On the mass transfer rates in fluidized bed membrane reactors

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Highlights

- Bubble concentration profiles in a fluidized with high temporal and spatial resolution.
- Visualization of the mass transfer surrounding membranes is achieved with IR cameras.
- Effects of gas extraction on mass transfer in fluidized beds have been elucidated.

1. Introduction

An interesting development in the field of reforming reactors is the application of the membrane reactors, where the in-situ selective extraction of hydrogen results in a shift in the equilibrium, which allows operation at lower temperatures while still achieving higher conversions. Moreover, no downstream separation is required since pure hydrogen is produced. Thin-film palladium-based membranes have the largest potential for integration in membrane reactors for hydrogen production due to their extremely high permeation fluxes and perm-selectivities. The permeation of hydrogen through the membrane depends only on the hydrogen partial pressure difference across the membrane. However, due to the high hydrogen flux, the mass transfer towards the membrane can become limiting, which effect is known as concentration polarization. In the case of fixed bed reactor configurations, the concentration polarization can significantly increase the required membrane area. The application of a gas-solid fluidized bed reactor configuration can decrease the concentration polarization effects due to its higher gas-solids mixing. However, concentration polarization should still be accounted for when designing fluidized bed membrane reactors [1]. The extent of concentration polarization could in principle be adequately predicted with a film layer approach, where the thickness of the mass transfer boundary layer depends on the bed hydrodynamics. However, there are no accurate correlations available in the literature that account for the presence of the membranes and the selective extraction of hydrogen through the membranes on the bed hydrodynamics and mass transfer processes. An innovative technique was developed exploiting infrared radiation to measure virtually instantaneously whole-field concentration profiles in the dilute zones of a fluidized bed [2]. The current study aims at applying this novel technique to study the mass transfer processes surrounding membranes immersed into a fluidized bed.

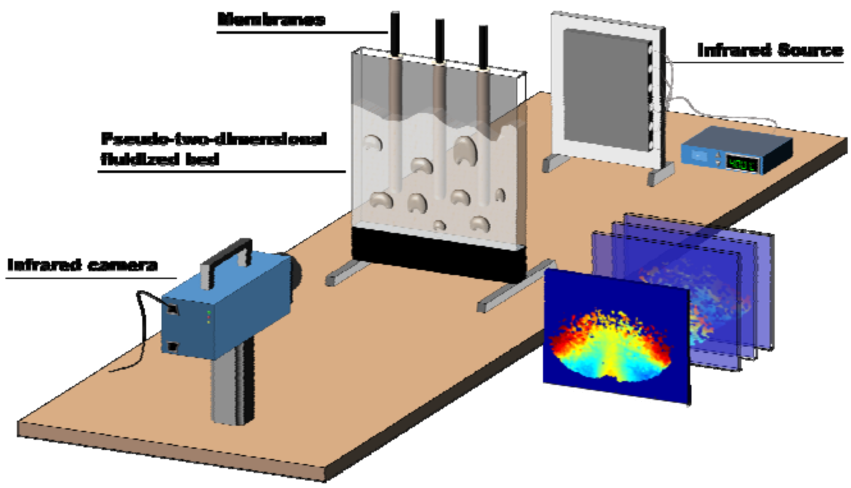

Figure 1 Schematic representation of the IR transmission setup.

2. Methods

The novel IR transmission technique makes use of the IR absorbing properties of a tracer gas. In order to measure the tracer gas composition an IR source is aligned with a pseudo two-dimensional fluidized bed and a high-speed IR camera. The fluidized bed is made out of quartz to allow for IR transmission. To detect the tracer gas the IR camera is equipped with a filter at a specifically selected wavelength which corresponds to the absorbance peak of the tracer gas. In this work, propane is used as tracer gas which has a high absorbance peak in the IR wavelength range of around 3.4 µm. The output signal of the camera can be directly correlated to the IR absorption and via Lambert-Beer's law to the tracer gas concentration. In this way an instantaneous whole-field concentration profile is obtained, which is used to study the mass transfer surrounding gas separation membranes submerged in the fluidized suspension [1]. A schematic representation of the measurement system is shown in Figure 1.

3. Results and discussion

Unlike in fixed bed reactors, the gas passes through a fluidized bed via two phases, viz. the bubble and the emulsion phase, with different gas residence times. In addition, there is mass transfer between the bubble and the emulsion phase. In the case of gas extraction through the membranes there is also mass transfer to the membrane surface. The IR technique has been applied to quantify bubble-to-emulsion mass transfer rates for single and multiple bubble injections into a fluidized bed at incipient fluidization conditions and bubble injections into a fluidized bed in the freely bubbling regime. The results clearly show that the membranes significantly affect the bubble properties and its turn the mass transfer rates [3]. The integration of membranes into the fluidized bed results in enhanced bubble breakage, affecting the bubble size distribution as well as the gas dispersion. With the IR technique the gas residence time distribution was measured and the gas back-mixing in the fluidized bed quantified. The extent of concentration polarization was studied with perm-selective membranes, where the selectivity and permeation flux through the membranes was carefully selected to invoke the concentration polarization effect. On the basis of the generated experimental data closure correlations are developed for the description of the extent of concentration polarization.

4. Conclusions

Measurements of instantaneous whole-field concentration profiles inside the bubbles in a membrane-assisted fluidized bed have been achieved, extending the work to quantify the concentration polarization effects. The effects of the membranes on the mass transfer is mainly governed by the change in bubble size. However, the results also reveal the importance of the contact time of the membrane with the emulsion and bubble phases. A closure correlation is developed for the description of concentration polarization in a membrane-assisted fluidized bed.

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Keywords
Concentration polarization; Membrane reactor; Steam reforming; IR measurement.