Benefits of Crude Oil Fouling Testing

Matthew R. Lane
Engineer, Research
Outline

• Overview of HTRI and crude oil fouling program
• Testing capability at HTRI
• Testing key parameters
  • Operating conditions
  • Properties of the surface and fluid
• Key parameters when observing crude oil fouling
  • Current knowledge
  • Value they provide to the refinery
Heat Transfer Research, Inc. (HTRI)

• A for-profit consortium
  • Established in 1962
  • Now ~1400 members worldwide

• Research-based correlations for designing heat exchanger equipment
Research & Technology Center (RTC)
HTRI has three crude oil fouling rigs

High Temperature Fouling Units

HTFU-1
1993
Rebuilt 2016

HTFU-2
2015

Rotating Fouling Unit

RFU
2014
Goals of HTRI’s crude oil fouling program

1. **Collect** best-in-class data
2. **Translate** rig data to the field
3. **Mitigate** fouling

4. **Predict** fouling
   - Develop fouling models
     \[
     \frac{dR_f}{dt} = f
     \]
     \begin{align*}
     \text{operating conditions} & \\
     \text{physical properties} & \\
     \text{chemical properties} & \\
     \text{fitted parameters} & 
     \end{align*}
   - Simulate preheat train (SmartPM™)
   - Link chemistry
Crude oil fouling is an issue of opportunity
Challenges with refinery data

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

Conclusions are often anecdotal
Key differences between rigs and pre-heat trains (PHTs)

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Test rig</th>
<th>Refinery PHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of operation</td>
<td>Recirculating fluid</td>
<td>Continuous once-through</td>
</tr>
<tr>
<td>Purpose</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>• uniform composition</td>
<td>• variable composition</td>
</tr>
<tr>
<td>Heating method</td>
<td>Constant flux/duty</td>
<td>~Constant wall temperature</td>
</tr>
<tr>
<td>Fouling assessment</td>
<td>Highly instrumented</td>
<td>Limited instrumentation</td>
</tr>
</tbody>
</table>

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High Temperature Fouling Units (HTFUs) at HTRI

- Intube flow
- Removable tube that can be cut open and inspected
- Uniform heating operating conditions controlled via software
- Fouling tests lasting for 3 to 6 weeks
- Multiple data points per test
  - Two data points for HTFU-1
  - Four data points for HTFU-2
Some applications of fouling tests

• Measuring fouling resistance over a period of time
• Validating new technologies
  • Coatings
  • Surface finishes
  • Additives
• Comparing fouling propensity of different crude oils
• Testing the fouling propensity of blends
## Fouling test variables

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating conditions</td>
<td>Flow rate</td>
</tr>
<tr>
<td></td>
<td>Bulk temperature</td>
</tr>
<tr>
<td></td>
<td>Surface temperature</td>
</tr>
<tr>
<td></td>
<td>Pressure</td>
</tr>
<tr>
<td>Surface and fluid</td>
<td>Metallurgy/roughness</td>
</tr>
<tr>
<td></td>
<td>Fluid chemistry</td>
</tr>
</tbody>
</table>
The impact of operating conditions on fouling: 
Velocity

What is currently known?

• Increasing velocity decreases fouling
• Shear stress is considered most influential flow parameter
• Impact of flow is not yet fully supported by data

Value testing can provide

• Quantify fouling trend with flow
• Determine important design parameter (i.e., velocity, shear stress, Reynolds number, etc.)
• Compare redesign bundle vs. use of antifoulant

Experimental results

- A higher fouling rate was observed at a lower shear stress

![Graph showing experimental results with fouling rate and shear stress relationship](image)
The impact of operating conditions on fouling: **Bulk temperature**

**What is currently known?**
- Increasing bulk temperature can increase or decrease fouling depending on the fluid
- Literature suggests the trend depends on interplay between diffusion limitations and solubility

**Value testing can provide**
- Identify fouling trends/thresholds

**Experimental results**

A higher fouling rate was observed at a lower bulk temperature

Other conditions:
- $\Delta T_i = 150 \, ^\circ F$
- $\tau_i = 2 \, \text{Pa}$
The impact of operating conditions on fouling: Surface temperature

What is currently known?
- A higher initial surface temperature results in a higher fouling rate
- Surface temperature (not wall or film temperature) is what matters
- Increasing surface temperature has an exponential increase in fouling rate that is well captured by an Arrhenius relationship

Value testing can provide
- Identify fouling trend/threshold
- Inform design/operation

Experimental results

Higher fouling rates were observed at a higher initial wall temperatures
The impact of operating conditions on fouling: Pressure

What is currently known?

• Boiling may have very significant impact on result; must maintain single phase
• Impact of pressure is not well supported for single-phase flow (1 citation)

Value testing can provide

• Inform customer about the impact of boiling on fouling because customer suspects boiling is impacting fouling
The impact of fouling surface/fluid on fouling: Metallurgy/Surface Roughness

What is currently known?

• Metallurgy
  • Stainless steel fouls less than carbon steel (F-22)

• Roughness (Surface metal and deposit)
  • It clearly influences fouling
    • Crevices promote deposition (no/low flow)
    • Impact on $h \rightarrow$ surface temperature
  • Smoother surfaces tend to foul less

Value testing can provide

• Determine whether to use carbon or stainless steel
• Evaluate benefit of coatings
The impact of fouling surface/fluid on fouling:
Fluid Chemistry

What is currently known?
• Mechanisms and “bad actors” are known (e.g., asphaltene precipitation)
• Iron seems to play a significant role in fouling
• Interaction between “bad” components is poorly understood

Value testing can provide
• Study chemical differences between Crudes A vs. B and use them to predict fouling
• Study how blending oils impacts the fouling rate
• Evaluate fouling of a new product/feedstock
• Analyze the benefit of antifoulant
• Determine the impact of other additives
Can certain chemical characterizations be used to predict fouling?

Literature suggests that the following characterizations might be correlated with fouling:

- Heptane Insolubles, ASTM 3279
- Colloidal Instability Index (CII), ASTM D4184 & D4124
- Olefins, ASTM D6733
- TAN, ASTM D664
- Basic Nitrogen, UOP-269
- Salt Content, ASTM D-3230
How well can crude chemistry indicate the fouling tendency of crude oils?

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<th>Crude B</th>
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<td>8.5 w/w%</td>
<td>6.3 w/w%</td>
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<td>Colloidal Instability Index (CII), ASTM D4184 &amp; D4124</td>
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<td>0.45</td>
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<td>0.000 w/w%</td>
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Fouling tests show **Crude A** is the higher fouler.
HTRI Case Study
Antifoulant evaluation

Background
• Enhanced oil recovery operation
• Production additives that increase fouling

Customer objectives
• Identify antifoulant that can help counteract fouling due to production additives
• Identify optimal antifoulant concentration
HTRI Case Study
Antifoulant evaluation

![Graph showing Antifoulant A and Antifoulant B comparison]

Fouling Rate vs Antifoulant Concentration

Antifoulant A
Antifoulant B
**HTRI Case Study**

**Antifoulant evaluation**

**Conclusions**
- Antifoulants logarithmically increased fouling; neither A nor B were effective
- Increase in fouling is likely due to adverse chemical reaction

**Customer benefits**
- 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
Example of blending crude oils

Northern US refinery wants to blend heavy Canadian crude

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

• Fouling study
  • Evaluate 0, 5, 10, 20% blends of Canadian with baseline blend
  • Evaluate a high and low flow rate at the same surface temperature in each test
Example of blending crude oils (continued)

• Quantify trend fouling with blend percentage

<table>
<thead>
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<th>Fouling rate</th>
<th>Blend %</th>
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• Make informed decision
  • Blend percentage
  • Cost/benefit of bundle redesign (high velocity)

• Avoid costly online issues

• Identify alternate options
Summary of fouling testing benefits

• Simulate field conditions in a controlled way
• Provide a definitive way to assess mitigation methods (i.e., coatings, antifoulants, etc.)
• Provide a way to reduce the risk of a new process or charge (crude blend)
• Allow failures to occur in test rig, not in preheat train