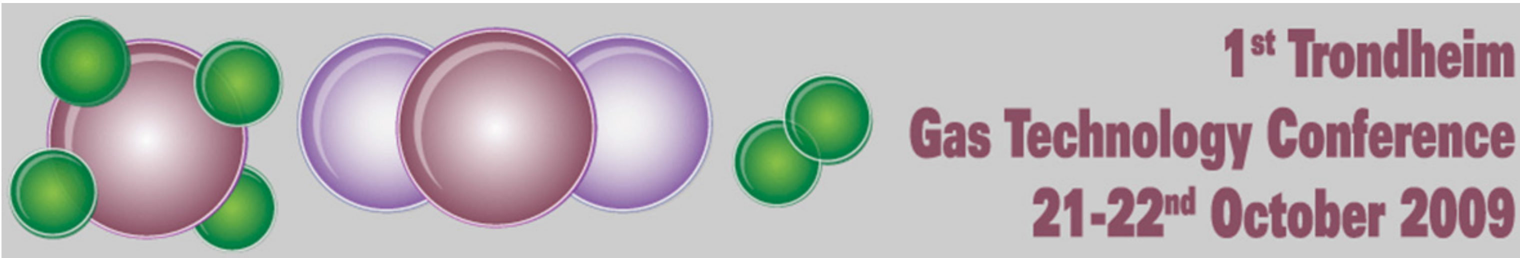
2nd Trondheim
Gas Technology Conference
2-3 November 2011

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

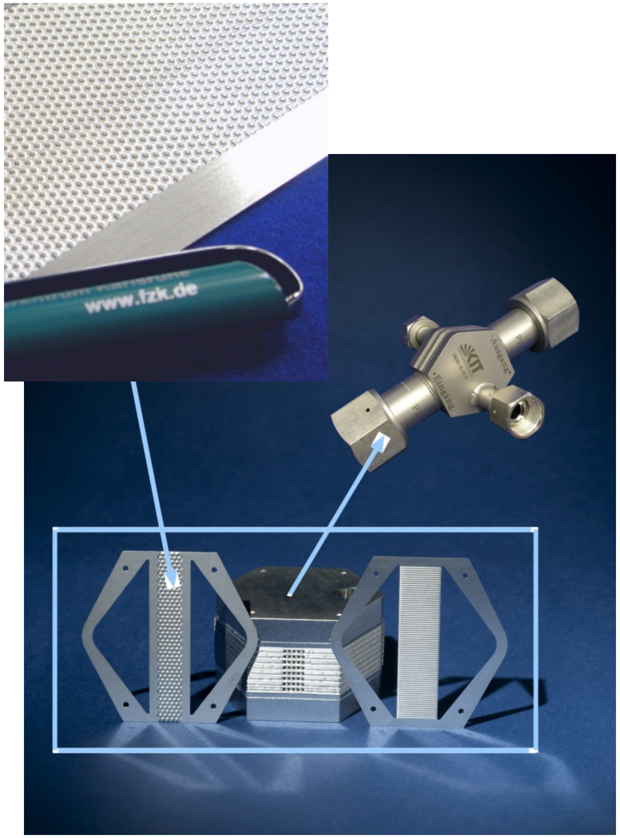
⇒ Microchannel reactors ?

Microchannel reactors

Large number of small, parallel channels in µm range

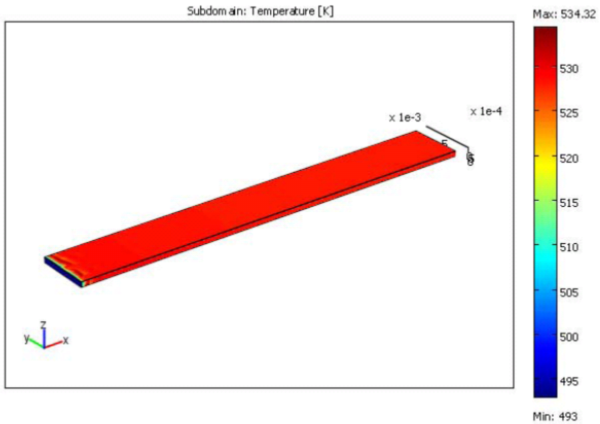
- Short distance to wall
- High surface/volume ratio
- Enhanced heat and mass transfer properties

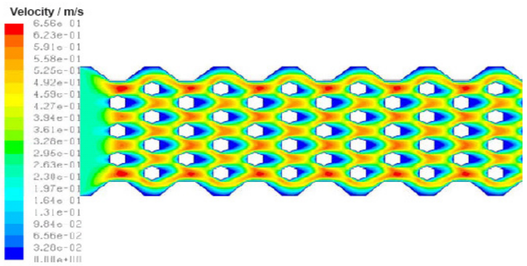
⇒ Especially suited to economical production on a small scale

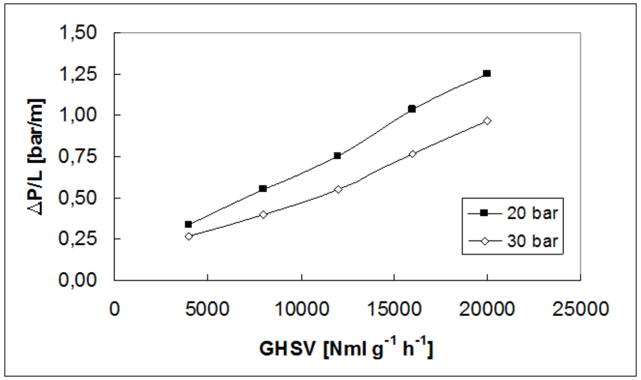


Microchannel reactor for GTL application

- Lab scale 2 cm^3 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

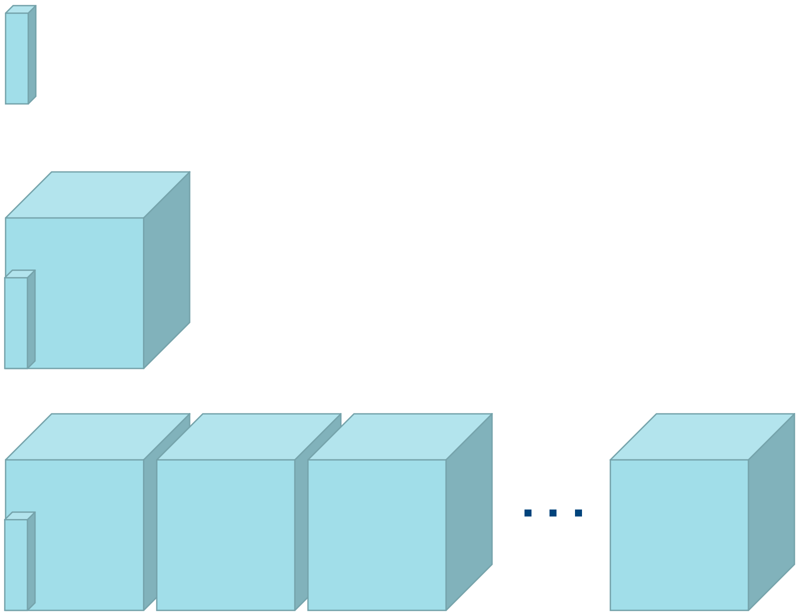






Scale-up strategy: Methanol synthesis

- 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

Parameter	Conventional Reactor	Microchannel Reactor
Production Capacity, TPD	5000	1000
Pressure, bar	77	80
Temperature, °C	255 (bed exit)	255 (isothermal)
Feed gas	Conventional feed	$H_2/CO/CO_2/N_2$ (65/25/5/5 mol%)
Catalyst	Commercial Cu/Zn/Al	
Catalyst particles, mm	5,5	0,08
Recycle ratio	4,7	No recycle
CO Conversion	19 %	63 % (single pass)
Carbon efficiency	82 %	49 %
Kinetics	Bussche & Froment, 1996	

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

Parameter	Commercial reactor	Microchannel reactor
Capacity, TPD	5000	1000
Ratio A	0,61	0,085
Ratio B	1,01	2,83

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

Parameter	Commercial reactor	Microchannel reactor
Capacity, TPD	5000	1000
Ratio A	0,61	0,085
Ratio B	1,01	2,83

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. $CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$
  2. $CO + 2H_2 \leftrightarrow CH_3OH$
  3. $CO + H_2O \leftrightarrow H_2 + CO_2$
- Temperature profiling

  (High T – High activity, low equil. conv.

  Low T – Low activity, high equil. conv.)

$\Rightarrow$ Increased catalyst productivity

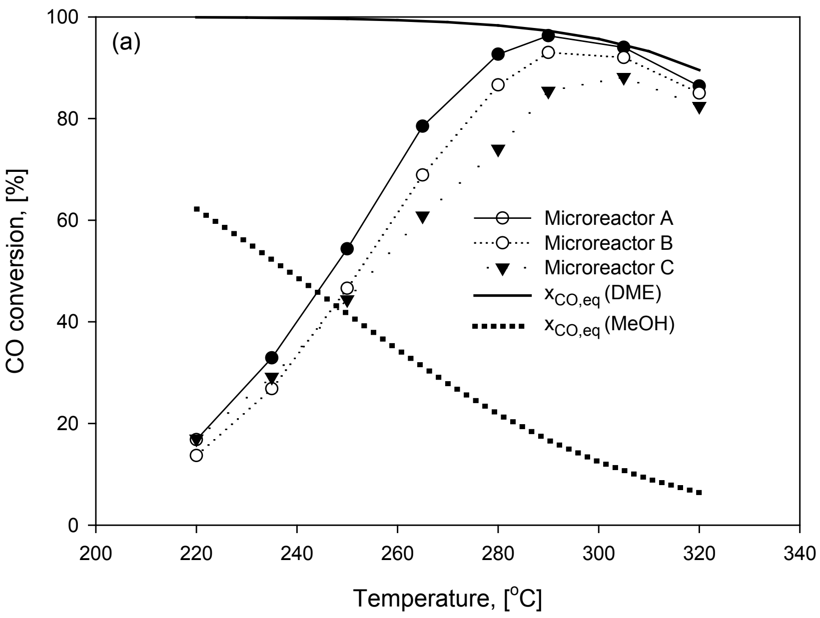
$\Rightarrow$ Increased reactor productivity

Approaches to improving the productivity, II

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

$$CO + 2\,H_2 \leftrightarrow CH_3OH$$

$$2\,CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$$



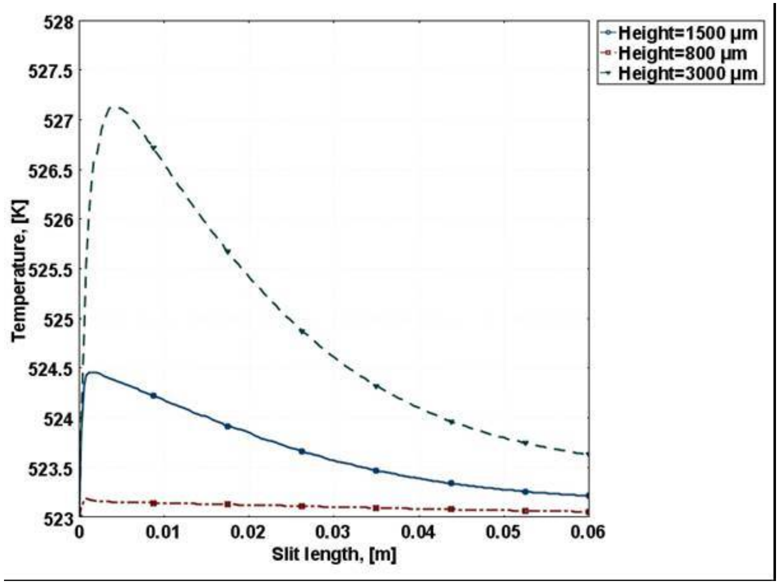
⇒ Increased catalyst productivity

⇒ 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