Scale-up of microchannel reactors for small scale GTL processes

Rune Myrstad
Department of Process Chemistry
SINTEF Material and Chemistry
Trondheim, Norway
• Microstructured reactors in compact conversion of natural gas and biomass to liquid fuels and hydrogen, Hilde Venvik, NTNU

• Fischer-Tropsch synthesis in a microstructured reactor, Rune Myrstad, SINTEF
Since then..

**Microchannel reactor demo units:**

- **Velocys / Oxford Catalysts**
  - 2010: SGC Energia, Güssing, Austria, <1 bpd BTL
  - 2011: Petrobras, Fortaleza, Brazil, 6 bpd GTL
  - 2012: SGC Energia, Brazil, 50 bpd BTL

- **CompactGTL**
  - 2010: Petrobras, Aracaju, Brazil, 20 bpd GTL
Background and motivation

1. ~25% of natural gas reserves are “stranded” (Associated gas, Arctic gas, Remote gas)
   - Long distance to market
   - Volume too low for pipeline
   - Complicated production

2. Biomass-to-liquid challenge
   - Distributed
   - Safe
   - Efficient
Requirements - Stranded gas/BTL conversion process

- Direct (one step) process
- Compact
- Economic in small-medium scale
- Safe (off-shore, farmland localization etc.)
- Reactor design for proper heat exchange
- Small/medium scale conversion
Could small scale GTL become feasible?

- Commercial GTL 15,000 – 140,000 bpd
- Stranded GTL 1,000 – 2,000 bpd
- BTL 500 – 2,000 bpd

⇒ Microchannel reactors?
Microchannel reactors

Large number of small, parallel channels in µm range

• Short distance to wall
• High surface/volume ratio
• Enhanced heat and mass transfer properties

⇒ Especially suited to economical production on a small scale
Microchannel reactor for GTL application

- Lab scale 2 cm³ reactor, 8 catalyst filled foil structures with cross-flow oil heating channels.
- Characterized and performance verified for F-T, MeOH and DME-synthesis:
  - By experiments and modeling demonstrated an isothermal and isobaric reaction environment, free of mass and heat transfer limitations.
Scale-up strategy: Methanol synthesis

- Reactor productivity obtained for 2 cm$^3$ lab scale reactor by lab experiments and modelling
- Reactor mass and MeOH productivity calculated for a 630 x scale-up to a 17x17x24 cm unit (identical channel geometry)
- Adding up units to 1000 bpd total capacity
- Compared with data for 5000 bpd commercial methanol plant
## Comparison, basis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Reactor</th>
<th>Microchannel Reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Capacity, TPD</td>
<td>5000</td>
<td>1000</td>
</tr>
<tr>
<td>Pressure, bar</td>
<td>77</td>
<td>80</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>255 (bed exit)</td>
<td>255 (isothermal)</td>
</tr>
<tr>
<td>Feed gas</td>
<td>Conventional feed</td>
<td>H₂/CO/CO₂/N₂ (65/25/5/5 mol%)</td>
</tr>
<tr>
<td>Catalyst</td>
<td>Commercial Cu/Zn/Al</td>
<td></td>
</tr>
<tr>
<td>Catalyst particles, mm</td>
<td>5,5</td>
<td>0,08</td>
</tr>
<tr>
<td>Recycle ratio</td>
<td>4,7</td>
<td>No recycle</td>
</tr>
<tr>
<td>CO Conversion</td>
<td>19 %</td>
<td>63 % (single pass)</td>
</tr>
<tr>
<td>Carbon efficiency</td>
<td>82 %</td>
<td>49 %</td>
</tr>
<tr>
<td>Kinetics</td>
<td>Bussche &amp; Froment, 1996</td>
<td></td>
</tr>
</tbody>
</table>

- **Comparison, basis**:
  - 90 tons of catalyst
  - 340 tons of steel
  - 15 tons of catalyst
  - 490 tons of steel
# Productivity comparison

Ratio A: Kg of methanol produced per hour per mass of steel  
Ratio B: Kg of methanol produced per hour per mass of catalyst

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Commercial reactor</th>
<th>Microchannel reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity, TPD</td>
<td>5000</td>
<td>1000</td>
</tr>
<tr>
<td>Ratio A</td>
<td>0.61</td>
<td>0.085</td>
</tr>
<tr>
<td>Ratio B</td>
<td>1.01</td>
<td>2.83</td>
</tr>
</tbody>
</table>
Conclusion, I

1. 2-3 x higher catalyst productivity in microchannel reactor
   But, since
2. 490 tons steel applied in 1000 bpd microchannel reactor vs. 340 tons steel in 5000 tpd large scale reactor

⇒ Dramatically lower productivity /kg steel in microchannel reactor

However, ..
Approaches to improving the productivity, I

- 3-4 x higher catalyst activity reported in literature
- Interstage condensation of Methanol and Water could increase the productivity up to 20% through shifting the equilibrium
  1. \( \text{CO}_2 + 3\text{H}_2 \leftrightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \)
  2. \( \text{CO} + 2\text{H}_2 \leftrightarrow \text{CH}_3\text{OH} \)
  3. \( \text{CO} + \text{H}_2\text{O} \leftrightarrow \text{H}_2 + \text{CO}_2 \)
- Temperature profiling
  (High T – High activity, low equil. conv.
  Low T – Low activity, high equil. conv.)

⇒ Increased catalyst productivity
⇒ Increased reactor productivity
Approaches to improving the productivity, II

- Conversion of MeOH to DME
- Alleviation of the equilibrium methanol limitation!

\[
\text{CO} + 2 \text{H}_2 \leftrightarrow \text{CH}_3\text{OH}
\]

\[
2 \text{CH}_3\text{OH} \leftrightarrow \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O}
\]

⇒ Increased catalyst productivity
⇒ Increased reactor productivity
Approaches to improving the productivity, III

- Optimization of the microchannel structure and hence decreasing mass of steel

  ⇒ Decreased mass of steel
  ⇒ Increased reactor productivity
Conclusion, II

- Promising aspects of an microchannel reactor application in small to medium scale gas conversion are demonstrated
- Robust scale-up
- Elimination of product recycle

- *Still, approaches to further minimize the reactor body mass are required.*
Thank you for your attention!

Acknowledgements

- Dr. Hamidreza Bakhtiary-Davijany and Dr. Fatemeh Hayer
- Professor Hilde Venvik and Professor Anders Holmen
- Dr. Peter Pfeifer and Dr. Roland Dittmeyer