Process Integration in Petroleum Refineries - A Perspective and Future Trends

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Outline

1. Background

2. Heat Recovery in Crude Oil Distillation Systems

3. Case Study

4. Utility System Optimization

5. Case Study

6. Concluding Remarks
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Crude oil refining

1. Atmospheric distillation uses heat to separate crude oil into naphtha, light oils, and heavy oils.

2. Atmospheric residue is further distilled to extract oils under vacuum conditions.

3. Heavy oils are cracked into usable products, using several processes.

4. Blending creates final products.
Refinery CO₂ emissions breakdown by process

150,000 bbl/d
Hydroskimming refinery
0.6 Mt/a CO₂

150,000 bbl/d
Conversion refinery
1.4 Mt/a CO₂


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Energy Consumption within refineries

The chart presents the final energy use (in TBTu) for various processes within refineries, categorized by electricity, steam, and fuel. The processes include:

- Desalter
- CDU
- VDU
- Thermal Cracking
- FCC
- Hydrocracking
- Reforming
- Hydrotreater
- Deasphalting
- Alkylates
- Aromatics
- Asphalt
- Isomers
- Lubes
- Hydrogen
- Sulfur
- Other

The pie chart on the right indicates the proportion of energy consumption sources: Fuel, Steam, and Electricity.
Heat Integration using Pinch Analysis

Well established methodology
- many successful applications around the world
Pinch Analysis - Summary

- An approach to the design of heat recovery systems based on thermodynamic rules
- Applies well to the design of new systems
- Fundamentally not suited to retrofit
  - Tries to turn the existing design into a grassroot design in a single step
  - Often leads to complex and uneconomic retrofits
- Fundamentally not suited to operational optimization
**Pinch Analysis - Summary**

**BUT**

- It is a useful tool used in the right way on the right problems
- Can be used to set target performance for new processes
- Can be used to set the ultimate performance of an existing process, **but this will not necessarily be economic**
- It is one of a number of tools that can be used to improve the performance of processes
Superstructure Optimization

Initial Design (Superstructure)

- Difficult mathematical optimization problem - due to nonlinear nature of the problem
- Difficult to get practical solutions reliably for large complex problems
- Designer is removed from decision making

Final Design

Optimize
• Superstructure approach now well developed

• More powerful optimization engines will increase the application of the approach and the quality of the solutions

BUT.....

Most users still demand the insights that automated techniques do not provide
Optimisation Methods

- Trial & Error
- NLP
- MINLP
- MILP
- Stochastic Search Methods

Complexity vs. Number of Design Configurations

Graphical Approaches
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Energy use in crude oil distillation

Medium size refinery

6 million tonnes of crude per year (110,000 bbl/day)

70 MW furnace duty (ADU+VDU)

~ 15 million Euros per year in furnace operating costs
Strategies to reduce energy consumption

Retrofit

- Capital investment required
- Benefits increase with higher capital investment
- Downtime required for implementation

Operational Optimisation

- No capital investment required
- Limited benefits due to fixed configuration
- Changes can be readily implemented

CDU and HEN should be optimised together
Challenges to optimising heat-integrated distillation systems

- Complex configuration
- Subject to many practical constraints

Installed heat transfer area, capacity of pumps, bypasses, plant layout, etc.
Approach to optimising heat-integrated distillation systems

- Surrogate models using ANN have been particularly effective
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CASE STUDY

Carried out by Process Integration Ltd
Industrial Case Study

Project background
• Complex Chinese refinery, processing 6 millions tonne/y of opportunity crudes

Project Objectives
• 5-year energy management contract (EMC)
• Improve system energy efficiency by HEN retrofit

Constraints
• Very tight product quality specifications
• Limited condenser duty
• Fuel gas with varying composition
• Complex existing HEN: 47 exchangers

Implementation completed in January 2016
Industrial Case Study

- Historical data for 2 years were analysed to identify representative crude oils from the variety processed in that period

- Main challenge was the complexity of the existing system: five distillation columns
Industrial Case Study – Procedure

1. Data collection
   - E.g. feed and product properties, main operating cases, HE geometry data

2. Develop rigorous simulations
   - Based on collected data and validated with process engineers

3. Analyses using rigorous simulations
   - E.g. sensitivity analysis to propose CDU operational changes, pinch analysis

4. HEN design developed
   - Revamping options proposed with various levels of investment

5. Verification of results
   - Results revised and verified with process engineers

6. Implementation and validation
   - Implementation strategy, data collection and savings calculations
Industrial Case Study – Predicted results

Train A

Train B

Change from base case

+ 25 °C  
- 8 °C

+ 14 °C  
+ 4 °C

+ 48 °C  
+ 21 °C

Number of heat exchangers
Industrial Case Study – Predicted results

- Train A
  - 1
  - 2
  - 2
  - 2
  - 1
  - 3
  - 3
  - 6
- Train B
  - 1
  - 1
  - 2
  - 3
  - 3
  - 8

Additional heat transfer area
- 7,230 m²

Fuel savings
- 22%
- 4.3 MM €/y
## Industrial Case Study – Retrofit modifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total additional area ((m^2))</td>
<td>7,230</td>
</tr>
<tr>
<td>New heat exchangers</td>
<td>6</td>
</tr>
<tr>
<td>Exchangers with additional area</td>
<td>9</td>
</tr>
<tr>
<td>Relocated exchangers</td>
<td>8</td>
</tr>
</tbody>
</table>
## Track record on CDU studies

Implemented retrofit and new design 15 projects since 2009 considering energy efficiency improvement and yield optimisation. Summary of the latest projects:

<table>
<thead>
<tr>
<th>Project name</th>
<th>Client</th>
<th>Year</th>
<th>Project Description / Economic benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Optimisation and Retrofit Optimisation Study of Crude Oil Distillation Unit</td>
<td>European Refinery, Spain</td>
<td>2016</td>
<td>Savings from operational and yield optimisation = 4.5 MM€/yr (verified) for current scenario and 6.4 MM€/yr (estimated) for future scenario</td>
</tr>
<tr>
<td>Crude Distillation Unit Preheat Revamping</td>
<td>Sinopec, China</td>
<td>2016</td>
<td>EMC: Implemented. Capacity: 3.0 mt/y; CIT increase = 48.2°C; 13.5 MW reduction in furnace duty; additional area: 4,000 m²</td>
</tr>
<tr>
<td>Crude Distillation Unit Preheat Revamping</td>
<td>Sinopec, China</td>
<td>2016</td>
<td>EMC: Detailed Engineering. Capacity: 3.0 mt/y; CIT increase = 67 °C; 18.5 MW reduction in furnace duty; additional area: 10,300 m²</td>
</tr>
<tr>
<td>Crude Distillation Unit Preheat Revamping</td>
<td>Sinopec, China</td>
<td>2015</td>
<td>EMC: Implemented. Capacity: 5.2 mt/y; CIT increase = 43 / 22 °C; 10 MW reduction in furnace duty; additional area: 7,805 m²</td>
</tr>
<tr>
<td>Benchmark Studies On Crude Unit Optimisation</td>
<td>European Refinery, Spain</td>
<td>2014</td>
<td>Savings from operational optimisation = 0.85 MM€/yr; Savings from medium size revamping = 2.62 MM€/year</td>
</tr>
<tr>
<td>Overall Refinery Simulation and Optimisation</td>
<td>PetroChina, China</td>
<td>2013</td>
<td>Average CIT increase by 10°C after implementation, Operating cost reduced by 1.64 MM$/year</td>
</tr>
</tbody>
</table>

EMC: Energy Management Contract
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Utility system – the scope
Process integration in utility system

- Utility system accounts for 20% to 30% of total energy consumption in oil refineries

Technically, utility system is the most energy consuming process in a refinery

How can process integration technologies come to help?
Comprehensive utility system modeling and optimization

- Pipeline model with existing modeling and optimization technologies:

A large mixer
Comprehensive utility system modeling and optimization

• In practice, the pipeline is a complex network. It has issues such as flow direction, pressure drop and heat loses etc.
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CASE STUDY

Carried out by Process Integration Ltd
Case study – Project background

• A Sinopec refinery that processes 5,000,000 tons of crude oil per year
• Site power demand is about 50MW
• Site MP consumption: 210—240t/h
• Site LP consumption: 170—210t/h
Case study – Analysis & Diagnosis

- Mathematical data reconciliation verified site level steam balance
- Flowrate for some streams without flow measurement instruments estimated based on data reconciliation
- Reconciled letdown flowrate proven to be greater than previous estimates. Still scope to reduce the letdown
System modelling using i-Steam
Case study – Operational optimisation

• Overall, 3.1% of total operating cost can be saved with operational optimisation
  – Optimisation operational strategies provided for the CHP, saving 1.7% of total operating cost
  – Optimising MP system pressure could save 0.4% of total operating cost
  – Optimising LP system pressure could save 1.0% of total operating cost
Case study – Retrofit optimisation

- Additional 3.8% of total operating cost can be saved with small scale retrofit
  - Easy to fit pipe retrofit within the sulphur recovery and FCC processes (0.8% saving)
  - Fixing a unit in a FCC WHB (1.3% saving)
  - Very small retrofit to the existing low temperature heat recovery system (1.7%)
### Track record on Utility studies

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Saving (US M$/yr)</th>
<th>Saving in %</th>
<th>Pay back months</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Operational optimisation for site utility system</td>
<td>13.7</td>
<td>7%</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>Operational optimisation for site utility system</td>
<td>2.4</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>Operational optimisation for site utility system</td>
<td>4.6</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Operational optimisation for site utility system</td>
<td>2</td>
<td>2%</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Operational optimisation for site utility system</td>
<td>7.5</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Operational optimisation for site utility system</td>
<td>0.65</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>Operational and retrofit study for site utility system</td>
<td>4</td>
<td>8%</td>
<td>14</td>
</tr>
<tr>
<td>2011</td>
<td>Operational optimisation for site utility system</td>
<td>0.67</td>
<td>7%</td>
<td>-</td>
</tr>
<tr>
<td>2012-2013</td>
<td>Driver configuration design - New refinery</td>
<td>6.8-13.7</td>
<td>1.5-3%</td>
<td></td>
</tr>
<tr>
<td>2013-2015</td>
<td>Operational optimisation for site utility system</td>
<td>1.85</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Retrofit designs</td>
<td>2.27</td>
<td>4%</td>
<td>6</td>
</tr>
<tr>
<td>2015-2016</td>
<td>Total site utility project</td>
<td>2.1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>2015-2016</td>
<td>Online operational optimisation - ongoing</td>
<td></td>
<td></td>
<td></td>
</tr>
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Where do we stand?

- Significant progress has been made in developing and applying new methodologies for process integration in petroleum refining.
  - heat recovery in crude oil distillation systems
  - utility systems
- **BUT**, retrofit remains a significant problem.
- Obtaining cost effective retrofits is still our biggest challenge in heat recovery.
  - Not just new equipment, but minimize piping modifications and civil engineering
• Need to find more effective ways to include layout constraints in the retrofit decision making.
Additional Area and Retrofit

- Retrofit often requires additional area around the network including places other than where the network structure is to be modified.
  - can be expensive (especially pipework and civil engineering)
- Need to find cost effective ways to achieve this.

Heat Transfer Enhancement
Crude oil fouling

- Need to be able to model the fouling
  - Laboratory measurements not relevant
  - Every crude oil (and crude mix) is different
- Include fouling models in design, retrofit and operational optimization.
Thank you!