Process Integration Case Study for the Second Generation Ethanol Production

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Objectives

• Increase the ethanol production by integrating 1\textsuperscript{st} and 2\textsuperscript{nd} generation plants with energy saving, without any additional biomass
Methodology

- Integration of 1\textsuperscript{st} and 2\textsuperscript{nd} Generation plants
- Increase ethanol production
- Improve process efficiency
Applications of Process Integration

Pinch Analysis is integral part of Process Integration, when

• Integrating heat needs with waste heat
• Generating steam/heat “appropriately”,
• Reusing / recovering raw materials,
• Integrating many processes / Co-production / Technology synergies,
• Upgrading byproducts
Principle of Pinch Analysis

Typical composite curves

TEMPERATURE

HEAT FLOW

HOT COMPOSITE

Q_C min

SCOPE FOR PROCESS HEAT RECOVERY

Q_H min

COLD COMPOSITE

ΔT_MIN

PINCH
Pinch Analysis Example

First Generation Sugar Cane Ethanol Plant
3 million tons crush during 180-day harvest
Sugarcane Ethanol Plant

16666 t/d Sugarcane → Crushing and Milling → Juice Treatment (14.4% solids) → Juice Evaporation (22% solids) → Fermentation

1.41 MMlit/d Distillation → Dehydration → Anhydrous Ethanol

219 t/h Steam to the Process

40 t/h Steam to the Cogen Plant

20 MW Power to the Process

75 MW Exported Power

2204 ODt/d Bagasse

Cogeneration Plant

22% solids

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## Sugarcane Plant Main Heat Duties

<table>
<thead>
<tr>
<th>Description</th>
<th>Heat demand, GJ/h</th>
<th>Steam consumption, GJ/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juice preheating before liming</td>
<td>87</td>
<td>24</td>
</tr>
<tr>
<td>Juice heating after liming</td>
<td>89</td>
<td>76</td>
</tr>
<tr>
<td>Imbibition and wash water heating</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>Juice evaporation</td>
<td>141</td>
<td>141</td>
</tr>
<tr>
<td>Wine preheating (to distillation)</td>
<td>79</td>
<td>0</td>
</tr>
<tr>
<td>Distillation (stripper column)</td>
<td>161</td>
<td>161</td>
</tr>
<tr>
<td>Distillation (rectifier column)</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Molecular Sieves heating</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Boiler Feed Water heating</td>
<td>41</td>
<td>76</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>723</strong></td>
<td><strong>560</strong></td>
</tr>
</tbody>
</table>
Sugarcane Plant Composite Curves

Interval Temperature $T^*$ (deg C)

Enthalpy Change (GJ/h)

$Q_{\text{MIN}} = 415$ GJ/h

$Q_{\text{CMIN}} = 304$ GJ/h

Pinch Temperature = 95°C
Sugarcane Plant Pinch Results

- Pinch Temperature: 95 °C
- Minimum ΔT selected: 10 °C
- Minimum heating utility (QHMIN): 415 GJ/h
- Actual process steam consumption: 554 GJ/h
- Maximum scope for heat recovery: 139 GJ/h
Second Generation Ethanol Plant

Cellulosic Ethanol and Acetic Acid from Bagasse Feedstock
Second Generation Ethanol Plant

• American Process has developed hemicellulose extraction process termed “Green Power +™”
  – Liquid Hot Water digestion of Bagasse
  – Hemicelluloses are acid hydrolyzed to Pentose sugars and Acetic Acid
  – Acetic Acid is separated by evaporation & purified
  – The sugars are fermented to beer
  – The beer is distilled to produce ethanol
  – Unreacted solids material are concentrated and burned in the boiler.
Green Power+™ 2nd Gen. Plant

Bagasse from sugarcane plant

Digester → Washing → Residues Pressing → Biomass To Boiler

Extract

Acid

Hydrolysis Reactor → Evaporation & HAc Removal → Fermentation & Distillation

Extractate → Acetic Acid Purification

Ethanol
The sugar solution evaporation and concentration of acetic acid is performed in Mechanical Vapor Compression (MVR) Evaporator.
GP+ Plant Pinch Results

- Pinch Temperature: 101 °C
- Minimum ΔT selected: 10 °C
- Minimum heating utility (QHMIN): 103 GJ/h
## Combined 1st & 2nd Generation Plants

<table>
<thead>
<tr>
<th></th>
<th>Host sugarcane ethanol plant</th>
<th>Host ethanol plant combined with GP+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane crush, t/d</td>
<td>16666</td>
<td>16666</td>
</tr>
<tr>
<td>Anhydrous ethanol production, MMlit/d</td>
<td>1.41</td>
<td>1.65</td>
</tr>
<tr>
<td>Acetic Acid production, t/d</td>
<td>-</td>
<td>123</td>
</tr>
<tr>
<td>Bagasse generated from process, ODt/d</td>
<td>2203</td>
<td>2203</td>
</tr>
<tr>
<td>Steam generated from Bagasse, GJ/h</td>
<td>1183</td>
<td>791</td>
</tr>
<tr>
<td>Steam generated from Bagasse, t/h</td>
<td>414</td>
<td>292</td>
</tr>
<tr>
<td>Specific steam generation from bagasse, t/t</td>
<td>2.16</td>
<td>2.61</td>
</tr>
<tr>
<td>Steam consumed in the plant, t/h</td>
<td>259</td>
<td>259+47 (at least) =306</td>
</tr>
<tr>
<td>Steam consumed in the process, t/h</td>
<td>219</td>
<td>219+47 (at least)=266</td>
</tr>
<tr>
<td>Power consumption, MW</td>
<td>20</td>
<td>37</td>
</tr>
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</table>

The steam consumption is more than available from leftover bagasse solids!
Pinch Analysis for the Integrated plant

First Generation Sugarcane Ethanol Plant with Green Power+ Bagasse Extraction to Cellulosic Ethanol and Acetic Acid

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Composite Curves for Integrated Plant

**Q_{MIN} = 493 GJ/h**

**Q_{HMIN} = 526 GJ/h**

**Pinch Temperature = 101°C**
Integrated Plant Pinch Results

- Pinch Temperature: 101 °C
- Minimum ΔT selected: 10 °C
- Minimum heating utility (QHMIN): 526 GJ/h
Comparison of Performance before and after Integration of 2\textsuperscript{nd} Gen. Ethanol

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<thead>
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<th>Integrated plants with 2\textsuperscript{nd} generation ethanol</th>
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<tr>
<td>Sugarcane crush, t/d</td>
<td>16656</td>
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<td>Anhydrous ethanol production, MMlit/d</td>
<td>1.41</td>
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<td>Steam consumed in the plant, t/h</td>
<td>259</td>
<td>244 (306)</td>
</tr>
<tr>
<td>Steam consumed in the process, t/h</td>
<td>219</td>
<td>233 (266)</td>
</tr>
<tr>
<td>Steam consumed in the cogeneration plant, t/h</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>Process steam consumption per ton of cane, kg/t</td>
<td>316</td>
<td>336</td>
</tr>
<tr>
<td>Steam to the turbine condenser, t/h</td>
<td>158</td>
<td>51</td>
</tr>
<tr>
<td>Total Power generation, MW</td>
<td>95</td>
<td>54</td>
</tr>
<tr>
<td>Power consumption, MW</td>
<td>20</td>
<td>29 (37)</td>
</tr>
<tr>
<td>Net exported power, MW</td>
<td>75</td>
<td>25 (17)</td>
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Simulation Model in apiMAX™
Results Summary

• Pinch Analysis was applied to stand-alone sugarcane ethanol mill to find **25% steam energy savings**
• The integration resulted in **17% increase in ethanol** and by-product acetic acid production **without any additional biomass**
Conclusions

• Combination of two optimized plants can be improved by process integration
• Reducing steam consumption allows leveraging of existing boiler and turbines
• Common distillation system can be used for 17% incremental ethanol production
• Additional cellulosic ethanol can be made from bagasse without bringing additional biomass to the site
• Techno-economic evaluation is necessary to calculate trade-off with power sales and the investment payback