Dynamic Optimization of Profit and Olefin Production using Profit Controller and Profit Optimizer in Ethylene Plant

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LG Petrochemical Corporation Ltd.
Sung-Mo Ahn and Ravi Nath
Honeywell Process Solutions
Contents

- Introduction of Company
- Project Overview
- Project Progress
- APC & DQP Design
- Benefits Achieved
- Conclusions
Company History

1978. 3  Established LG Petrochemical CO., Ltd.
1991. 9  Dedicated Naphtha Cracking Center
1992.10 Dedicated Aromatics & HDPE Plant
1993.11 Acquired ISO 9002 Certification of HDPE Plant (DNV)
1994. 5  Dedicated Pentane Plant
1996. 8  Revamped NCC & HDPE Plant
1997.12 Acquired ISO 14001 Certification
1998. 9  Revamped BTX Plant
2000.12 Acquired Korea Energy Grand Prize
Company Overview

- Paid-up Capital : 226 KRW bn
- Employees : 554 (As of Apr. 2003)
- Annual Sales : 1,286 KRW bn (in Fiscal Year of 2003)
- Plant site : 462,043 m² (In the Yeosu petrochemical complex)
- Business Activities : Manufacturing, Selling and Purchasing of Petrochemicals, Utilities and Electric Power
Dynamic Optimization in an Ethylene Plant

Products and Capacity

Naphtha Cracking Center

- **Naphtha**
  - **C\textsubscript{4} LPG Gas Oil**

**Naphtha Cracking Center**

- **Ethylene** 750 → **HDPE Plant** → **HDPE** 265
- **Propylene** 370 → **Butadiene / C\textsubscript{4} HTU Plant**
  - **Butadiene** 118
  - **C\textsubscript{4} LPG**
  - **Raffinate-1**
  - **Benzene** 200
  - **Toluene** 85
  - **Xylene** 42
  - **Mixed-C\textsubscript{5}**

**Mixed C\textsubscript{4}**

**Pyrolysis Gasoline**

- **Aromatics Plant**
  - **Toluene** 85
  - **Xylene** 42
  - **Mixed-C\textsubscript{5}**

**C\textsubscript{5} Plant**

- **High Purity Pentane** 20
Petrochemical Business of LG Group

Accomplished the perfect vertical integration from oil refining to production of a large variety of petrochemical products.

(Unit: 1,000MT/YR)

<table>
<thead>
<tr>
<th>LG - Caltex Oil</th>
<th>LG Petrochem</th>
<th>LG Chem</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Naphtha</td>
<td>• Basic Petrochem 1,565</td>
<td></td>
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<tr>
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<td>- Ethylene</td>
<td></td>
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<td></td>
<td>- Propylene</td>
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<tr>
<td></td>
<td>- Butadiene</td>
<td></td>
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<tr>
<td></td>
<td>- BTX</td>
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<td></td>
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<td></td>
<td>- HDPE</td>
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<td>• Monomer 2,200</td>
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<td>- VCM</td>
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<td></td>
<td>- SM</td>
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<td>- MMA ...</td>
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<td>• Polymers 2,280</td>
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<td>- PVC</td>
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<td>- ABS</td>
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<td></td>
<td>- LDPE ...</td>
<td></td>
</tr>
</tbody>
</table>
LG’s Participation in Yeosu Complex

**Production Amount**

- **LG Petrochem**
  - 100%
  - (21.6 trillion won)
  - 72%
  - (15.6)

- **5% (1.1)**

**Employees**

- **LG Petrochem**
  - 100%
  - (12,600 employees)

- **3.8% (470)**

- **LG**
  - 100%
  - (28% (3,600))
Dynamic Optimization in an Ethylene Plant

**Vision**

To be a world class petrochemical company growing with our customers by creating differentiated value

**Shared Value**

- Trust & Teamwork
- Challenge & Breakthrough
- Abiding by Principles

**Management Policies**

- Enhancing the talents of each employee
- Development of core technologies
- Implementation of Cash flow-oriented management
Goal & Strategy for Existing Business

**Goal**

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales (KRW bn)</th>
<th>Ordinary Income (KRW bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1,074</td>
<td>91</td>
</tr>
<tr>
<td>2005</td>
<td>1,262</td>
<td>133</td>
</tr>
</tbody>
</table>

**Strategy**

- Achievement of the world’s best cost competitiveness
- Implementation of strategic new business and high-value-add by-product business
- Development of core technologies
- Development of specialty products and increase of sales ratio of specialties
- Achievement of cost leadership
- Pursuit of M&A and strategic alliance to promote competitiveness

**CAGR**: Compound Annual Growth Rate
Dynamic Optimization in an Ethylene Plant

Goal & Strategy for New Business – BPA (Bis Phenol A)

NCC

LG Petrochemical

Benzene: 160,000 tons/year
Propylene: 87,000 tons/year

Cumene: 240,000 tons/year

Phenol/Acetone: 180,000 tons/year

BPA: 120,000 tons/year

Phenol
Acetone
BPA

LG-DOW

Polycarbonate

S Korea S/D balance

Demand CAGR 16.3%

Capa

Demand

2001 2003 2005

35 127 135

2005

259

Asia S/D balance, ex-JPN

Demand CAGR 11.3%

Capa

Demand

2002 2007

600 651

1,155 1,188

< Valuation >

• Capex: W200bn
• Coming out 1Q05
• Feasibility: IRR 19.5%, sales W205bn
• Expected operating income: 30%

LG-DOW

Polycarbonate

NCC
Core Competence

Ethylene production capacity
(1,000 MTA/YR)

Capacity up: 195%  
Revamping (150) 

1992: 385  
1996: 600  
2001: 750 (754)  
2006: 850

Dynamic Optimization in an Ethylene Plant

Core Competence

Specific energy consumption
(Kcal/kg, Ethylene)

- 1992: 6,130
- 1996: 5,350
- 2001: 4,649
- 2005: 3,990

World best level
Dynamic Optimization in an Ethylene Plant

BA101: Ethane-only
BA103, 111: Co-cracking
BA112, 113: Split-cracking

BA102/111: Co-cracking
BA112/113: Split-cracking

Ethane
DA101: Gasoline Fractionator
DA104: Quench Tower
DA207: Dryer Feed Wash Tower
DA202: Condensate Stripper
E-FF201: Charge Gas Dryer
DA201: Gasoline Stripper

Ethane
Fuel Oil

Ethane Recycle

GB201: Charge Gas Compressor
GB501: C-O R Compressor
GB601: C-O R Compressor

GB601
C2H4

DA402: Ethylene Fractionator
DA404/414: Depropanizer No.1/2
DA415: Depropanizer No.3
DA406/407: Propylene Fractionator
DA405: Debutanizer

DA207: Dryer Feed Wash Tower
DA401: Deethanizer
DA405: Debutanizer

DA404: Quench Tower
DA301: Demethanizer
DA401: Deethanizer

DA401: Deethanizer
DA405: Debutanizer

DA104: Quench Tower
DA401: Deethanizer
DA405: Debutanizer

Mixed-C4

DA406/414

DA406

DA406/407

C3 LPG

C2H2

C2H4

H2, CH4

C3 H6

MAPD

Conv.

Conv.
PROCESS CHARACTERISTICS

- Significant feed quality variations
- Furnace decoking
- Periodic operations (e.g. dryer switching)
- Others
  - Filter plugging, catalyst breakthrough
  - Ambient condition variations

Process is very dynamic, seldom steady!
Dynamic Optimization in an Ethylene Plant

APC History

1st implementation by the E&C Company

- Not successful because
  - Stead state optimizer,
    - Maintenance issue
  - Process seldom steady,
    - Infrequent optimization
  - Overall low benefits, high maintenance cost

Still convinced of the benefits decided to give it a second try in 2000
Current APC project

Kicked off in March 2000 with the following objectives

- Stabilize fractionators operation
- Energy Savings
- Increase Olefins production
- Develop internal expertise
Solution Technology Selection

Considered all available offerings, and chose Honeywell

- Robust controller
- Simpler controller tuning
- Ease of adding optimization layer
- Dynamic Optimization
- Local support
Project Team

Composed of limited internal resources and Honeywell staff

• LGPC resources has actively taken part in
Dynamic Optimization in an Ethylene Plant

Project Progress (1)
2000 - 2003

- Training of in-house staff
- Cold side controllers to stabilize column operation
  - Step testing, model identification and commissioning of the following:
    - Demethanizer / C₂ Refrigerant
    - Deethanizer
    - Ethylene fractionator / C₃ Refrigerant
    - Depropanizer
    - Propylene fractionator
Project Progress (2)
Sept. 2003

- Attention shifts to hot side control
  - Step testing, model identification and commissioning of the following:
    - 1 Ethane only heater
    - 11 Naphtha only heaters
    - 2 Naphtha and ethane co-cracking heaters
    - 1 Ethane and naphtha selection heater
Dynamic Optimization in an Ethylene Plant

Project Progress (3)
Nov. 2003 – March 2004

- Attention shifts to dynamic optimizer
- On-line execution of customized furnace yield model
  - for calculation of severity and yield gains
- Severity gain mapping
- Closing of 2 still open loops
- Bridge Model identification
- Profit Optimizer
  - configuration / gain updating / closed loop commissioning
Dynamic Optimization in an Ethylene Plant

System configuration

- PHD (Database)
- Custom HTR model
- TCP/IP Network
- Workstation for customized heater model
- Profit Optimizer
  - Pre_dqp
  - GEMPO toolkit
  - GMPC toolkit
  - Hot section APC
- Cold section APC
- LCN
- US/GUS
- APP 23
- APP 25
## Profit Controller Overview

<table>
<thead>
<tr>
<th>Process Area</th>
<th>CV</th>
<th>MV</th>
<th>DV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot side:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heater #1</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #2</td>
<td>8</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Heater #3</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #4</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #5</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #6</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #7</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #8</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #9</td>
<td>7</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Heater #10</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #11</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #12</td>
<td>11</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Heater #13</td>
<td>11</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Heater #14</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Heater #15</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cold side:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demethanizer / C₂ Refrigerant</td>
<td>17</td>
<td>11</td>
<td>6</td>
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<tr>
<td>Deethanizer</td>
<td>13</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Ethylene Fractionator / C₃ Refrigerant</td>
<td>9</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Dehepanizer No. 1/2</td>
<td>12</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Dehepanizer No. 3</td>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Propylene Fractionator</td>
<td>8</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>182</td>
<td>91</td>
<td>33</td>
</tr>
</tbody>
</table>
Dynamic Optimization in an Ethylene Plant

Graphical User Interface

- Profit Viewer for Engineer / User Station standard graphics for Operator

![Graphical User Interface Example](image-url)

<table>
<thead>
<tr>
<th>APL</th>
<th>CV#</th>
<th>CV Description</th>
<th>Status</th>
<th>Value</th>
<th>RMFCT SS</th>
<th>DQP SS</th>
<th>LO Limit</th>
<th>HI Limit</th>
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<tbody>
<tr>
<td>18</td>
<td>A146911 PV</td>
<td>GOOD</td>
<td>492.34</td>
<td>491.00</td>
<td>491.00</td>
<td>490.00</td>
<td>487.00</td>
<td>495.00</td>
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<tr>
<td>18</td>
<td>A140717 PV</td>
<td>GOOD</td>
<td>0.0431</td>
<td>0.0056</td>
<td>0.0233</td>
<td>0.00</td>
<td>1.000</td>
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<tr>
<td>18</td>
<td>14334 PV</td>
<td>GOOD</td>
<td>25.47</td>
<td>25.13</td>
<td>25.34</td>
<td>25.00</td>
<td>26.00</td>
<td>16.00</td>
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<tr>
<td>18</td>
<td>14340 PV</td>
<td>DROP</td>
<td>0.6974</td>
<td>0.6808</td>
<td>0.6356</td>
<td>0.6000</td>
<td>0.6200</td>
<td>0.7200</td>
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<tr>
<td>18</td>
<td>14342 PV</td>
<td>DROP</td>
<td>105.00</td>
<td>4.4819</td>
<td>4.4901</td>
<td>0.0500</td>
<td>105.00</td>
<td>105.00</td>
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<tr>
<td>18</td>
<td>14350 PV</td>
<td>DROP</td>
<td>306.74</td>
<td>19.545</td>
<td>16.257</td>
<td>0.00</td>
<td>304.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Profit Controller Design(1)

Hot section

- Typical controlled variables
  - Severity or conversion
  - Tube outlet temperature
  - Cross over temperature
  - Valve positions

- Typical manipulated variables
  - Coil outlet temperature
  - Feed flow rate
  - Steam to HC ratio
Profit Controller Design (2)

Cold section

- Typical controlled variables
  - Overhead purity
  - Bottom purity
  - Compressor speed
  - Discharge pressure
  - Pressure difference
  - Tray temperature
  - Valve positions

- Typical manipulated variables
  - Steam flow rate
  - Reflux flow rate
  - Side draw flow rate
  - Pressure
Customized Heater Model Design (1)

- Step testing, model identification and commissioning of 15 heaters
- Customized Heater Model was developed by internal resources.
Customized Heater Model Design (2)
Pre_DQP for Customized Heater Model
Profit Optimizer Design (1)

One for all controllers
- 15 Hot section controllers
- 6 Cold section controllers
- 4 Dummy controllers

More than Summation
- 9 Bridge models
- 39 Combined constraints
Profit Optimizer Design(2)

Bridge model
- Dynamic model between column feed and heater MV
- Dynamic model between olefin production and heater MV
- Obtained from step test and historical operation data

Combined constraint model
- Total hydrocarbon flow
- Furnace yield and overall propylene / ethylene ratio
- Coking rates
- Total fuel consumption and total steam generation
Profit Optimizer Design(2)

Bridge model

Material Balance Flow sheet
Benefits achieved (1):
Cold side controllers: Ethylene fractionator
Benefits achieved (2):
Cold side controllers: Ethylene fractionator

Comparison ethane composition of ethylene product before APC with after APC

<table>
<thead>
<tr>
<th>Item</th>
<th>Ethane Composition (ppm)</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>St. Dev.</td>
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<tr>
<td>Before APC</td>
<td>462.7</td>
<td>32.39</td>
</tr>
<tr>
<td>After APC</td>
<td>491.7</td>
<td>9.78</td>
</tr>
</tbody>
</table>

The Productivity Increase of ethylene fractionator after APC application

<table>
<thead>
<tr>
<th>Item</th>
<th>Product (T/H)</th>
<th>Reflux Ratio</th>
<th>Reduced Reflux (T/H)</th>
<th>Red. Energy (Gcal/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>88.20</td>
<td>4.087</td>
<td></td>
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<tr>
<td>After APC</td>
<td>88.57</td>
<td>4.069</td>
<td>1.6</td>
<td>0.16</td>
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</table>
Benefits achieved (3):
Cold side controllers: Depropanizer
Benefits achieved (4):

Cold side controllers: Deethanizer & Depropanizer

### The Energy savings of deethanizer after APC application

<table>
<thead>
<tr>
<th>Item</th>
<th>Top C₃ (%)</th>
<th>BTM C₂ (ppm)</th>
<th>Reflux ratio</th>
<th>Reduced Reb. Steam (T/H)</th>
<th>Reduced Top Condenser Duty (Gcal/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before APC</td>
<td>0.353</td>
<td>1.4</td>
<td>0.600</td>
<td>0.32</td>
<td>0.11 (0.13 HS T/H)</td>
</tr>
<tr>
<td>After APC</td>
<td>0.443</td>
<td>1.8</td>
<td>0.589</td>
<td></td>
<td></td>
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</table>

### The Energy savings of depropanizer after APC application

<table>
<thead>
<tr>
<th>Item</th>
<th>TOP C₄ (ppm)</th>
<th>BTM C₃ (ppm)</th>
<th>Reflux ratio</th>
<th>Reduced Reb. Steam (T/H)</th>
<th>Reduced Top Condenser Duty (Gcal/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before APC</td>
<td>4</td>
<td>124</td>
<td>1.02</td>
<td>0.46</td>
<td>0.326 (0.28 HS T/H)</td>
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<tr>
<td>After APC</td>
<td>429</td>
<td>77</td>
<td>0.82</td>
<td></td>
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</table>
## Benefits achieved (5):
### Cold side controllers: Benefits Summary

<table>
<thead>
<tr>
<th>Ethylene Productivity</th>
<th>Item</th>
<th>Productivity (T/H)</th>
<th>Total (T/H)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reflux Ratio Decrease</td>
<td>+0.388</td>
<td>+0.514</td>
</tr>
<tr>
<td></td>
<td>C2 - Loss in BTM</td>
<td>-0.236</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2 Composition Correction in Feed</td>
<td>+0.362</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Energy Savings</th>
<th>Item</th>
<th>Energy Savings (T/H)</th>
<th>Total (T/H)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Deethanizer Reb. STM (LS)</td>
<td>-0.32</td>
<td>-0.78</td>
</tr>
<tr>
<td></td>
<td>Deethanizer Cond. C3 Refriger (HS)</td>
<td>-0.13</td>
<td>-0.41</td>
</tr>
<tr>
<td></td>
<td>Depropanizer Cond. C3 Refriger (HS)</td>
<td>-0.28</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recovery of Higher Value Product</th>
<th>Item</th>
<th>Composition</th>
<th>Profit (T/Y)</th>
<th>Total ($/Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ethane Increase in Ethylene Product</td>
<td>30 ppm</td>
<td>24$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4’s Increase in Propane Product</td>
<td>400 ppm</td>
<td>68$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Propylene Decrease in Propane Product</td>
<td>1.3%</td>
<td>210$</td>
<td>30,000$</td>
</tr>
</tbody>
</table>
Benefits achieved (6):  
Cold side controllers: Operator satisfaction
Benefits achieved (7):
Dynamic Optimization : Constraint handling
Benefits achieved (8):
Dynamic Optimization : Olefin maximization trend
Benefits achieved (9):
Dynamic Optimization : Comparison before DQP with after DQP
Benefits achieved (10):
Dynamic Optimization: Comparison before DQP with after DQP

![Graph showing trend of feed and product after and before DQP application]

Stabilization & about 0.4% Increase of Olefins Production and Naphtha Feed
CONCLUSIONS

• APC and dynamic optimization of the entire Olefins plant
  • Using limited internal resources
  • Some consultation from Honeywell

• Sustained APC and optimization benefits
  • stabilized plant operation with all loops closed
  • uptime > 95%
  • olefins production increase of 0.97% (1.25T/hr)

• Now considering other measures of productivity improvement
  • Automation of furnace transients
  • ASM
  • Operator training