Hydrodynamics and mass transfer phenomena in fluidized beds membrane reactors

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HYDRODYNAMICS AND MASS TRANSFER PHENOMENA IN FLUIDIZED BED MEMBRANE REACTORS

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Abstract:
Fluidized bed membrane reactors have been proposed for various processes to selectively extract gas components from (e.g. hydrogen) or add gas components to (e.g. oxygen) the reaction mixture, see Gallucci et al. [1], Adris et al. [2], Mleczko et al. [3]. Compared to fixed bed membrane reactors, fluidized bed membrane reactors have better mixing properties, resulting in reduced mass transfer limitations towards the membranes (reduced concentration polarization). The hydrodynamics and mass transfer phenomena of the fluidized suspension can be strongly affected by the membrane configuration.

Hydrogen production via Steam Methane Reforming (SMR) often takes place in fixed bed type catalytic reactors. To obtain ultra-pure hydrogen, complicated and energy intensive separation units are required. When a fluidized bed membrane reactor is used for SMR, the hydrogen is extracted selectively from the system via membranes, which reduces thermodynamic limitations, allows operation at reduced temperatures and provides a pure hydrogen stream. If all methane and CO are converted, the main reactor exhaust will be CO2 and steam, which can be separated easily. A high degree of process integration is achieved because the reaction and separation steps take place in the same reactor.

The present work is a numerical investigation into the hydrodynamics and mass transfer phenomena in fluidized beds with hydrogen extraction via membranes mounted in two opposing confining walls of the reactor. The focus of the work is on hydrodynamics and mass transfer phenomena near the membranes at various operating conditions. A newly developed version of the OpenFOAM® Two Fluid Model (TFM) including species balance equations is used to perform the investigation.

Figure 1 presents a TFM simulation result of a bubbling fluidized bed with hydrogen extraction via the left and right boundary. The figure shows that model can simulate detailed information on solids hold-up and species concentrations in the reactor. The hydrogen mass fraction profile in the bubbling fluidized bed with hydrogen extraction indicates that there are mass transfer limitations towards the membranes (see Figure 2). The effects of using perm-selective membranes in fluidized bed reactors on mass transfer limitations will be further outlined using the newly developed TFM. Finding methods and operating conditions to reduce mass transfer limitations will be important for the design and experimental/pilot scale usage of fluidized bed membrane reactors.

Simulations of fluidized bed membrane reactor systems, performed with the newly developed Two Fluid Model including species balance equations, have generated valuable information on the effect of the membranes on hydrodynamics and mass transfer phenomena. Bubble properties, the effect of various operating conditions on the system and the effect of mass transfer limitations near the membrane can be quantified.

Reference 4:

Highlight 1: OpenFOAM’s Two-Fluid Model has been extended to model mass transfer phenomena & membranes