PROCESS INTENSIFICATION DURING POWER GENERATION VIA MEMBRANE-BASED REACTIVE SEPARATIONS

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Highlights

- A membrane reactor (MR) is investigated for potential application in power generation
- The MR improves the efficiency of the water gas shift reaction and process economics
- A multi-scale model is validated against the experimental data
- Membranes and catalyst are robust under IGCC-relevant conditions

1. Introduction

Producing syngas from coal and/or biomass gasification is a key first step towards environmentally-benign power generation from these important raw resources. The current IGCC process involves first reacting coal and/or biomass with steam and/or oxygen in a gasifier to produce syngas. The syngas is then, typically, cooled down to remove various contaminants such as H_2S, NH_3, tars, organic vapors, etc.; it is then reheated to be further reacted with steam in a water gas shift (WGS) reactor to increase its hydrogen content. The WGS reaction is exothermic, and its equilibrium conversion decreases with temperature. Therefore, typically, two reactors are deployed, one operating at high temperatures (HTS) and the other at a lower temperature (LTS), in order to overcome simultaneously both equilibrium and kinetic limitations, and to thus increase CO conversion at practical space velocities. The total process, as it is now envisioned, is complex and energy-intensive, and thus not very attractive for application in the context of power generation with carbon capture and sequestration (CCS).

To supplant the conventional WGS reactor process, this team has proposed a novel technology, termed the "one-box" process [1]. The heart of the process is a catalytic membrane reactor (MR) making use of carbon molecular sieve membranes (CMSM). The MR also incorporates a $Co/Mo/Al_2O_3$ catalyst. Project efforts involve experimental studies in the laboratory for conditions relevant to the IGCC process, i.e., pressures up to 25 bar and temperatures up to 300 ^oC, with a number of different simulated syngas compositions. These are coupled with extensive field-testing of commercial-scale CMSM modules in the real coal/biomass gasification environment, which are conducted at the US NCCC coal gasification facility [2], with a key focus being the development of such membranes, which are robust for the proposed IGCC application. Both membrane and catalysts have been shown to date to be robust to coal- or biomass-derived syngas environments. Another goal of the ongoing efforts is the development of data-validated reaction kinetics for the catalysts employed and of multi-scale reactor models. Such models are used for optimal process design and for the technical and economic analysis (TEA) of the proposed process.

2. Methods

MR experiments have been carried out in a laboratory apparatus capable to operate under IGCC-relevant conditions, i.e., temperatures up to 300 ºC and pressure up to 25 bar. Field-tests are conducted at the US NCCC under conditions suitable for the "one-box" process.

3. Results and discussion

The feasibility of the "one-box" process was previously proven in the laboratory for pressures up to 5 bar [1]. The focus of our recent efforts was to expand the testing for higher pressures (up to 25 bar), which are more relevant to the coal gasification environment. Figure 1, for example, shows experimental CO conversions for the 'one-box' system for feed pressures of ~ 14 bar, and compares such conversions with those measured with a packed-bed reactor (PBR). The MR shows superior performance to that of the PBR for the whole range of conditions studied. A multi-scale WGS-MR model is also tested against the experimental data. The model employs the data-validated rate expression and accounts for axial dispersion and diffusional limitations inside the catalyst particles. Figure 2 compares membrane reactor experimental conversions with predictions of the multi-scale model.

Fig. 1. Conversion of MR and PBR.

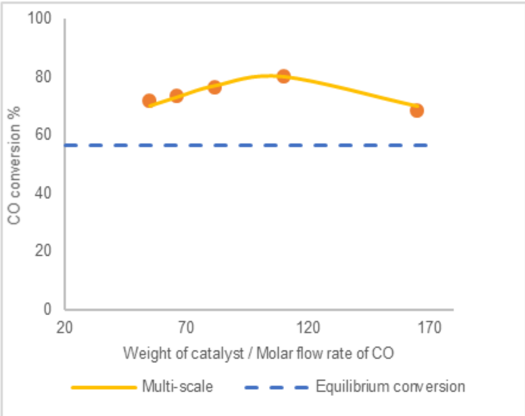

Fig. 2. Conversion vs. (weight of catalyst /molar flow rate of CO) for MR (no sweep).

4. Conclusions

A novel technology, termed the "one-box" process has been proposed in order to economically produce pure hydrogen from coal/biomass gasification for use during power generation. It utilizes a catalytic MR making use of CMSM and $Co/Mo/Al_2O_3$ catalysts resistant to syngas impurities. Experimental studies have been carried out in the laboratory to determine the catalytic reaction kinetics, membrane characteristics, and the MR performance. A multi-scale model is validated against the experimental data. In parallel, field-testing of the technology, membranes and catalyst have been shown robust to raw coal-derived and/or biomass-derived syngas.

References

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Keywords

Water-gas shift reaction; Carbon molecular sieve (CMS) membrane; $Co/Mo/Al_2O_3$ sour-shift catalyst; Hydrogen production.