Modelling & Optimization of a Distillation Train

Vegard Skogstad

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Goal
Find steam savings
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Process overview

Optimisation

Steam distribution

Potential savings

Realistic savings

Conclusions

The Process

Feed → ISOM 1 → ISOM 2 → PRAL → IBAL Heavy ends → PRAL product

Feed → ISOM 1 → ISOM 2 → NBAL → NBAL product → NBAL heavy ends
Over-purification

Assumption:
Excess steam usage gives over-purification of products
Over-purification

Feed

ISOM 1

IBAL Heavy ends

ISOM 2

PRAL

IBAL product

PRAL product

NBAL

NBAL heavy ends

NBAL product

Spec Base case

[Specifications and Run data table]

<table>
<thead>
<tr>
<th>Spec</th>
<th>Base case</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.996</td>
</tr>
<tr>
<td>I</td>
<td>0.002</td>
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<tr>
<td>N</td>
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</table>
Over-purification

Feed

PRAL
IBAL Heavy ends

ISOM 1

ISOM 2

PRAL product

IBAL product

NBAL

Spec Base case
P 0.996 0.9995
I 0.002 0.0002
N 0 0

P 0.001 0.0002
I 0.996 0.9983
N 0.002 0.0006

P 0 0
I 0.0012 0.0004
N 0.996 0.9974

NBAL Heavy ends

NBAL product

Realistic savings

Conclusions
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Realistic savings
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Over-purification

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Over-purification

We do have over-purification!
The optimisation problem

\[
\max_M Z = M_{PRAL} p_{PRAL} + M_{IBAL} p_{IBAL} + M_{NBAL} p_{NBAL} - E_{tot} H_{vap} p_{steam}
\]

\[
c_{\text{Ibal in PRAL}} \leq 0.002
\]

\[
c_{\text{Pral in IBAL}} \leq 0.001
\]

\[
c_{\text{Nbal in IBAL}} \leq 0.002
\]

\[
c_{\text{Ibal in NBAL}} \leq 0.0012
\]
Results

- Pral price needs to be 8 times as large as other products before constraint non-active
Results

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- Ib3al price needs to be 7 times as large as other products
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- Pral price needs to be 8 times as large as other products before constraint non-active
- Ibal price needs to be 7 times as large as other products
- Nbal price needs to be 8 times as large as other products
• Pral price needs to be 8 times as large as other products before constraint non-active
• Ibal price needs to be 7 times as large as other products
• Nbal price needs to be 8 times as large as other products
• For common price estimates, the optimal solution is always to minimise steam usage!
Steam distribution in Isomer columns

Assumption:
Uneven separation in Isomer columns gives steam losses
Steam distribution in Isomer columns

Assumption:
Uneven separation in Isomer columns gives steam losses

- What is optimal steam distribution?
  - As much separation as possible in ISOM 1
  - As much separation as possible in ISOM 2
  - Equal separation in both columns
Steam distribution in Isomer columns

<table>
<thead>
<tr>
<th>Units</th>
<th>Duty ISOM 1 (kJ/h)</th>
<th>Duty ISOM 2 (kJ/h)</th>
<th>Total duty (kJ/h)</th>
<th>Savings (kr/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>3.57E+07</td>
<td>3.17E+07</td>
<td>9.60E+07</td>
<td></td>
</tr>
<tr>
<td>Same concentration</td>
<td>3.76E+07</td>
<td>2.86E+07</td>
<td>9.47E+07</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-1.91E+06</td>
<td>3.18E+06</td>
<td>1.27E+06</td>
<td>127</td>
</tr>
</tbody>
</table>

- Product streams identical
- Yearly savings of ≈ 1 million
- Increased steam usage in ISOM 1
- Decreased steam usage in ISOM 2
Steam distribution in Isomer columns

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- Product streams identical
- Yearly savings of ≈ 1 million
- Increased steam usage in ISOM 1
- Decreased steam usage in ISOM 2
Potential savings

We would like to reduce over-purification
Potential savings

We would like to reduce over-purification

Where would it be most profitable to improve control?
Potential savings

Table: Changing concentrations from base case values to maximum allowable values

<table>
<thead>
<tr>
<th></th>
<th>Ibal in PRAL</th>
<th>Pral in IBAL</th>
<th>Nbal in IBAL</th>
<th>Ibal in NBAL</th>
<th>Total duty</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,00028</td>
<td>0,00023</td>
<td>0,002</td>
<td>0,00042</td>
<td>9,03E+07</td>
<td>582</td>
</tr>
<tr>
<td></td>
<td>0,002</td>
<td>0,00023</td>
<td>0,00062</td>
<td>0,00042</td>
<td>9,42E+07</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>0,00028</td>
<td>0,001</td>
<td>0,00062</td>
<td>0,00042</td>
<td>9,53E+07</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>0,00028</td>
<td>0,00023</td>
<td>0,00062</td>
<td>0,0012</td>
<td>9,27E+07</td>
<td>347</td>
</tr>
</tbody>
</table>

- The largest potential savings are from the Isomer columns
Realistic savings

- At the set point we will violate the constraint 50% of the time
- need back-off
- How much can we decrease back-off without violating the constraints?
Probability distributions

![Graph showing probability distributions for concentration of NBAL in IBAL product and concentration of IBAL in NBAL product.](image-url)
Savings with new set points

Table: Changing the concentrations out of the ISOM 2 column to meet new specified set points for the product streams

<table>
<thead>
<tr>
<th></th>
<th>Nbal in IBAL</th>
<th>Ibal in NBAL</th>
<th>Total duty</th>
<th>Steam savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured data base case</td>
<td>0.062</td>
<td>0.042</td>
<td>9.60E+07</td>
<td></td>
</tr>
<tr>
<td>Isomer set points 1% failure</td>
<td>0.091</td>
<td>0.058</td>
<td>9.18E+07</td>
<td>421.58</td>
</tr>
<tr>
<td>Isomer set points 2.27% (Norm distr.)</td>
<td>0.143</td>
<td>0.078</td>
<td>9.05E+07</td>
<td>543.29</td>
</tr>
</tbody>
</table>
Results

• For common price estimates, the optimal solution is always to minimise steam usage
• The largest potential savings are from the Isomer columns
• Identical separation in Isomer columns leads to steam savings without changing product streams
• To achieve this: Decrease steam usage in ISOM 2, increase steam usage in ISOM 1