# OPERATIONAL PERFORMANCE OF A 5 kW SOLAR CHEMICAL REACTOR FOR THE CO-PRODUCTION OF ZINC AND SYNGAS

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We report on the operational performance of a 5 kW solar chemical reactor for the combined ZnO-reduction and CH$_4$-reforming "SynMet" process. The reactor features a pulsed vortex flow of CH$_4$ laden with ZnO particles, which is confined to a cavity-receiver and directly exposed to solar power fluxes exceeding 2000 kW/m^2. Reactants were continuously fed at ambient temperature, heated by direct irradiation to above 1350 K, and converted to Zn(g) and syngas during mean residence times of 10 seconds. Typical chemical conversion attained at the reactor outlet was 100% to Zn and up to 70% to syngas. The thermal efficiency was in the 15-22% range. The experimental results indicate that the solar chemical reactor technology can be further up-scaled and developed for an industrial application.

1   INTRODUCTION

The solar chemical reactor technology for the "SynMet"-process, i.e. the solar co-production of zinc and synthesis gas (syngas) by the combined reduction of ZnO and reforming of CH$_4$, is being developed for converting solar energy into storable and transportable fuels [1]. The overall reaction can be represented by:

$$ZnO + CH_4 \rightarrow Zn + 2H_2 + CO$$
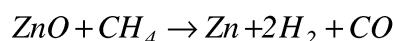
The produced Zn can be stored and transported. On demand, it can be used either for direct electricity generation or for H$_2$ production. The chemical product is ZnO, which is recycled to the solar reactor. The thermochemical cycle is depicted in Figure 1.
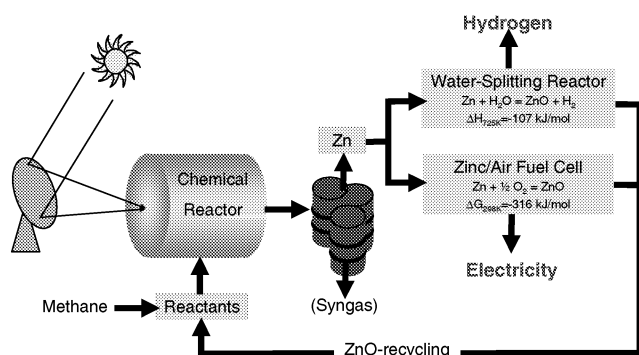

Fig. 1: Storage and transport of solar energy via the SynMet process.

In previous papers we examined the chemical thermodynamics and kinetics of the *SynMet* process [1,2], performed a life cycle assessment and economic analysis [3], and described the engineering design, fabrication, and experimental investigation of a 5 kW prototype solar reactor for effecting the reaction using concentrated solar energy [4-6]. In the present note we report on recent experimental results of the test campaign conducted at PSI's high-flux solar furnace during summer 2001 [7].

2   REACTOR DESIGN

Figure 2 shows schematically the SynMet-reactor. It consists of a 240 mm-length 110 mm-diameter cylindrical cavity that contains a 6 cm-diameter windowed aperture to let in concentrated solar energy. The quartz window is cooled and protected from condensable gases by an auxiliary gas flow. Both reactants CH$_4$ and ZnO are fed at ambient temperature. ZnO powder (mean particle size = 0.4 μm) is continuously fed axially while CH$_4$ is simultaneously pulse-injected tangentially, creating a stoichiometric gas-particle helical stream that absorbs efficiently the incoming solar irradiation. The mean residence time of reactants inside the reaction chamber is 10 seconds. The reaction products (Zn vapor and syngas) exit through a water-cooled Pyrex tube where part of the zinc condenses. Particle filters collect the remainder solid products downstream. The gaseous products are analyzed on-line by gas chromatography while representative solid product samples are analyzed by x-ray diffraction. Solar power input and power flux intensities through the reactor's aperture were measured optically using a calibrated CCD camera aimed at an Al$_2$O$_3$-coated Lambertian target.
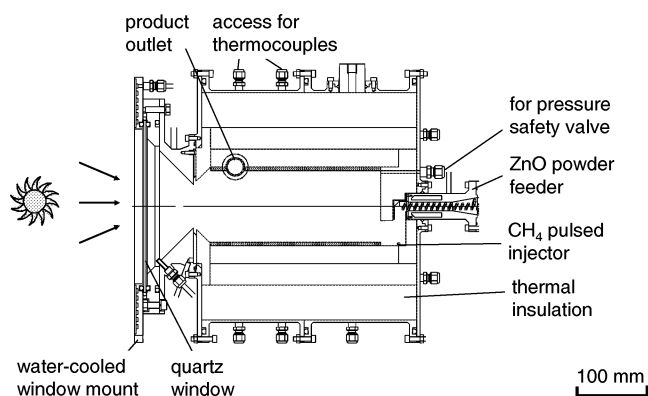

Fig. 2: Scheme of the improved SynMet solar chemical reactor [6].

3 EXPERIMENTAL

We report on eight solar runs, grouped in three categories: 1) Run I used a fixed-bed of ZnO subjected to a continuous flow of CH_4 that was injected via a pipe positioned under the bed; 2) Runs II-VI used the continuous axial feeding of ZnO and pulsed tangential feeding of CH_4; 3) Runs VII and VIII used same feeding conditions as Runs II-VI, with an additional CH_4 flow via the same pipe as in run I.

The zinc yield, defined as the amount of Zn produced divided by the maximum amount of Zn that would have been recovered if the reaction had gone to completion, was 100 % for every experiment. The conversion of CH_4 increased with temperature and reached 96% at 1676 K. Typical H_2:CO and CO_2:CO molar ratios in the syngas were 1.5-3 and 0.08-0.25, respectively.

Figure 3 shows the complete energy balance for each experimental run, indicated in percent of the solar power input. The conduction heat loses through the reactor walls (outlet, rear, front and cylinder) vary between 20-26 % and re-radiation losses through the aperture vary between 20-30 %. The power used for heating the reactants and for driving the chemical reaction was between 15-22 % of the solar input.
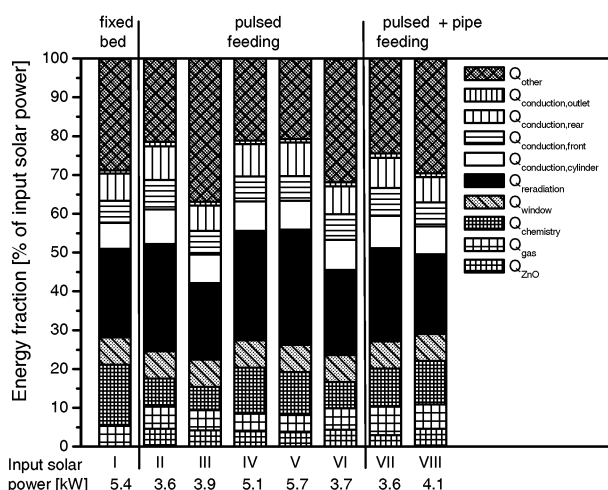

Fig. 3: Energy balance for each solar run [7].

The thermal efficiency is defined as

$$\eta_{thermal} = \frac{\Delta H^{\circ}_{reac \tan ts\,@\,298\,K \rightarrow products\,@\,T_{reactor}}}{Q_{solar,input}}$$

where Q_{solar} is the solar energy input and ΔH° the standard enthalpy change of the reaction when the reactants are fed at 298 K and the products are obtained at $T_{reactor}$. $\eta_{thermal}$ obtained in solar experimental runs at approximately steady-state conditions is plotted in Figure 4 as a function of $T_{reactor}$.
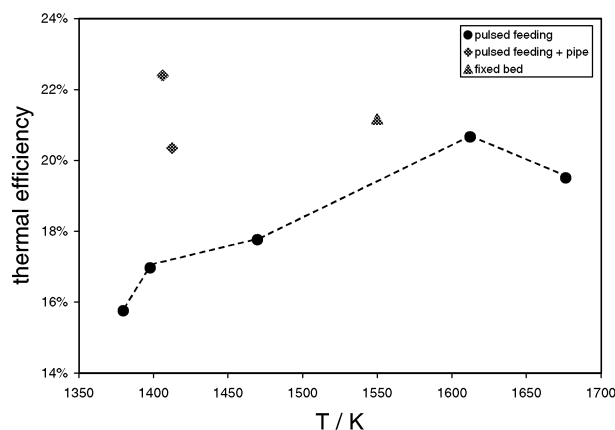

Fig. 4: Variation of the thermal efficiency as a function of the nominal reactor temperature.

4 CONCLUSION

A vortex ZnO-CH_4 flow solar reactor for co-producing Zn and syngas was tested in the temperature range 1406-1676 K and for an input solar power between 3.6 and 5.7 kW. The reactor and peripheral components, including the quartz window at the reactor's aperture, performed trouble-free under approximate steady state conditions. High chemical yields and reasonable energy conversion efficiencies were obtained. The experimental results indicate that the solar chemical reactor technology can be further up-scaled and developed for an industrial application of ZnO-reduction combined with the reforming of natural gas or other hydrocarbons.

5 ACKNOWLEDGEMENTS

6 REFERENCES

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