Hydrogen Recovery from UCG Gas: experimental data of hydrogen separation from UCG gas using a polymer membrane

M.V. van Schagen [a], V. Linkov [b], B.J Bladergroen [b], K. Govender [c], G. Gericke [c]

a) University of Twente, Enschede, The Netherlands
b) University of the Western Cape, South African Institute for Advanced Materials Chemistry, Bellville, South Africa
c) Eskom Group Technology Division, Johannesburg, South Africa

Abstract: The ability of asymmetric poly(p-phenylene oxide) (PPO) membranes to separate H_2 from UCG fuel gas was investigated. The H_2 concentration was increased from 10 vol% in the feed to 30 vol% in the permeate stream. The results show that polymer membranes could be applied in a process to separate H_2 and CO_2 from underground coal gasification (UCG) fuel gas.

Introduction

Hydrogen (H_2) is envisioned to be a major energy carrier in a hydrogen based economy[1]. H_2 can be used for efficient decentralized power generation using fuel cell technology. Furthermore, fuel cells find application in the transportation sector providing a clean and efficient alternative to fossil liquid fuels of which resources are declining.

UCG yields a fuel gas rich in H_2, CO_2, CO, N_2 and CH_4. The hydrogen content typically varies between 15 and 20 vol%. UCG gas may be considered as a source of Hydrogen if an economically viable separation technology can be identified that is suitable to isolate H_2 from the gas mixture.

Polymer membranes have the ability to separate hydrogen and other gases from the UCG fuel gas. Membranes are proven to be cost effective in numerous applications and are used by various industries. In this study polymer hollow fibre membranes were tested on the UCG fuel gas. The active membrane material is poly(p-phenylene oxide) (PPO) which is located on the outside of the porous fibre in the form of a thin dense layer of 30 nm. A schematic representation of such fibre is given in Figure 1. The fibre has a diameter of 0.6 mm and a length of 30 cm. The feed gas enters the core of the fibre at one end, part will permeate through the dense membrane layer, the remaining gas (reject) exits via the core at the other end.

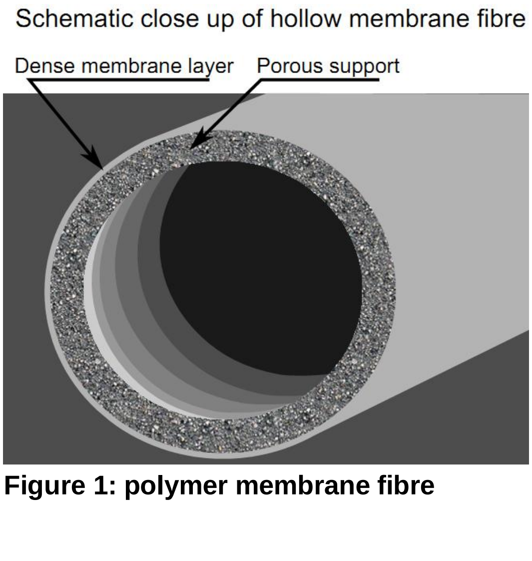

Figure 1: polymer membrane fibre

Experimental

A membrane module containing thousands of PPO membrane fibres was tested at Eskom's Majuba UCG pilot plant in Mpumalanga, South Africa. UCG fuel gas was taken directly from the plant. The feed pressure was regulated between 2.5 and 8 bar(G) with a maximum feed gas flow of 5 Nm^3/h (at 273 K and 1 atm). Data of the gas flow, pressure, temperature and gas compositions of the feed, permeate and reject flows were captured.

Results

Gas analysis measurements indicated a significant difference between the feed gas and the permeate gas composition. While the feed gas contained only 11 vol% H_2 and 18 vol% CO_2, the permeate contained 30 vol% H_2 and 41vol% CO_2. The N_2 concentrations were 63 and 23 vol% in the feed and permeate respectively. The concentrations of CO and CH_4 in the permeate gas were only slightly lower than in the feed gas. The compositions of the feed-, permeate- and reject- gas for one of the experiments are shown in Figure 2.

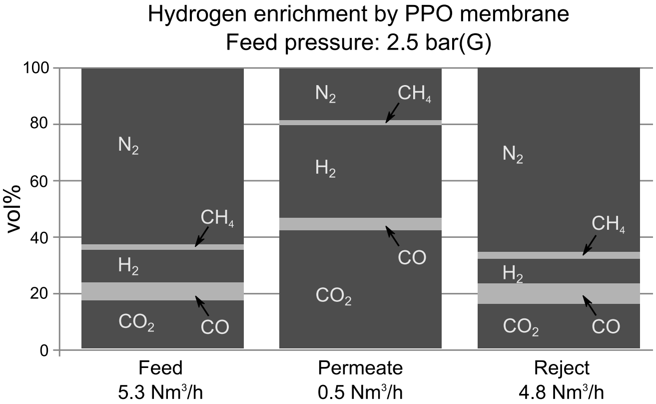

Figure 2: resulting concentrations from experiment

Outlook

A commercial UCG plant is likely to have higher H_2 and CO concentrations.[2] The data from the experiments can be extrapolated to a hypothetical feed composition at a pressure of 8 bar(G). The resulting permeate is given in Table 1 and shows H_2 concentrations on above 43 vol% with a significant H_2 recovery up to 73%.

Table 1 concentrations (vol%) when data is extrapolated to a hypothetical feed

	Feed	Permeate	Reject
H_2	16.0	43.0 - 44.8	5.9 - 10.7
CO_2	18.0	38.4 - 38.5	10.3 - 14.3
N_2	52.0	10.2 - 11.6	59.6 - 67.1
CO	10.0	4.8 - 5.1	4.5 - 4.7
CH_4	4.0	1.4 - 2.1	10.9 - 12.0
Flow [mol/h]	446	69 - 122	325 - 377
H_2 recovery	43 - 73 %		

A permeate stream containing >40 vol% of H_2 can be upgraded to pure H_2 (99.999%) using commercially available and mature technology such as pressure swing adsorption (PSA). Combining membrane technology and PSA could lead to a viable process for the production of H_2 from UCG gas. Such a H_2 plant can be designed on different scales for the following possible uses:

- A small plant: supply of H_2 to cool the generators of a power plant.
- A medium plant: supply of fuel for silent, zero-emission fuel cell busses in the city of Johannesburg, improving local air quality.
- A large plant: supply of H_2 for South Africa's vehicle fleet when fuel cell cars are widely used in the future.

The permeate obtained with the PPO membrane is rich in both H_2 and CO_2 which shows the potential of membranes not only in H_2 but also CO_2 recovery. Reduction of CO_2 emissions is widely seen as the option for responsible use of fossil fuels.[3]

Conclusion

Asymmetric poly(p-phenylene oxide) (PPO) membranes have potential as first stage separation technology for the recovery of H_2 and CO_2 from UCG product gas. Application of this membrane on a commercial UCG product gas can yield a permeate flow containing >40 vol% H_2 and CO_2.

Acknowledgements

This research was made possible with financial support from Eskom TSI.

References

1] McDowall, W. and Eames, M. (2006) Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature, Energy Policy **34:** 1326-1250

2] Van der Riet, M. (2010) Eskom's Experience with UCG, http://www.eskom.co.za/content/20100419_EskomUCG_experience.pdf, acquired on 03-07-2011

3] Beck, B.; Surridge, T.; Liebenberg, J.; Gilder, A. (2011) The current status of CCS development in South Africa, Energy Procedia **4**:6157-6162