The Value of Model Predictive Control

Industrial Applications – CT505

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Title – Process Technical Consultant
Date – March 25/26, 2015
MPC – Web Enabled

Figure 8.1. Pavilion8 Console Login Page.
Typical Project KPI – Monitor & Tracking
MPC – Performance Metrics
### NGL Fractionation ROI Example

#### ROI Calculation for NGL Fractionation Model Predictive Control (MPC)

<table>
<thead>
<tr>
<th>Estimated Capital Investment</th>
<th>Justification Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Range Increase in Production (from data)</td>
</tr>
<tr>
<td></td>
<td>1.613% 16 Bbl/day</td>
</tr>
<tr>
<td></td>
<td>5.000% 49 Bbl/day</td>
</tr>
<tr>
<td></td>
<td>% Range Increase in PRC Yield (from data)</td>
</tr>
<tr>
<td></td>
<td>5.730% 40 Bbl/day</td>
</tr>
<tr>
<td></td>
<td>15.690% 110 Bbl/day</td>
</tr>
<tr>
<td></td>
<td>% Range Energy Savings (from experience)</td>
</tr>
<tr>
<td></td>
<td>0% 0 Btu/day</td>
</tr>
<tr>
<td></td>
<td>5% 0 Btu/day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating Capacity</th>
<th>Std Operating Margin 35%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(minimum Projections)</td>
</tr>
<tr>
<td>unit feed rate 20.50 MMSCFD</td>
<td></td>
</tr>
<tr>
<td>Current Production Capacity 700.00 Bbl/day</td>
<td></td>
</tr>
<tr>
<td>Operating Days 365</td>
<td></td>
</tr>
<tr>
<td>Generator On-Stream Factor 99%</td>
<td></td>
</tr>
<tr>
<td>Total Annual Capacity 252,945 Bbl/year</td>
<td></td>
</tr>
<tr>
<td>NGL/gas feed yield 1.388 gpm/MMSCFD</td>
<td></td>
</tr>
</tbody>
</table>

**Pricing**

- NGL value $1.36/s/gallon
- Natural Gas Price $3.50/MMBTU
- Estimated nat gas costs $0/yr (Not calculated)

**Total Benefit** $941,561/yr
## Biofuel ROI Example

### Estimated Capital Investment

<table>
<thead>
<tr>
<th>Item</th>
<th>Year 0</th>
<th>Year 1+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavilion Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maint. Agreement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLC/DCS programming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC Hardware/Comm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel and Living</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Justification Calculations

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budgeted Capacity</td>
<td>240,000 m3 per year</td>
</tr>
<tr>
<td>Avg Ethanol Price</td>
<td>$ 528/m3</td>
</tr>
<tr>
<td>Com Price</td>
<td>$ 196/MT</td>
</tr>
<tr>
<td>DDGS MT/Liters</td>
<td>0.90 MT/Liter</td>
</tr>
<tr>
<td>DDGS $/Ton</td>
<td>$ 243/MT</td>
</tr>
<tr>
<td>Maint. Agreement</td>
<td>$ 75,275</td>
</tr>
<tr>
<td>Maint. Agreement</td>
<td>$ 75,275</td>
</tr>
<tr>
<td>Enzyme Cost</td>
<td>$ 10.5/kL</td>
</tr>
<tr>
<td>Enzyme Costs</td>
<td>$ 10.5/kL</td>
</tr>
<tr>
<td><strong>Gross Margin</strong></td>
<td>$ 191.44</td>
</tr>
</tbody>
</table>

### Margin Calculations (€/m3)

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling Price of EtOH + DDGS</td>
<td>$ 746.60</td>
</tr>
<tr>
<td>Com Cost</td>
<td>$ 519.40</td>
</tr>
<tr>
<td>Gas Cost</td>
<td>$ 0.08</td>
</tr>
<tr>
<td>Enzyme Cost</td>
<td>$ 10.50</td>
</tr>
<tr>
<td>Electrical Cost</td>
<td>$ 10.00</td>
</tr>
<tr>
<td>Denaturant Cost</td>
<td>$ 15.18</td>
</tr>
<tr>
<td><strong>Total Variable Cost</strong></td>
<td>$ 555.16</td>
</tr>
<tr>
<td><strong>Expected Savings</strong></td>
<td>$ 1,965,440 per year</td>
</tr>
</tbody>
</table>

### Benchmark Metrics

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Plant Capital Investment</td>
<td>€ 700 per m3</td>
</tr>
<tr>
<td>APC Capital Investment</td>
<td>€ 160 per m3</td>
</tr>
<tr>
<td>APC Benefits Metric</td>
<td>€ 8 per m3</td>
</tr>
</tbody>
</table>

### Natural Gas

- **Cost**: 7385.983517 kJ/lit
- **Cost per MJ**: 0.01040 €
- **Annual Costs for natural gas**: $ 18,427,503 per year

### Natural Gas Savings

- 0.0% - $ - per year
- 0.0% - $ - per year

### Moisture Increase in DDGS

- 0.0% - $ - per year
- 0.0% - $ - per year
Large Markets – Project Results

**Typical Project Payback: 3 to 9 months!**

**CPG**
- Typical Benefits
  - 5 to 8% production increase
  - 30 to 60% moisture variability reduction
  - 20 to 50% off-spec product reduction
  - 5 to 10% energy consumption reduction

**CMM**
- Typical Benefits
  - 2 to 5% production increase
  - 2 to 5% energy savings

**Chemicals and Polymers**
- Typical Benefits
  - 4 to 8% prime product yield increase
  - 35 to 75% product variability reduction
  - 20-40% transition time reduction
  - 3 to 7% feedstock wastage reduction

**Bio-fuels**
- Typical Benefits
  - 4 to 12% ethanol production capacity increase
  - 2 to 5% ethanol yield increase
  - 3 to 6% energy use/gallon reduction
  - 1 to 2% DDGS yield increase
Large Markets – Project Results

CPG
- Spray Dryers
- Evaporators
- Energy Centers
- Crystallizers
- French Fry Machines

Process Types
- Milk Powder
- Coffee
- Laundry Detergent
- Conc. Juice
- French Frys
- Sugar

CMM
- Typical Benefits
  - 2 to 5% production increase
  - 2 to 5% energy consumption reduction
  - 20 to 40% product variability reduction
  - 10 to 30% off-spec product reduction

Chemicals and Polymers
- Typical Benefits
  - 4 to 8% prime product yield increase
  - 35 to 75% product variability reduction
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Biofuels
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  - 1 to 2% DDGS yield increase

Typical Benefits
- 2 to 5% production increase
- 2 to 5% energy consumption reduction
- 20 to 40% product variability reduction
- 10 to 30% off-spec product reduction

2 to 5% energy consumption reduction
20 to 40% product variability reduction
10 to 30% off-spec product reduction

4 to 8% prime product yield increase
35 to 75% product variability reduction
20-40% transition time reduction
3 to 7% feed stock wastage reduction

4 to 12% ethanol production capacity increase
2 to 5% ethanol yield increase
3 to 6% energy use/gallon reduction
1 to 2% DDGS yield increase
Dryer Moisture Soft Sensor Results

Product In
8-15% solids

Product Out
45 -55% solids

The Business Value is
Achieved by
“raising the bar” with
Confidence
Dryer and Evaporator Balance – Value

- Plant Obedience (reduced variability) enables:
  - **Moisture** – Lift moisture targets to Limit or revised uplift
  - **Evaporator capacity** – Optimize Solids to current UCL to reduce variability
  - **Dryer capacity** – Improve evaporation capability within proven heat envelope

- **Reduce Rework** - Product & Cost

- **Reduce Energy** – Dryer & Evaporation Balancing reduces the energy cost profile per tonne of product produced.

- **Improve Quality & Consistency**
- **Optimize Evaporator & Dryer Efficiency**
  - Squeeze more value from the existing asset
  - Produce more product with the same operating profile
  - Reduce Variable Cost
  - Sell more free water
  - Enable product mix flexibility to gain more higher value products
Dairy spray dryer
- Inlet temp controlled with gas valve
- Exhaust temp controlled with feed pump speed
- Feed is pumped through nozzles and the backpressure from the nozzles is a key constraint
- Inlet temp sp to valve output, response of pid algorithm
- Inlet temp to nozzle press, response of exhaust temp pid algorithm rejecting disturbance from inlet temp change.
- Exhaust temp to nozzle press, response of exhaust temp pid algorithm. As with Inlet temp, omitting the overshoot will cause cycling and possibly trip the dryer.
Large Markets – Project Results

CPG
Typical Benefits
- 5 to 8% production increase
- 30 to 60% moisture variability reduction
- 20 to 50% off-spec product reduction
- 5 to 10% energy consumption reduction

CMM
- Crushing/Grinding
- Preprocessing
- Kilns & Drying
- Stockpile Blending

Process Types
- Cement
- Minerals
- Fertilizer
- Ammonia

Chemicals and Polymers
Typical Benefits
- 4 to 8% prime product yield increase
- 35 to 75% product variability reduction
- 20-40% transition time reduction
- 3 to 7% feed stock wastage reduction

Bio-fuels
Typical Benefits
- 4 to 12% ethanol production capacity increase
- 2 to 5% ethanol yield increase
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- 1 to 2% DDGS yield increase
Rotary Cement Kiln Typical Layout

- Raw Material Feed Stream
- Fuel Addition
- Calciner
- Riser Pipe
- Kiln
- Main Burner
- Fuel Addition
Production Rate 4 Months Before/After MPC

With Pyroprocessing MPC Solution

Without Pyroprocessing MPC Solution

$\Delta = +14\%$

220 tph

Multiple Slowdowns

190 tph
<table>
<thead>
<tr>
<th>Major Market</th>
<th>Process Types</th>
<th>Typical Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CPG</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CMM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chemicals and Polymers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biofuels</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Chemicals and Polymers
- **Process Types**
  - Polymers
    - PE, PP, PS, PC
  - Ethylene Plants
  - Styrene Plants
  - Crude Refining
  - Gas Plants

### Typical Benefits
- **CPG**
  - 5 to 8% production increase
  - 30 to 60% moisture variability reduction
  - 20 to 50% off-spec product reduction
  - 5 to 10% energy consumption reduction

- **CMM**
  - 2 to 5% production increase
  - 2 to 5% energy consumption reduction
  - 20 to 40% product variability reduction
  - 10 to 30% off-spec product reduction

- **Biofuels**
  - 4 to 12% ethanol production capacity increase
  - 2 to 5% ethanol yield increase
  - 3 to 6% energy use/gallon reduction
  - 1 to 2% DDGS yield increase
## Before & After APC Comparison

<table>
<thead>
<tr>
<th>variables (PV-SP)</th>
<th>Before APC STD</th>
<th>After APC STD</th>
<th>APC Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC201</td>
<td>12.23</td>
<td>4.48</td>
<td>63%</td>
</tr>
<tr>
<td>AIC202</td>
<td>148.5</td>
<td>46.03</td>
<td>69%</td>
</tr>
<tr>
<td>DIC241</td>
<td>2.540</td>
<td>1.29</td>
<td>49%</td>
</tr>
<tr>
<td>DIC251</td>
<td>2.402</td>
<td>1.58</td>
<td>34%</td>
</tr>
<tr>
<td>PIC402</td>
<td>0.01739</td>
<td>0.0032</td>
<td>82%</td>
</tr>
<tr>
<td>AIC402</td>
<td>0.00254</td>
<td>0.000296</td>
<td>88%</td>
</tr>
<tr>
<td>AIC403</td>
<td>0.00535</td>
<td>0.002977</td>
<td>44%</td>
</tr>
</tbody>
</table>
AIC201/AIC202) H2 concentration in Loop 1&2 reactor
Transition: V30G $\rightarrow$ Z30S, APC OFF

Time: 7.5 hours
Transition: V30G → Z30S, APC ON

time: 3.3 hours
Large Markets – Project Results

**CPG**
- Typical Benefits
  - 5 to 8% production increase
  - 30 to 60% moisture variability reduction
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  - 5 to 10% energy consumption reduction

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  - 3 to 7% feedstock wastage reduction

**Biofuels**
- DDGS Evap/Dryer
- Water Balance
- Fermentation
- Distillation

**Process Types**
- Corn Ethanol
- Cane Ethanol
- Bio-diesel
BioEthanol Process Overview

MPC Objectives:
• Optimize plant throughput
• Maximize ethanol and DDGS yield
• Minimize energy/gallon ethanol

Fermentation MPC

Distillation/Sieves MPC

Dryers/Evap & TO MPC
The Challenge: Cascading Dryers

- Optimize NG energy in drying – 2 lines, 2 dryers/line, 2 parallel lines

Natural gas Dryers A, B

Dryer A
- Wet Cake
- Moisture

Dryer B
- Moisture

Dryer C
- Moisture

Dryer D
- DDGS Product

Natural gas to Dryers C, D

Natural gas Dryers C, D
- Moisture
# Dryer Operations Snap-shot

## Inlet Dryers

<table>
<thead>
<tr>
<th></th>
<th>Dryer A</th>
<th>Dryer C</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed cake flow</td>
<td>636</td>
<td>628</td>
<td>G/M</td>
</tr>
<tr>
<td>Feed cake moisture</td>
<td>65.0</td>
<td>65.0</td>
<td>%</td>
</tr>
<tr>
<td>Feed syrup flow</td>
<td>10.41</td>
<td>10.47</td>
<td>G/M</td>
</tr>
<tr>
<td>Feed Syrup moisture</td>
<td>65</td>
<td>65</td>
<td>%</td>
</tr>
<tr>
<td>Total mixed feed flow</td>
<td>646</td>
<td>638</td>
<td>G/M</td>
</tr>
<tr>
<td>Total mixed feed moisture</td>
<td>65.00</td>
<td>65.00</td>
<td>%</td>
</tr>
<tr>
<td>Dry feed flow</td>
<td>226</td>
<td>223</td>
<td>G/M</td>
</tr>
<tr>
<td>Dryer outlet flow</td>
<td>382</td>
<td>389</td>
<td>G/M</td>
</tr>
<tr>
<td>Outlet flow moisture</td>
<td>40.78</td>
<td>42.57</td>
<td>%</td>
</tr>
<tr>
<td>Moisture removed from dryer</td>
<td>264.37</td>
<td>249.36</td>
<td>G/M</td>
</tr>
<tr>
<td>Gas flow</td>
<td>38.2</td>
<td>39.6</td>
<td>MMBTU/H</td>
</tr>
<tr>
<td>Dryer Spec gas</td>
<td>0.0201</td>
<td>0.0221</td>
<td>MMBTU/lb</td>
</tr>
</tbody>
</table>

## Outlet Dryers

<table>
<thead>
<tr>
<th></th>
<th>Dryer B</th>
<th>Dryer D</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed from first dryer</td>
<td>382</td>
<td>389</td>
<td>G/M</td>
</tr>
<tr>
<td>Dryer inlet moisture</td>
<td>40.78</td>
<td>42.57</td>
<td>%</td>
</tr>
<tr>
<td>Feed syrup</td>
<td>34.2</td>
<td>32.1</td>
<td>G/M</td>
</tr>
<tr>
<td>Syrup moisture</td>
<td>65</td>
<td>65</td>
<td>%</td>
</tr>
<tr>
<td>Total mixed feed flow</td>
<td>416</td>
<td>421</td>
<td>G/M</td>
</tr>
<tr>
<td>Total mixed feed moisture</td>
<td>42.77</td>
<td>44.28</td>
<td>%</td>
</tr>
<tr>
<td>Dry feed flow</td>
<td>238</td>
<td>235</td>
<td>G/M</td>
</tr>
<tr>
<td>Dryer outlet flow</td>
<td>271.0</td>
<td>272.9</td>
<td>G/M</td>
</tr>
<tr>
<td>Moisture in DDG Lab data</td>
<td>12.1</td>
<td>14.0</td>
<td>%</td>
</tr>
<tr>
<td>Moisture removed from dryer</td>
<td>145.23</td>
<td>148.30</td>
<td>G/M</td>
</tr>
<tr>
<td>Gas flow</td>
<td>28.76</td>
<td>37.77</td>
<td>MMBTU/H</td>
</tr>
<tr>
<td>Dryer Spec gas</td>
<td>0.0275</td>
<td>0.0354</td>
<td>MMBTU/lb</td>
</tr>
</tbody>
</table>
The Challenge: Cascading Dryers

- **Dryer A**
  - Moisture: 0.0201 MMBTU/lb

- **Dryer B**
  - Moisture: 0.0275 MMBTU/lb

- **Dryer C**
  - Moisture: 0.0221 MMBTU/lb

- **Dryer D**
  - Moisture: 0.0354 MMBTU/lb

**Wet Cake**

**DDGS Product**
## The Solution: Natural gas Dryer Optimization

<table>
<thead>
<tr>
<th>Task</th>
<th>MPC</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize the Natural gas use</td>
<td>Automatically computes dryer loading to minimize Natural gas</td>
<td>Not done because it was too complex</td>
</tr>
<tr>
<td>Controlling moisture targets of each dryer</td>
<td>Targets incorporate current moisture levels and are <strong>proactively</strong> adjusted</td>
<td>Targets set at installation and <strong>reactively</strong> changed once out-of-spec</td>
</tr>
<tr>
<td>Dryer constraint handling</td>
<td>Uses models of the process to <strong>proactively</strong> manage constraints</td>
<td>Only <strong>reactively</strong> changes moisture if equipment alarms are triggered</td>
</tr>
<tr>
<td>Recording of moisture levels</td>
<td>Once per minute</td>
<td>Every 2 hours</td>
</tr>
<tr>
<td>Frequency of Natural gas target change</td>
<td>Once per minute</td>
<td>Depends on the operators judgment</td>
</tr>
</tbody>
</table>
### Actual Plant Results: Reduced Variability & Increased Stability

<table>
<thead>
<tr>
<th>Plant Key Performance Indicators</th>
<th>Mean Value Change</th>
<th>STD Value Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abs</td>
<td>Rel</td>
</tr>
<tr>
<td>• Plant Production Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Corn Grain Feed [lbs/min]</td>
<td>+15.30%</td>
<td></td>
</tr>
<tr>
<td>200 Proof Flow [gpm]</td>
<td>+17.61%</td>
<td></td>
</tr>
<tr>
<td>• Specific Energy Consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Gas [BTU/gal-EtOH]</td>
<td>-11.70%</td>
<td></td>
</tr>
<tr>
<td>Natural gas for Dryers [lbs/gal-EtOH]</td>
<td>-3.73%</td>
<td></td>
</tr>
<tr>
<td>Total Natural gas [lbs/gal-EtOH]</td>
<td>-8.53%</td>
<td></td>
</tr>
<tr>
<td>• Ethanol Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gallons of Ethanol per Bushel of Grain</td>
<td>+0.59%</td>
<td></td>
</tr>
</tbody>
</table>

Significant reduction in standard deviation of all variables
Fermenter Data – Reduced Residual Sugars (USA)

Drop Glucose

Without Fermenter MPC

Fermenter MPC online

Key Target

Specification or Limit

Before Model Predictive Control

With Model Predictive Control and Optimization

Concentration

Batch #

Time
Fermenter data – Increased Ethanol Conc.

Drop Ethanol

Without Fermenter MPC

Fermenter MPC online

Concentration vs. Batch #
Who is Windsor Utilities?

Windsor Utilities Commission: Service Area

WUC sells and distributes water to all of Windsor, and sells water to the towns of LaSalle and Tecumseh.
Pressure Locations
Drinking Water - System Overview

- Total daily supply capacity: 349 ML (92 MGD)
- Reservoir storage capacity: 118 ML (31 MG)
- Number of treatment plants: 2
- Number of pumping stations: 3
- Number of Elevated Storage Tanks: 2
- Length of water main: 1,100 km (690 Miles)
- The Albert H. Weeks Water Treatment Plant supplies an average of 140 ML (37 MG) of water to City residents per day.
The Opportunity

- 238 Main Breaks per year (average)
- 44 average age of distribution water main (one of the oldest in Ontario/Canada)
- Increasing Electricity costs
- Inconsistent system pressures during peak/low demand periods
### APC Faceplate in FTView

<table>
<thead>
<tr>
<th>Minimum Pressures</th>
<th>AJ Brian Pumps</th>
<th>Pressure Controllers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode</strong></td>
<td><strong>Status</strong></td>
<td><strong>FCV</strong></td>
</tr>
<tr>
<td>Downtown #10</td>
<td>R</td>
<td>85%</td>
</tr>
<tr>
<td>Seminal #2</td>
<td>S</td>
<td>0%</td>
</tr>
<tr>
<td>Lauzon #3</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Rhodes #3</td>
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<td>Mercer #5</td>
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<td>Beals #13</td>
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<td>Malden #15</td>
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</tr>
<tr>
<td>Hanna</td>
<td>S</td>
<td></td>
</tr>
</tbody>
</table>

**Hannah Level**

- Min: 60%
- Max: 85%

**Pressure Control Settings**

- **VSD**
- **Manual**
- **Optimized**
- **Stopped**
- **Running**
- **Pressure Control**
- **Manual Control**
- **Optimized**
- **Stopped**
- **Running**
Before MPC

Pump start/stop cycles
Results – After with MPC

When were the pumps started?
Thank You! Questions?