Benefits of Fouling Testing

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Crude oil fouling is a crude quality issue

Decrease in thermal performance
Increase in pressure drop

Total cost of fouling = 0.1 – 0.3% of GDP

Approx. US$37 billion/year (assuming 0.2% of 2016 GDP)
Crude chemistry alone is a poor indicator of fouling tendency

<table>
<thead>
<tr>
<th></th>
<th>Crude A</th>
<th></th>
<th>Crude B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heptane insolubles, ASTM 3279</td>
<td>8.5 w/w%</td>
<td>Higher fouler</td>
<td>6.3 w/w%</td>
<td>Lower fouler</td>
</tr>
<tr>
<td>Colloidal Instability Index (CII), ASTM D4184 &amp; D4124</td>
<td>0.23</td>
<td>Lower fouler</td>
<td>0.45</td>
<td>Higher fouler</td>
</tr>
<tr>
<td>Olefins, ASTM D6733</td>
<td>0.059 w/w%</td>
<td>Higher fouler</td>
<td>0.000 w/w%</td>
<td>Lower fouler</td>
</tr>
<tr>
<td>TAN, ASTM D664</td>
<td>0.4 mg KOH/g</td>
<td>Lower fouler</td>
<td>0.95 mg KOH/g</td>
<td>Higher fouler</td>
</tr>
<tr>
<td>Basic nitrogen, UOP-269</td>
<td>1793 mg/kg</td>
<td>Lower fouler</td>
<td>1100 mg/kg</td>
<td>Higher fouler</td>
</tr>
<tr>
<td>Salt content, ASTM D-3230</td>
<td>8.3 lb/1000 bbls</td>
<td>Higher fouler</td>
<td>3.5 lb/1000 bbls</td>
<td>Lower fouler</td>
</tr>
</tbody>
</table>

**Fouling test shows Crude A is the higher fouler**
Challenges with refinery data

- Inconsistent feed
  - Oil properties
  - Slop addition
  - Desalter problems
- Flow and temperature fluctuations

Conclusions are often anecdotal
Goals of HTRI’s crude oil fouling research

1. **Collect** world-class data
2. **Translate** rig data to the field
3. **Mitigate** fouling
4. **Predict** fouling
   - Develop fouling models
   - Simulate preheat train (SmartPM™)
   - Link chemistry

\[
\frac{dR_f}{dt} = f \left( \text{Operating conditions} \right)
\]

\[
\left\{ \begin{array}{l}
\text{Physical properties} \\
\text{Chemical properties} \\
\text{Fitted parameters}
\end{array} \right.
\]

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What is the **ideal** fouling test rig?

- Enables well controlled operating conditions
- Measures changes in thermal resistance and pressure drop
- Mimics field conditions
  - Temperatures (surface and bulk)
  - Pressures
  - Flow (velocity, Reynolds number, shear stress)
- Uses once-through flow
- Produces results in a timely fashion

Not all criteria can be achieved
### Key differences between rigs and Preheat Train

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Test rig</th>
<th>Refinery Preheat Train</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode of operation</strong></td>
<td>Batch</td>
<td>Once-through</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Scientific research</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>• Highly controlled</td>
<td>• Highly variable</td>
</tr>
<tr>
<td></td>
<td>• Very clean at start</td>
<td>• Fouling at start</td>
</tr>
<tr>
<td></td>
<td>• Same fluid</td>
<td>• Variable fluid</td>
</tr>
<tr>
<td><strong>Heating method</strong></td>
<td>Constant flux/duty</td>
<td>~Constant wall temperature</td>
</tr>
<tr>
<td><strong>Fouling assessment</strong></td>
<td>Highly instrumented</td>
<td>Limited instrumentation</td>
</tr>
</tbody>
</table>
Laboratory-scale fouling units

Ideal traits
• Small volume (≤ 1 gal)
• Less costly
• Short-test durations (because of low flow rates)

Non-ideal traits
• Flow deviates from turbulent intube flow found in PHT

Ideal uses
• Screening
• Studies in which flow is considered a non-factor
Hot-wire probe

Ideal traits
• External surface (visual inspection)
• Short run duration (< 1 day)
• Disposable test section

Non-ideal traits
• Batch system
• Not intube flow
• No flow; strongly influenced by natural convection (density variation)
• Particle settling
Once-through capillary  (Falex and Alcor units)

**Ideal traits**
- External surface (visual inspection)
- Short run duration (< 1 day)
- Continuous

**Non-ideal traits**
- Annular flow
- Deep laminar flow
- Small flow path area (flow constriction effects)
Spinning cup

Current HTRI laboratory-scale fouling rig

**Ideal traits**
- Small volume
- External surface (visual inspection)
- Short run duration
- Flow control
- Higher shear stress than other laboratory units

**Non-ideal traits**
- Batch system
- Not intube flow
Pilot-scale fouling units

**Ideal traits**

- Larger cross-sectional flow area
- Most intube flow
- Field velocities and shear stress
- Larger volume (> 10 gal) – more representative sample
- Multiple test sections possible

**Non-ideal traits**

- Generally batch
- Larger volume (> 10 gal) – supply of sample can be a challenge
- Longer test durations (2 – 4 weeks) – because of high flow rate
- More expensive to build and operate
Once-through slip stream

Theoretically – best fouling rig scenario
Practically – very challenging; virtually impossible for 3rd party

Ideal traits
• Continuous
• Intube flow
• Field flow rates
• Heat exchanger

Non-ideal traits
• Access for installation very challenging (highly sensitive area of refinery)
• Subject to refinery operations; difficult to produce research quality data
Double-pipe heat exchanger

**Ideal traits**
- Intube flow
- Field flow rates
- Heat exchanger
- Long heated length

**Non-ideal traits**
- Batch
- Surface temperature and fouling measurement more challenging
- Heating and control of second hot fluid ($$$)
- Permanent internal surface (no inspection, surface reused between tests)
Annular probe

Former HTRI fouling rig design

**Ideal traits**
- External surface allows deposit inspection

**Non-ideal traits**
- Non-circular conduit
- Flow maldistribution
- Short heated length
Sleevd tube

Current HTRI fouling rig design

**Ideal traits**
- Intube flow
- Removable tube that can be cut open and inspected
- Increased heating uniformity

**Non-ideal traits**
- Short heated length
Methods matter

Improper technique can adversely impact results from any fouling rig

• Mixing
• Fluid storage and handling
• Pressurization
• Controls
• Start-up sequence
• Data analysis/interpretation methods
• Cleaning/turnaround/maintenance
Fouling rigs may be used to study impact of test conditions

<table>
<thead>
<tr>
<th>Test condition</th>
<th>Possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk temperature</td>
<td>• Vary wall-bulk temperature difference</td>
</tr>
<tr>
<td>Wall temperature/test section power</td>
<td>• Identify fouling trend/threshold</td>
</tr>
<tr>
<td></td>
<td>• Inform design/operation</td>
</tr>
<tr>
<td>Flow rate – shear stress/velocity</td>
<td>• Quantify trend with flow</td>
</tr>
<tr>
<td></td>
<td>• Redesign bundle vs. use antifoulant</td>
</tr>
<tr>
<td></td>
<td>• Cost benefit – added pressure drop vs. fouling</td>
</tr>
<tr>
<td>Pressure</td>
<td>• Customer’s suspicion that boiling impacts fouling</td>
</tr>
</tbody>
</table>
Fouling rigs may be used to study impact of test conditions

<table>
<thead>
<tr>
<th>Test condition</th>
<th>Possibilities</th>
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</thead>
<tbody>
<tr>
<td>Surface metallurgy/coating</td>
<td>• Carbon steel vs. stainless</td>
</tr>
<tr>
<td></td>
<td>• Evaluate benefit of coatings</td>
</tr>
<tr>
<td>Fluid</td>
<td>• Crude A vs. B</td>
</tr>
<tr>
<td></td>
<td>• Blend study</td>
</tr>
<tr>
<td></td>
<td>• Evaluation of fouling of new product/feedstock</td>
</tr>
<tr>
<td></td>
<td>• Benefit of antifoulant</td>
</tr>
<tr>
<td></td>
<td>• Impact of other additives</td>
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</table>
Benefits of fouling testing

• Reduce risks
  – Risk: New fluid – heat exchanger is not designed appropriately for fouling
  – Risk: Antifoulant does not help (or makes it worse)
  – Risk: Production additives increase fouling
  – Risk: New blend leads to shutdown every 6 months

• Obtain conclusive answers through high quality research

• Fail offline
Example scenario

Benefits of fouling testing

Northern US refinery wants to blend heavy Canadian crude

• Risks
  – Increased fouling leads to more cleanings/shutdowns
  – Costs due to fouling exceed savings from opportunity crude

• Fouling study
  – Evaluate 0, 5, 10, 20% blend of Canadian with baseline blend
  – Each test evaluates a high and low flow rate at same surface temperature
**Example scenario**

**Benefits of fouling testing**

- Quantify trend fouling with blend percentage

  ![Chart showing fouling rate vs. blend percentage](chart)

- Confidence to make informed decision
  - Blend percentage
  - Cost/benefit of bundle redesign (high velocity)

- Avoid costly online issues

- Identify alternate options
Case study

Antifoulant evaluation

Background

- Enhanced oil recovery operation
- Production additives increase fouling

Customer objectives

- Identify antifoulant that can help counteract fouling due to production additives
- Identify optimal antifoulant concentration
Case study

Antifoulant evaluation

Effective = 50% reduction in initial fouling rate compared to baseline
Case study

Antifoulant evaluation

- Graph showing fouling rate vs. antifoulant concentration
- Two types of antifoulant concentration, AF-A and AF-B
- Antifoulant Concentration, ppm on the x-axis
- Fouling Rate, $m^2 K/W d$ on the y-axis

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Case study

Antifoulant evaluation

Conclusions

• Antifoulants logarithmically increased fouling; neither A or B were effective
• Increase in fouling is likely due to adverse chemical reaction

Customer benefits

• Provided definitive assessment
• Avoided increasing fouling in field exchanger from online trial
  – Performance loss
  – Cleaning cost
  – Downtime (opportunity loss)
  – Cost of antifoulant that would not work
Summary

• Fouling is a crude quality issue
• Fouling rig types have different trade-offs from an ideal
• Testing methods matter as much as rig design
• Fouling testing provides a means of assessing fouling tendency and mitigation options
• Key benefits of fouling testing
  – Reduce risk
  – Obtain definitive answers
  – Collect data with high confidence
  – Fail offline
Outline

• Overview of HTRI and crude oil fouling research
• Fouling defined
• Fouling test rigs
• Use and benefits of fouling tests
HTRI

• A for-profit consortium established in 1962 with approximately 1400 member companies worldwide
• Research-based correlations for designing and trouble shooting heat exchanger equipment
Research & Technology Center (RTC)

Eleven operating research units in 22500 ft$^2$ controlled environment
HTRI Crude Oil Fouling Task Force

• Subset of HTRI membership
  – ~25 persons
  – Representatives from oil refineries, including most oil majors

• Responsibilities
  – Review the status of current research
  – Offer advice on interpreting research data
  – Provide guidance for future direction of HTRI’s crude oil fouling research
  – Donate oil

• 5 – 6 meetings per year
Three fouling rigs at RTC

**High Temperature Fouling Units**

- **HTFU-1**: 1993; rebuilt 2016
- **HTFU-2**: 2015

**Rotating Fouling Unit**

- **RFU**: 2014

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