## Cost Estimation

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass production/yr</td>
<td>25 tonnes</td>
</tr>
<tr>
<td>Tank Surface Area</td>
<td>940.5 m²</td>
</tr>
<tr>
<td>Yearly operation period</td>
<td>330 days (18h/d)</td>
</tr>
<tr>
<td>Energy costs</td>
<td>$7692 per year</td>
</tr>
<tr>
<td>Flocculant</td>
<td>$15000/year</td>
</tr>
<tr>
<td>Capital interest for investment</td>
<td>16.5%/yr</td>
</tr>
<tr>
<td>Unit Description</td>
<td>Includes: tankage, pumps, motors, internal piping, c/s package unit, building, air compressor, mix tank, control panel</td>
</tr>
<tr>
<td>Total BM Cost 2011 (assume error +20%)</td>
<td>$4,722,400</td>
</tr>
</tbody>
</table>


Rotary Vacuum Drum Washers In Kraft Mill Pulping

- 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

- 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

<table>
<thead>
<tr>
<th>Cost</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOB</td>
<td>$45,412.48</td>
</tr>
<tr>
<td>Installation</td>
<td>$90,824.96</td>
</tr>
<tr>
<td>Correction factor</td>
<td>$90,824.96</td>
</tr>
<tr>
<td>Piping</td>
<td>$38,146.48</td>
</tr>
<tr>
<td>Total BM (1970)</td>
<td>$265,208.89</td>
</tr>
<tr>
<td>Total BM (2011)</td>
<td>$1,312,828.04</td>
</tr>
</tbody>
</table>

### Wash water costs

<table>
<thead>
<tr>
<th>Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate (kg/year)</td>
<td>43,431,844.51</td>
</tr>
<tr>
<td>Cost ($/kg)</td>
<td>0.00002</td>
</tr>
<tr>
<td>Cost per year ($/year)</td>
<td>$868.64</td>
</tr>
</tbody>
</table>
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


Removal of CO$_2$ from natural gas by polymeric membrane

**Unit Overview**

- **Piping requirements:**
  - Maximum of 2% CO$_2$

- **Membrane single stage separation unit:**
  - Spiral wounds;
  - Acetate Cellulose;

- **Separation principles:**
  - Permeability: diffusivity and sorption coefficients;
  - Selectivity;
  - Driving force: Partial pressure difference.

- **Piping Network**

- **Inlet Processing**
  - Up to 50% CO$_2$
  - Produced gas

- **Acid Gas Removal**
  - Dehydration
  - Dewpointing

- **Processes:**
  - Produced gas
  - Inlet Processing
  - Acid Gas Removal
  - Dehydration
  - Dewpointing
  - Piping Network

- **Volumes and Pressures:**
  - 1.64 m$^3$/s, 20% CO$_2$, 800 psia
  - 0.96 m$^3$/s, 2% CO$_2$
  - 0.67 m$^3$/s, 46% CO$_2$, 20 psia
  - 43 modules, 860 m$^2$
## Cost Estimation-Single stage membrane unit

<table>
<thead>
<tr>
<th>Capital Cost</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane housing</td>
<td>$200 per m² of membrane module</td>
<td>$240,000 (inflated from 1998), # of modules : 43</td>
</tr>
<tr>
<td>Working Capital</td>
<td>10% of fixed capital cost</td>
<td>$24,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating cost</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane replacement</td>
<td>$90 m² of membrane</td>
<td>$77400 every 3 years</td>
</tr>
<tr>
<td>Maintenance cost per year</td>
<td>5% of fixed capital cost</td>
<td>$1,2000 every year</td>
</tr>
<tr>
<td>Natural gas price</td>
<td>$3.77 per 1000 cubic ft</td>
<td>$6,880,250 every year</td>
</tr>
</tbody>
</table>

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.

References:
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  \( Q = 3.6LWVcL_{F3}F \)
• 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
**CO₂ Absorber Overview**

**Goal:** Removal of CO₂ from gaseous streams  
**Solvent:** Monoethanolamine (MEA)  
**Applications:** Natural Gas and Syngas cleaning

**Mechanism:**
- Reaction driven absorption
  - \( \text{CO}_2 + 2 \text{HOCH}_2\text{CH}_2\text{NH}_2 \leftrightarrow \text{HOCH}_2\text{CH}_2\text{NH}_3 + \text{HOCH}_2\text{CH}_2\text{NH}(\text{CO}^-) \)
- 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 $\text{SO}_x$ and $\text{NO}_x$ 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

\[ \eta_{\text{spray efficiency}} = 1 - \exp\left(\frac{-3RL}{2D_dG}\eta_{\text{single drop}}\right) \]

\[ \eta_{\text{filter efficiency}} = 1 - \exp\left(-f\eta_{\text{single body}}\right) \]

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

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

\[ m_{\text{removed by spray}} = m_{\text{dust in}} \times (\eta_{\text{spray efficiency}}) \]

\[ m_{\text{removed by filter}} = m_{\text{removed by spray}} \times (\eta_{\text{filter efficiency}}) \]

Combining the 3 mass equations:

\[ m_{\text{dust in}} (1 - \eta_{\text{spray efficiency}})(1 + \eta_{\text{filter efficiency}}) = m_{\text{dust escaped}} \]
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)(9cents/kWh) = $7733/year
Evaporator unit used in INSITU process to purify water using compression as the driving force of heat transfer.
### PIECE OF EQUIPMENT

<table>
<thead>
<tr>
<th>PIECE OF EQUIPMENT</th>
<th>COST – HIGH ESTIMATE</th>
<th>COST – LOW ESTIMATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator</td>
<td>$130 000</td>
<td>$70 000</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>$105 000</td>
<td>$45 000</td>
</tr>
</tbody>
</table>

### LABOUR

<table>
<thead>
<tr>
<th>LABOUR</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator x 4</td>
<td>$280 000</td>
</tr>
<tr>
<td>Supervisor x 1</td>
<td>$100 000</td>
</tr>
<tr>
<td>Maintenance x 1</td>
<td>$75 000</td>
</tr>
<tr>
<td>Engineering x 2</td>
<td>$200 000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$655 000</strong></td>
</tr>
</tbody>
</table>

### ENERGY SOURCE

<table>
<thead>
<tr>
<th>ENERGY SOURCE</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>$6 130 000</td>
</tr>
</tbody>
</table>

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


- combination of a sedimentation and filtering centrifuge
- Solids in the range of 20 to 200 µm
- Washing and drying in the screen section
<table>
<thead>
<tr>
<th>Capital</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Price</td>
<td>$380,000</td>
</tr>
<tr>
<td>Variable-Speed Drive</td>
<td>$95,000</td>
</tr>
<tr>
<td>Installation</td>
<td>$57,000</td>
</tr>
<tr>
<td>Total Cost per unit</td>
<td>$532,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>$28,500</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>$13,000</td>
</tr>
<tr>
<td>Labour/monitoring</td>
<td>$9,200</td>
</tr>
<tr>
<td>Total Cost per unit per year</td>
<td>$50,700</td>
</tr>
</tbody>
</table>


Solid Liquid Separator

Disc Nozzle Centrifuge

Oyeniyi Olaoye
Rodas Fisseha
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

\[
\text{Yearly utility cost} = \text{Power requirement} \times \frac{\text{hours of operation}}{\text{week}} \times \text{total throughput} \times \text{electricity cost} \times \frac{48 \text{ weeks}}{\text{year}}
\]

\[
= $26,313.25
\]

• Capital Cost

\[\text{FOB}^{2012} = $20,000-$50,000\]

• References


Solids Conveying Disc-Bowl Centrifuge
For Separation of Acetylsalicylic Acid from Mother Liquor

\[ v_o = \frac{(\rho_{Aspirin} - \rho_{MotherLiquor}) \cdot g \cdot D_p^2}{18 \cdot \mu} \]
\[ v_o = \frac{(1400 - 1082) \cdot 9.81 \cdot 0.0002^2}{18 \cdot 0.950} = 7.30 \times 10^{-6} \text{ m/s} \]
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
Type 13X zeolite molecular sieve for the adsorption of CO₂ and H₂O 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

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

\[
\text{Cost} = \left(\text{Steam Req.}\right) \left(\$ 27.7/1000 \text{ kg steam}\right)
\]

*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

Diagram of soybean leaching process:
- Meal Inlet
- Solvent Inlet
- Extractor (DVT)
- Extract Outlet
- Spent Meal Outlet

Diagram showing the process:
- Crushed beans
- Beans + solvent
- Solvent + oil
- Extracted beans + solvent
- Solvent
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?

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):

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amortization of Capital (8.75% interest/20 years)</td>
<td>$13,400</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$6250</td>
</tr>
<tr>
<td>Energy Costs</td>
<td>$2400</td>
</tr>
<tr>
<td>Usage</td>
<td>$18000</td>
</tr>
<tr>
<td>Delivery</td>
<td>$2750</td>
</tr>
<tr>
<td>Total Annual Cost</td>
<td>$42800</td>
</tr>
<tr>
<td>Unit cost</td>
<td>$0.27/3.8 L</td>
</tr>
</tbody>
</table>

### 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:
- \( \rho_s \) and \( \rho_m \) are in equilibrium (exerting equal forces on the inner wall)
- \( \rho_s \) is the density of the heavier liquid
- \( \rho_m \) 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

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit/year</th>
<th>$/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>1 kWh/m³</td>
<td>3,739</td>
</tr>
<tr>
<td></td>
<td>$0.08/kWh</td>
<td></td>
</tr>
<tr>
<td></td>
<td>46,740 m³/yr</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>1 Operator=4.4 Personnel</td>
<td>308,000</td>
</tr>
<tr>
<td></td>
<td>Salary: $70,000</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>5-10% of Equipment Cost</td>
<td>12,337</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>324,076</td>
</tr>
</tbody>
</table>

References for more information: