SolarPACES 2023, 29th International Conference on Concentrating Solar Power, Thermal, and Chemical Energy Systems

Operations, Maintenance, and Component Reliability

https://doi.org/10.52825/solarpaces.v2i.945

Selective Hydrogen Removal in Parabolic Trough Plants

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Abstract. A procedure is investigated for removing hydrogen selectively and efficiently from the heat transfer fluid of parabolic trough power plants. Catalytic conversion is shown to work at low temperatures and also in the presence of heat transfer fluid vapor.

Keywords: Parabolic Trough, Heat Transfer Fluid, Hydrogen, Heat Loss, HCE

1. Introduction

Parabolic trough power plants are operated with an eutectic mixture of biphenyl (BP) and diphenyl oxide (DPO) as heat transfer fluid (HTF) in the solar field. The design field outlet temperature is 393 °C in most cases. At these temperatures the fluid is slowly degraded giving rise to formation of low and high boiling degradation products as well traces of molecular hydrogen [1]. Hydrogen permeates through hot steel surfaces and accordingly it enters the evacuated insulation of the heat collecting elements (HCE). To prevent hydrogen accumulation in the HCE non-evaporable getters (NEGs) are located within the vacuum insulation. NEGs absorb hydrogen and thus maintain high vacuum conditions. According to literature data, hydrogen load of NEGs depends on the gas pressure in contact with the material [2]. When the hydrogen load reaches a critical level the heat losses of a HCE increases significantly due to the excellent heat conductivity of the gas [3]. To avoid such heat losses some manufacturers demand limit concentrations for dissolved hydrogen in the HTF. In some cases, plants were operated at too high hydrogen levels and heat losses were detected via hot surface temperatures of the HCEs [4].

Meanwhile, many plants have taken some measures against hydrogen accumulation like regular partial exchange of the nitrogen blanket gas in the expansion or overflow vessels in the HTF system or processing of the HTF to maintain low levels of degradation products as they accelerate hydrogen considerably compared to unused HTF. Selective hydrogen removal was proposed as well aiming at reducing the hydrogen concentration in the blanket gas which is ought to be in close exchange with the HTF [5]. Selective permeation through a palladium membrane is already pursued at the Nevada Solar One plant [6]. The system extracts nitrogen from the expansion vessel and after separating HTF vapor from the gas the latter is pumped through a heated membrane contactor to reduce the hydrogen concentration by selectively transporting hydrogen along the concentration gradient to the atmospheric side. In this study, an alternative approach for selective hydrogen removal is examined based on catalytic conversion of hydrogen.

2. Approach

For catalytic conversion a nanostructured material with platinum nanoparticles is used. The material is prepared by plasma coating of titanium meshes by neoxid GmbH, Germany. Tests with this material are performed in this study using gas mixtures without and with presence of HTF vapor to check any issues of HTF on the catalytic process. Conversion of hydrogen is checked by micro gas chromatography analysis at the inlet and the outlet of the lab reactors.

The first experiment allows for tests with pressurized gas mixtures (see Figure 1). Pressures up to 10 bar and temperatures up to 300 °C can be realized with variation of the gas composition. Flow rates up to 20000 sccm can be tested up to 2 bar and up to 140 °C with fixed gas composition in this experiment.

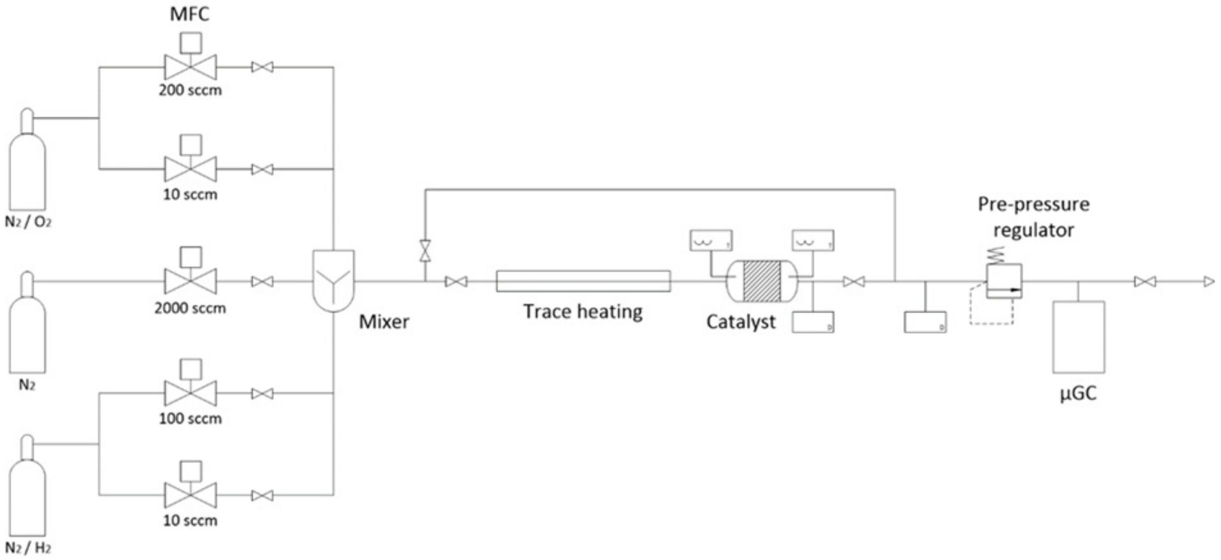

Figure 1. *Experimental setup 1 for catalytic tests with pressurized gas mixtures.*

A second experiment is used for tests with HTF vapor in the gas stream (see Figure 2). This experiment provides up to 200 sscm gas mixture at 2 bar and up to 300 °C.

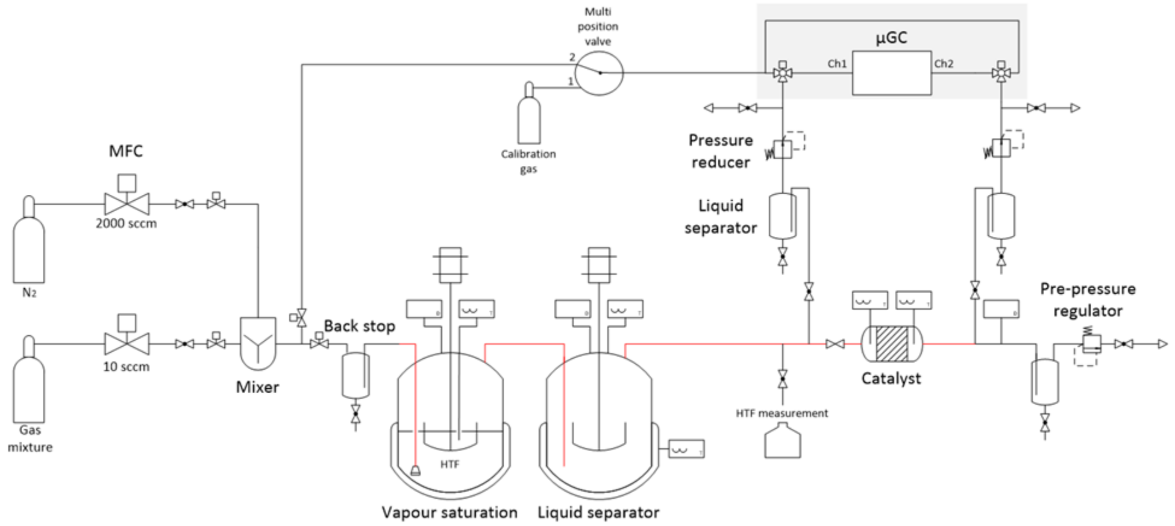

Figure 2. *Experimental setup 2 for catalytic tests with gas mixtures enriched with HTF vapor.*

3. Results

Complete conversion (98 – 100%) of 1000 – 6000 ppm hydrogen is confirmed with experiment 1 at 500 sccm, 2 bar and 200 °C. Accordingly, linear increase of conversion rate is found when hydrogen concentration increases at constant flow rate.

Experiment 1 allows for flow rates up to 20000 sccm when pre-mixed gas mixtures are supplied via the largest mass flow controller of the setup. Using a mixture of 2000 ppm hydrogen and 1000 ppm oxygen (in nitrogen) the flow is varied from 2000 to 20000 sccm at 2 bar. The gas temperature decreases from 220 °C to 142 °C at the highest flow rate as the heating power is not sufficient to maintain constant temperatures. Despite the decreasing temperature, conversion only dropped from 100% to 98% and accordingly, the rate of hydrogen conversion increases linearly (see Figure 3).

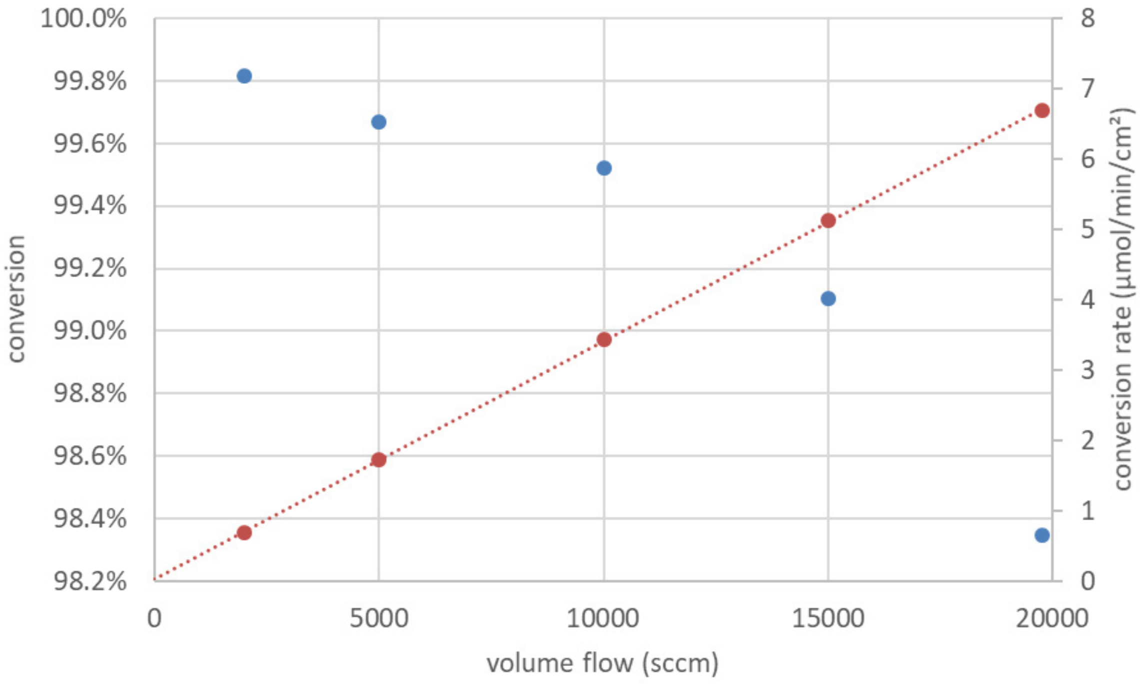

Figure 3. *Conversion of 2000 ppm hydrogen/1000 ppm oxygen at 2 bar with experiment 1 starting at 220 °C (at 2000 sccm) to 142 °C (at 20000 sccm). Blue: conversion in %, red: conversion rate per geometrical catalyst surface in µmol/min/cm².*

Complete conversion is found when the pressure is increased to 10 bar at 500 sccm or 2000 sccm, 200 °C inlet and 2000 ppm hydrogen indicating that pressure has no significant impact on the reaction.

Temperature is expected to be more relevant and experiment 1 is used to check for thermal impact on the reaction with two catalysts operated at 2000 sccm and 2000 ppm hydrogen. Complete conversion is observed at 80 °C and beyond. Even at ambient temperature significant hydrogen conversion is detected (see Figure 4).

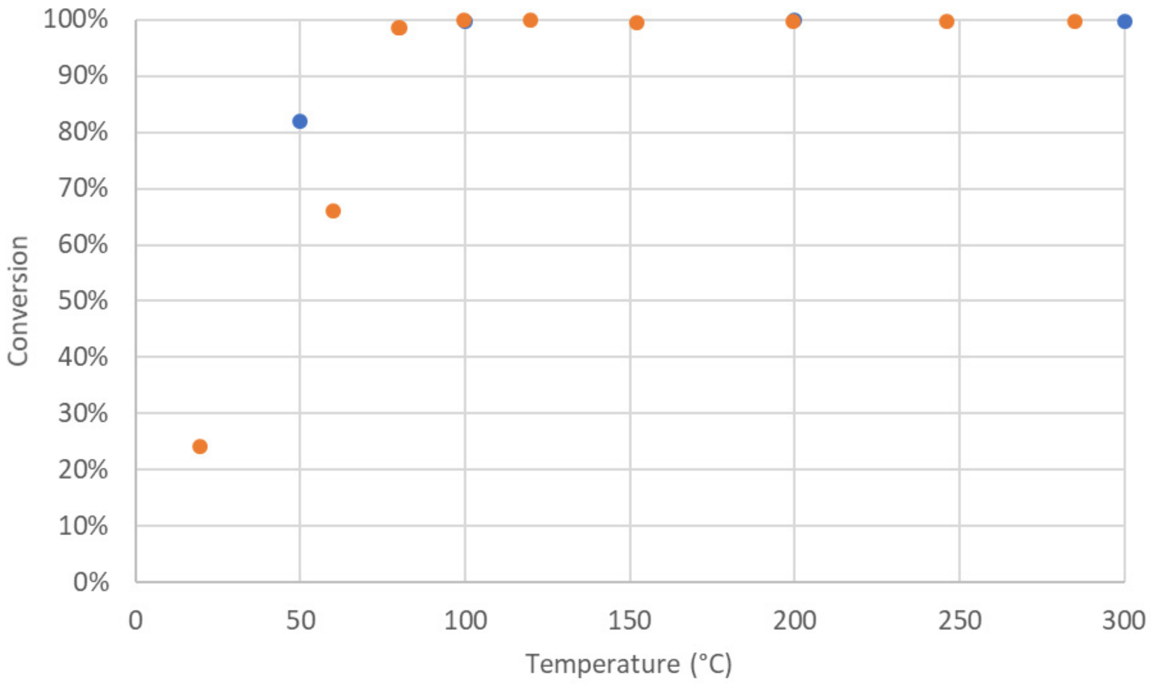

Figure 4*. Conversion of hydrogen in nitrogen with experiment 1 at different temperatures (blue: catalyst option 1, orange: catalyst option 2).*

Saturation with HTF vapor in experiment 2 is tested at 150 and 300 °C HTF temperature as these temperature levels are to be expected in the HTF expansion vessel during the night and the day respectively. The catalyst and the tubing are maintained at 300 °C for these tests to avoid any condensation and hence any decrease of HTF vapor concentration.

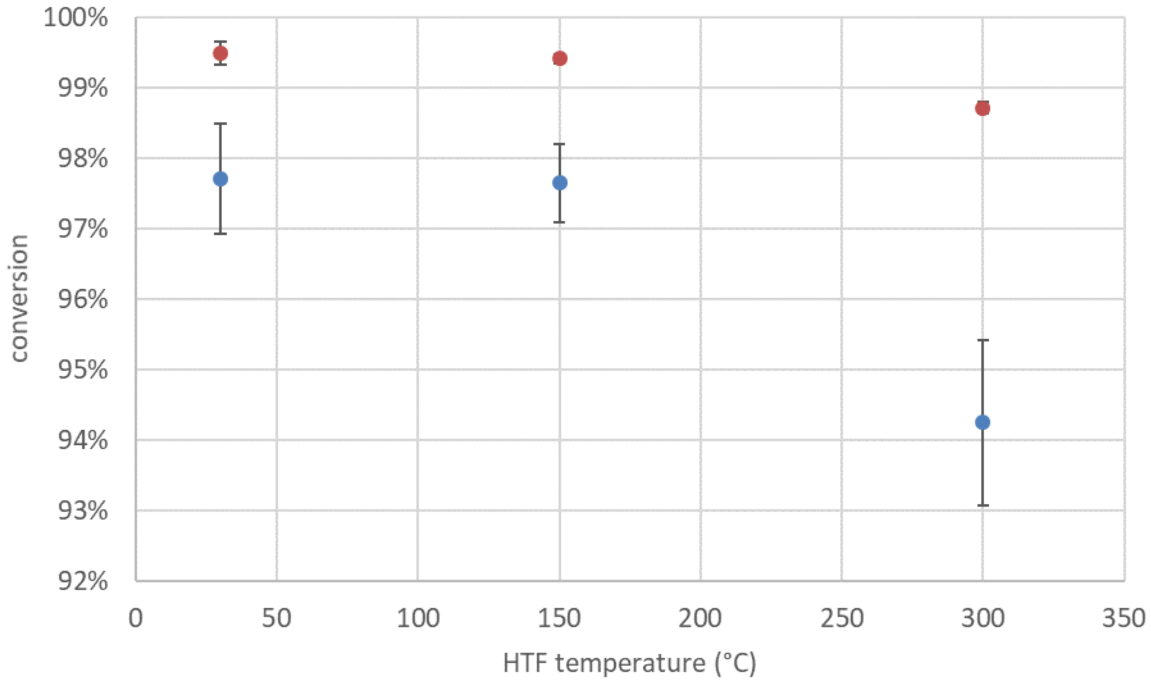

Figure 5*. Conversion of 2000 ppm hydrogen in nitrogen enriched with HTF vapor at different temperatures (red: experiments at 50 sccm, blue: experiments at 200 sccm).*

As flow rates have to be limited to 200 sccm to avoid quick draining of HTF from the vapor saturator only some tests at comparably slow volumes flows are performed. Hydrogen conversion of 94 to almost 100% is reached (see Figure 5). Smaller conversion is assumed to be caused by condensation of liquid HTF on the catalyst. No irreversible deactivation is observed.

4. Discussion

It could be shown that complete hydrogen conversion can be reached with the catalytic process tested so far at comparably low temperatures as the reaction is already active at ambient temperature conditions. HTF vapor has only minor impact on the conversion. The impact of HTF on the catalyst is reversible as full activity is maintained when less HTF vapor is supplied to the experiment after testing at higher HTF concentration. Within the lab tests no significant limit on the flow rate could be found with respect to complete conversion.

Hence, total removal of hydrogen can be achieved within a single passage through the catalyst at moderate temperature even in presence of HTF vapor. While the catalytic process can achieve zero hydrogen in the purified nitrogen, a membrane filtration process can be expected to perform less efficient as it is driven by a concentration gradient. Hence, reaching hydrogen levels below 0.3 mbar is expected to be more challenging with membrane filtration compared to the chemical removal of hydrogen.

As the lab studies are very promising with regard to catalytic activity and selectivity of the process, a demonstration project has already been initiated. This plant is currently prepared at a Spanish parabolic trough power plant.

Data availability statement

No additional data are available to this publication.

Underlying and related material

No additional material is available to this publication.

Author contributions

Christian Jung prepared the manuscript. Carsten Spenke developed and supervised the experiments, evaluated and prepared data and figures for this paper.

Competing interests

The authors declare that they have no competing interests.

Funding

The author would like to express his gratitude for the public funds that were granted for the research project “Active Hydrogen Control in Solar Thermal Parabolic Trough Plants” (Hyrec^3, grant 03EE5073A) by the Federal Ministry for Economic Affairs and Climate Action (BMWK) of Germany.

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