In-Situ Upgrading of Bitumen and Shale Oil by Controlled Pyrolysis

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PyroPhase, Inc.
Objectives of In-situ Upgrading Bitumen

- Reduce viscosity so that product can be pipelined
- Avoid building costly above-ground upgrading plant
- Avoid using water and natural gas
- Reduce cost of upgrading in refinery
- Reduce sulfur, nitrogen, heavy metals
- Sequester coke in the ground
Which controls upgrading?

- pyrolysis temperature
- or pyrolysis extent
  - Determined by time & temperature
  - Determined by how when product is obtained
- Lab data answers questions.
Pyrolysis Lab Experiment
Methods

- **Bomb reactor**
  - totally contained
  - best for kinetics measurement

- **Destructive distillation**
  - Product vapor outflow - Fisher Assay, TGA
  - Simulates above-ground retort

- **Pipe reactor**
  - product liquid and gas outflow
  - Simulates in-situ production
Empirical Component Definitions

- Coke
- Asphaltenes
- Heavy oils (boiling > 420 °C)
- Middle oils (180 – 420 °C)
- Light oils boiling below 180 °C, and
- Gases
Bitumen Pyrolysis at 420 °C (Phillips 1985)

![Graph showing the yield of different products (Asphaltenes, Mid Oil, Gas, Light Oil, Heavy Oil, Coke) as a function of reaction time (in hours).]
Phillips Model B

Diagram showing the flow of materials between different oil and gas concentrations, labeled as A1 to A6 with corresponding concentrations x1 to x6.
\[ \frac{dx_1}{dt} = k_1 x_2 \]
\[ \frac{dx_2}{dt} = -k_1 x_2 - k_2 x_2 - k_3 x_2 + k_4 x_3 \]
\[ \frac{dx_3}{dt} = k_2 x_2 - k_4 x_3 - k_5 x_3 + k_4 x_4 \]
\[ \frac{dx_4}{dt} = k_5 x_3 - k_4 x_4 - k_6 x_4 + k_4 x_5 \]
\[ \frac{dx_5}{dt} = k_6 x_4 - k_4 x_5 \]
\[ \frac{dx_6}{dt} = k_3 x_2 \]
Fig. - Comparison of reaction rate at low temperatures.
Calculations at 325°C

![Graph showing the fraction of C1 (Coke) and C2 (Asphaltenes) over time. The graph shows an increase in C1 and a decrease in C2 with time.]

- C1 (Coke)
- C2 (Asphaltenes)
Which controls upgrading?

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# Pyrolysis Time vs Yield

<table>
<thead>
<tr>
<th>Time, hrs</th>
<th>% Upgraded</th>
<th>Oil Yield, %</th>
<th>Gas Yield, %</th>
<th>Coke Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>25</td>
<td>79</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>150</td>
<td>31</td>
<td>72</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>250</td>
<td>35</td>
<td>69</td>
<td>7</td>
<td>31</td>
</tr>
</tbody>
</table>
## Pyrolysis Temperature vs Yield

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Light Oil, %</th>
<th>Coke, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>325°C, 90 hrs</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>420°C, 0.3 hrs</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>420°C, 2 hrs</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>
Viscosity vs % Upgraded
Henderson, 1965
Which controls upgrading?

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Oil Shale TGA Pyrolysis

\[ k = 8.7 \times 10^{-7} \exp \left(-\frac{45,425}{RT}\right) \]
Lab Work Sponsored by DOE
## Oil Shale Pipe Reactor (Needham 1976)

<table>
<thead>
<tr>
<th></th>
<th>Gas combustion Pilot Retort</th>
<th>Pipe Reactor, 427°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>API gravity</td>
<td>20.3</td>
<td>32</td>
</tr>
<tr>
<td>Wt % FA oil recovered</td>
<td>85</td>
<td>81</td>
</tr>
</tbody>
</table>
Conclusions

- To Upgrade Bitumen
  - Produce Oil at 15 – 25 % Conversion
  - Feasible at 325 °C, also at 420 °C
- Similar Result for Oil Shale
- Next Step: Reservoir Engineering
Objectives Achieved

- Reduce viscosity so that product can be pipelined
- Avoid building costly above-ground upgrading plant
- Avoid using water and natural gas
- Reduce cost of upgrading in refinery
- Reduce sulfur, nitrogen, heavy metals
- Sequester coke in the ground
Bitumen Viscosity vs T (°C)