New Energy Efficient Redesign of an Existing Crude Oil Distillation Unit

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Outlines

- Introduction
- Energy Efficient Distillations
- Motivation and Challenging Problems
- New Retrofit Approach for Refinery Distillation Units
- Case Study
- Results and Discussion
- Conclusions and Future Work
Introduction

- Energy is a fundamental driver of economic growth
- Distillation industry contributes significantly to operation costs and is environmentally challenging
- Crude distillation is energy intensive; it consumes approximately an equivalent of 2% of the crude oil processed
- Building new refinery units is very costly
  - Therefore, many retrofit projects on existing installations are considered to increase the production capacity, improve profit and minimise the energy consumption

_i.e. energy is expensive and its efficiency is very low for typical distillations_
Energy Efficient Distillations

Simple Column

Column Sequence

Divided-wall Column

Heat Pump

iHIDiC

Progressive Distillation
Motivation and Challenges

- Very complex structure
- Many products
- Interactions between units
- Energy intensive process
- Expensive to modify
- Environmentally harmful
- Economically challenged
- Tedious to model and simulate
Motivation and Challenges

Refineries aim to reuse existing installations for:

- Processing more throughput
- Saving energy
- Processing new crude feed stocks
- Changing product yields
- Debottlenecking
- Reducing atmospheric emissions
- Less total operating costs
- Low capital expenditure
- Minimum structural modifications
- Large profit

Preferably with:
New Retrofit Approach

Base Case Data → Development of Rigorous Model → Validation of Model → Optimisation → Structural Modifications

Structural Modifications:
- Pre-flash
- Pre-Fractionator
- New Pump-Around
- Heat transfer enhancement
Optimisation can be for minimum energy by maximising energy recovery using Pinch Analysis or total cost or emissions cut.
Case Study (MIDOR)

- 100,000 bbl/d of crude oil (50% Arabian light and 50% Arabian heavy)
- 5 products: Vapours (Naphtha), kerosene, light diesel (LD), heavy diesel (HD), and residue (RES)

| Over head vapour flow (kg/hr) | 125,000.23 |
| Kerosene flow (t/hr) | 49.2 |
| LD flow (t/hr) | 106.3 |
| HD flow (t/hr) | 11.4 |
| Residue flow (t/hr) | 293.5 |
| Duty of furnace (MMkcal/hr) | 55.7 (≈65 MW) |
| Energy Cost ($/yr) | 3,330,245 |
Existing HEN

2\textsuperscript{nd} preheat train

130 °C

1\textsuperscript{st} preheat train

20 °C

Crude oil

Vacum residue

HVGO

PA around 2

LD

Kerosene

PA around 1

Reflux

LVGO

HD

366 °C

264 °C
Case Study Objectives

- Development of a rigorous process design model for the existing refinery distillation plant
- Increasing the energy efficiency
- Optimisation of the current operating conditions to minimise energy consumption and total costs
- ......
- ............capacity.....
- ............different feed stocks...
Results and Discussion
1- Rigorous Process Design Model
Validation of The Base Case

<table>
<thead>
<tr>
<th>Parameter of comparison</th>
<th>MIDOR data</th>
<th>HYSIS results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet crude flow (t/hr)</td>
<td>57,399</td>
<td>57,600</td>
</tr>
<tr>
<td>Crude temperature before furnace (°C)</td>
<td>264</td>
<td>265</td>
</tr>
<tr>
<td>Crude temperature after furnace (°C)</td>
<td>365</td>
<td>365</td>
</tr>
<tr>
<td>Duty of furnace (MMKcal/hr)</td>
<td>55.7</td>
<td>55.25</td>
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<tr>
<td>Reflux ratio</td>
<td>0.80</td>
<td>0.85</td>
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<tr>
<td>Condenser duty (MMkcal/hr)</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>First pump around flow (m³/h)</td>
<td>570.1</td>
<td>570.1</td>
</tr>
<tr>
<td>Second pump around flow (m³/h)</td>
<td>505.30</td>
<td>505.33</td>
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</tbody>
</table>
Validation of Rigorous Model

Flow rates (kg/hr)

- Over head vapour
- Kerosene
- LD
- HD
- Residue

MIDOR
HYSIS
2- Column Optimisations

Changing the lower pump-around flow rate

- Temperature of crude oil before furnace increased from 264 to 271 °C
- Duty of furnace decreased from 55.25 MMkcal/hr to 47.76 MMkcal/hr,
- % Reduction in energy = 13.55 %.

**PA flow rate vs Qh min**

- Optimum PA flow rate is 540 m³/hr
- Fixed column specifications
3- HEN Optimisation

- By adding additional area of \textbf{600 m}^3 which will cost \textbf{86,085 $}
- The crude oil exits from the last heat exchanger at \textbf{274 °C} instead of \textbf{264 °C}
- The duty of the furnace decreased from \textbf{55.25 MMkcal/hr} to \textbf{46.7 MMkcal/hr},
- The reduction % of energy equals \textbf{15.4 %}

<table>
<thead>
<tr>
<th>Exchanger</th>
<th>Actual area</th>
<th>Modified area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m(^2)</td>
<td>m(^2)</td>
</tr>
<tr>
<td>1</td>
<td>420</td>
<td>773.8</td>
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<tr>
<td>2</td>
<td>480</td>
<td>254.5</td>
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<tr>
<td>3</td>
<td>1616</td>
<td>872.2</td>
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<tr>
<td>4</td>
<td>170</td>
<td>359.5</td>
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<tr>
<td>5</td>
<td>429</td>
<td>240.8</td>
</tr>
<tr>
<td>6</td>
<td>429</td>
<td>485</td>
</tr>
<tr>
<td>7</td>
<td>600</td>
<td>55.3</td>
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<tr>
<td>8</td>
<td>1456</td>
<td>0.9</td>
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<tr>
<td>9</td>
<td>1436</td>
<td>330.8</td>
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<tr>
<td>10</td>
<td>1152</td>
<td>438.9</td>
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<tr>
<td>11</td>
<td>1708</td>
<td>669.5</td>
</tr>
</tbody>
</table>
New Exchanger Network (HEN)

Crude oil

1st preheat train

2nd preheat train

366 °C

274 °C

142 °C

20 °C

Vacuum residue

HVGO

PA around 2

LD

Kerosene

PA around 1

Reflux

LVGO

HD

Cooler

Additional area
4- Simultaneous Optimisation in both Column and HEN

- By simultaneously applying both column and HEN optimisations.
- The temperature of crude oil before the furnace increased to be $278.3 \, ^\circ C$ instead of $264 \, ^\circ C$.
- The duty of the furnace decreased from $55.25 \, \text{MMkcal/hr}$ to $44.98 \, \text{MMkcal/hr}$.
- The reduction % of energy equals $18.58 \%$. 
5- Using Pre-flash before Furnace

- Furnace duty: 55.25 to 30.47 MMkcal/hr
- % Reduction = 44.8%
- Due to removal of relatively large amount of vapour from furnace (vap. fr. = 0.437)
## Results Summary

<table>
<thead>
<tr>
<th>parameter</th>
<th>Base Case</th>
<th>Column Optimisation</th>
<th>HEN Optimisation</th>
<th>Simultaneous Optimisation</th>
<th>Pre-flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. before furnace (°C)</td>
<td>264</td>
<td>271</td>
<td>274</td>
<td>278.3</td>
<td>264</td>
</tr>
<tr>
<td>Duty of furnace (MMkcal/hr)</td>
<td>55.70</td>
<td>47.76</td>
<td>46.70</td>
<td>44.98</td>
<td>30.47</td>
</tr>
<tr>
<td>% Reduction in energy demand</td>
<td>13.6</td>
<td>15.4</td>
<td>18.6</td>
<td>44.8</td>
<td></td>
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<tr>
<td>Additional capital cost ($)</td>
<td>69,642</td>
<td>111,910</td>
<td>161,005</td>
<td>72,290</td>
<td></td>
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<tr>
<td>Energy saving (fuel cost, $/yr)</td>
<td>451,624</td>
<td>513,285</td>
<td>619,275</td>
<td>1,493,194</td>
<td></td>
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<tr>
<td>Pay back time (year)</td>
<td>0.15</td>
<td>0.22</td>
<td>0.26</td>
<td>0.05</td>
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</tr>
</tbody>
</table>
Conclusion and Future Work

- New retrofit approach is applicable to existing refinery distillation units
- Rigorous process models are of great significance in retrofit studies
- Energy can be reduced substantially with optimisation
- Column and HEN can be dealt with simultaneously
- Structural modifications improve energy efficiency further
- Energy and fuel costs can be reduced by up to 44%

- Automation of optimisation algorithm