Overall Energy Conservation
in both process unit and utility
through HERO Service
&
Energy Saving Distillation Technology
SUPERHIDIC®

Singapore Energy Efficiency Symposium
for the Energy and Chemicals Industry

October 15th and 16th 2019
TOYO ENGINEERING CORPORATION
Target Customers

Those who are struggling to find further solution for energy-saving and reduction of GHGs emission.

  e.g. Pinch technology has been already done...
  Lots of process/plot constraints

What TOYO Offers in this presentation...

  ➢ Technology applied to distillation unit
  ➢ Methodology to bring you new idea
Summary

- Proven technology through commercial production plant operation
- Offering tremendous energy conservation and reduction of GHGs emission to conventional distillation by 40-75%!
- Reducing utility consumption at not only reboiler (steam, fuel gas, fuel oil) but also condenser (cooling water, electricity at AFC)
- Can be applied to both new plants and revamping/upgrading
- Attractive economics like IRR of 15-40% in suitable applications
<table>
<thead>
<tr>
<th>Process Unit</th>
<th>Service Name</th>
<th>Energy Saving</th>
<th>Example</th>
<th>Capacity</th>
<th>Conv. Dist.</th>
<th>SUPERHIDIC®</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[%]</td>
<td>[kMTA]</td>
<td>[MW]</td>
<td>[MW]</td>
<td>[MW]</td>
</tr>
<tr>
<td>p-Xylene</td>
<td>Tol. Column</td>
<td>68</td>
<td>1380 p-Xylene</td>
<td>238</td>
<td>0</td>
<td>27.5</td>
</tr>
<tr>
<td>p-Xylene</td>
<td>Finishing Col.</td>
<td>45</td>
<td></td>
<td>98.1</td>
<td>0</td>
<td>19.6</td>
</tr>
<tr>
<td>p-Xylene</td>
<td>Xy. Splitter</td>
<td>54</td>
<td></td>
<td>181</td>
<td>12.6</td>
<td>26.1</td>
</tr>
<tr>
<td>m-Xylene</td>
<td>m-Xylene Col.</td>
<td>50</td>
<td>23 t/h feed</td>
<td>4.3</td>
<td>0</td>
<td>0.78</td>
</tr>
<tr>
<td>o-Xylene</td>
<td>o-Xylene Col.</td>
<td>73</td>
<td>17.5 t/h feed</td>
<td>9.93</td>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>C4 Isom.</td>
<td>C4 Splitter</td>
<td>57</td>
<td>180 iC4</td>
<td>11.6</td>
<td>0</td>
<td>1.85</td>
</tr>
<tr>
<td>C5 Isom.</td>
<td>C5 Splitter</td>
<td>64</td>
<td>270 iC5</td>
<td>29.7</td>
<td>0</td>
<td>3.91</td>
</tr>
<tr>
<td>C6 Isom.</td>
<td>De-iC6</td>
<td>48</td>
<td>46 t/h feed</td>
<td>6.98</td>
<td>0</td>
<td>13.2</td>
</tr>
<tr>
<td>C4 Dehydro.</td>
<td>BD Prefrac.</td>
<td>75</td>
<td>71 t/h feed</td>
<td>32.4</td>
<td>0</td>
<td>2.95</td>
</tr>
<tr>
<td>FCC</td>
<td>FCC NP Splitter</td>
<td>52</td>
<td>280 t/h feed</td>
<td>23.7</td>
<td>0</td>
<td>4.03</td>
</tr>
<tr>
<td>FCC</td>
<td>Light Cracked NP</td>
<td>44</td>
<td>30.2 t/h feed</td>
<td>24.4</td>
<td>0</td>
<td>4.87</td>
</tr>
</tbody>
</table>
## Summary

<table>
<thead>
<tr>
<th>Process Unit</th>
<th>Service Name</th>
<th>Energy Saving</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>[%]</td>
<td>[kMTA]</td>
</tr>
<tr>
<td>VCM</td>
<td>Light End Col.</td>
<td>43</td>
<td>200</td>
</tr>
<tr>
<td>VCM</td>
<td>Heavy End Col.</td>
<td>51</td>
<td>654 EDC</td>
</tr>
<tr>
<td>IPA</td>
<td>Azeotropic Col.</td>
<td>41</td>
<td>163</td>
</tr>
<tr>
<td>2EH</td>
<td>C4 Alde. Splitter</td>
<td>52</td>
<td>240 NBAL</td>
</tr>
<tr>
<td>SM</td>
<td>EB/SM Splitter</td>
<td>41</td>
<td>240 SM</td>
</tr>
<tr>
<td>MEK</td>
<td>MEK Fractionator</td>
<td>56</td>
<td>100 MEK</td>
</tr>
<tr>
<td>1-Butene</td>
<td>1st Column</td>
<td>74</td>
<td>63 1-C4=</td>
</tr>
<tr>
<td></td>
<td>2nd Column</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iso-Butene</td>
<td>iC4= Fractionator</td>
<td>62</td>
<td>70 iC4=</td>
</tr>
<tr>
<td>Caprolactam</td>
<td>Cyclohexane Col.</td>
<td>50</td>
<td>11.5 Anon</td>
</tr>
</tbody>
</table>
Heat Integrated Distillation Column
- Fundamental -

Ideal

Reversible Distillation

- Infinite stages
- Heat removal @ all stages with infinitesimal duty

Reality

HIDiC

- Increased pressure, subsequent increased temp. @ rectifying section

Feed → Distillate → Reboiler → Bottoms

Condenser → Feed → Striping → Rectifying

Heat transfer
Fundamental Heat Integrated Distillation Column - HIDiC vs VRC Heat Pump

- Temperature [°C]
- Stage: Top, Middle, Bottom
- Sections: Rectifying, Stripping, Conv. Distillation
- Heat Exchanges: Internal (Side)
- Compression Ratio: HIDiC < VRC
Conventional HIDiC

Does enthalpy profile agree with that in reversible distillation?
Findings through intensive thermodynamics study
- Ideal heat duty is dependent on the composition (stage).
- Some composition may require heat while some others may not. Thus, discrete side H/Ex allocation.
- Seldom to have ideal heat duties at the same elevation.
- Stage having similar heat duty demand should be combined.

Inappropriate side H/Ex manner = Increase in column loading in vain = Increase in compressor

Discrete & a few side H/Ex
Different heat duty at each side H/Ex
Appropriate stage to be exchanged not at same level
【Features】

- **Side exchangers**
  - Normal stabbed-in type H/Ex (Normal S/T H/Ex can be used)
  - Installed at the desired composition
  - Freedom in pairing of stages
  - Heat transfer area is variable
  - Limited number (around 4) only

- **Column**
  - Strip. sect. elevated above rect. sect.
    - No pump is required for circulation
  - Normal tray or packing

- Maintenance possible
- Applicable to any process scheme, e.g. side-cut product draw-off, multi-feed
- Optimal side heat duty allocation close to reversible distillation achievable

Patent registered by Toyo/AIST
Actual Performance in Commercial Plant

- Awarded for world-1st HIDiC commercial application with SUPERHIDiC® in 2014 Q3

Contract Summary
- Client: Maruzen Petrochemical
- Site: Chiba, Japan
- Process Unit: MEK
- Scope: License & EPC TKLS
- Replacement of conventional distillation column

Results
- Energy Conservation: 57% reduction to conventional distillation
- Stable Operation w/ 0 kW Reboiler Duty
- More than 3 years commercial operation
Actual Performance in Commercial Plant

STM : steam
SW : sea water

Reboiler Duty "0" kW in stale operation!! (6135 kW@conv. dist)
# Actual Performance in Commercial Plant

<table>
<thead>
<tr>
<th></th>
<th>SUPERHIDIC</th>
<th>Conv. Distillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate [S kL/h]</td>
<td>19.5</td>
<td>19.5</td>
</tr>
<tr>
<td>Operating pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low pressure column @OVHD [kPa]</td>
<td>109</td>
<td>109</td>
</tr>
<tr>
<td>High pressure column @OVHD [kPa]</td>
<td>229</td>
<td>-</td>
</tr>
<tr>
<td>Separation specifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEK @distillate [wt%]</td>
<td>99.94</td>
<td>99.94</td>
</tr>
<tr>
<td>MEK @bottoms [wtppm]</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Energy consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reboiler duty [kW]</td>
<td>0</td>
<td>6135</td>
</tr>
<tr>
<td>Compressor power [kW]</td>
<td>915</td>
<td>0</td>
</tr>
<tr>
<td>Reflux/dist. Pump [kW]</td>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>Bottoms pump [kW]</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>Recycle pump [kW]</td>
<td>34</td>
<td>-</td>
</tr>
</tbody>
</table>

Energy Saving [%] = \[ 1 - \frac{Q_{r-SH}}{Q_{r-conv}} + \frac{W_{SH}}{W_{conv}/0.366} \] \times 100

- \( Q_{r-SH} \): Reboiler duty in SUPERHIDIC [MW]
- \( Q_{r-conv} \): Reboiler duty in conv. Distillation [MW]
- \( W_{SH} \): Compressor & pumps power in SUPERHIDIC [MW]
- \( W_{conv} \): Compressor & pumps power in conv. distillation [MW]

Energy Saving 56.7% to Conv. Distillation
GHGs Emission

[Conventional Distillation]
✓ Reboiler : 6,135 kWh/h
  \[ \times 8,000 \text{ h/y} \times 3.6/1,000 \text{ GJ/kW} \times 0.0477 \text{ tCO}_2/\text{GJ} = 8,428 \text{ ton-CO}_2/\text{yr} \]
✓ Pump : (55+10) kWh/h
  \[ \times 8,000 \text{ h/y} \times 0.00050 \text{ tCO}_2/\text{kWh} = 260 \text{ ton-CO}_2/\text{yr} \]
Total CO\(_2\) emission : 8,688 ton-CO\(_2\)/yr

[SUPERHIDIC®]
✓ Reboiler : 0 kWh/h
  \[ \times 8,000 \text{ h/y} \times 3.6/1,000 \text{ GJ/kW} \times 0.0477 \text{ tCO}_2/\text{GJ} = 0 \text{ ton-CO}_2/\text{yr} \]
✓ Pump + Compressor : (25+27+34+915) kWh/h
  \[ \times 8,000 \text{ h/y} \times 0.00050 \text{ tCO}_2/\text{kWh} = 4,004 \text{ ton-CO}_2/\text{yr} \]
Total CO\(_2\) emission: 4,004 ton-CO\(_2\)/yr

Reduction of CO\(_2\) emission : 8,688 – 4,004 = 4,684 ton-CO\(_2\)/yr
\[ \rightarrow 54\% \text{ reduction} \]
Recommendable Service for SUPERHIDIC®

Service where SUPERHIDIC® offers attractive energy saving and economics

- Temp. difference btw OVHD and bottoms even up to 80 deg C
  - Much larger difference compared to vapor re-compression heat pump system

- Large scale reboiler and/or condenser duty

- Expensive utilities

- Less fouling
Awards

- 2014 Nikkei Green Innovation Prize
- 2017 ENAA Engineering Excellence Award
- 2018 Energy Conservation Grand Award (METI Prize)
- 2018 SCEJ Award for Outstanding Technical Development
- 2018 JPI Award for Technological Progress
- 2019 SSEJ Award for Outstanding Technical Development
Next

✶ How to apply such nice technology to your plant

✶ How to achieve energy-saving and reduction of GHGs emission even without such super-technology
Energy Conservation & Reduction of GHGs Emission for Overall Process/Utility Plant by Mathematical Optimization

— Hybrid Energy system Re-Optimization —

2019

TOYO ENGINEERING CORPORATION
Agenda

- Overview

- Illustrative example (on the presentation only)

- Features of optimization model

- Achievements in a national project

- Business scheme
Simultaneous Optimization on both Process and Utility Systems

Comprehensive model optimizes both systems simultaneously for direct minimization of external utility resource usage.

Objective
Minimization of external utility usage

Fuel
Sell/Buy Electricity

Comprehensive mathematical optimization model

Requested heat duty
Pressure Flowrate of consumed supplied STM
Heat

Process Sys.

Power
Requested Power
Power Supply / Pressure Flowrate of consumed STM
Utilities Sys.
What makes such big difference?

Primal three features for breaking the limit of conventional approaches, such as pinch analysis.

- Comprehensive mathematical optimization model
  - Objective
    - Fuel
    - Sell/Buy Electricity
  - Process Sys.
    - Requested heat duty
    - Power
  - Utility Sys.
    - Pressure Flowrate
    - Power Supply / Pressure Flowrate
    - of consumed STM
    - of supplied STM

Superior optimization on process sys.
Superior optimization on utility sys.
Superior Process System Optimization

Comprehensive mathematical optimization model

- Requested heat duty
- Pressure Flowrate
- Power
- Heat
- Fuel
- Sell/Buy
- Electricity

Objective

- Implementation of new HEXs
- Multi-effect dist. intensification
- Implementation of heat-pump distillation etc...
Optimization on Heat Exchanges

All options which might be effective are covered.

- Cooling: Condenser, heat recoveries at outlets
- Heating: Reboiler, feed preheaters

From the all combinations, effective configuration is selected.
Operating pressures of distillation columns are also optimized.

Linearized models for several ranges of operation pressure are embedded.
Examination of Heat-Pump Distillation

As for each distillation column, implementation of heat-pump distillation — especially SUPERHIDIC®, is also examined.
Superior Utility System Optimization

Comprehensive mathematical optimization model

- Requested heat duty
- Pressure Flowrate of supplied STM
- Heat
- Process Sys
- Utility Sys
- Power Supply / Pressure Flowrate of consumed STM

Objective

- Fuel
- Sell/Buy
- Electricity

☑️ Turbine refit
☑️ Header press. change
☑️ Letdown adjustment etc...

- 33 -
Optimization on Steam System

Alternation of turbine-inlet steam is examined.

Power to process system.

Steam usage/generation at process sys.

Implementation of additional header level is examined.
Scale of Optimization

In the case of x 6 columns & 4 levels of STM headers

- # of ope. press. ranges: 4
- # of feed state ranges: 4
- SUPERHIDIC® option: included
- # of candidate press. of each STM header: 3

Heat-exchange comb.  Dist. col.  STM header
ope. range  ope press.

\[ 2^{(2 \times 6) \times (3 \times 6)} \times (4^2 \times 2)^6 \times 3^4 \approx 10^{75} \text{ conditions} \]

Corresponds to: \( 2^{(# \text{ of possible comb.})} \)

Even this alone results in \( 10^{63} \) conditions

Solve 1 case w/ 1 sec \( \Rightarrow 10^{57} \) years

HERO’s efficient search using Mixed Integer Linear Prog. can find out the solution within moderate calc. time.
Customization for “Best” Modification

- Precise performance diagnosis of existing equipments
  - Design press. & temp.
  - Column hydraulics

- Limitation on equipment modification
  (Indirect consideration of CAPEX for the modification)
  - Column replace (entire replace/internal replace )
  - Heat exchanger replace
  - Piping installation for new heat exchanges

- Condition of external utilities
  - Available utility list (fuel, steam, electricity, etc)
  - Exportable utility list
  - Prices of the available/exportable utilities
Agenda

- Overview
- Illustrative example (on the presentation only)
- Feature of optimization model
- Achievements in a national project
- Business scheme
# Achievements (through a National Project)

## Case 1

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Proposal</th>
<th>Energy Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Steam</td>
<td>31.3</td>
<td>18.9</td>
<td>12.4 (39.7% Saving)</td>
</tr>
</tbody>
</table>

## Case 2

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Proposal</th>
<th>Energy Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Steam</td>
<td>9.24</td>
<td>9.24</td>
<td>0</td>
</tr>
<tr>
<td>MP Steam</td>
<td>-2.7</td>
<td>-15.48</td>
<td>12.78 (473% for Sell)</td>
</tr>
</tbody>
</table>

## Case 3

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Prop. 1 Prop. 2</th>
<th>Energy Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Oil</td>
<td>12.32</td>
<td>9.85 MW 9.51 MW</td>
<td>Prop. 1: 2.47 (20% Saving) Prop. 2: 2.81 (23% Saving)</td>
</tr>
</tbody>
</table>
Business Scheme

Development of **tailor-made** model for specific process & utility configuration → Proposal of “Overall” Optimum

- **Min. initial charge**

Client

- **Configuration:**
  - Process & utility systems
  - Operation/Design Data
  - Operation Philosophy

TOYO

- **Optimal operation target**
- **Modification plan**

- **Energy saving score**

- **Proposal C**
  - Proposal B
  - Proposal A

- **Investment**
  - (or Equip. modification degree)

- **Performance-based reward**
  - Concept Purchase
  - ΔOPEX-based charge
Information to be provided

Followings are to be provided at the beginning of the projects

- **Technical information regarding operation and design:**
  - PFD/UFD/MB・HB
  - Design pressure & temperature (MSD or writing down on PFD/UFD)
  - Plot plan
  - (Vapor-liquid equilibrium data, in some cases)

- **Constraints on modification:**
  - Possibility for replace/retrofit of each existing equipment
  - Possibility for installing new piping on pipe rack (room in rack)
  - Constraints on new heat exchanges (plot & process point of view)

- **Unit price of utilities:**
  Significant gap between actual and applied values severely misdirects the optimization.

- **Investment requirement:** Upper bound of investment & requested economics
Schematic Plan of Project Execution

Interview of prerequisite
- Contents mentioned in previous slide

Initial fee

Step 1: Development of modification plan regarding operation & equipment
TOYO’s work:
- Establishment of trace model
- Mathematical optimization
- Summarizing equip. modification

Step 2: Support for precise estimation of CAPEX
TOYO’s work:
- Clarifying modification plan on P&ID basis

Rough evaluation of economics by client
- Reward for basic concept
- Final evaluation of economics by client
- FID by client
- Finalizing the docs. for starting EPC

Step 3: Document finalization
TOYO’s work:
- Finalization for starting EPC

EPC Execution
- The contractor(s) can be others than TOYO.

Start of operation
- Performance-based reward
- For a few years after 1st year operation

Req. duration: 1 months
- Req. duration: 6 months
- Req. duration: 1 months
Output

🌟 Step 1: Information for rough estimation of modification costs

✓ PFD & UFD (with piping size of main process lines, without process control)
✓ Major utility consumption summery (preliminary)
✓ Equipment list with brief information
  (Process sketch with description of modification for reused equips.)
✓ Brief plot plan

🌟 Step 2: Information for precise estimation of modification cost

✓ P & ID with markup of modified parts

🌟 Step 3: Finalized ver. of necessary documents for starting EPC

✓ PFD, UFD, MB・HB, Utility summary, P&ID
✓ Equipment summary, Equipment datasheet
✓ Brief plot plan
Thank you for your kind attention!

For more details...

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Environment and Energy Management Development Department
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Recommendable Service for SUPERHIDIC®

- Process units that have been confirmed as suitable for SUPERHIDIC so far -

Flowchart:
- LPG Treatment: C4 separation
  - Refinery: Alkylation, C4 isomerization, C5 isomerization, C6 isomerization, FCC, PDH, C4 de-hydro.
  - NP
  - Gasoline, Kerosene, Gas oil, Asphalt
- Steam Cracker: LPG, Ethylene, Propylene, C4s, Py. Gasoline
- Cracker Downstream:
  - VCM
  - EB/SM
  - Oxo-alcohol (2EH)
  - Allyl-alcohol
  - IPA
  - Cumene
  - Isobutene, 1-butene
  - MEK, 1-hexene
  - Propylene
  - Caprolactam
- Aromatics Complex: Bz/Tol Extraction, C8 isomerization, p-xylene, Trans-alkylation, Disproportionation
Conclusion

- HIDiC has been evolved to *SUPERHIDIC®,* which has been finally commercialized and becomes *proven* technology.

- *SUPERHIDIC®* has achieved an energy saving of over 55% compared with conventional distillation.

- The start-up operation has been carried out successfully as expected.
Limitation of Pinch Analysis

Additional Heat Exchange at inlet/outlet flows? Alternation of operation pressure

⇒ Numerous candidates

Conv. methodology + trial & err can hardly find the global optimum
Does Pinch Analysis + Trial & Err works?

- Cooling by utility
- Heating by utility

Heat release from condenser of column 3

Column 3 ope. press. ↑ does not go well?

Heat exchange in process (Heating/cooling without utilities)
NO! it does not in many cases

Trial & err often results in that unexpected demerit cancels the merit.

Synergetic combination of multiple options is needed.

Heat duty is increased due to ope. press. ↑

Heat exchanged in process is increased.

Heat exchange in process

Increase of heat duty at reboiler of column 3

CANCEL
HERO’s Result

29.8% (9.2 MW) Energy saving

To Rx

From Rx

110°C

151°C

1.6 MPaA

0.1 MPaA

46°C

198°C

217°C

172°C

182°C

196°C

249°C

278°C

0.2 MPaA

0.08 MPaA