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Parallel and series multi-bed pressure swing adsorption processes for H_2 recovery from a lean hydrogen mixture

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ABSTRACT

The demand for clean energy sources has made H_2 recovery from various lean hydrogen mixtures increasingly attractive. In this study, parallel and series pressure swing adsorption (PSA) processes were investigated experimentally and theoretically, and > 99% pure H_2 was produced from a lean hydrogen mixture (H_2:CO:N_2:CO_2 = 19.9:0.1:44.6:35.4 mol%) at 10 bar. A mathematical model for a PSA process using activated carbon and zeolite 13X was simultaneously validated with results from breakthrough experiments and a parallel two-bed PSA process. The parallel two-bed PSA process using a layered bed (lower bed: activated carbon, upper bed: zeolite 13X) experimentally produced H_2 with a purity of 94.6–98.3% and a recovery of 33.5–63.2%; CO was not detected in the H_2 product. In the parallel four-bed PSA process, the H_2 recovery was drastically increased to 77.3% due to an additional pressure equalization step, but the increase in H_2 purity was minute. The series PSA process, which was divided into the bulk separator and the purifier, was theoretically studied under various operating conditions. The series three- and four-bed PSA processes could produce H_2 with over > 99% purity and a recovery of 62.478% and 82.643%, respectively, due to the additional pressure equalization step and the utilization of blowdown gas. The parallel four-bed PSA process showed the highest H_2 productivity (33.58 mol_{H2} kg_{ads}^{-1} day^{-1}), while the series four-bed PSA process achieved an H_2 productivity of 23.96 mol_{H2} kg_{ads}^{-1} day^{-1} with > 99% H_2 purity.

1. Introduction

Hydrogen (H_2) is one of the most important chemicals used in numerous important industrial applications, such as hydrotreating, hydrocracking, and hydrogenation [1]. Furthermore, due to the fact that the combustion of fossil fuel induces global warming, H_2 has become a more attractive and important clean energy source for fuel cells and power generation. Therefore, H_2 has the potential to provide economically feasible, socially advantageous, and energetically efficient solutions to the ever-increasing global demand for clean energy [2].

Currently, most industrial H_2 production is achieved through the catalytic steam reforming of natural gas [3] and naphtha cracking [4]. Large amounts of H_2 can also be produced from syngas from coal gasification [5,6] and coke oven gas in the iron and steel industries [7]. However, the need for alternative routes of H_2 production has become more urgent with the increasing demand for H_2 as a clean energy source in industry and society to achieve a more sustainable future [8]. Furthermore, due to the expansion of natural gas production, H_2 production via steam methane reforming is rapidly increasing to meet the demands of hydrogen vehicles [9,10].

Pressure swing adsorption (PSA) gas separation processes are widely applied for the production of H_2 from various H_2-rich mixtures in industry because of its energy-saving and economical feasibility. Furthermore, in many H_2 PSA processes, no compressor and vacuum facility are needed when feeds are supplied from high-pressure reactors. Multi-bed PSA processes that can recover over 80–95% of H_2 have been reported [11–13]. Naturally, a tail gas (lean hydrogen mixture)

Abbreviations: AC, activated carbon; BPR, back pressure regulator; BFDM, backward finite difference method; BFG, blast furnace gas; CFDM, centered finite difference method; CO-IR, IR analyzer for CO; DSL, dual-site Langmuir; FFDM, forward finite difference method; L/D ratio, length/diameter ratio; LDF, linear driving force; MFC, mass flow controller; MTZ, mass transfer zone; P/F ratio, purge to feed flowrate ratio; PSA, pressure swing adsorption; SRK, Soave-Redlich-Kwong; TSA, temperature swing adsorption; VSA, vacuum swing adsorption; WGM, wet gas meter; TEG, triethylene glycol dehydration.

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