Microwave-Assisted Syngas Cleanup: Catalytic Reforming of Gasifier Tar Using a Low-Cost Iron Catalyst

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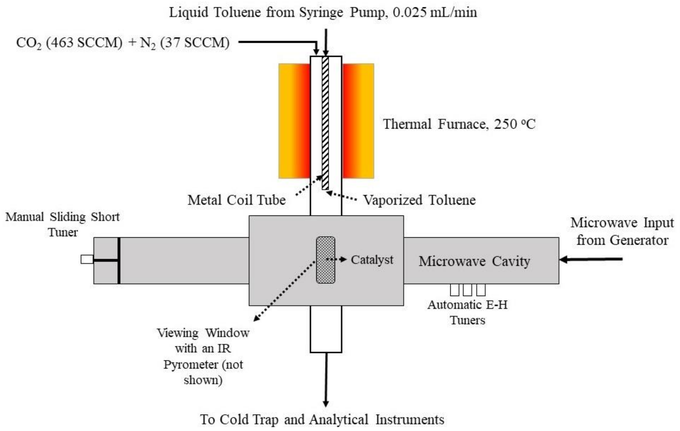
Background

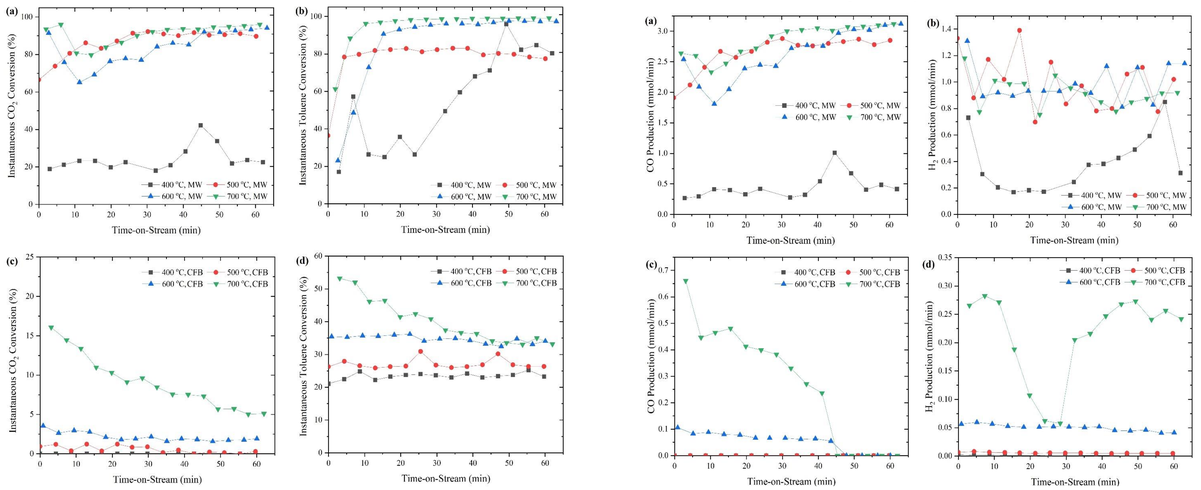
The presence of tars from the gasification of plastic wastes and biomass could result in downstream lines blockage, reactor down time, and costly maintenance. Therefore, reducing or removing tar is desired. Due to its chemical complexity, toluene, which is one of the main tar constituents, could be used as a model tar compound. Microwave (MW)-incorporated catalytic reactor design has been applied in energy-intensive processes because of its potential in process intensification based on its features such as modular design, simple installation, and better energy efficiency. In this work, the microwave-assisted catalytic dry reforming of toluene was studied using Fe/Al_2O_3 as a catalyst, under CO_2 at different reaction temperatures.

Materials & Methods

- 10 wt.% Fe on Al_2O_3 was produced by ball milling the mixture of magnetite and alumina for 10 hours; then was reduced at 700 °C under 20 vol% H_2 for 2 hours, in a conventional furnace.
- MW tests were performed using a max 1.2 kW, 2,450 MHz microwave reactor system. The power used was 200–350 W.
- Temperatures tested ranged from 400 to 700 °C. Experiments were also carried out in a conventional fixed-bed (CFB) reactor for reference.



CFB vs. MW Comparison



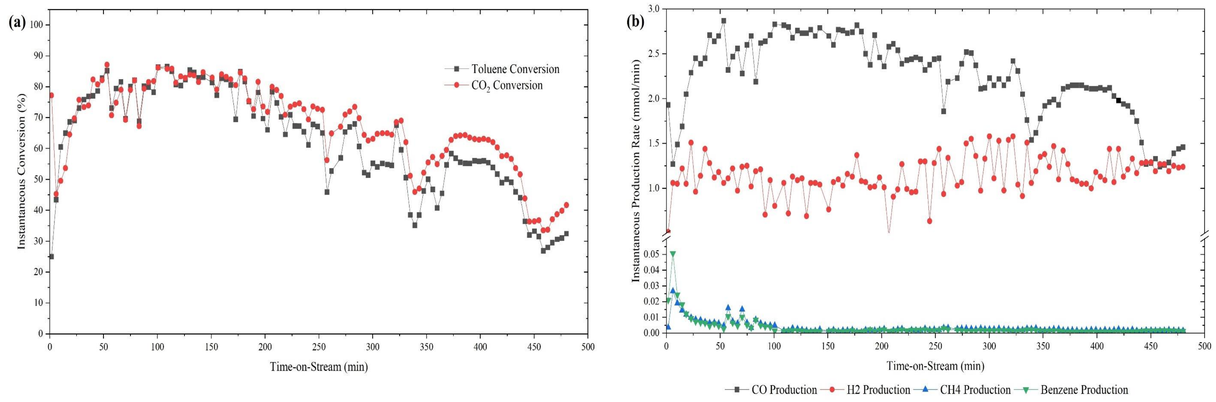
Trends for MW

- CO_2 conversion was high at the beginning, then lowered down, and recovered back.
- Toluene conversion was low at the beginning, then increased to a high level.
- CH_4 and benzene productions were high at the beginning, then decreased (except 400 °C run).
- At lower temperatures, CH_4 and benzene productions were higher at the end of the run.

Trends for CFB

- CO_2 conversion continued decreasing, while toluene conversion decreased to 20-40% level.
- At high temperatures (700 °C), CH_4 and benzene productions were high at the beginning, then decreased.
- At lower temperatures, negligible CH_4 and benzene productions were observed.

Stability Test



Energy Balance Analysis

Heating Mode (Method – Temperature)	P_T (kWh)	H_2 Energy Efficiency (mmol/kWh)	CO Energy Efficiency (mmol/kWh)
Microwave – 400 °C	0.1105	195.2	240.7
Microwave – 500 °C	0.1016	585.5	1559
Microwave – 600 °C	0.1880	311.2	838.4
Microwave – 700 °C	0.2616	204.2	645.4
Conventional – 600 °C	0.3776	7.822	8.636
Conventional – 700 °C	0.4987	24.56	31.68

Power absorbed by material for tar reforming (P_{fwd})

Power delivered to material ($P_{in} = P_{fwd} + P_{ref}$)

Energy to power MW (P_T)

$$\eta_{ab} = \frac{P_{fwd}}{P_{in}} = \frac{P_{in} - P_{ref}}{P_{in}}$$

$$P_T = \frac{P_{in}}{\eta_e} \quad \text{where } \eta_e = 0.85$$

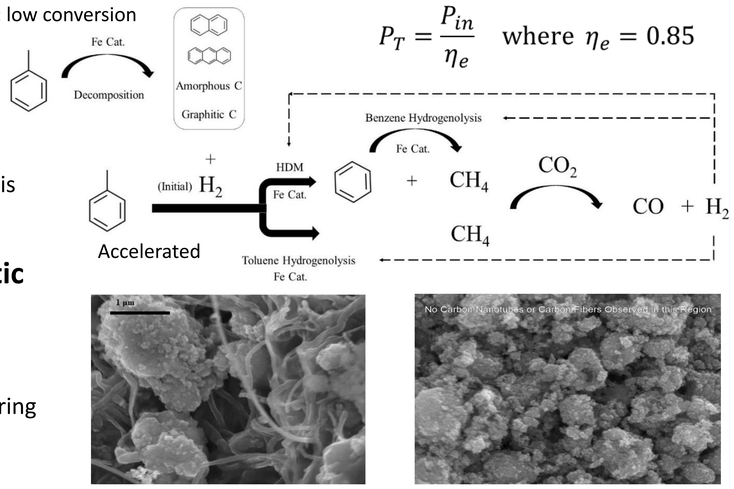
Reaction Pathway

"Hot-spots"

- ~100-290 °C higher than the bulk, depending on the material
- 78-124 °C temperature difference in this case

Synergy between electromagnetic field and "Hot-spots"

- Toluene hydrodemethylation
- Aromatics hydrogenolysis
- π-electron polarization of the benzene ring



Conclusions

- Dry reforming of toluene as a tar model compound over the low-cost Fe-Al_2O_3 catalyst has been carried out in the MW reactor, with >80% CO_2 and toluene conversions were achieved at 500 °C.
- Catalyst lasted 3 hours time-on-stream and remained partially active after 8 hours.
- Microwave-material interaction was illustrated, evidenced by enhanced tar conversion.

Disclaimer

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