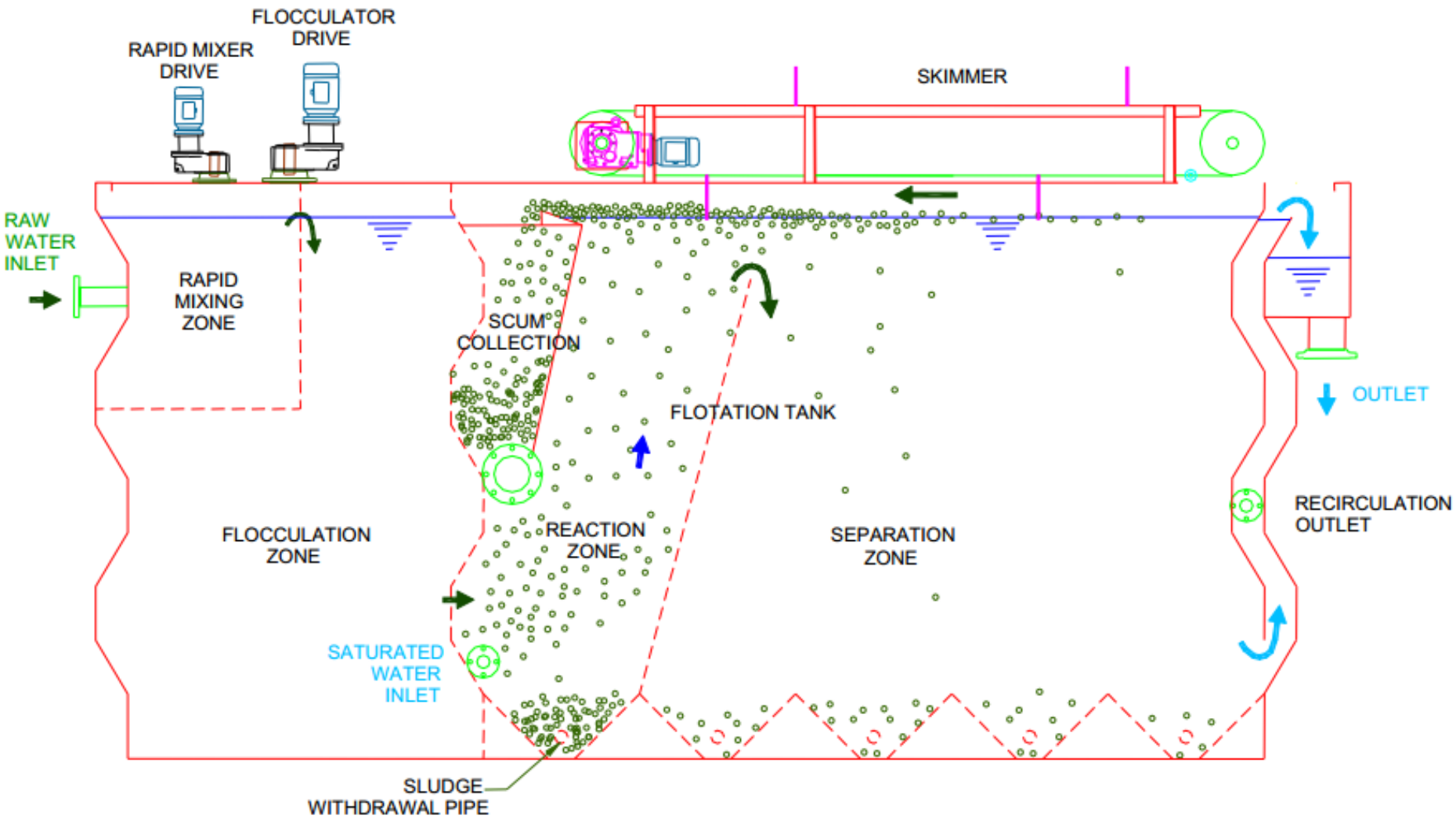
Flocculation and Dissolved Air Flotation



Sean Bowen, Aleah Henry

Cost Estimation

Biomass production/yr	25 tonnes
Tank Surface Area	940.5 m^2
Yearly operation period	330 days (18h/d)
Energy costs	$7692 per year
Flocculant	$15000/year
Capital interest for investment	16.5%/yr
Unit Description	Includes: tankage, pumps, motors, internal piping, c/s package unit, building, air compressor, mix tank, control panel
Total BM Cost 2011 (assume error +-20%)	$4,722,400

[1] US Department of Energy. National Algal Biofuels Technology Roadmap. Energy Efficiency and Renewable Energy. May 2010. Pages 37-101
[2] Chun-Yen Chen, Kuei-Ling Yeh, Rifka Aisyah, Duu-Jong Lee, Jo-Shu Chang, Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review, Bioresource Technology, Volume 102, Issue 1, January 2011, Pages 71-81

Rotary Vacuum Drum Washers In Kraft Mill Pulping

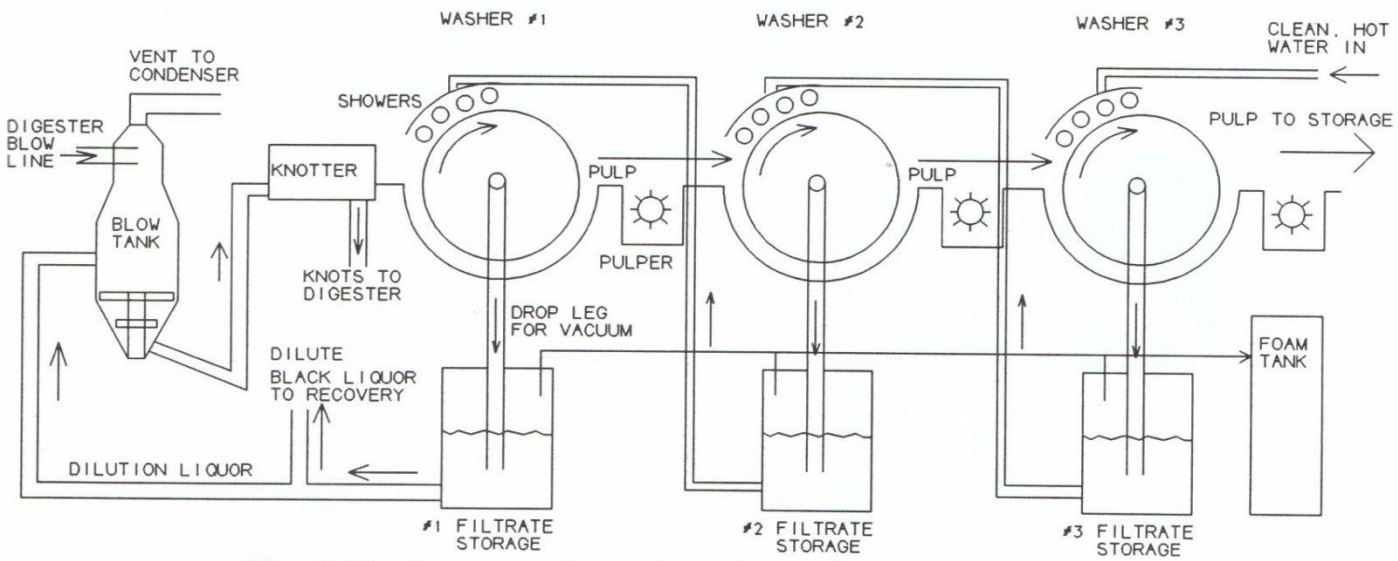


Fig. 3-24. Brown stock washers showing countercurrent flow.

- Each washer operates at 80% filtering efficiency therefore 3 washer in series are connected
- In separation of pulp it is the cake formation
- Approximately 7 tons of black liquor form for each ton of pulp

Design Criteria

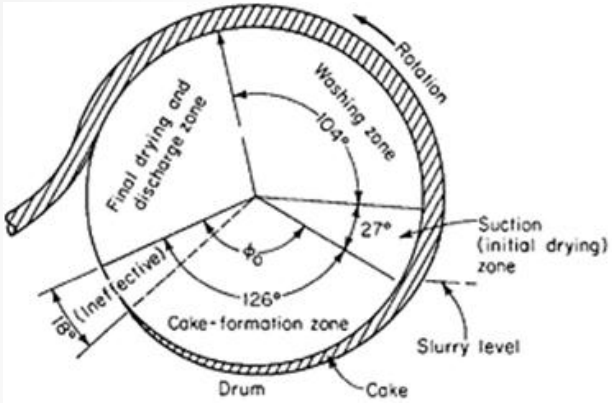


Figure 2: Rotary vacuum drum filter

$$A_{drum} = \frac{\dot{m}_{pulp}}{\dot{m}_{filt,fin}}$$

- Minimum cake thickness is 6 mm
- Effective filtration rate per unit area of the drum surface area depends on submerged circumference
- The drum takes up approximately 15% by volume of the entire washer unit
- Rotation speed depends on the time spent in each zone

Vacuum Drum Washer Costs

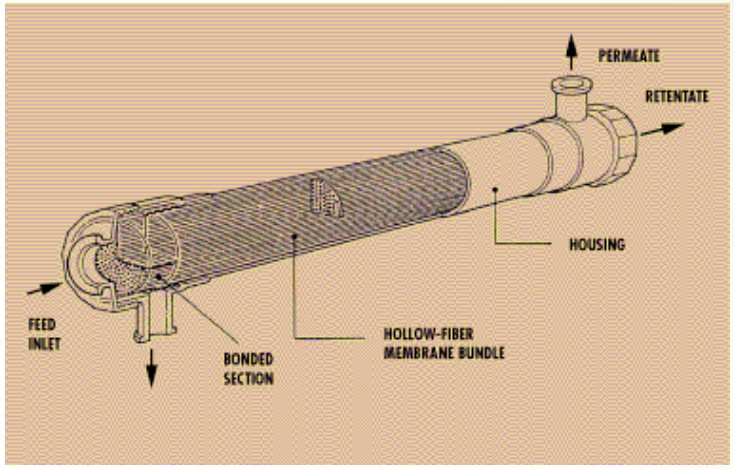
Equipment Costs

Cost	Values
FOB	$45,412.48
Installation	$90,824.96
Correction factor	$90,824.96
Piping	$38,146.48
Total BM (1970)	$265,208.89
Total BM (2011)	$1,312,828.04

Wash water costs

Variables	Values
Flow rate (kg/year)	43,431,844.51
Cost ($/kg)	0.00002
Cost per year ($/year)	$868.64

Ultrafiltration



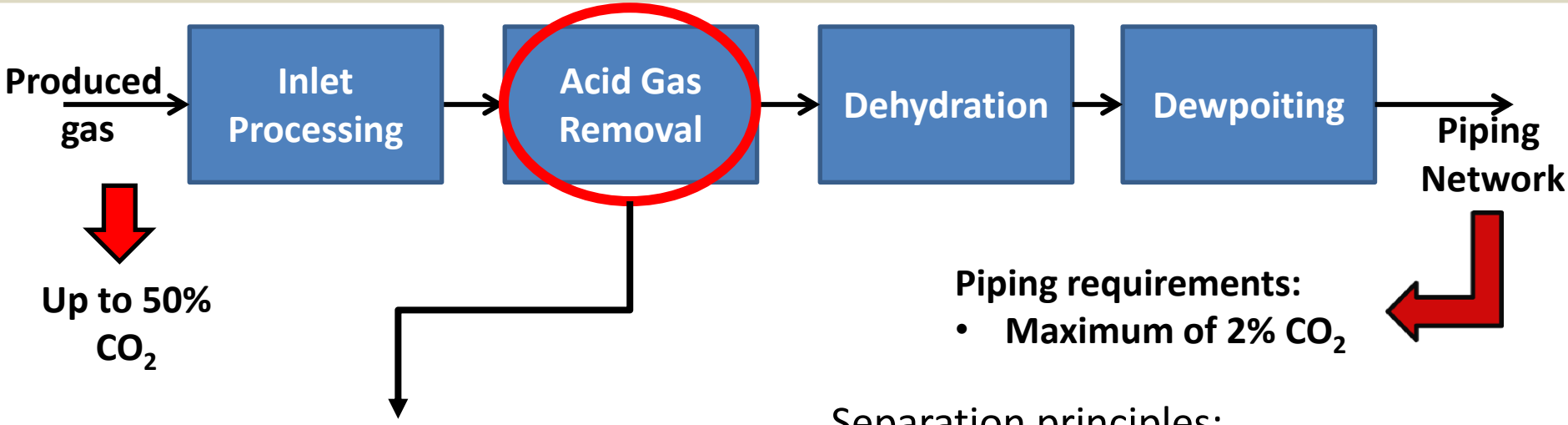
- based on the ability of pressure-driven filtration membranes to separate multicomponent solutes according to molecular size, shape, and chemical bonding
- Hydraulic pressure drives substances with a smaller molecular size through a membrane while the larger molecules are held back

Annual Operating Costs

- Capital Cost for Ultrafiltration Membrane Separation unit: $31,324 to $73,088 one time fee.
- Utilities: $121,680 per year
- Cleaning and Maintenance: $10,000 per year

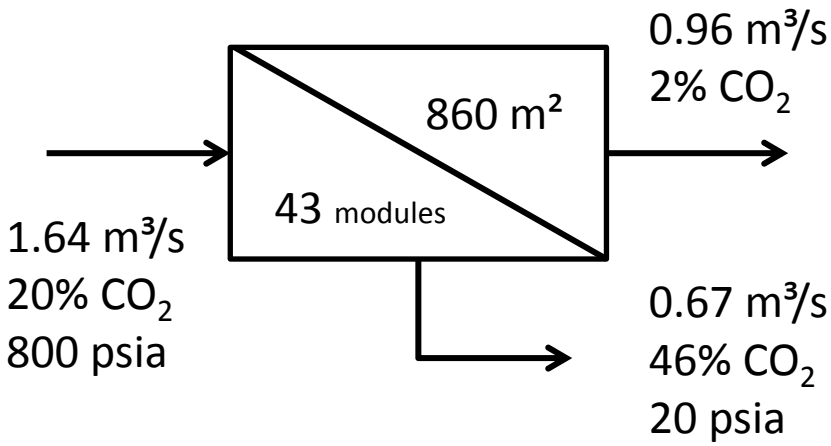
1. Klinkowski, Peter R. "Ultrafiltration: An Emerging Unit Operation." Dorr-Oliver, Inc., Stamford, n.d.
2. A. Ault, *The Monosodium Glutamate Story: The Commercial Production of MSG and Other Amino Acids*, Mount Vernon: Journal of Chemical Education, March 2004, Vol 81, No. 3.

Removal of CO_2 from natural gas by polymeric membrane-Unit Overview



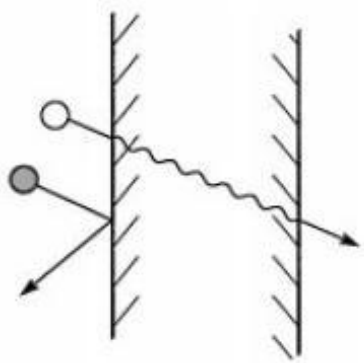
Membrane single stage separation unit:

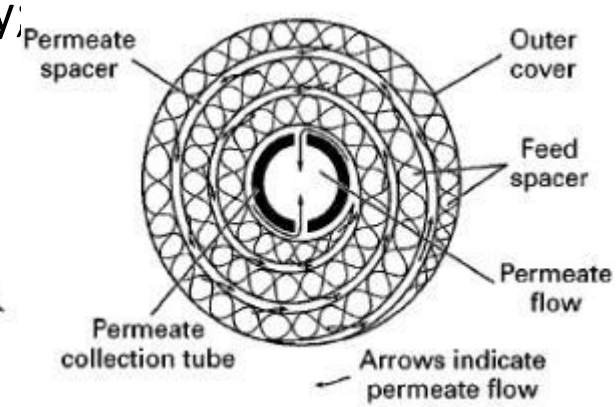
- Spiral wounds;
- Acetate Cellulose;



Separation principles:

- Permeability: diffusivity and sorption coefficients;
- Selectivity;





- Driving force: Partial pressure difference.

Cost Estimation-Single stage membrane unit

Capital Cost		
Membrane housing	\$200 per m^2 of membrane module	\$240,000 (inflated from 1998), # of modules : 43
Working Capital	10% of fixed capital cost	\$24,000

Operating cost		
Membrane replacement	\$90 m^2 of membrane	\$ 77400 every 3 years
Maintenance cost per year	5% of fixed capital cost	\$1,2000 every year
Natural gas price	\$3.77 per 1000 cubic ft	\$6, 880,250 every year

Estimated capital cost of one membrane unit is \$ 265,000 and the operating cost is estimated to be 6,900,000. The cost are based on single unit consisting 43 modules.

- If the modules are added in series then the cost will change
- If the recycle streams are used then requires compressor
  -Trade off-Additional cost of compressor but higher recovery so low raw material cost.

<u>References:</u>

Bakes, Richard W., and Lokhandwala, Kaaeid; *Natural Gas Processing with Membranes: An Overview*, Membrane Technology and Research, Inc., 2007.

Wilson, Ian, editor-in-chief; Cooke, Michael and Poole, F. Colin eds.; *Encyclopedia of Separation Science, Ten-Volume Set*; Elsevier Science Ltd., 2000.

Process Overview – Magnetic Separation

Unit Process

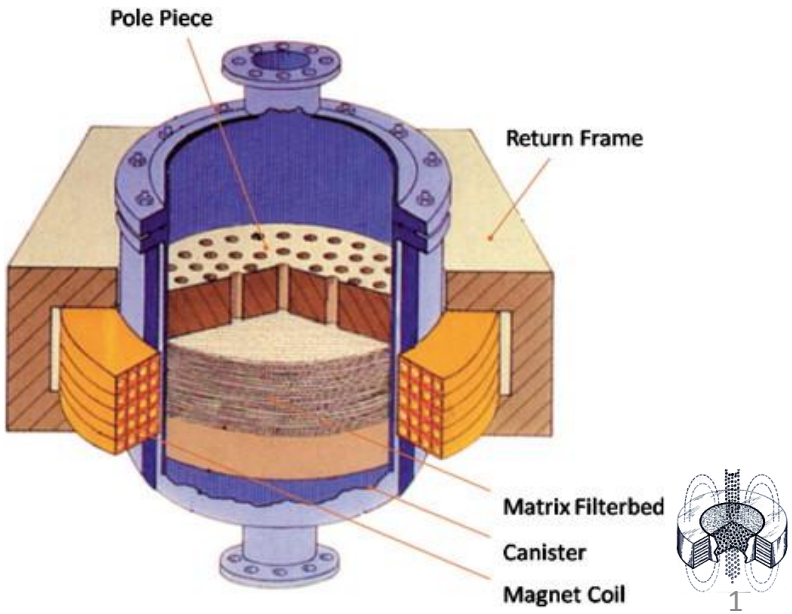
- Particle gain of charge inside magnetic field: ferro, para, diamagnetic
- Iron separated because of high magnetic susceptibility, either para or ferromagnetic
- Matrix is within a magnetic field produced by electromagnet
- Para and Ferro material is attracted to the matrix
- Diamagnetic passes through the matrix
- Magnetic field is turned down and desired material is washed out

Why does the separation occurs?

- $Fm > Fg + Fd + Fc$

Mass balance

- Capacity: 305 t/h ($Q = 3.6LWV_cL_{F3}F$)
- Feed In: 23% solids, 77% water
- Iron Ore Recovery: 24t/h (70% Separation)
- Iron Ore Composition: 45% Iron, 55% Waste



Economics

Cost

- Cost of a continuous high gradient separator: $3.6 M ± 40% ($2.34 M - $5.46 M)

Operating Cost – 1980 for 360 t/h capacity

- Energy Cost: 0.011856 $/Tonne
- Diluting Water: 0.01482 $/Tonne
- Wash Water: 0.044459 $/Tonne
- Unit Wear: 0.029639 $/Tonne

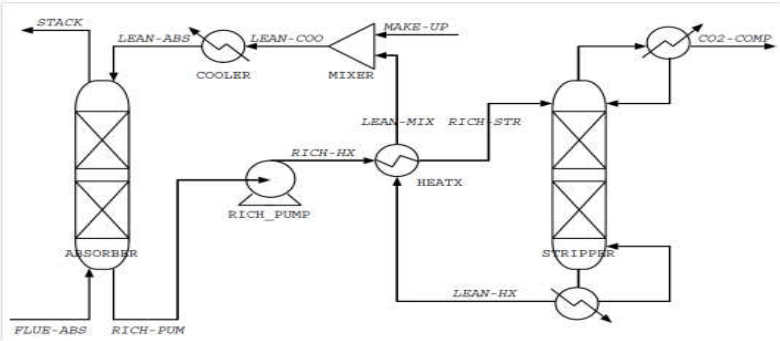
Total: 0.103737 $/Tonne

- Yearly Cost 2011: $460000/Year ± 40% ($276000 - $644000)
- Calculations based on 304t/h (85% of potential capacity)

References

- Perry, RH, *Perry's Chemical Engineers' Handbook*, 7th Edition, McGraw-Hill, 1999, Pages 1796-1805
- Ullmann, F, *Ullmann's encyclopedia of industrial chemistry*, 6th, Wiley Interscience, 2003, Vol. 22, Pages 133-144

CO_2 Absorber Overview



Goal: Removal of CO_2 from gaseous streams

Solvent: Monoethanolamine (MEA)

Applications: Natural Gas and Syngas cleaning

Mechanism:

- Reaction driven absorption
  - $CO_2 + 2\ HOCH_2CH_2NH_2 \leftrightarrow HOCH_2CH_2NH_3 + HOCH_2CH_2NH(CO^-)$
- Mass transfer occurs mainly due to:
  - Reaction
  - Eddy diffusivity

Annual Operating Costs

- Maintenance regularly required on absorber because of corrosive nature of MEA
- Replenishing lost MEA caused by:
  - React with SO_x and NO_x to form heat-stable salts
  - Oxidative degradation
  - Carbamate polymerization

Further Readings:

- Perry's Chemical Engineers' Handbook (Chapter 14), by Perry and Green
- Gas Purification (Up to Chapter 2), by Kohl and Nielsen

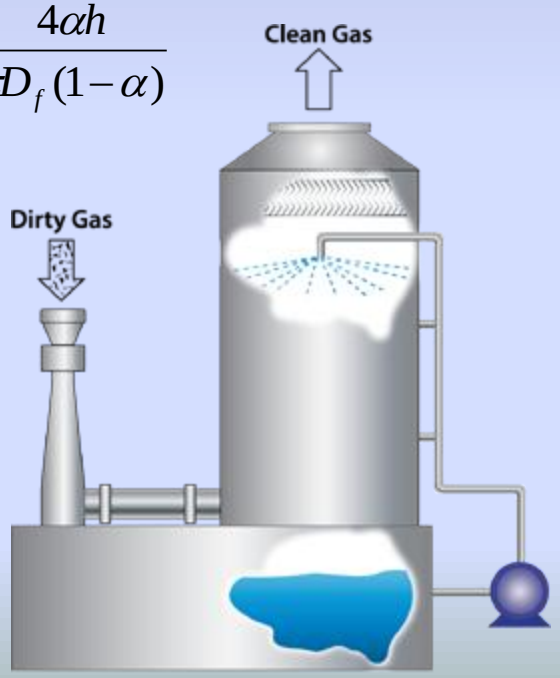
Design Equations of a Scrubber

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

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

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

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



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

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

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

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

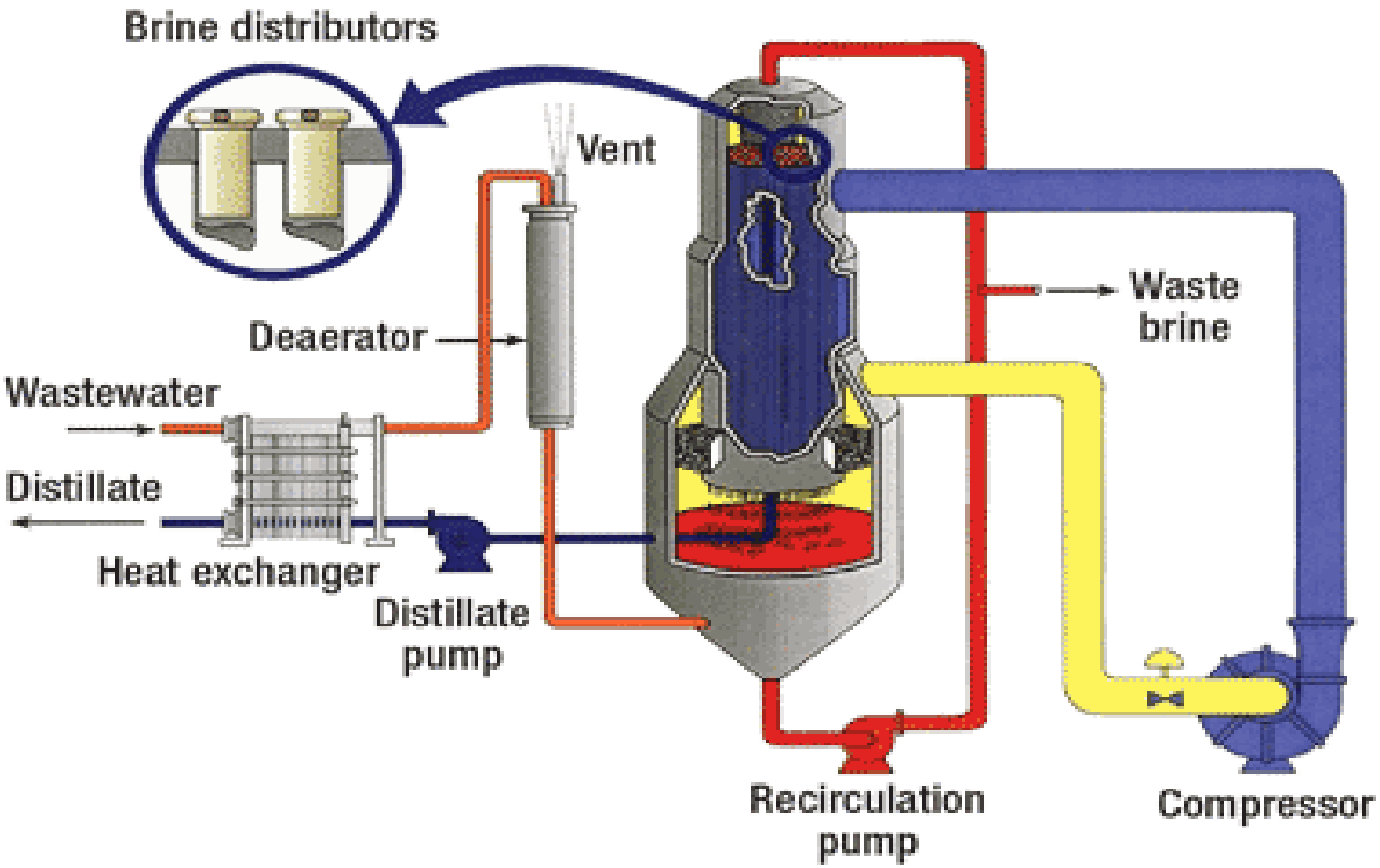
Today’s Pump Cost = $2984

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



Evaporator unit used in INSITU process to purify water using compression as the driving force of heat transfer.

PIECE OF EQUIPMENT	COST – HIGH ESTIMATE	COST – LOW ESTIMATE
Evaporator	$ 130 000	$ 70 000
Heat Exchanger	$ 105 000	$ 45 000

LABOUR	COST
Operator x 4	$ 280 000
Supervisor x 1	$ 100 000
Maintenance x 1	$ 75 000
Engineering x 2	$ 200 000
TOTAL	$ 655 000

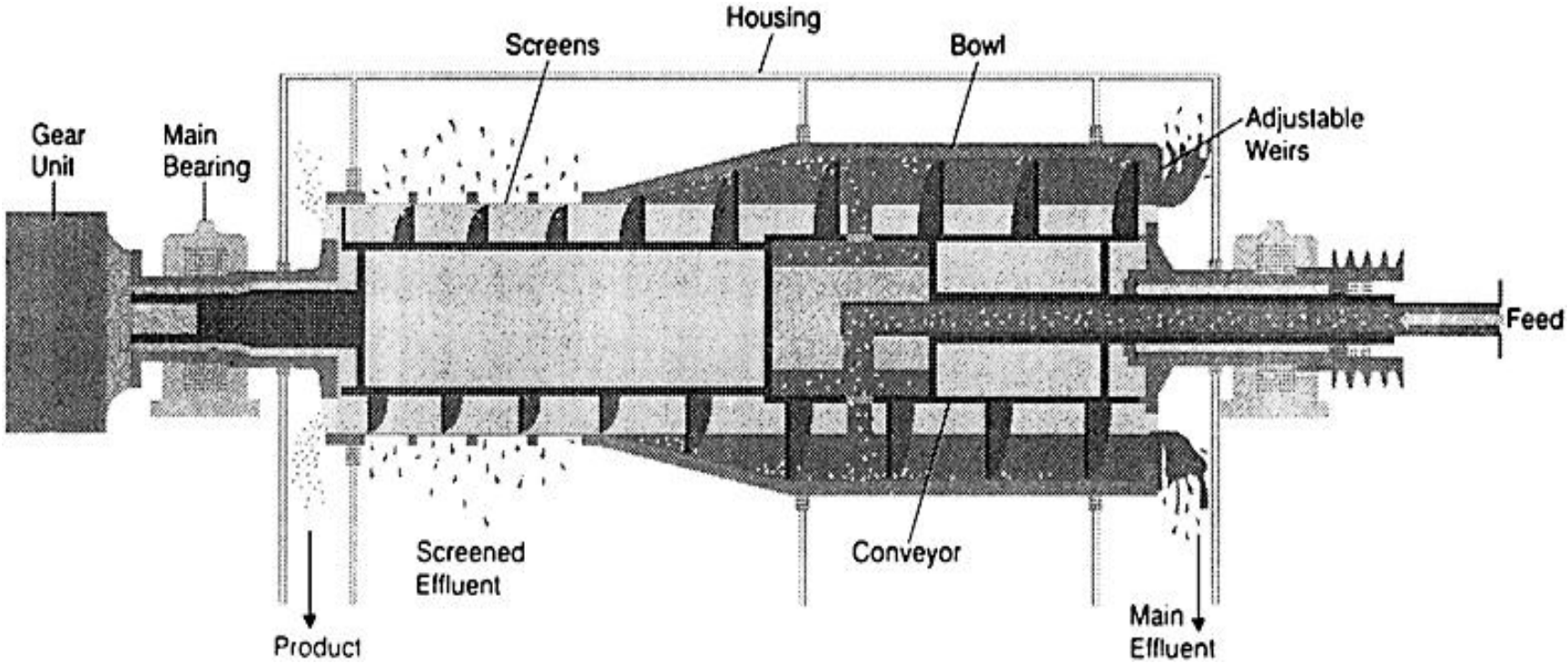
ENERGY SOURCE	COST
Natural Gas	$ 6 130 000

Note: these costs are for running 1 evaporation unit. To accommodate for the volume of water that must be treated, and for increased reliability, 4 units will be run in parallel.

REFERENCES

[1] http://www.worldoil.com/October-2007-Vertical-tube-evaporator-system-provides-SAGD- quality-feed-water.html

[2] http://www.usbr.gov/pmts/water/publications/reportpdfs/Primer%20Files/07%20-%20Lime%20Softening.pdf



- combination of a sedimentation and filtering centrifuge
- Solids in the range of 20 to 200 µm
- Washing and drying in the screen section

Capital	Cost
Purchase Price	$380,000
Variable-Speed Drive	$95,000
Installation	$57,000
Total Cost per unit	$532,000
Operating	**Cost**
Maintenance	$28,500
Energy consumption	$13,000
Labour/monitoring	$9,200
Total Coat per unit per year	$50,700

- Robert Perry; Don Green: Perry's Chemical Engineers' Handbook, Eighth Edition Contributors. CENTRIFUGES , Chapter (McGraw-Hill Professional, 2008 1997 1984 1973 1963 1950 1941 1934)
- PVC – Poly Vinyl Chloride. Chemicals & Petrochemicals Manufacturer's Association of India. Accessed November 17. http://cpmaindia.com/pvc_about.php

Solid Liquid Separator

Disc Nozzle Centrifuge

Oyeniyi Olaoye
Rodas Fisseha

2012-11-20

Principle of Operation

- Starch and gluten mixture are separated based on their difference in specific gravity
- For a good separation: high d, large density difference, large separation radius…
- Solids are discharged continuously through nozzles (24) spaced around the periphery of the bowl.
- Centrifugal gravity acts in an outward direction
- Gluten is gotten at the overflow, while starch is gotten at the underflow

Cost

- **Operational Cost**

$$\text{Yearly utility cost} = \text{Power requirement} \times \frac{\text{hours of operation}}{\text{week}} \times \text{total thoughput} \times$$

$$\text{electrcity cost} \times \frac{\text{48 weeks}}{\text{year}}$$

$$= \$\,26{,}313.25$$

- **Capital Cost**

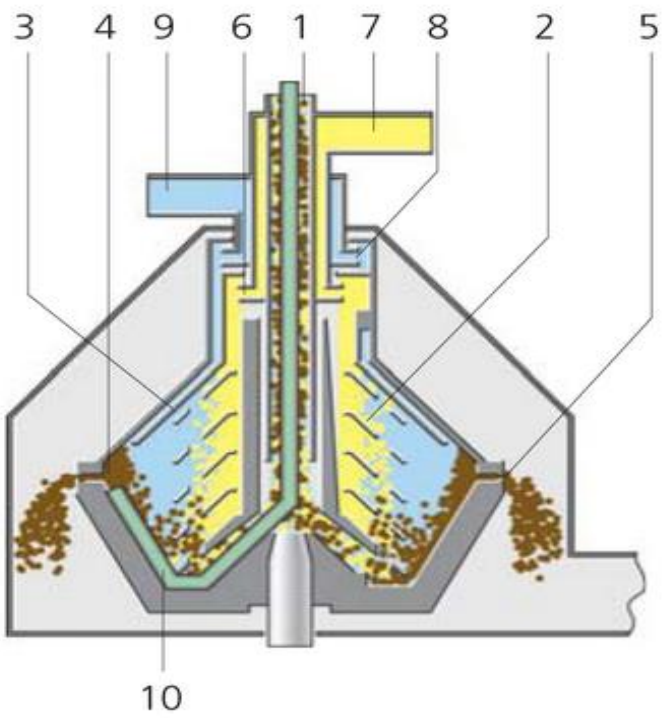
FOB[2012] = $20,000-$50,000

- **References**

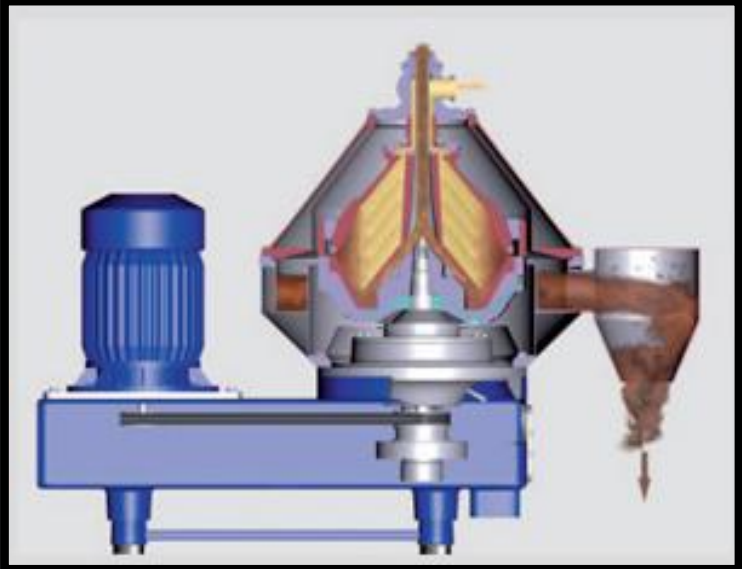
1. Perry, RH, Green, DW Perry's Chemical Engineers' Handbook, 8th Edition, McGraw-Hill, (2008) Page 18-121
2. Global Marketplace for online sourcing and shopping, Jiangsu Peony Centrifuge, http://mudancentrifuge.en.alibaba.com/product/562969429-200124319/Automatic_Nozzle_Wheat_Starch_Separator.html

Solids Conveying Disc-Bowl Centrifuge

For Separation of Acetylsalicylic Acid from Mother Liquor



1: Product feed, 2: Disc stack, 3: Separating disc, 4: Concentrate chamber, 5: Nozzles, 6: Centripetal pump for light phase, 7: Discharge of light phase, 8: Centripetal pump for medium phase, 9: Discharge of medium phase, 10: Feed for wash water or concentrate recycle



$$v_o = \frac{\left(\rho_{Aspirin} - \rho_{MotherLiquor}\right) \cdot g \cdot D_p{}^2}{18 \cdot \mu}$$

$$v_o = \frac{(1400 - 1082) \cdot 9.81 \cdot 0.0002^2}{18 \cdot 0.950} = 7.30 \times 10^{-6}\ m/s$$

Capital and Operating Cost Considerations

- Centrifuge Capital Investment

Purchase Price = $64,904

- Annual Operating Expenses

Electrical Usage = $5,395
Raw Materials = $3,065,066

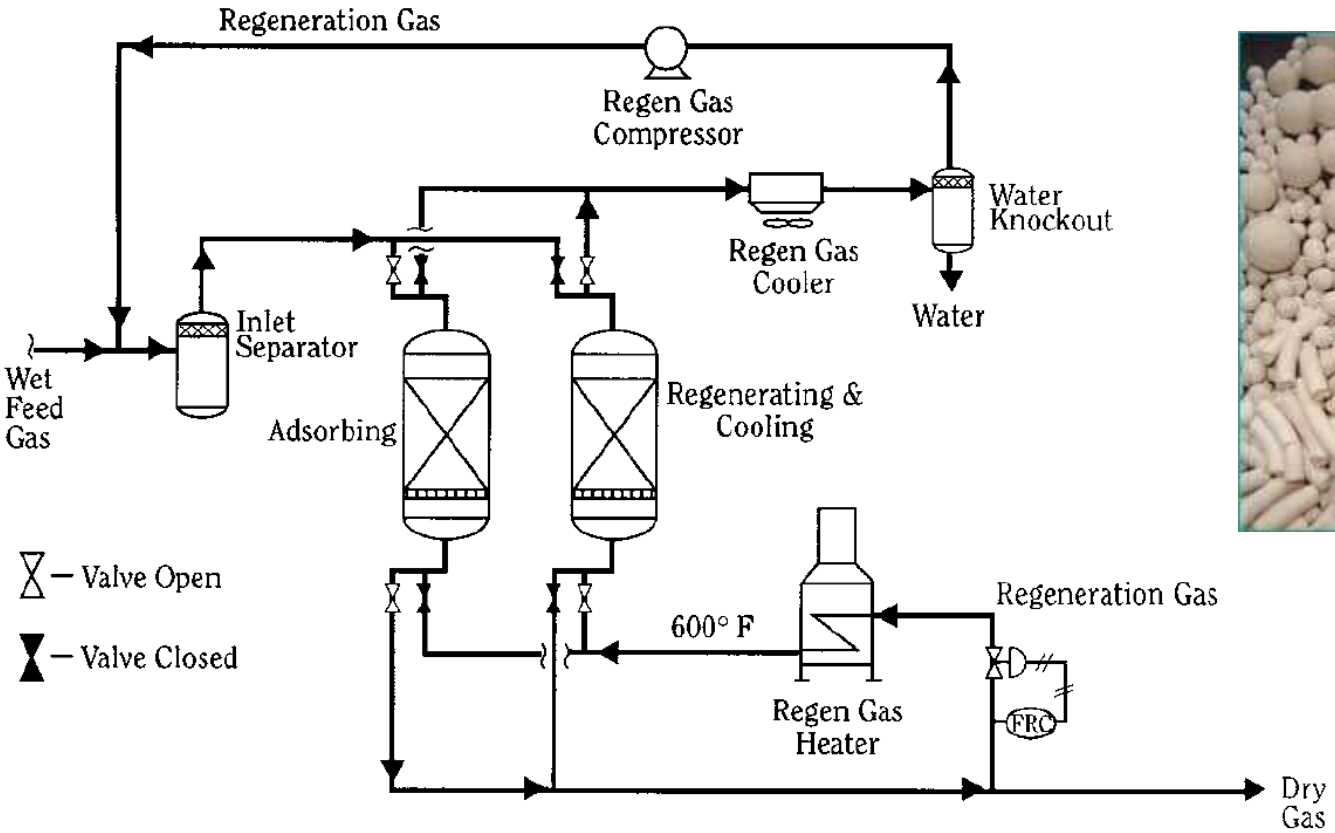
Additional References:

1) Principles of Bioseparations Engineering
Author: Raja Ghosh; Relevant Pages: 86-87 and 194-196

2) Industry Review Article:
http://www.celerosinc.com/pdfs/CentrifugeFocusFiltSep08-05.pdf

Zeolite Molecular Sieve

Type 13X zeolite molecular sieve for the adsorption of CO_2 and H_2O upstream of cryogenic gas distillation



Yearly Operating Costs

- Cost for Regeneration - **Steam**
- 2-8 hour operating window before regeneration
- 0.2 kg Steam per kg Zeolite

$$Steam\ Req. = \left(0.2\,\frac{kg\ steam}{kg\ zeolite}\right)\left(kg\ zeolite\right)\left(\frac{24\,hrs/day}{2\,hrs/cycle}\right)\left(365\,day/year\right)$$

$$Cost = \left(Steam\ Req.\right)\left(\$\,27.7/1000\,kg\ steam\right)$$

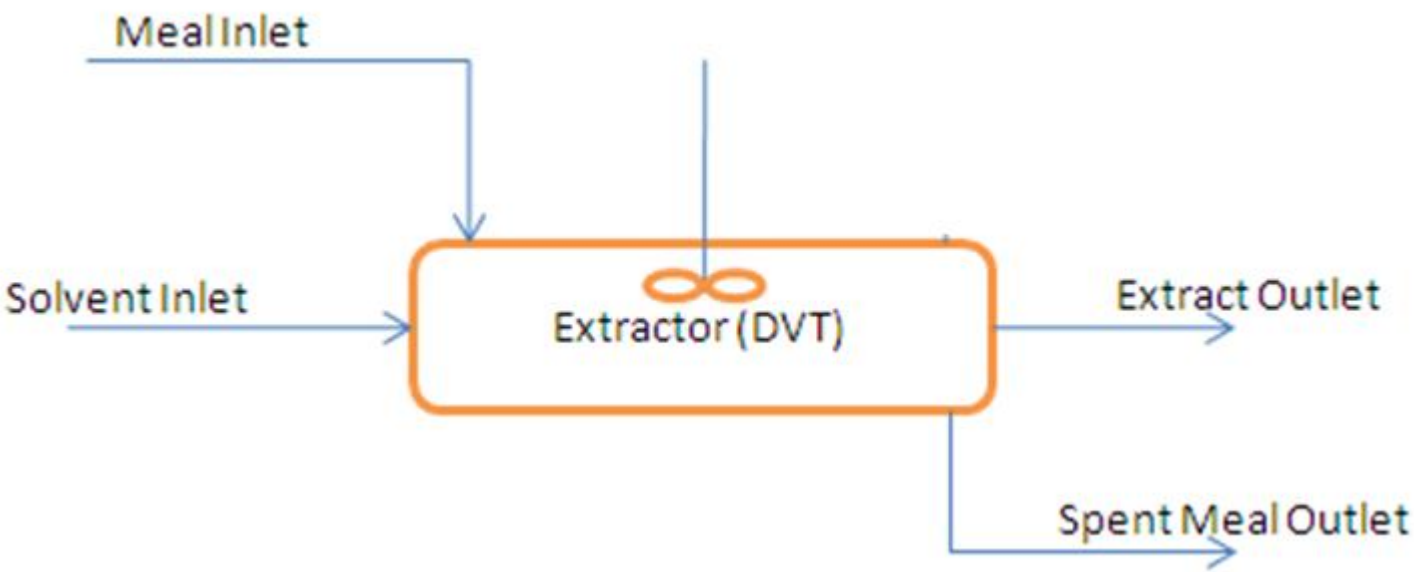
Handbook of Zeolite Science and Technology

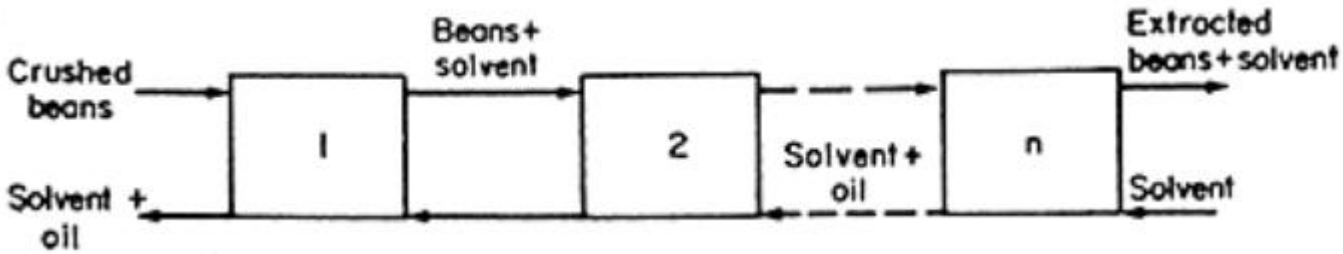
Y. Wang, M. D. LeVan - Adsorption Equilibrium of Carbon Dioxide and Water Vapor on Zeolites 5A and 13X and Silica Gel: Pure Components [McMaster LibAccess]

R.M. Thorogood - Developments in air separation* [McMaster LibAccess]

Video from Air Liquide on Cryogenic Distillation

SOYBEAN LEACHING





OPERATING COST

- 5000 MT raw materials / day
- Soybean price = $400/Ton
- Raw material Total price = $2,000,000/day
- Hexane price = $4,842,856.8 (hexane is recovered and recycled)

Wanna Read More?

[1] "How to Design Settling Drums", B. Sigales, Chemical Engineering Magazine, June 1975

[2] Seader, J. D., and Ernest J. Henley. Separation Process Principles. 2nd ed. New York: Wiley, 1998. Print.

Adsorption for Wastewater Treatment

Purpose: removal of particulates which were solubilized in preceding digester via hydrolyzing enzymes

Unit: fixed bed absorber in down-flow operation with packed activated carbon

-used when separation of components can be damaged if separated under high pressures or separated by more vigorous processes

Mechanism: Increase concentration of a particular component at the surface or between the interface of two phases

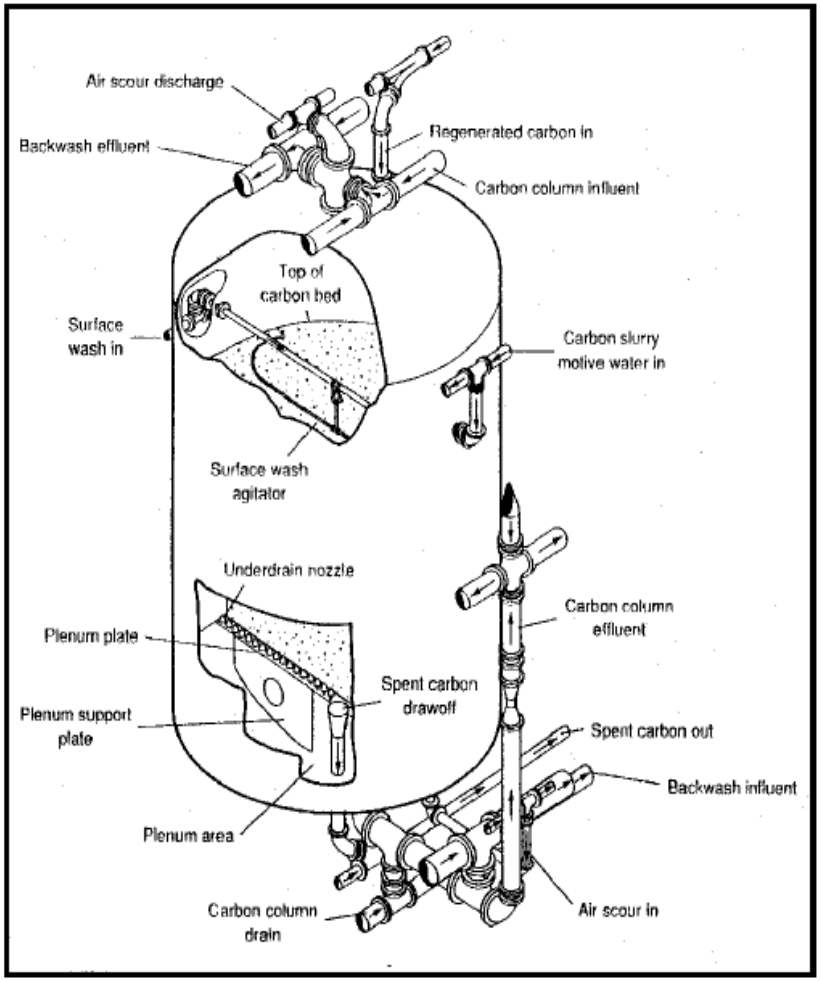
Adsorbant : activated carbon

Adsorbate: waste water contaminants

-physical adsorption-relatively weak intermolecular forces

-adsorbate filled solvent travels through the bed adsorbing onto carbon until bed is exhausted

-Pressurized vessels are usually recommended as they save space and can be operated at higher loading rates

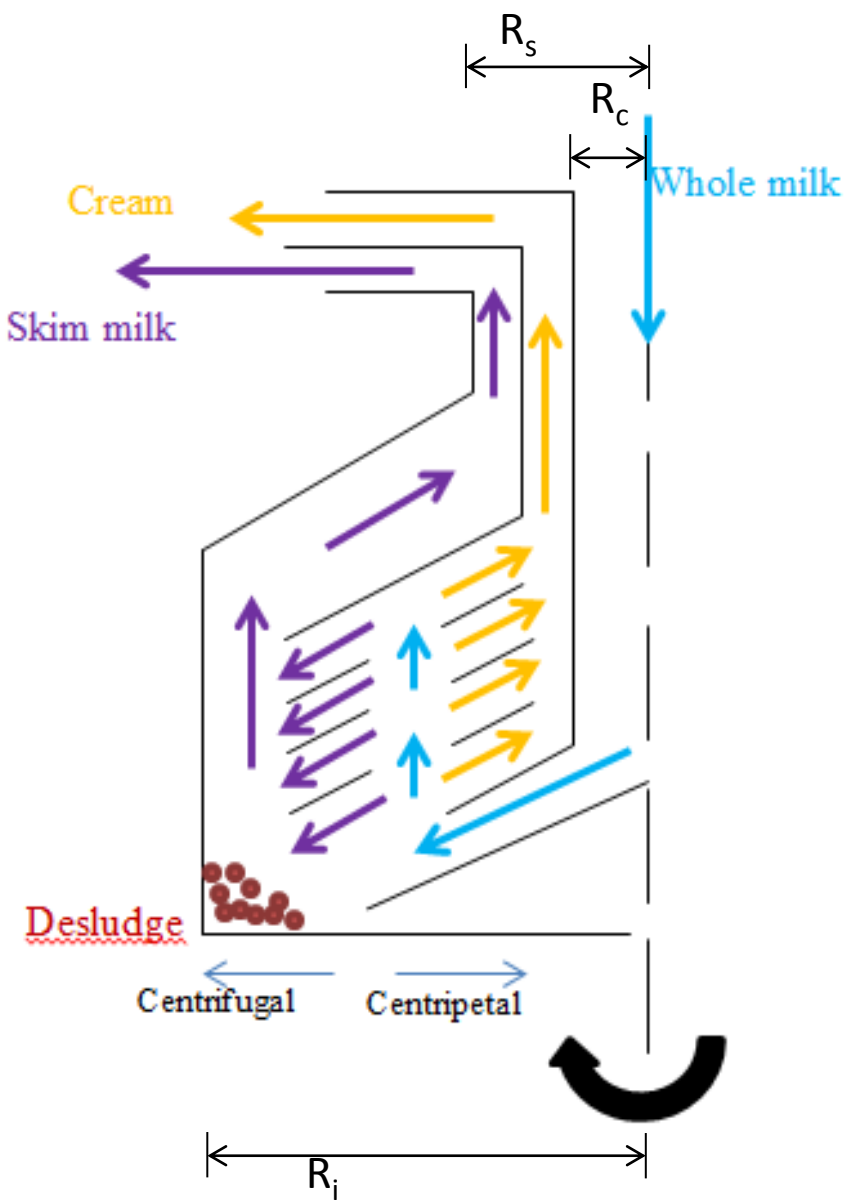


Annual Operating Costs (Quoted by EPA):

Amortization of Capital (8.75% interest/ 20 years)	$13,400
Maintenance	$6250
Energy Costs	$2400
Usage	$18000
Delivery	$2750
Total Annual Cost	$42800
Unit cost	$0.27/3.8 L

References:
-Adsorption Processes for Water Treatment (Samuel D. Faust)
-Physical-Chemical Treatment of Water and Wastewater (Arcadio P. Sincero)

Disk Bowl Centrifuge



Control the fat content of the milk using:

$$\frac{\rho_m}{\rho_s} = \frac{{R_i}^2 - {R_s}^2}{{R_i}^2 - {R_c}^2}$$

Where:

- ρ_s and ρ_m are in equilibrium (exerting equal forces on the inner wall)
- ρ_s is the density of the heavier liquid
- ρ_m is the density of the lighter liquid
- R_i is the inner radius of the centrifuge
- R_c is the radius of the ring of cream
- R_s is the radius of the ring of separated milk

$$\downarrow \frac{\rho_m}{\rho_s} = \uparrow \text{\% m.f. in skim milk}$$

Annual Operating Costs

Equipment cost: $123, 370

Item	Unit/year	$/year
Power Consumption	1 kWh/m^3 $0.08/kWh 46, 740 m^3/yr	3,739
Labour	1 Operator=4.4 Personnel Salary: $70, 000	308, 000
Maintenance	5-10% of Equipment Cost	12, 337
Total		324, 076

References for more information:

- Kessler, H.G. “Disc Bowl Centrifuge” in *Food Engineering and Dairy Technology*, Germany: Verlag A. Kessler, 1981, Ch 3, pp. 65-71.
- Goudédranche, H., Fauquant, J., & Maubois, JL., "Fractionation of globular milk fat by membrane microfiltration," *Lait*, vol. 80, 2000, pp. 93-98.