point for economics part) 5](#_Toc536609050)

[January 17, 2019 7](#_Toc536609051)

[Engineering Economics Packet 7](#_Toc536609052)

[January 22, 2019 7](#_Toc536609053)

[Membrane Design – Due January 23 7](#_Toc536609054)

[January 24, 2019 7](#_Toc536609055)

[Cost Correlations Homework – Due January 25 7](#_Toc536609056)

[Engineering Economics Packet I 7](#_Toc536609057)

[January 29, 2019 8](#_Toc536609058)

[Engineering Economics Homework I – Due January 30 8](#_Toc536609059)

[January 31, 2019 8](#_Toc536609060)

# January 8, 2019

## Membrane Separation Literature

* [Membrane\_Filtration\coupled-concentration-dependent-diffusivities-of-ethanol-water-mixtures-through-a-polymeric-membrane.pdf](Membrane_Filtration/coupled-concentration-dependent-diffusivities-of-ethanol-water-mixtures-through-a-polymeric-membrane.pdf) (Yang & Lue, 2013)
* [Membrane\_Filtration\membrane-filters.pdf](Membrane_Filtration/membrane-filters.pdf) (Okos, 2019)
* [Membrane\_Filtration\membraneosmonics-filtration-spectrum.pdf](Membrane_Filtration/membraneosmonics-filtration-spectrum.pdf) (The Filtration Spectrum)
* [Membrane\_Filtration\optimum-design-of-reverse-osmosis-system-under-different-feed-concentration-and-product-specification.pdf](Membrane_Filtration/optimum-design-of-reverse-osmosis-system-under-different-feed-concentration-and-product-specification.pdf) (Lu, Hu, Zhang, Wu, & Liu, 2006)
* [Membrane\_Filtration\pure-water-handbook.pdf](Membrane_Filtration/pure-water-handbook.pdf) (Osmonics, 1991)
* [Membrane\_Filtration\shuler-ch11.pdf](Membrane_Filtration/shuler-ch11.pdf) (Shuler & Kargi, 2002)

## Membrane Filtration

* Driving force of a membrane: pressure
* Pressure and velocity higher at beginning of pipe
* Colburn analogy: Equation 7.3-13 (Geankoplis, 2003)
* Changes from beginning to end are nonlinear

## Design Problem

* Many pipes and membranes in series and parallel
* Pump at beginning of each group of membrane tubes
* Equipment costs from Peters, Timerhaus, and West
* Process:
  + Calculate flux: know change in pressure, can calculate osmotic pressure
  + Calculate how much water is coming through and how much glucose is coming through (Nw, Ng)
  + Calculate new velocity and new pressure.
    - Determine laminar or turbulent flow
      * Laminar: Hagan-Poiseuille ??? equation (Geankoplis, 2003)
      * Turbulent: Friction factor equation (Section 2.10C (Geankoplis, 2003))
  + Continue this cycle for length of membrane
  + Figure out pressure at the end and then figure out how much power the pump must use to boost back up to desired pressure (50 atm)

## Homework for Thursday

Come up with a preliminary design for the membrane

* [design-problem.docx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/design-problem.docx)
* [atherton\_ro\_design.m](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/atherton_ro_design.m)

## Homework for Monday

13.2-1, 2-2, 10.1, 10.3, 11.1, 11.2 (Geankoplis, 2003)

* [atherton\_membrane\_filtration\_homework.mlx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Homework/atherton_membrane_filtration_homework.mlx)

# January 10, 2019

## Pre-Quiz 1: Membrane Separation

A membrane system is being designed to concentrate a 10 kg glucose/m3 solution at 25oC (Mw glucose = 180.16 g/mol). The membrane pure water permeability constant Aw = 4.1e-4 kg water/s.m2.atm and the glucose permeability constant As = 1.01e-7 m/s. Since the mass transfer constant kc = 1e-7 m/s the osmotic pressure will be affected by concentration polarization. Assume the transmembrane pressure is maintained at 50 atm. R = 82.075e-3 m3.atm/kg mol.K.

Show how you would calculate the initial permeate flux, solute flux, and concentration of glucose on both sides of the membrane.

### Given Equations:

### Solution:

* From Equation 5b:
* Substitute into Equation 2:
* From Equation 4:
* From Equation 3:
* Solve for Ns:
* Rearrange result from Equation 4:
* From Equation 1: (
* Rearrange:
* From Okos: Check everything from here on for accuracy!!!
* Solve for c3:
* Solve for c2:
* Substitute into result of Equation 5b:
* Substitute into Equation 2:

# January 15, 2019

## Quiz 1: Membrane Separation

* Use first equation:
* , calculate c3
* Calculate (assume c2 = 0)
* Then calculate , (cw2 = ρwater)
* Use the values of c2 and c3 to re-do the steps until convergence.
* Select things to be zero that are much smaller and close to zero

## Design Problem: Evaluate the Cost of the Process

### Chapter 6 of plant design book: cost estimation (starting point for economics part)

#### Figure 6-1: tree diagram showing cash flow for industrial operation

* Operation for complete project: sales coming in, costs for operations going out
* Leftovers are gross profit (prior to depreciation)
  + Depreciation: value of process decreases over time
  + Government allows subtraction of depreciation (i.e. of equipment you purchased) from gross profit little by little to pay back capital investment
  + Gross profit gets taxed
  + Income taxes: (sales – cost – depreciation) \* tax rate
  + Profits after taxes, add depreciation back (already used money, so you don’t have to keep taking away little by little)
* Profits invested into capital sink as well as:
  + Loans
  + Preferred stock
  + Common stock
  + Bonds
  + Capital input
* Capital sink goes to
  + Investments
  + Repayment of borrowed capital
  + Stockholders
  + Capital investment
    - Manufacturing investment
    - Nonmanufacturing investment
    - Working capital
      * Amount of money available to spend at any time
      * Pay employees, bills, for materials, etc.
    - Goes into operations for complete project! Full circle

#### Cumulative cash position

* Timeline (time before production starts to invest in land, building plant, buying equipment, etc.)
* At time zero start in the hole
* Start producing, making product, getting income
* Breakeven point = paying back capital investment (does not take into account interest)
* Return on investment

#### Breakeven chart

* Design plant for 100% capacity, what is lower end when they start losing money?
* Fixed costs plotted as straight line
* Operating costs (total product costs)
  + Increase rate of production, value goes up
  + Past 100% capacity, costs increase
* Total income (products sold)
* Difference between costs and income
  + Ideally want to operate at max gross earnings, or at least above breakeven point but definitely above fixed costs production rate otherwise you operate at a lost

#### What goes into the cost?

* Direct costs
  + Purchased equipment
  + Purchased equipment installation
  + Instrumentation and controls
  + Piping
  + Electrical systems
  + Buildings (services)
  + Yard improvements
  + Service facilities
  + Land
* Indirect costs
  + Engineering and supervision
  + Legal
  + Construction
  + Contractor fee
  + Contingency

Know the size of equipment: find the capital cost (book is 1970, raise cost to 2019 prices)

# January 17, 2019

## Engineering Economics Packet

* [atherton-engineering-economics-i.pdf](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Engineering-Economics/atherton-engineering-economics-i.pdf)

# January 22, 2019

## Membrane Design – Due January 23

* [design-problem.docx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/design-problem.docx)
* [atherton\_membrane\_report.docx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/atherton_membrane_report.docx)
* [atherton\_ro\_design.m](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/atherton_ro_design.m)
* [atherton\_ro\_design.mlx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Membrane_Filtration/Design/atherton_ro_design.mlx)

# January 24, 2019

## Cost Correlations Homework – Due January 25

* [Cost-Correlations.pdf](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Cost-Correlations/Cost%20Correlations.pdf)
* [atherton-cost-correlations-homework.pdf](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Cost-Correlations/atherton-cost-correlations-homework.pdf)
* [atherton\_cost\_homework.mlx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Cost-Correlations/atherton_cost_homework.mlx)
* [atherton\_cost\_homework.m](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Cost-Correlations/atherton_cost_homework.m)

## Engineering Economics Packet I

A company is currently buying milk solids from a vendor at an annual cost of $30,000. A drying plant can be purchased from APV for an installed cost of $100,000. The plant has a life expectancy of ten years and negligible salvage value. The building site is valued at $10,000 and does not depreciate. Assuming interest is 16% compounded annually, what are the annual maintenance and operating charges that can be paid to make the purchase of the drying plant a break-even proposition?

* Currently $30,000
* Proposed
  + PI = $100,000
  + N = 10 years
  + I = 0.16
  + PL = $10,000
  + Op cost = ?
* + = annual plant cost
  + $2,069.20 = annual land cost
  + $469.00 = Future annual land value
  + Operating costs = $30,000 – 20,692.08 - $2069.20 + $469 =

A company is considering the purchase of a plant for $350,000 which would have a life of ten years and which would yield annual sales of $500,000. The annual operating expenses are $300,000 . The value of land, equipment, buildings, etc. at the end of 10 years is estimated to be $100,000. The company uses straight line depreciation. The tax rate is 47% and required working capital is $50,000. The company requires a 25% tax rate of return (I = 25%). Is this an acceptable investment?

* $350,000 - $100,000 = $250,000 / 10 = $25,000
* Gross profit = $500,000 - $300,000 = $200,000
  + Net profit = $200,000 - $25,000 = $175,000 (taxable)
* $175,000 \* (1 - 0.47) = $92,750 = net cash flow
* P = $350,000 + $50,000 = $400,000 = total capital investment
* Does net cash flow pay for investment?

$10,000

Loan $114,000 at 4% (25% of 6%)???

F = P(1 + i)^n

# January 29, 2019

## Engineering Economics Homework I – Due January 30

* [atherton-engineering-economics-i.pdf](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Engineering-Economics/atherton-engineering-economics-i.pdf)
* [atherton\_engineering\_economics\_i.mlx](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Engineering-Economics/atherton_engineering_economics_i.mlx)
* [atherton\_engineering\_economics\_i.m](https://d.docs.live.net/a6815758e2b5dbf9/ABE_558/Cost_Estimation/Engineering-Economics/atherton_engineering_economics_i.m)

# January 31, 2019

## Insulation costs

* Plot net cost of energy vs. inches of insulation
* 15% return (slope = -0.15)
* Cost of insulation and energy must be considered
* The minimum of the plot is where the cost is most effective
  + Energy costs decrease as insulation increases
  + Insulation cost increases as insulation increases
  + Where slope = 0
* Go to where the incremental return is 15%, -0.15

### Example Problem: Alternative Investment Analysis Based on Incremental Investment Return

The management of an existing plant has been concerned with the large amount of energy that is being lost in waste gases. It has been proposed to reduce the operating costs by recovering some of the het that is now being lost. Four different heat exchangers have been designed to recover the heat. All installation, operating, and fixed costs as well as savings have been calculated for each of the designs. The results of these calculations are presented in the following table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Design** | | | |
|  | **No. 1** | **No. 2** | **No. 3** | **No. 4** |
| Total initial installed cost, $ | 10,000 | 16,000 | 20,000 | 26,000 |
| Operating costs, $/year | 100 | 100 | 100 | 100 |
| Fixed charges, % of initial cost/year | 20 | 20 | 20 | 20 |
| Value of heat saved, $/year | 4100 | 6300 | 7300 | 8850 |

Company policy demands at least a 15 percent annual return before taxes based on the initial investment for any unnecessary investment. Only one of the four designs can be accepted. Using before-tax return on investment as the basis, which design should be recommended?

Cost per year = operating costs + fixed charges \* initial installed costs

Net savings = cost per year – value of heat saved

Percent return = net savings / total initial installed costs

* Option 1:
  + Cost per year = $100 + 0.2 \* $10,000 = $2,100
  + Net savings = $4,100 – $2,100 = $2,000
  + Percent return = $2,000 / $10,000 = 20%
* Option 2:
  + Cost per year = $100 + 0.2 \* $16,000 = $3,300
  + Net savings = $6,300 - $3,300 = $3,000
  + Percent return = $3,000 / $16,000 = 18.75%
* Option 3:
  + Cost per year = $100 + 0.2 \* $20,000 = $4,100
  + Net savings = $7,300 - $4,100 = $3,200
  + Percent return = $3,200 / $20,000 = 16%
* Option 4:
  + Cost per year = $100 + 0.2 \* $26,000 = $5,300
  + Net savings = $8,850 - $5,300 = $3,550
  + Percent return = $3,550 / $26,000 = 13.65%

Option 4 is out because it does not get us at least 15% return

Compare Options: Net savings difference / Initial investment difference = Return on additional investment

* Compare 1 & 2:
  + ($3,000 - $2,000) / ($16,000 - $10,000) = 16.67%
* Compare 1 & 3:
  + ($3,200 - $2,000) / ($20,000 - $10,000) = 12%
* Compare 2 & 3:
  + ($3,200 - $3,000) / ($20,000 - $16,000) = 5%

2 is the best option because the return on the additional investment from option 1 is greater that 15%

### Example Problem: Investment Comparison for Required Operation with Limited Number of Choices

A plant is being designed in which 204,000 kg per 24-hr day of a water-caustic soda solution containing 5 percent by weight caustic soda must be concentrated to 40 percent by weight. A single-effect or multiple-effect evaporator will be used, and a single-effect evaporator of the required capacity requires an initial investment of $18,000. This same investment is required for each additional effect. The serice life is estimated to be 10 years., and the salvage value of each effect at the end of the service life is estimated to be $6,000. Fixed charges minus depreciation amount to 20 percent yearly, based on the initial investment. Steam costs $1.32/1000 kg, and administration, labor, and miscellaneous costs are $40 per day, no matter how many evaporator effects are used.

If X is the number of evaporator effects, 0.9X equals the number of kilograms of water evaporated per kilogram of steam for this type of evaporator. Assume that there are 300 operating days per year and an income tax rate of 35 percent. If the minimum acceptable return after taxes on any investment is 15 percent, how many effects should be used?

* Depreciation = ($18,000 - $6,000) / 10 \* 300 = $4/day per effect
* Fixed – Depreciation = $18,000 \* 0.2 / 300 = $12/day per effect
* Steam cost:
  + Water evaporation
    - 204,000 \* 0.05 = NaOH kg initial
    - 204,000 \* 0.05 / 0.4 = NaOH kg final
    - 204,000 – (204,000 \* 0.05 / 0.40) = water to be evaporated
  + Steam required
    - X \* 0.9 kg water / kg steam
  + Steam cost
    - Water to be evaporated / steam required \* cost of steam ($1.32 / 1000 kg steam) = $269,280/X per day

# February 5, 2019

# February 7, 2019

# February 12, 2019

## Heat exchanger

* Plot energy transferred through heat exchanger vs. time, see a decrease in heat transfer
  + Overall U value is decreasing with time
  + Q = UA(ΔT)
  + When this happens, stop the process, clean, and restart
  + Time of oberation, tb, time to clean, tc
  + How long do you operate before cleaning to optimize heat transfer?
* How does U change with time?
  + U = (1/(aθb + c)) ^ ½
  + dQ/dt = UA ΔT = A ΔT/(aθb + c) ^ ½
  + integrate from Q = 0 to Q = Q
    - A ΔT \* integral from 0 to θb 1/(aθb + c) ^ ½
    - Q = 2 A ΔT/a \* ((a θb + c) ^ ½ - c ^ ½)
  + QH = QC/cycle \* cycles/H
  + Q = 2 A ΔT/a \* ((a θb + c) ½ - c½) \* H/(θb + θc)
    - Heat transfer per cycle \* cycles per year
    - If θb is too short, dominated by cleaning; if θb is too long, dominated by low Q
* Cost
  + (C­C + Sθb)(H/θb+θc)\_
    - Cost of cleaning + cost of labor per hour)\*(cycles per year)
  + Relate cycles per year to Q
  + QH = 2 A ΔT/a \* ((a θb + c) ^ ½ - c ^ ½) \* H/(θb + θc)
    - dCt/d θb = 0
    - θb = C­c/Sb + 2/aS­b (acCCSb)1/2