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Conceptual design of a novel pressure swing CO_2 adsorption process based on self-heat recuperation technology

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ABSTRACT

CO_2 capture and storage (CCS) technology has attracted attention for the mitigation of CO_2 emissions. Among the dominant CO_2 capture technologies, pressure swing adsorption (PSA) is a promising alternative to amine-based absorption. However, its capture cost should be further decreased to facilitate its commercial implementation in industry. In this study, a novel low-cost PSA CO_2 capture process based on self-heat recuperation technology is discussed. An energy balance of the conventional process and the proposed process is simulated and compared using a commercial process simulator (PRO/II ver. 9.1, Invensys). In the proposed PSA process, the exothermic heat of adsorption is recuperated using a reaction heat transformer (RHT) and is recirculated for adsorbent regeneration. The waste residual gas pressure can also be recovered by an expander at the top of an adsorption tower. The simulation results indicate that the energy consumption of the proposed PSA process is 40% that of the conventional process.

1. Introduction

Fossil fuels are a primary energy source worldwide. Upon their combustion, large amounts of greenhouse gases (GHGs) are generated and emitted into the atmosphere [1,2]. Climate change has become a critical issue and is of great concern. It is caused by GHG emissions. A report from the Intergovernmental Panel on Climate Change (IPCC) indicated that CO_2 makes up a high proportion of these gases because of its presence in the atmosphere. It contributes to 70% of global warming effects among the GHGs [3]. Therefore, CO_2 capture and storage (CCS) from large point sources (i.e., fossil fuel fired power plant, steel or iron factory, cement plant and petrochemicals industry) is considered to be the most significant strategy to control the GHG effect and mitigate climate change [4,5].

Three main CO_2 capture strategies are applicable to the combustion of fossil fuels, namely post-combustion, pre-combustion and oxy-fuel combustion [6,7]. Among these, post-combustion capture (PCC) is considered the most effective strategy because retrofitting existing fossil fuel-based power plants can be done without much modification [8,9]. To date, absorption, adsorption, membrane and cryogenic methods are the dominant CO_2 capture technologies [10,11]. They have been widely investigated for the capture of GHGs from industrial post-combustion stations [12–14]. Absorption is the most mature technology and it is used commercially for scrubbing industrial emissions [15,16]. However, the integration of CCS units (such as MEA absorption) into a retrofitted coal-fired power plant for 90% CO_2 capture can reduce the thermal efficiency from an approximate 35% HHV (high heating value) basis to 24% at a cost of $80 to capture a ton of CO_2 [17]. Meanwhile, regeneration of rich solvents requires additional thermal (from 2.5 to 3.5 MJ/kg CO_2) of the solvent regeneration which 80% of the total energy consumption [18–20].

Pressure swing adsorption (PSA) technology is a promising alternative to the amine-based absorption process [21–23]. Compared to other CO_2 capture techniques, adsorption process shows many potential advantages, such as reduced energy for regeneration, greater capacity, selectivity and ease of handling [24,25]. The regeneration energy requirement for CO_2 capture using solid sorbent is significantly reduced more than that of the aqueous amine-based process, because of the absence of large amounts of water. Moreover, the heat capacity of solid sorbent is comparatively lower than that of an aqueous amine solvent [24]. However, the sorption or absorption reaction is an exothermic reaction. Therefore there is heat release from the system. The generated heat can adversely affect adsorption performance

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Nomenclature

H Enthalpy, J
T Temperature, °C
ΔT Temperature difference, K
Q Heat, J
W Work, J
c_p Heat capacity, J/K

Greek letters
ν Flow rate, kmol/h

Abbreviations
CCS CO_2 capture and storage
GHG Greenhouse gas
PSA Pressure swing adsorption
SHR Self-heat recuperation
RHT Reaction heat transformer
NGCC Natural gas combined cycle
PCC Post-combustion capture
MEA Monoethanolamine

because of the increase in temperature [26]. Therefore, it is necessary to add a cooling unit to manage the temperature of the adsorption column. Typically, exothermic heat is removed by cooling water [27]. On the other hand, the regeneration of adsorbents (in a desorption column) is an endothermic process, which requires the addition of heat. For the PSA process, this heat is usually supplied by decompressing the pressure of the bed [28]. As a result, the net electrical efficiency of a power plant would decrease by about 10% because of CO_2 capture unit retrofitting [29].

To overcome the issue of high energy consumption and improve the net efficiency of power plants, much effort has been put into optimizing the configuration of the CO_2 capture process. These include an inter-heated column, a split-stream, a bi-pressure stripper, a multi-pressure stripper, a stripper with vapor recompression and an absorber with inter-cooling [30–33]. Recently, self-heat recuperation has been suggested as a significant alternative to recover waste heat from chemical processes [34,35]. Using self-heat recuperation technology, the waste heat generated in thermal processes can be recovered by compression. All the latent and sensible heat is recycled in the process by well heat pairing.

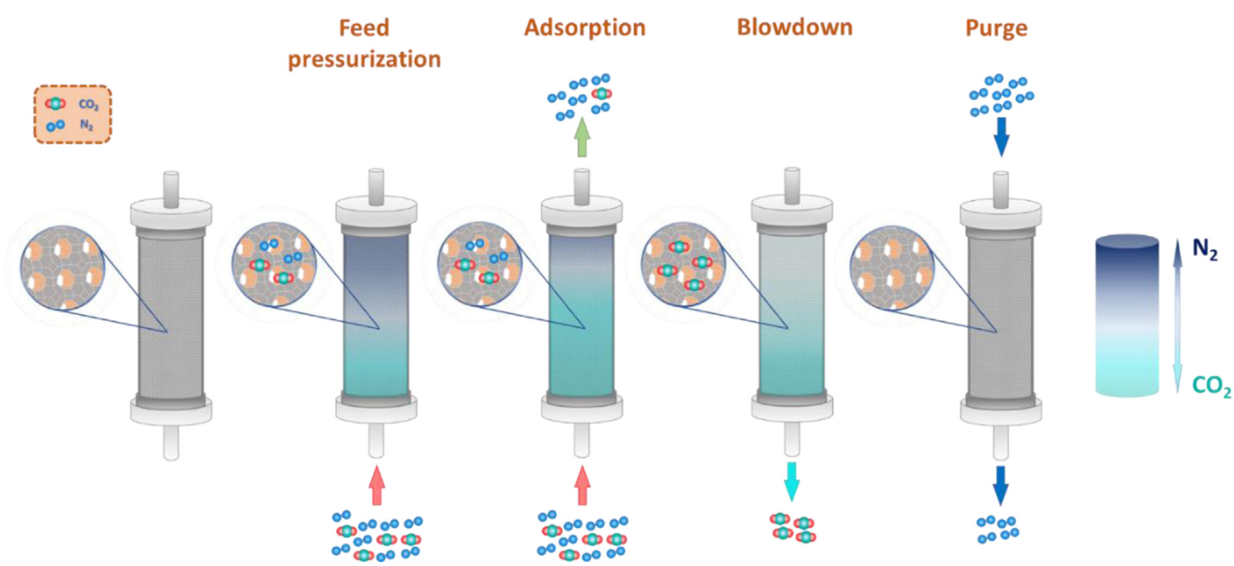

Fig. 1. Schematic diagram of a typical PSA process.

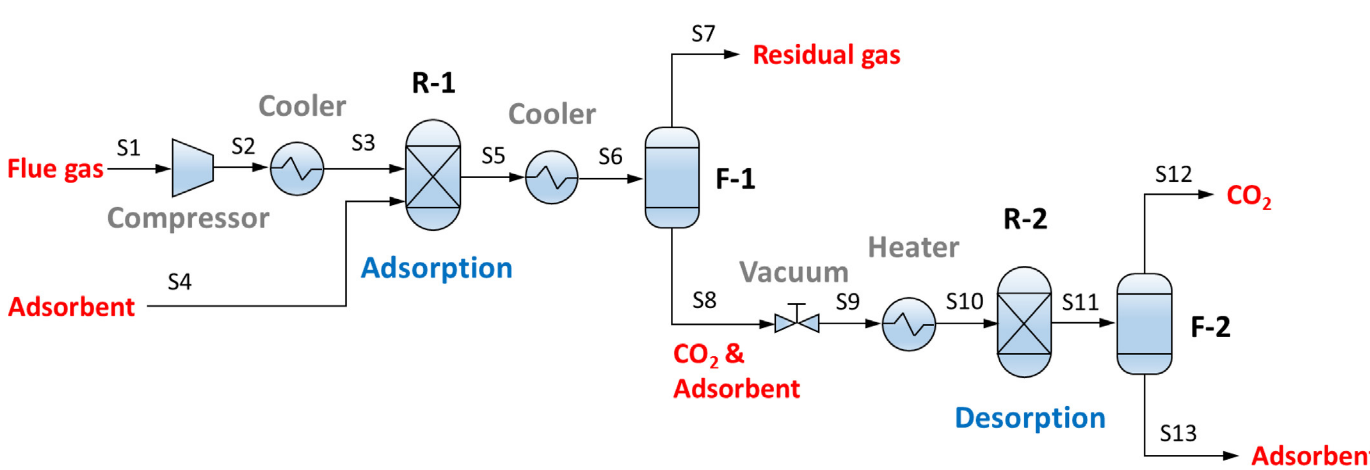

Fig. 2. Flow diagram of a conventional PSA CO_2 capture process.