Preheat train monitoring allows better management of crude oil fouling

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HTRI
Outline

• HTRI overview
• Describing the problem
• Managing crude oil fouling to improve overall performance
  – Case studies using SmartPM™
• Summary
HTRI overview

- Research and development consortium in process heat transfer
- For profit corporation established in 1962
- Corporate headquarters and Research & Technology Center in Navasota, Texas, USA
- HTRI products in use at more than 1400 corporate sites in 62 countries
- Committees and Task Forces
  - Crude Oil Fouling Task Force

www.htri.net
Goals of HTRI Fouling Program

1. Oil companies working together with HTRI generating world-class data
   • More than 10 major oil companies actively participate in Crude Oil Fouling Task Force (from Brazil, France, India, Japan, Saudi Arabia, UK and USA)

2. Translating rig data to the field

3. Predicting fouling

\[
Fouling\ rate = \frac{Fouling\ Propensity\ Factor}{h} \exp\left(-\frac{E}{RT}\right)p
\]

4. Managing Fouling to save $ £ € ₹ ¥ ¢

SmartPM

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Problem

• Crude oil fouling in preheat train produces losses in energy and throughput

• Refineries face some key issues:
  – Can we predict and manage fouling?
  – When and which exchangers to clean?
  – How does running heavier fouling crudes affect maintenance?
  – What is the effect of revamp/retrofit projects?
  – Can we increase throughput with current pump and furnace constraints?
SmartPM: Shell-and-tube network simulation from Performance Monitoring to Predictive Maintenance

- Advanced data reconciliation of measured plant data
- Built-in data historian
  - Store all historic measurements and results, plus predictions
- Heat exchanger cleaning scheduling, with predictive dynamic fouling models
  - Cleaning for reduced energy and emissions and maximum savings
    - Also for pressure drop limits
    - Also for furnace limits
- Retrofitting and revamps, for reduced fouling, energy savings
What are the *annual* energy savings through effective exchanger cleaning schedules with SmartPM?

![Typical CDU Annual Energy Savings (MM USD)](image)

- **Selection of CDUs**
  - Energy cost = $23/MW.hr
  - $6.3/GJ, $6.7/MMBtu
- **Crude throughput bbl/day**
- **High fouling blend**
- **Low fouling blend**
Project outline of CDU case study

- Data supplied by refinery crude unit engineers
- SmartPM model built by HTRI
- 4 years of plant data imported
- Data reconciled
  - All historic heat exchanger and stream data calculated
- Cleaning schedules calculated
  - Best schedule for least heating energy use, minimum emissions
  - Best schedule to maximise throughput by optimizing flow split
Construct Network Model

Exchanger geometry  Process Flow Diagram  Stream properties

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Monitoring data

Reconciled data

Historical network performance
Review/study/analyze reconciled data

- View all heat exchanger parameters
- For example, for any exchanger see flow rate, crude slate and fouling
Case studies

Cleaning scenarios

1. Top five exchangers to clean “today” (now)
2. Scheduling cleaning until next turnaround
3. Scheduling if fired heater capacity limited
### Cleaning scenario 1

**“Top 5” to clean “today” for least energy use**

<table>
<thead>
<tr>
<th>Heat Exchanger / Unit Name</th>
<th>Annual Net Benefit (USD)</th>
<th>Cost of Cleaning (USD)</th>
<th>HX / Unit Duty - Before Cleaning (MW)</th>
<th>HX / Unit Duty - After Cleaning (MW)</th>
<th>Network Duty Gained After Cleaning (MW)</th>
<th>Initial FIT Increase (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit C (2 shells)</td>
<td>700,000</td>
<td>123,000</td>
<td>18.2</td>
<td>30.1</td>
<td>7.1</td>
<td>13.8</td>
</tr>
<tr>
<td>Exchanger P</td>
<td>670,000</td>
<td>24,000</td>
<td>2.6</td>
<td>10.1</td>
<td>2.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Unit F (2 shells)</td>
<td>660,000</td>
<td>52,000</td>
<td>7.8</td>
<td>15.2</td>
<td>2.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Exchanger S</td>
<td>230,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Unit B (2 shells)</td>
<td>71,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Top 5 Exchanger Sets to Clean Together on 06 September 2017**

<table>
<thead>
<tr>
<th>Heat Exchanger / Unit Name</th>
<th>Annual Net Benefit (USD)</th>
<th>Cost of Cleaning (USD)</th>
<th>HX / Unit Duty - Before Cleaning (MW)</th>
<th>HX / Unit Duty - After Cleaning (MW)</th>
<th>Network Duty Gained After Cleaning (MW)</th>
<th>Initial FIT Increase (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit C</td>
<td>700,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.8</td>
</tr>
<tr>
<td>Unit C + Exchanger P</td>
<td>1,200,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17.5</td>
</tr>
<tr>
<td>Unit C + Exchanger P + Unit F</td>
<td>1,600,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19.8</td>
</tr>
<tr>
<td>Unit C + Exchanger P + Unit F + Exchanger S</td>
<td>1,700,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.4</td>
</tr>
<tr>
<td>Unit B + Unit C + Exchanger P + Unit F + Exchanger S</td>
<td>1,800,000</td>
<td></td>
<td>18.2</td>
<td>30.1</td>
<td>7.1</td>
<td></td>
</tr>
</tbody>
</table>

Cleaning benefit in isolation 30.1 – 18.2 = 11.9 MW

Network cleaning benefit 7.1 MW (60%)

Annualized cost benefits, accounting for all interactions between exchangers

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### Cleaning scenario 2

**Predictive cleaning schedule to next turnaround**

#### Summary of annual energy benefits (for constant throughput)

<table>
<thead>
<tr>
<th>Calculated Cleaning Benefits</th>
<th></th>
<th></th>
<th></th>
<th>Cleaning Benefit: Average Furnace Duty Saving</th>
<th>Cleaning Benefit: CO₂ Saving</th>
<th>Total Cleaning Cost</th>
<th>Total Net Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Start Date</td>
<td>End Date</td>
<td>Number of Cleans</td>
<td>MMBtu/hr</td>
<td>tons</td>
<td>US$</td>
<td>US$</td>
</tr>
<tr>
<td>1</td>
<td>01/01/2015</td>
<td>31/12/2015</td>
<td>8</td>
<td>18.31</td>
<td>8,800</td>
<td>260,000</td>
<td>717,800</td>
</tr>
<tr>
<td>2</td>
<td>01/01/2016</td>
<td>31/12/2016</td>
<td>8</td>
<td>39.38</td>
<td>18,900</td>
<td>220,000</td>
<td>2,114,900</td>
</tr>
</tbody>
</table>

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## Cleaning scenario 2

**Predictive cleaning schedule to next turnaround (least energy)**

<table>
<thead>
<tr>
<th>HX Name</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>EX1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Cleaning scenario 3
Helping refiner prevent turndown

• Large preheat train
• Variable crude slate
• Frequent turndown as furnace duty limit reached

Cleaning schedule seeks to raise furnace inlet temperature (FIT) to save energy, reduce furnace firing

*SmartPM now used to prevent turndown*
Cleaning scenario 3

Historic furnace inlet temperature (nondimensional)

Crude fouling caused loss of FIT of approximately 30 °C per year without cleaning

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Cleaning scenario 3

Historic (normalized) throughput

- Crude throughput also reduced when FIT reaches critical level
- Furnace duty (firing) limit breached, throttled back
Cleaning scenario 3

Measured and predicted throughput

Prediction using fouling model

- Flow rate, FIT, and exchanger fouling profiles match well
- Furnace limit reached after four months, so SmartPM selects exchangers to clean to maintain FIT and flow

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Cleaning scenario 3

Measured and predicted FIT

*Prediction using fouling model*

Flow rate, FIT, and exchanger fouling profiles match well
Cleaning scenario 3
Summary of economic benefits (increasing throughput)

<table>
<thead>
<tr>
<th>Year</th>
<th>Start Date</th>
<th>End Date</th>
<th>Number of Cleans</th>
<th>CO₂ Saving Cost (tonnes)</th>
<th>Total Cleaning Cost (USD)</th>
<th>Total Net Savings each year (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Month 1</td>
<td>Month 12</td>
<td>12</td>
<td>14,400</td>
<td>400,000</td>
<td>5,700,000</td>
</tr>
<tr>
<td>2</td>
<td>Month 1</td>
<td>Month 12</td>
<td>10</td>
<td>20,800</td>
<td>320,000</td>
<td>18,500,000</td>
</tr>
</tbody>
</table>
Crude identified that cause acute fouling problems

Refinery stopped using that crude because monitoring provided clean data associating the crude with the problem.
Summary

• Monitoring performance combined with network simulation allows estimation of simple fouling model

• Fouling model coupled with performance data helps estimate future performance and recommended cleaning schedules based on overall energy savings and emission reductions

• Establishing adequate cleaning schedules can lead to significant savings