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:


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 - $1.41/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](http://compost.css.cornell.edu/MSWFactSheets/msw.fs1.html)
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D – basket diameter</td>
<td>1 m</td>
</tr>
<tr>
<td>R – basket radius</td>
<td>0.5 m</td>
</tr>
<tr>
<td>t – massecuite thickness</td>
<td>0.195 m</td>
</tr>
<tr>
<td>d – massecuite ID</td>
<td>0.61 m</td>
</tr>
<tr>
<td>r – massecuite IR</td>
<td>0.305 m</td>
</tr>
<tr>
<td>( R_m ) – equivalent radius</td>
<td>0.410 m</td>
</tr>
<tr>
<td>h – height</td>
<td>1.4 m</td>
</tr>
<tr>
<td>C – volumetric capacity per cycle</td>
<td>1.1 m(^3)/cycle</td>
</tr>
<tr>
<td>( \omega ) – basket speed</td>
<td>1220 RPM</td>
</tr>
<tr>
<td>G – gravitational force</td>
<td>682 g – force</td>
</tr>
<tr>
<td>( \theta ) – cycles completed per hour</td>
<td>18.18 cycles per hours</td>
</tr>
<tr>
<td>Q – massecuite throughput per hour</td>
<td>20 m(^3)/hr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capital Cost (two batch centrifuges)</th>
<th>Operating Cost (two batch centrifuges)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment - $132798 +/- 40%</td>
<td>Electricity - $13277</td>
</tr>
<tr>
<td>Installation - $19918</td>
<td>Maintenance - $13279</td>
</tr>
<tr>
<td>Total - $132798 +/- 40% + $19918 for purchase and installation</td>
<td>Total - $26556/year</td>
</tr>
</tbody>
</table>

### References:


Lactic Acid Purification from Fermentation: Multi-Effect Evaporation

By: Derek Seguin & Nicole Rich-Portelli

GEA Process Engineering, Multi-Effect Evaporation:
Operating Costs: Evaporation

Major factor: Steam generation

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

\[ C_f = P \times \frac{(H_2-H_1)}{n} \]

- $n$ - 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) = $C_f \times \text{Flow rate of steam}$
Operating cost (steam) = $\$0.011/kg \times 29,185$kg/h = $\$2,812,000$/year

Resources:
Green, D., and Perry, R. Perry’s Chemical Engineers’ Handbook. 8th ed.
Solvent Extraction of Vegetable Oils
### Capital Cost

<table>
<thead>
<tr>
<th>Shallow Bed Extraction Unit</th>
<th>$212,016 ±20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = 4793 gal</td>
<td>$169,000 to $254,000</td>
</tr>
</tbody>
</table>

### Operating Costs

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>$349,305/year</td>
</tr>
<tr>
<td>Hexane (Solvent)</td>
<td>$22,442,770/year</td>
</tr>
</tbody>
</table>

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

• Addition of Butyl Acetate solution
• Able to operate in a continuous process
### CAPITAL COSTS

<table>
<thead>
<tr>
<th>Purchase Price</th>
<th>Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$185 000</td>
<td>$18 500</td>
</tr>
</tbody>
</table>

### OPERATING COSTS

<table>
<thead>
<tr>
<th>Energy Costs</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 000</td>
<td>$18 500</td>
</tr>
</tbody>
</table>


Solvent Extraction for Production of β-citronellol from Rose Petals

Governed by:
• $Da = \frac{[A]_{org}}{[A]_{aq}}$

For two-phase systems:
• $\alpha = \frac{Da}{Db}$
Capital and Operating Costs

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

<table>
<thead>
<tr>
<th>Object</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Equipment</td>
<td>$315 000/unit</td>
</tr>
<tr>
<td>Raw Feed (Rose Petals)</td>
<td>$729 700 000/year</td>
</tr>
<tr>
<td>Ethanol Solvent</td>
<td>$454 790/year</td>
</tr>
<tr>
<td>Utilities</td>
<td>$1524/year</td>
</tr>
</tbody>
</table>

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

By: Tamar Makdessian and Talia Ceti
### Cost Break down

<table>
<thead>
<tr>
<th>Equipment</th>
<th>FOB cost -40%</th>
<th>FOB cost +40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>$232 490</td>
<td>$406 858</td>
</tr>
<tr>
<td>Vessels (2)</td>
<td>$1 488 756</td>
<td>$2 605 323</td>
</tr>
<tr>
<td>Total cost</td>
<td>$1 721 246</td>
<td>$3 012 181</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Cost</th>
<th>Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>$2.75/ 100 ft³</td>
<td>$7 452 467</td>
</tr>
<tr>
<td>Zeolite</td>
<td>$2/ kg</td>
<td>$12</td>
</tr>
</tbody>
</table>

References:

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:

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

References:
\[ \mu_o = \frac{(\rho_{\text{starch}} - \rho_{\text{gluten}})gd^2}{18\mu} \]
\[ \Sigma = \frac{2\pi\omega^2(N - 1)(r_2^3 - r_1^3)}{3\gamma \tan \theta} \]
\[ Q_{\text{cut}} = 2vTSV \Sigma \]
\[ Q_{\text{cut}} = 250000 \text{L/h} \]

\( d_{\text{max}} = 6.2 \, \mu \text{m} \)
\( d_{\text{in}} = 1 \text{m} \)
\( d_{\text{out}} = 0.25 \text{m} \)
\( N = 160 \)

Corn starch density = 660 kg/m³
Corn gluten density = 400 kg/m³

\( \omega = 2471.49 \)
\( \theta = 45^\circ \)
\( \mu_o = 1.702 \times 10^{-10} \text{ m/s} \)
\( \Sigma = 2.06 \times 10^{11} \text{ m}^2 \)

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


• Recovers metals from solutions by electrochemical reactions
• Reactions are heterogeneous
• Cathodic and Anodic Ones
  • Electrons are transferred from the cathode
    • \( \text{Ni}^{2+} + 2e^- \rightarrow \text{Ni} \)
  • Electrons are transferred to the anode
    • \( 2\text{H}_2\text{O} - 4e^- \rightarrow \text{O}_2 + 4\text{H}^+ \)

• 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 \( \text{Ni}^{2+} \) and \( \text{cd}^{2+} \) as well as \( \text{Fe}^{3+} \) 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Operating Costs</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour and Maintenance</td>
<td>$27,000</td>
<td>Electrolytic Cell and Installation (4 Units 4000 Amperes)</td>
</tr>
<tr>
<td>($10 /hour in directly due to monitoring)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (0.07CDN/KWh)</td>
<td>$217,000</td>
<td></td>
</tr>
<tr>
<td>Electrode Replacement</td>
<td>$20,000</td>
<td></td>
</tr>
<tr>
<td>($200 each)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


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:

$$Total\ \ Capital\ \ Cost = \frac{\$4.5}{\text{McL}/\text{day}}$$ at 24.8 $\frac{\text{McL}}{\text{day}}$, Total Capital Cost is $111.6$ million

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

References:


Design Equations of a Scrubber

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

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

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

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

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)($0.09/kWh) = $7733/year