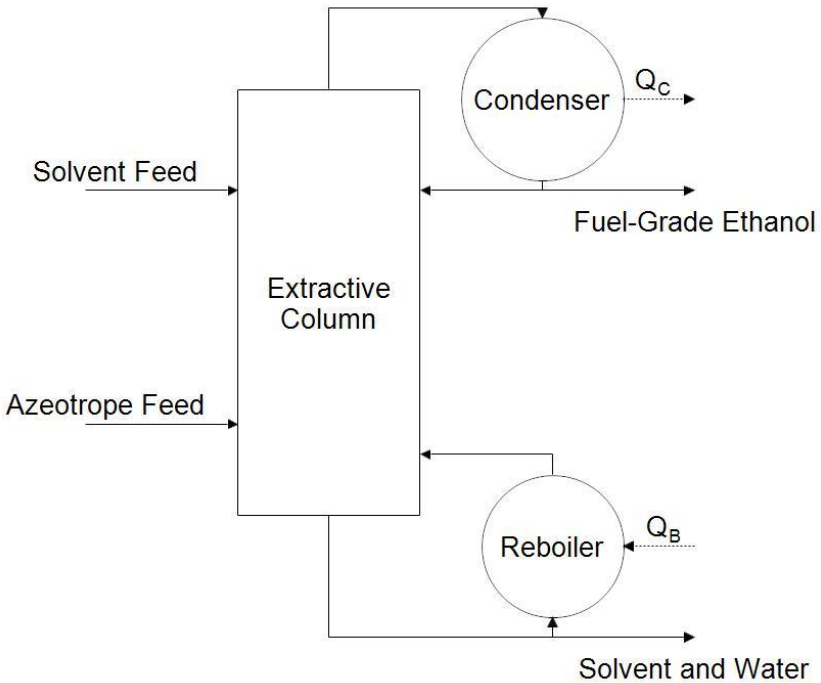
Separation of Ethanol and Water with Extractive Distillation

David LaJambe

Ethanol-Water Systems

- Maximum purity from regular distillation limited by low-boiling azeotrope to 90 mole% ethanol
- Fuel grade ethanol requires 98.7 mole% ethanol



Extractive Distillation

- Like normal distillation: uses volatility differences in components to separate them with the addition of heat (ESA)
- Adds additional solvent feed (MSA) above the mixture feed to modify activity coefficients of components, shifting azeotrope composition to higher purity

Extractive Distillation Column - Operating Costs

Production Capacity

- 70 million gallons of fuel-grade ethanol per year, worth $140 million
- Capital cost of $1.35 million

Operating Costs

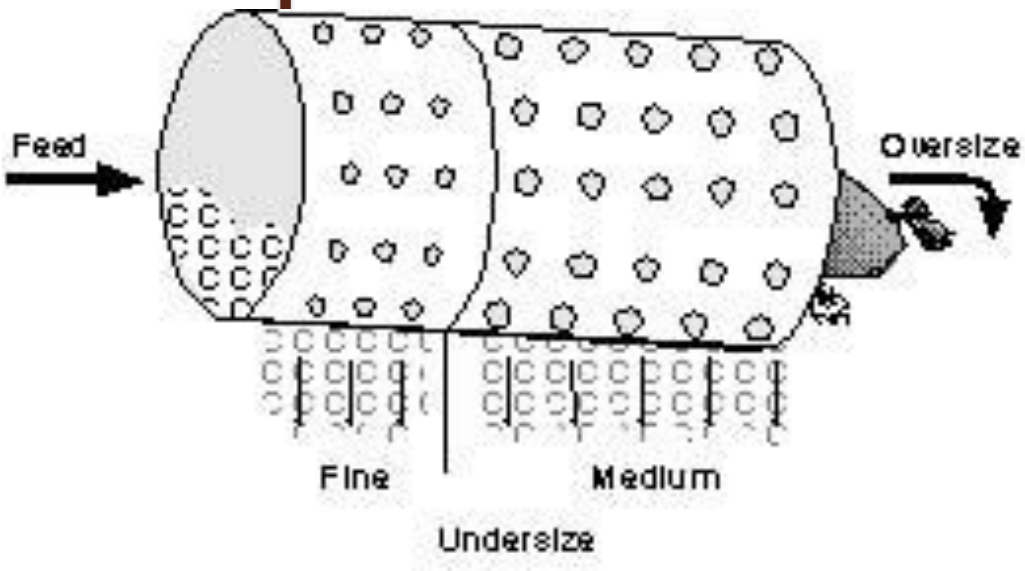
- Utilities and maintenance – $4700/day for high pressure steam (reboiler), chilled water (condenser), and labour (only ~$160 per day)
- Glycerol solvent – $4200/day based on 99% recovery of glycerol from regeneration column
- Capital Depreciation = $100 per day
- **Total Operating Costs = $9000/day = $3.3 million/year**

Suggested References:

[1] J. Smith, H. Van Ness and M. Abbott, "VLE by Modified Raoult's Law," in Introduction to Chemical Engineering Thermodynamics, New York, McGraw-Hill Companies, Ltd., 2005, pp. 358-359.

[2] J. Seader, E. J. Henley and D. K. Roper, "Extractive Distillation," in Separation Process Principles 3rd Edition, Hoboken, John Wiley & Sons, Inc., 2011, p. 424-428.

Screen Separators or Trommel



- Mainly used in Municipal Solid Waste (MSW) Management
- Used to separate solid particles of different sizes
- Fine particles (soil, grit, organic waste) fall through the screen as “unders”
- Large particles (plastic films, paper products) retained on the screen as “overs”

Installation and Operating Costs

- Can cost between $2000-$15000 (depending on size)
- A trommel processing 62.5 tons/ hr of MSW, the capital costs involved was $891,814
- Operating costs (per ton) with an input of 202,800 tons of MSW were:
  - Shredder only - $1.4 1 /ton
  - Trommel and Shredder - $1.31 /ton
- This results in a $109/ ton savings.
- On an annual basis this gives a return of 6.7% on the incremental capital cost.

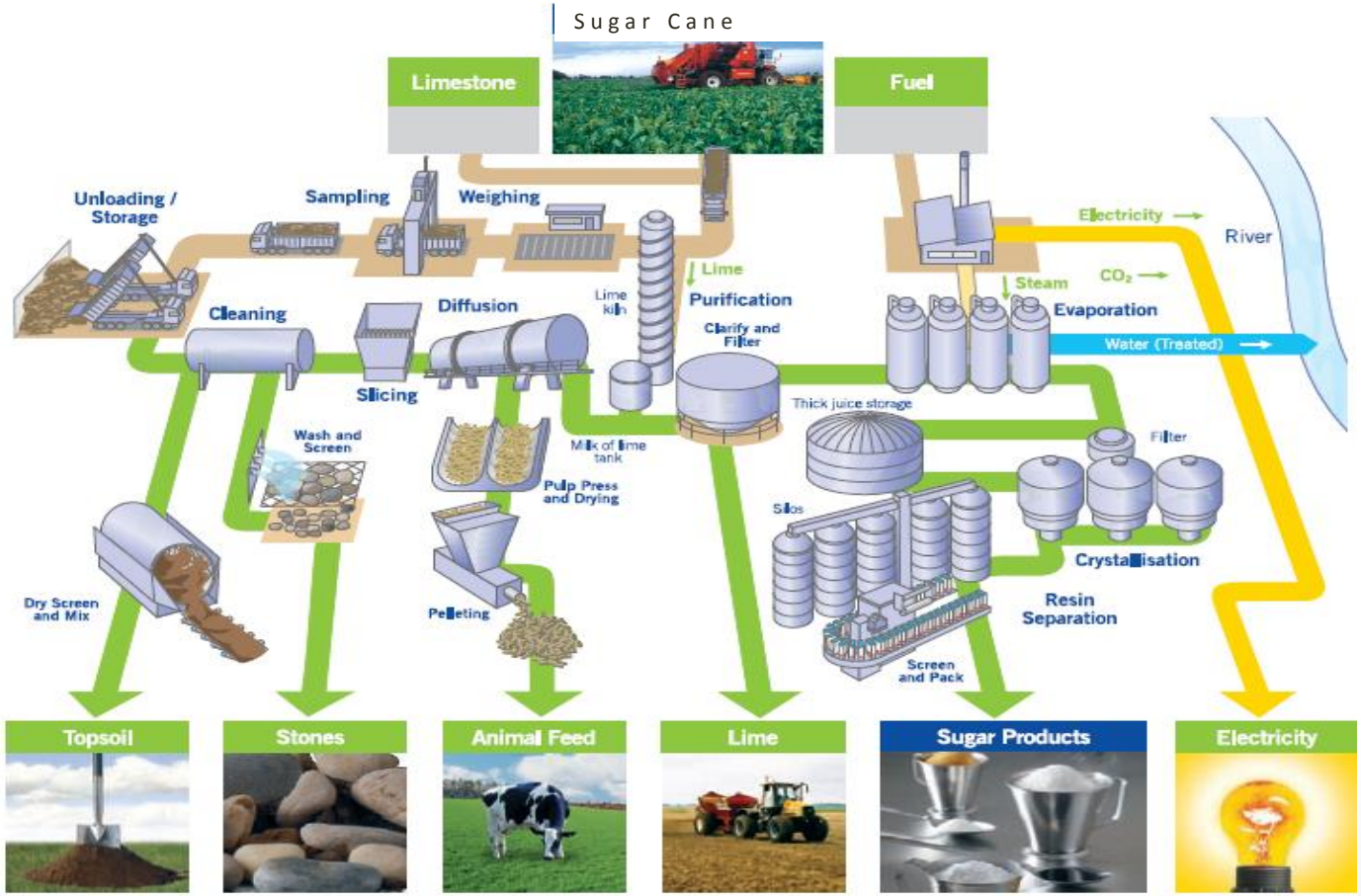
More Readings about Screen Separators

- http://compost.css.cornell.edu/MSWFactSheets/msw.fs1.html
- Christensen, Thomas H. "Solid Waste Technology and Management." Wiley. Book
- http://www.seas.columbia.edu/earth/wtert/sofos/nawtec/1978-National-Waste-Processing-Conference/1978-National-Waste-Processing-Conference-20.pdf

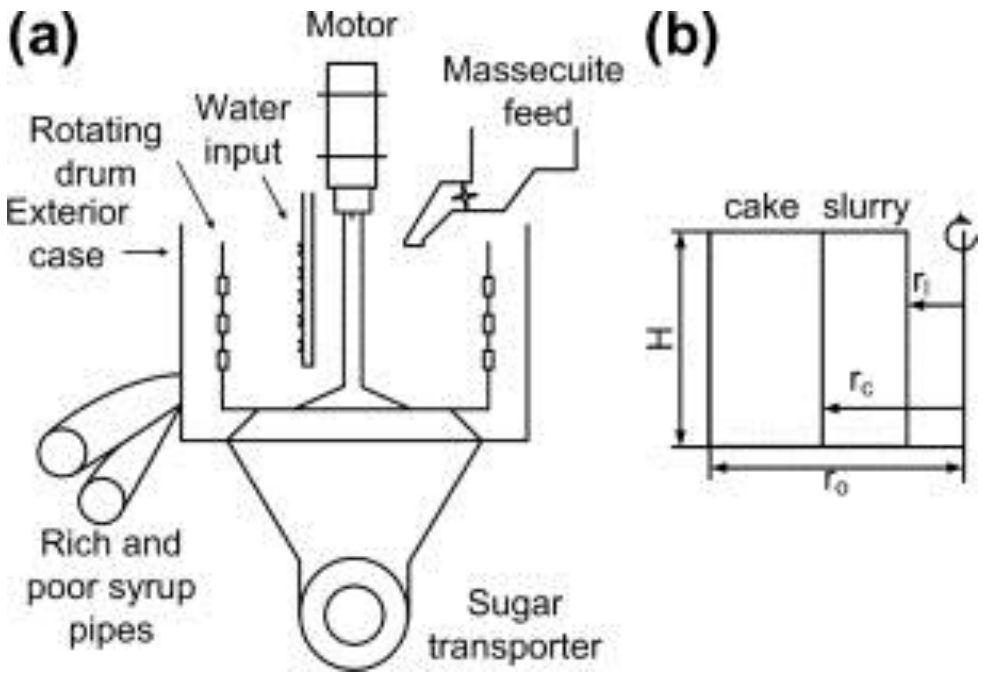
Production of Sugar

Syed Usman Ahmed

Laila Siddiqui



Batch Filtration Centrifuge



-Uses centrifugal force

$$m(r\omega^2)$$

- Takes advantage of density difference
- Spun at about 1200 RPM to filter sugar crystals from the uncrystallized solution it is suspended in(molasses).

Sizing and Cost

Parameter	Value
D – basket diameter	1 m
R – basket radius	0.5 m
t – massecuite thickness	0.195 m
d – massecuite ID	0.61 m
r – massecuite IR	0.305 m
R_m – equivalent radius	0.410 m
h – height	1.4 m
C – volumetric capacity per cycle	$1.1 m^3$/cycle
ω – basket speed	1220 RPM
G – gravitational force	682 g – force
θ – cycles completed per hour	18.18 cycles per hours
Q – massecuite throughput per hour	20 m^3/hr

Capital Cost (two batch centrifuges)	Operating Cost (two batch centrifuges)
Equipment - $132798 +/- 40%	**Electricity - $13277**
Installation - $19918	**Maintenance - $13279**
Total - $132798 +/- 40% + $19918 for purchase and installation	**Total - $26556/year**

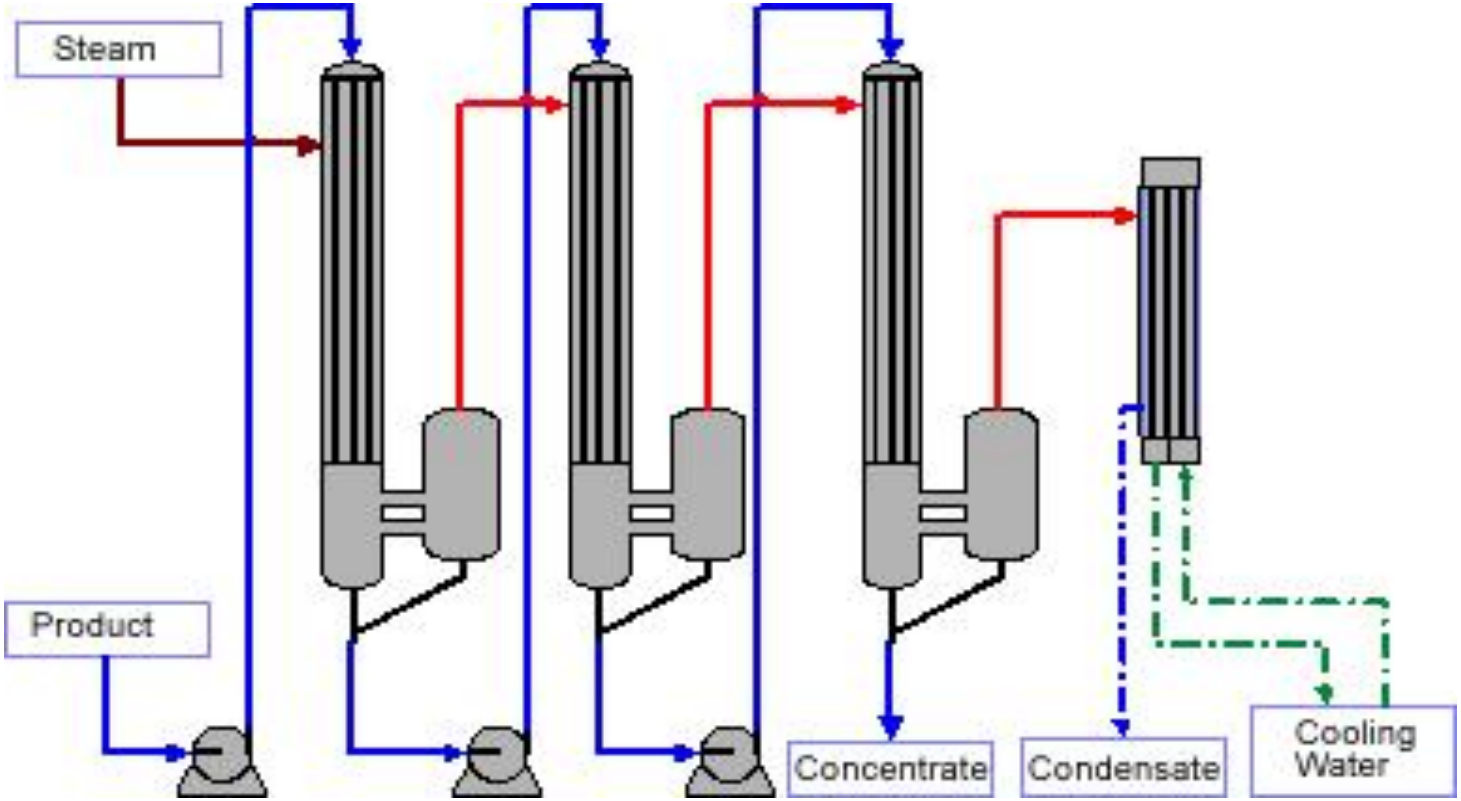
References:

Hugot, E., and G. H. Jenkins. *Handbook of Cane Sugar Engineering*. Amsterdam: Elsevier, 1986. Print.

Geankoplis, Christie J. *Transport Processes and Separation Process Principles: (includes Unit Operations)*. Upper Saddle River, NJ: Prentice Hall Professional Technical Reference, 2003. Print.

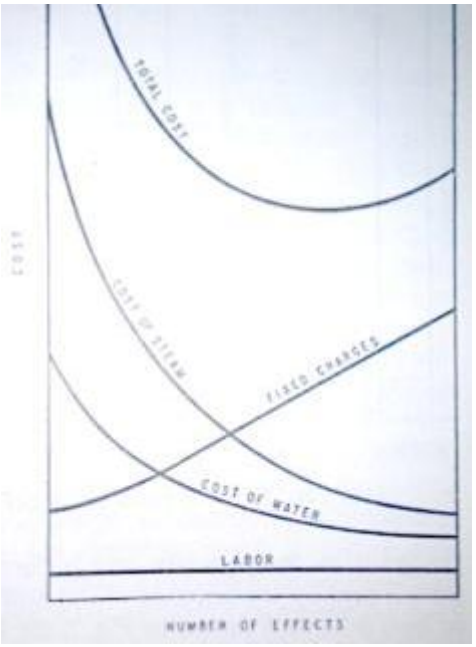
Lactic Acid Purification from Fermentation: Multi-Effect Evaporation

By: Derek Seguin & Nicole Rich-Portelli



GEA Process Engineering, Multi-Effect Evaporation: http://www.niroinc.com/evaporators_crystallizers/energy_evaporation_plants.asp 22Nov2012

Operating Costs: Evaporation



Major factor: Steam generation

Fuel cost (Cf) accounts for ~90% of the total cost of steam generation

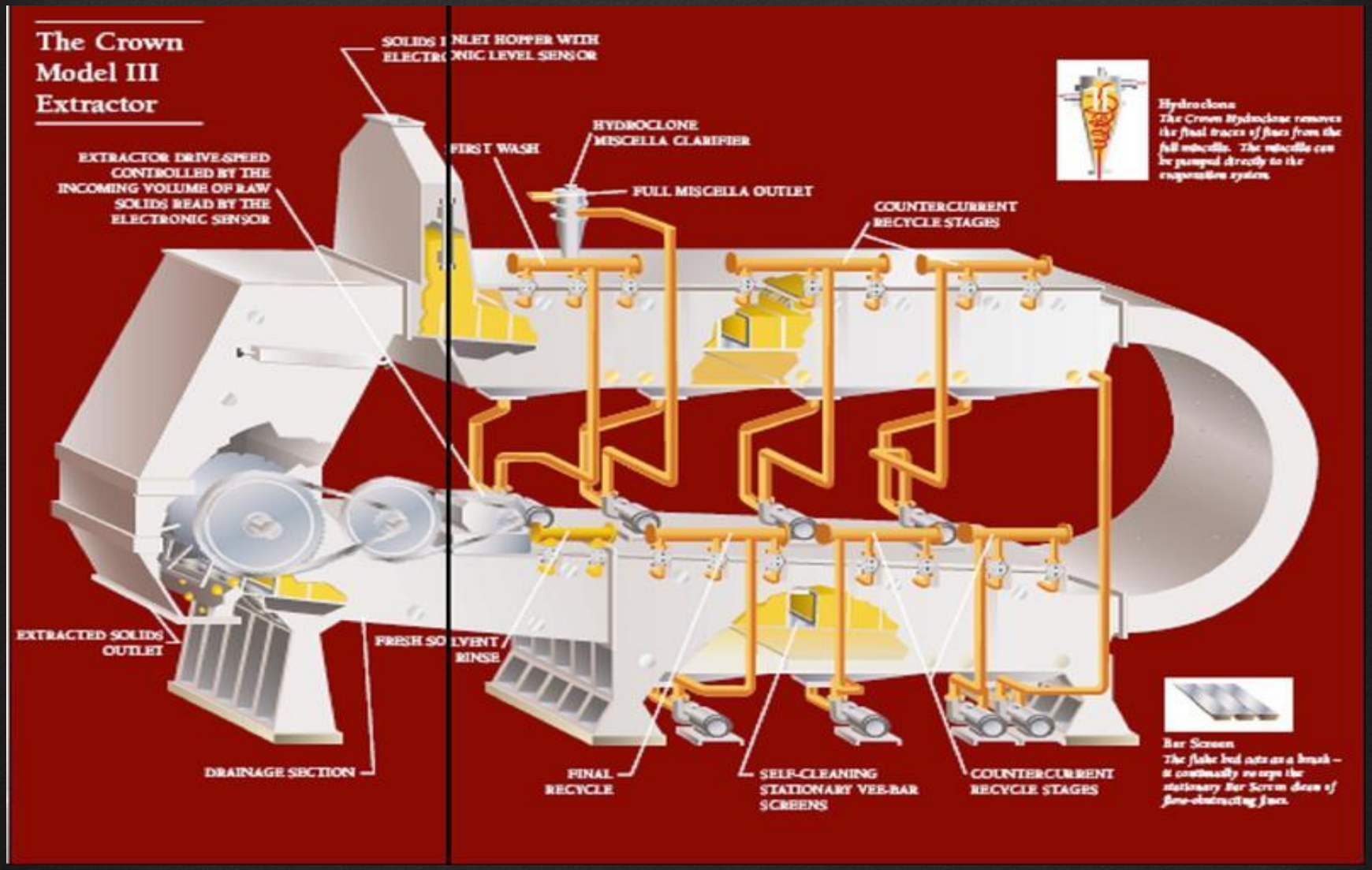
$$Cf = P * \frac{(H2 - H1)}{n}$$

n - Efficiency of the operating unit (typically 80%)
P - Price of fuel $3.3e-6/kJ
H - Enthalpies of incoming/exiting steam (kJ/kg) - from steam tables

Operating cost (steam) = Cf*Flow rate of steam
Operating cost (steam) = $0.011/kg * 29,185kg/h = **$2,812,000/year**

Resources:
Geankopolis, C. J. (2003). **Transport Processes and Unit Operations** (4th ed.)
Green, D., and Perry, R. **Perry's Chemical Engineers' Handbook**. 8th ed.

Solvent Extraction of Vegetable Oils



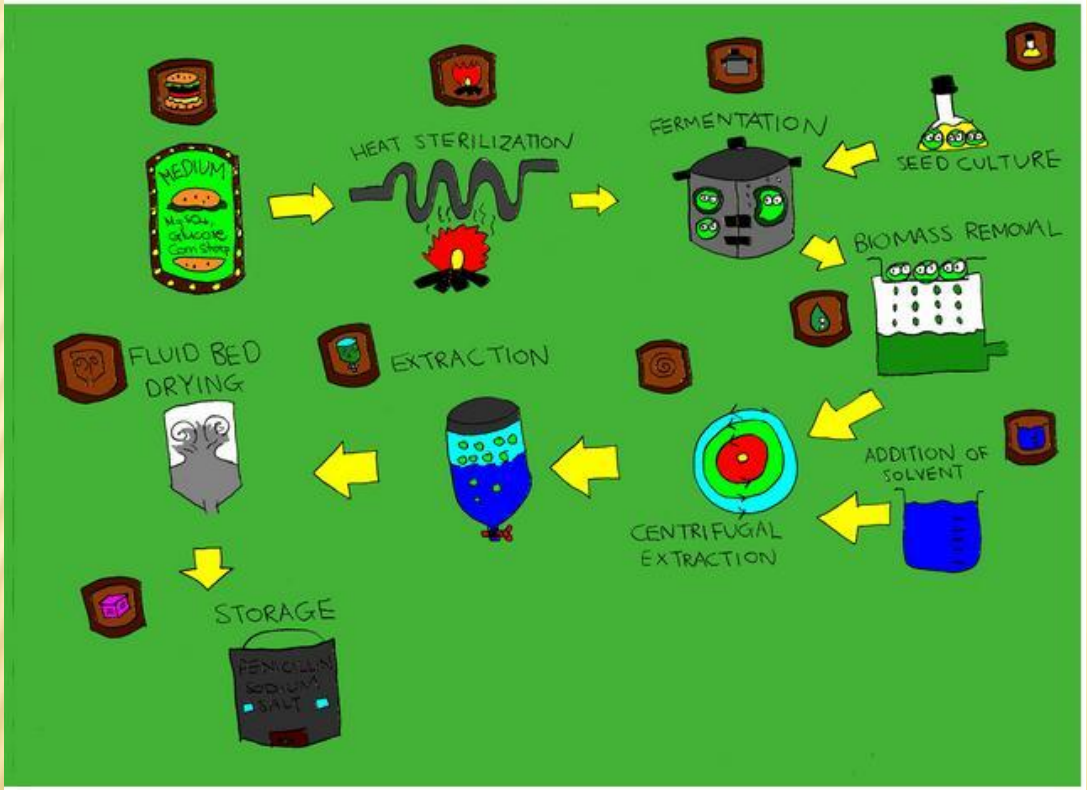
Capital Cost	
Shallow Bed Extraction Unit V = 4793 gal	$212,016 ±20% **$169,000 to $254,000**

Operating Costs	
Energy	$349, 305/year
Hexane (Solvent)	$22,442,770/year

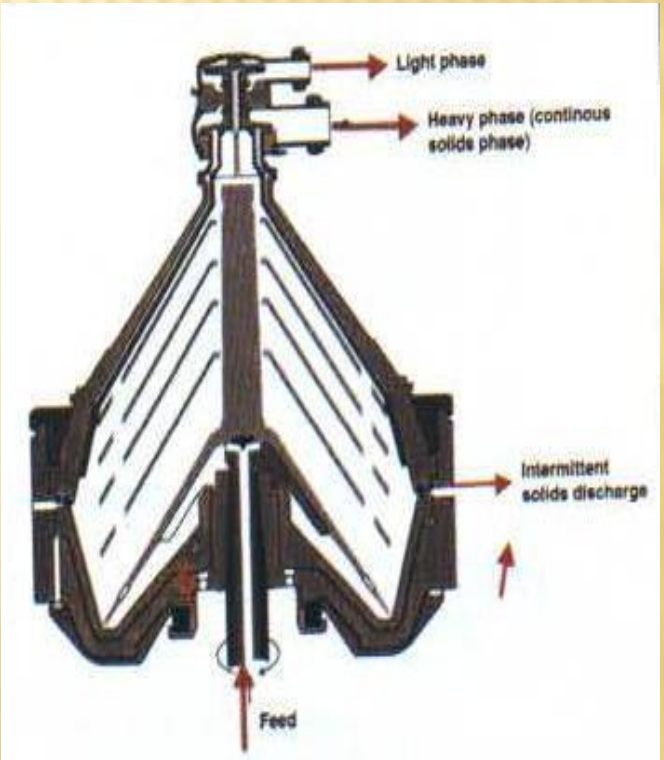
- Cerutti, Myriam. "Solvent Extraction of Vegetable Oils: Numerical and Experimental Study." *Food and Bioproducts Processing* 90(2): pp. 199-204, 2012.
- Williams, M.A. "Obtaining oils and fats from source materials." *Bailey's Industrial Oil and Fat Products, Fifth Edition.* John Wiley & Sons: New York, 1996.

PENICILLIN PRODUCTION

Faizan Abbasi
Richard Cenedese



- Addition of Butyl Acetate solution
- Able to operate in a continuous process



- Space between disks around 0.5 to 3 mm
- Disks used to reduce the sedimentation distance
- The driving force is the difference in densities

CAPITAL COSTS

Purchase Price	Installation
$185 000	$18 500

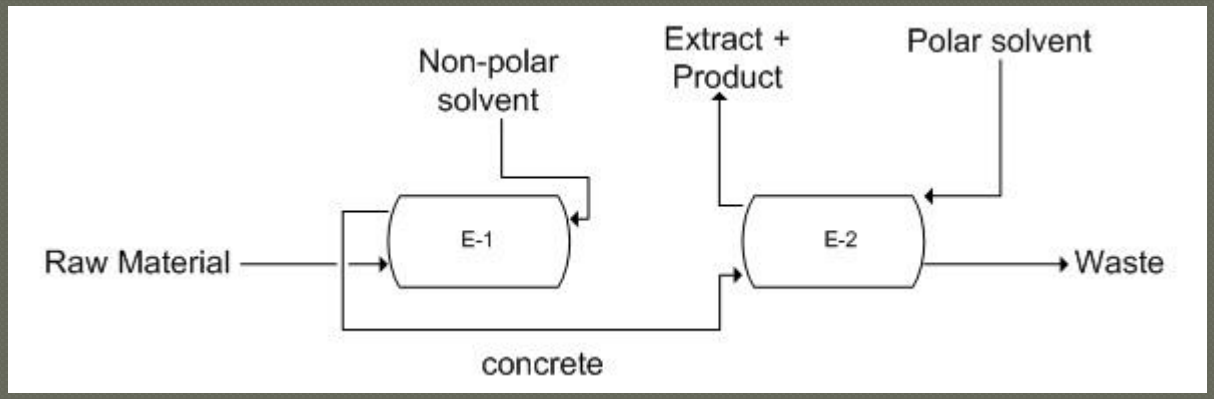
OPERATING COSTS

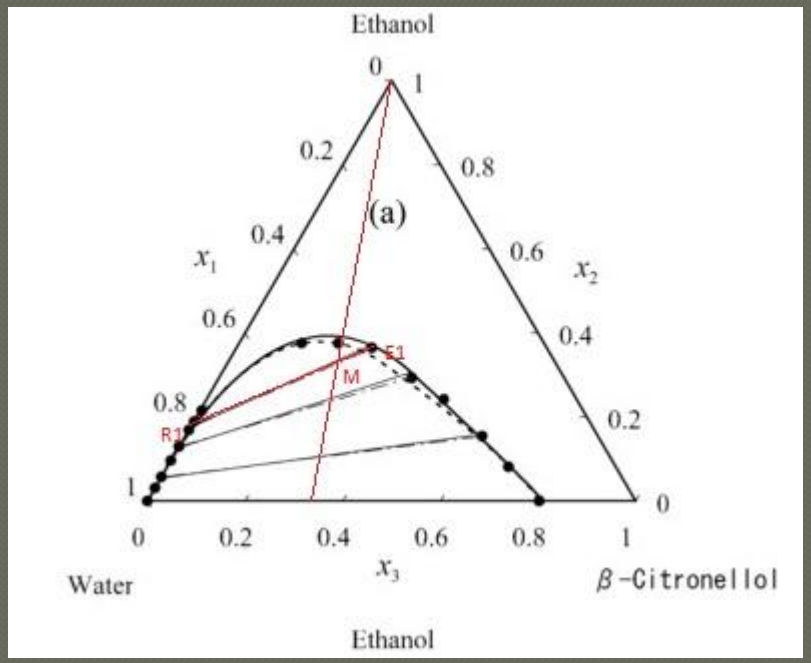
Energy Costs	Maintenance
$10 000	$18 500

[1] Dong , H. R., & Guo, Q. Z. (2009, February 23). Separation and purification of penicillin g from fermentation broth by solvent sublation. Retrieved from: http://www.sciencedirect.com/science/article/pii/S1383586608004139

[2] Perry, RH, *Perry's Chemical Engineers' Handbook*, 8th Edition, McGraw-Hill, 2008

Solvent Extraction for Production of β-citronellol from Rose Petals





Governed by:

- $Da = [A]_{org}/[A]_{aq}$

For two-phase systems:

- $\alpha = Da/Db$

Capital and Operating Costs

Table 1 – Estimated capital and operating costs for 3% global production of β-citronellol.

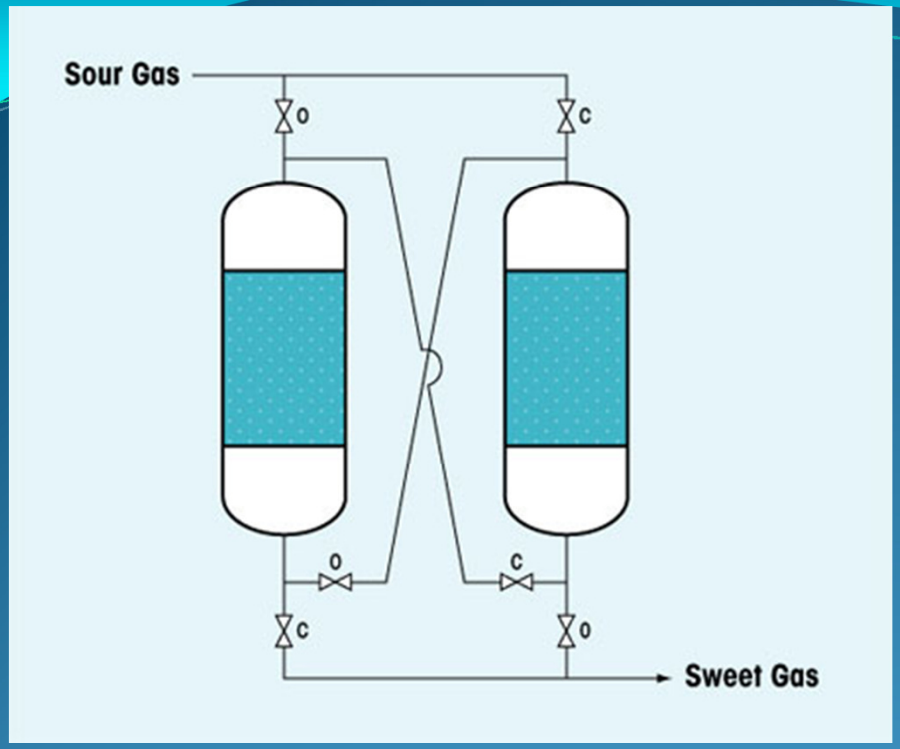
Object	Cost
Capital Equipment	$315 000/unit
Raw Feed (Rose Petals)	$729 700 000/year
Ethanol Solvent	$454 790/year
Utilities	$1524/year

References:

[1] Geankoplis, C.J., *Transport Processes and Separation Process Principles*, 4th ed., New Jersey: John Wiley & Sons, Inc., 2008.

[2] Bailes, P.J., et al., *Liquid-Liquid extraction: The process, the equipment,* University of Bradford (Great Britain), 1976.

Pressure – Swing Adsorption



Separating Methane from Natural Gas

- Pressure swing occurs during the regeneration stage
- Reducing the pressure empties the fully saturated adsorbent bed

Adsorbent: *Zeolites* , high selectivity and compatibility for polar compounds (such as H2S)

Adsorbate: *H2S*

By: Tamar Makdessian and Talia Ceti

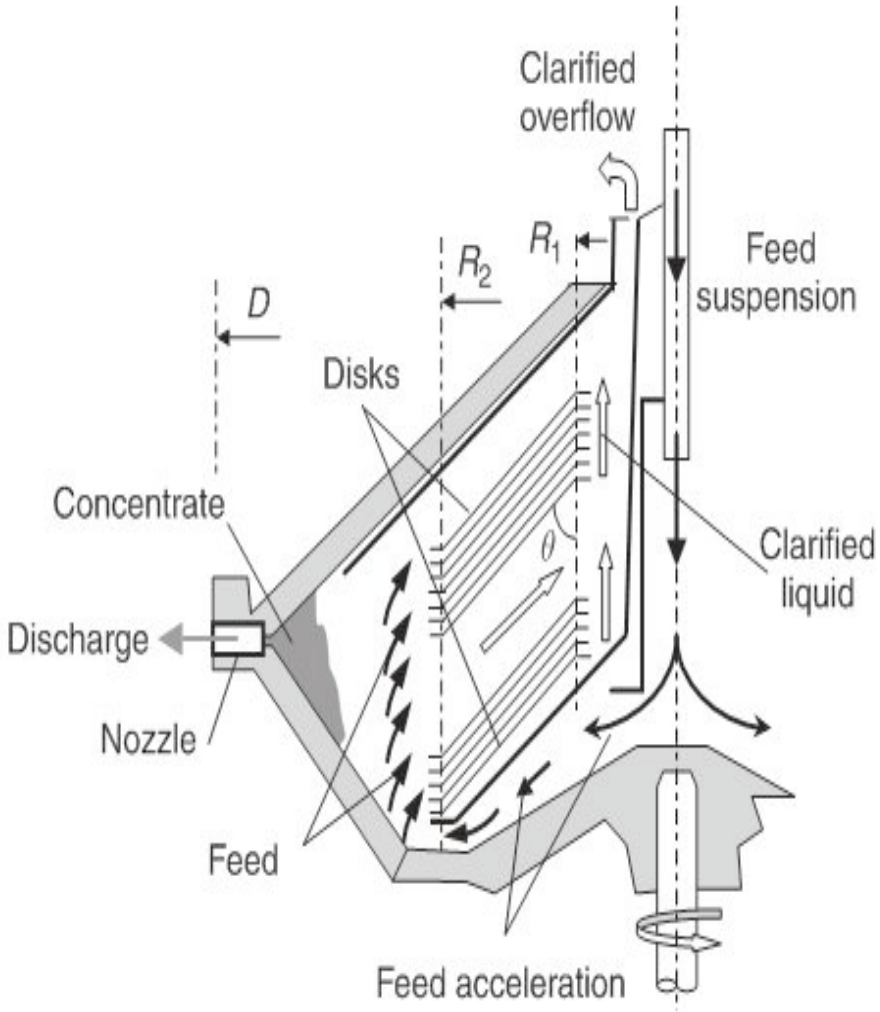
Cost Break down

Equipment	FOB cost -40%	FOB cost +40%
Compressor	$232 490	$406 858
Vessels (2)	$1 488 756	$ 2 605 323
Total cost	$ 1 721 246	$ 3 012 181

Raw Material	Cost	Per Year
Nitrogen	$2.75/ 100 ft^3	$7 452 467
Zeolite	$2/ kg	$12

References:
[1]Ruthven, Douglas, Farooq, Shamsuzzaman and Knaebel, Kent. Pressure Swing Adsorption. New York: 1994
[2] Cosoli, Paulo. Hydrogen Sulphide Removal from biogas by Zeolite Adsorption. Elsevier.
URL<http://www.mose.units.it/doc/p0371.pdf>

Disk-Bowl Centrifuge for Orange Juice Clarification



- Orange juice with 10-12 % pulp enters at top
- The feed is fed to rising channels and split to disks
- Density difference between pulp and fluid allow solid particles to flow to conical disks
- Solid particles slide to holding space and removed, clarified liquid removed from top

Terminal Settling Velocity:

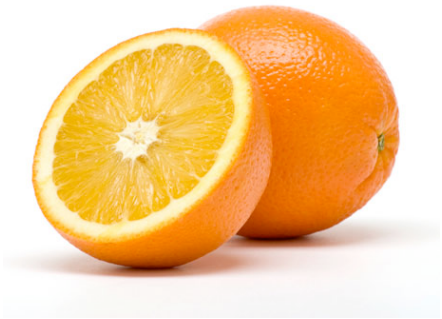
$$v = \frac{(\rho_p - \rho_f)\, g D_p^2}{18\mu_f}$$

Design Equation:

$$\Sigma = \frac{2\pi\omega^2 N(r_1^3 - r_2^3)}{3g\tan\theta}$$

By: Elaf Kasim, Sarah Najib

Disk-Bowl Centrifuge for Orange Juice Clarification



Costing

Based on feed rate of 19.4L/s:

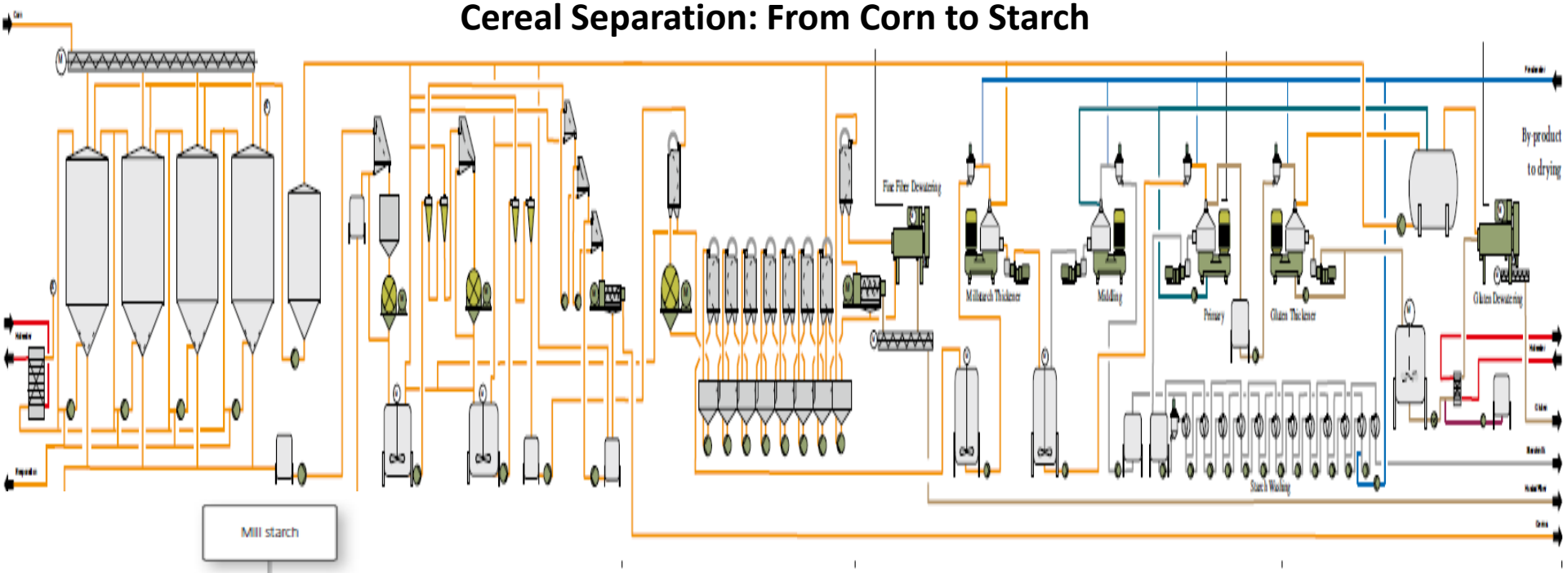
Cost	Amount
Capital Cost (includes equipment, contractors' fees, design contingency, installed instruments)	$1,053,262 ± 30%
Operating Cost (Yearly)	
• Labour	$40,000 × 4
• Electricity - 6 kW.s/L of feed required - Cost: 8 cents/kWh	$23,841
Maintenance	5-10% of Capital Cost

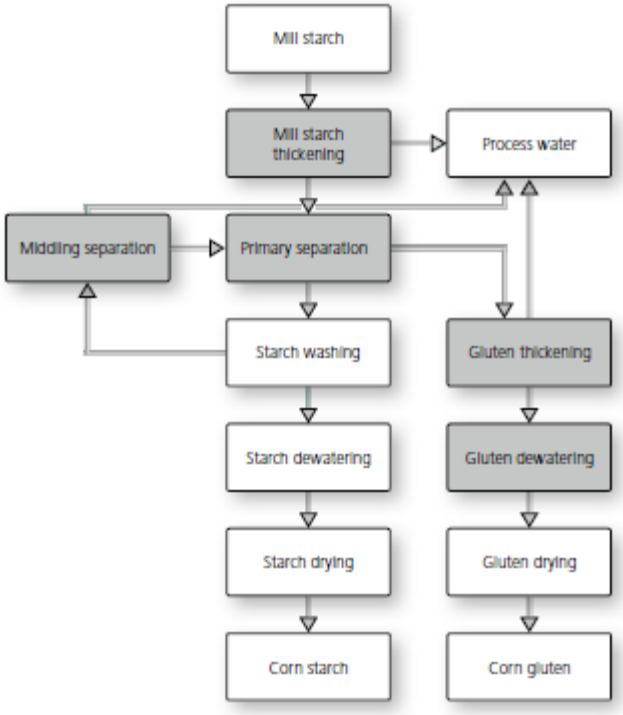
References:

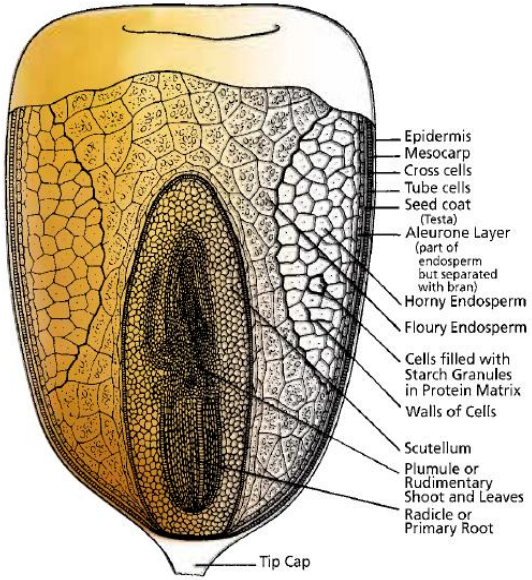
[1] Geankoplis, C.J. "Transport Processes and Separation Process Principles", Chapter 14

[2] Leung, Wallace W, Centrifugal Seperations in Biotechnology, Elsevier Science & Technology, 2007

Cereal Separation: From Corn to Starch

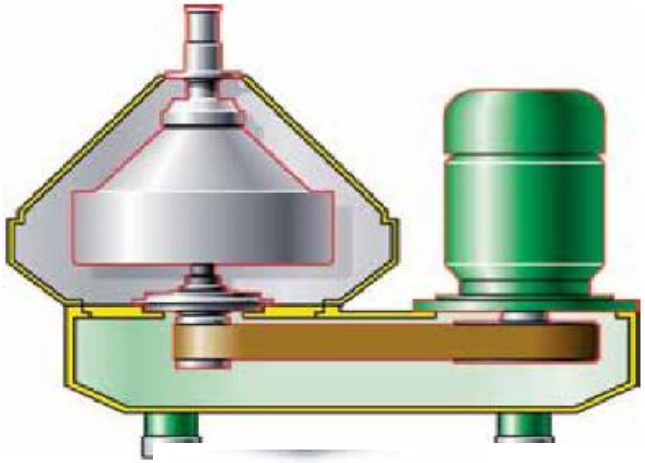






[1]

Anderson Pang 0953378



$$\mu_o = \frac{(\rho_{starch} - \rho_{gluten})gd^2}{18\mu}$$

$$\Sigma = \frac{2\pi\omega^2(N-1)(r_2^3 - r_1^3)}{3g\tan\theta}$$

Qcut = 2vTSV Σ

Qcut =250 000L/h

SDC 110/130/160 nozzle bowl centrifuge

With or without washing device or concentrate recycling system

SDC 160-..-003 Direct drive

SDC 160. Technical data and capacity

Installed power	160 kW
Number of nozzles	18
Rated capacity feed	max. 250,000 l/h
Rated capacity wash water	max. 40,000 l/h

d_{max}=6.2 µm
d_{in}=1m
d_{out}=0.25m
N=160
corn starch density =660 kg/m^3
corn gluten density=400 kg/m^3

ω= 2471.49

θ= 45°

μ_o =1.702*10^-10 m/s

$\Sigma = 2.06 * 10^{11}\ m^2$

Powered required is 160 kW
$11,356.8 per year.

Estimated cost from alibaba.com are $100 000 USD per unit.

[1]

Anderson Pang 0953378

References

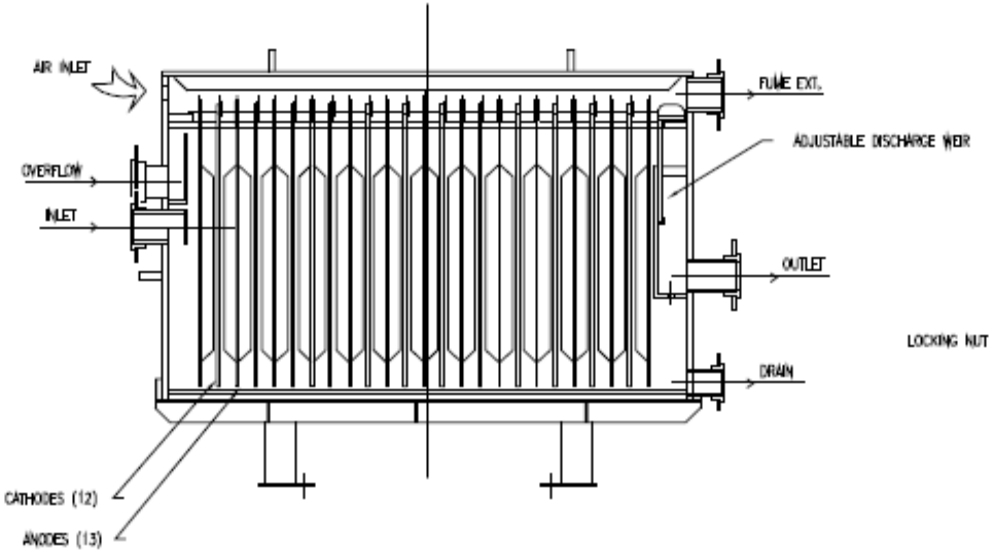
[1] "Start from Corn Separation technology for cereals." *GEA Mechanical Equipment* 1 (2012): 8. *GEA Westfalia Separator Group*. Web. 17 Oct. 2012.

[2] Dunn, Kevin . "Separation Processes." *4M03 Seperation Processes*. N.p., 10 Oct. 2012. Web. 17 Nov. 2012. <http://learnche.mcmaster.ca/wiki_4M3/images/a/a7/2012-4M3-class-03B.pdf>.

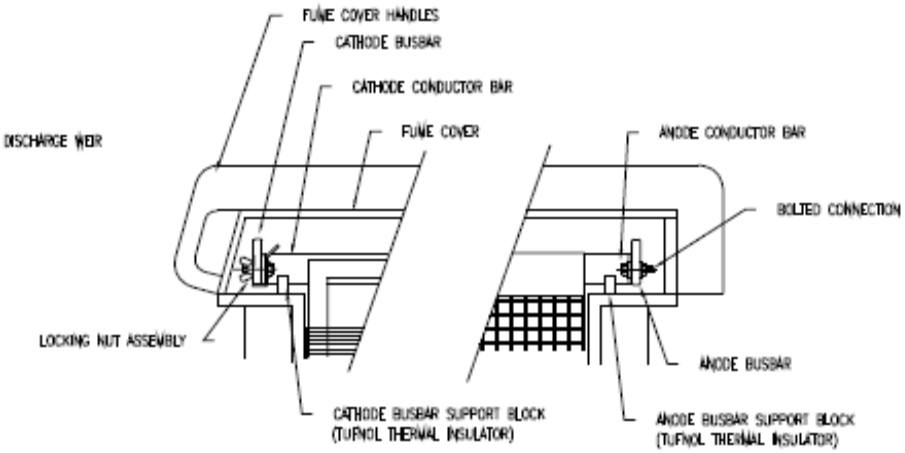
[3] Dr. A. Margaritis,. "5. Centrifugation Processes." *University of Waterloo*. N.p., n.d. Web. 17 Nov. 2012. <http://www.eng.uwo.ca/people/amargaritis/Margaritis%20CBE%20403a%20Fall%202007/CBE%20403a%20Course%20Notes%205%20%28centrifugation%20processes%29%20F%202007.pdf>.

[4] Dunn, Kevin . "The Design And Sizing Of A Centrifuge For SAB." *University of Cape Town* 1 (1998): 12. Print.

Electrowinning Cell Mechanism



SECTION ON CENTRELINE



DETAIL OF CATHODE AND ANODE CONNECTIONS

- Recovers metals from solutions by electrochemical reactions
- Reactions are heterogeneous
- Cathodic and Anodic Ones
- electrons are transferred from the cathode
  - $Ni^{2+} + 2e^- \rightarrow Ni$
- Electrons are transferred to the anode
  - $2H_2O - 4e^- \rightarrow O_2 + 4H^+$

- An electrowinning unit consists of an electrolytic cell a rectifier and a pump. The electrolytic cell is composed of a tank where cathodes and anodes are supplied with electrical potential. The rectifier converts AC into DC current, and the pump causes the solution of Ni2+ and cd2+ as well as Fe3+ to flow through the unit.

Costing of an Electrowinning Cell

Assumptions
Installation Costs are Included
Operated for 300 days a year
9 hours a day
20000 tons of batteries are recycled per year

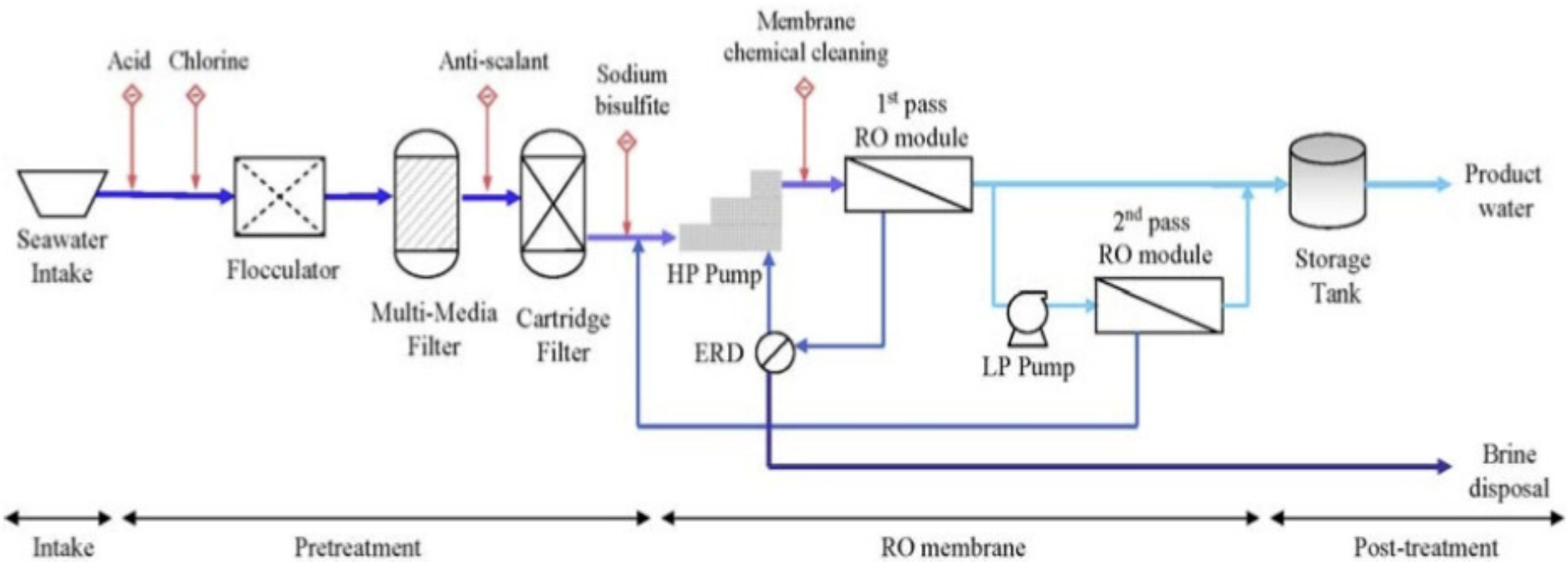
Source	Operating Costs
Labour and Maintenance ($10 /hour in directly due to monitoring)	$ 27, 000
Energy (0.07CDN/KWh)	$217,000
Electrode Replacement ($200 each)	$20,000

Capital Cost	
Electrolytic Cell and Installation (4 Units 4000 Amperes)	$300 000

Ewa Rudnik, Marek Nikiel, Hydrometallurgical recovery of cadmium and nickel from spent Ni–Cd batteries, Hydrometallurgy, Volume 89, Issues 1–2, September 2007, Pages 61-71, ISSN 0304-386X, 10.1016/j.hydromet.2007.05.006. (http://www.sciencedirect.com/science/article/pii/S0304386X07001144)
Keywords: Cadmium; Nickel; Electrowinning; Leaching; Ni–Cd batteries

http://biomine.brgm.fr/

Seawater Desalination



Reverse Osmosis unit for desalination of seawater

Nada Hosni
Maiyeah Ly

With 15% downtime annually and an average flow rate of 24.8 million gallons/day:

$Total\ Capital\ Cost = \frac{\$4.5}{\left(\frac{gal}{day}\right)}$ at 24.8 $\frac{MGal}{day}$, Total Capital Cost is $111.6 million

$Total\ Operating\ Cost = \frac{\$2.6}{1000\ gal}$ at 24.8 $\frac{MGal}{day}$ and 15% down time, Total Annual Operating Cost is $20 million

References:

- Jamal, K., M. A. Khan, and M. Kamil. "Mathematical Modeling of Reverse Osmosis Systems." *Desalination* 160 (2004): 29-42. *Science Direct*. Web. 6 Nov. 2012.

- Bartman, Alex R., Aihua Zhu, Panagiotis D. Christofides, and Yoram Cohen. "Minimizing Energy Consumption in Reverse Osmosis Membrane Desalination Using Optimization-based Control." *Journal of Process Control* 20.10 (2010): 1261-269. *Science Direct*. Web. 14 Nov. 2012.

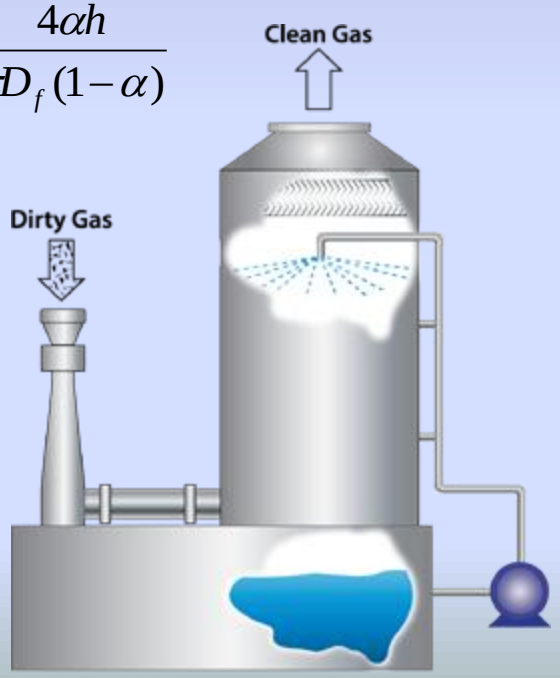
Design Equations of a Scrubber

$\eta_{\text{spray efficiency}} = 1\text{-exp}((-3RL/2D_dG)\eta_{\text{single drop}})$

$\eta_{\text{filter efficiency}} = 1\text{-exp}(-f\eta_{\text{single body}})$

$$\alpha = \frac{(\text{fiber volume})}{(\text{filter volume})} = \frac{(\text{volume of one fiber})(\text{\# of fibers in filter})}{(\text{filter height})(\text{filter thickness})(\text{filter width})}$$

$$f = \frac{(\text{gas volumetric flow swept by fibers, gas vol/s})}{(\text{gas volumetric flow through the entire filter, gas vol/s})} = \frac{4\alpha h}{\pi D_f(1-\alpha)}$$



$m_{\text{dust in}} = m_{\text{removed by spray}} + m_{\text{removed by filter}} + m_{\text{dust escaped}}$

$m_{\text{removed by spray}} = m_{\text{dust in}}(\eta_{\text{spray efficiency}})$

$m_{\text{removed by filter}} = m_{\text{removed by spray}}(\eta_{\text{filter efficiency}})$

Combining the 3 mass equations:

$m_{\text{dust in}}(1\text{-}\ \eta_{\text{spray efficiency}}(1+\ \eta_{\text{filter efficiency}}) = m_{\text{dust escaped}}$

Cost Estimation

Cost of Unit(1970)=(3100)(3140/5000)$^{0.7}$=$2238

Today's Unit Cost=(2238)(1490/300)$^{0.7}$=$6874

Today’s Fan Cost = $836

Today’s Pump Cost = $2984

Total Cost = $10694±40%

Power Ratings for pump and fan were calculated to be 740Watts and 10kWatts respectively.

Estimate 8000 working hours per year with electricity cost of 9cents/kWh.

Total Electricity Cost: (0.74kW+10kW)(8000hrs/year)($0.09/kWh) = $7733/year