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Performance exploration of temperature swing adsorption technology for carbon dioxide capture

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ABSTRACT

Adsorption technology is recognised to be a promising CO_2 capture method due to its desirable characteristics e.g. reusable nature of adsorbents, low capital investment and easy automatic operation. To further improve thermal performance, internal heat recovery is adopted for adsorption CO_2 capture through analogy with adsorption refrigeration. Based on carbon pump theory, thermal performance of 4-step temperature swing adsorption (TSA) processes is analysed at various adsorption/desorption temperatures and pressures. Exergy efficiency of adsorption CO_2 capture with and without heat recovery will be evaluated and compared by using experimental adsorption characteristics of activated carbon. Metal part and unused percentage of adsorption reactor are defined to further assess their influence on system performance in real application. Results indicate that sensible heat of adsorbents and adsorbed phase account for the major part of heat consumption. For different desorption/adsorption temperatures and pressures, theoretical exergy efficiency of 4-step TSA cycle ranges from 0.022 to 0.221. Heat recovery is conducive to exergy efficiency. Through heat recovery, exergy efficiency could be improved from 54.3% to 84.6% when mass ratio increases from 0 to 8. Similarly, the improvement by using heat recovery is up to 90% in terms of different unused percentages.

1. Introduction

Carbon capture and storage (CCS) has been gathering the momentum, which aims to prevent the release of large quantities of carbon dioxide (CO_2) to the atmosphere since it is considered to mitigate the contribution of fossil fuel emissions to global warming and ocean acidification [1]. Carbon capture technologies could be realized by three main methods: pre-combustion capture, post-combustion capture and oxyfuel combustion [2]. Among them, post-combustion capture plays a leading role due to the advantage of retrofitting existing industrial stations. Post-combustion capture could be achieved through a variety of methods e.g. cryogenic, membrane, adsorption, absorption process, etc. [3].

Absorption is once considered as the most likely commercialized technology for CO_2 capture. Nonetheless, energy penalty for large-scale application is also considerable [4]. It is extensively acknowledged that absorption and adsorption have many similarities. Solid adsorbents have several advantages e.g. low capital investment, easy to control, reversible characteristics, which ensure a relatively good performance for CO_2 capture [5]. Selection of adsorbents is one of major methods to improve the overall efficiency of CO_2 adsorption process. Materials i.e. zeolite 5A, zeolite 13X, activated carbon (AC) and silica gel have been widely investigated for adsorption refrigeration and CO_2 capture [6,7]. Several novel materials e.g. metal organic framework (MOF) have once aroused burgeoning attentions due to large adsorption capacity and high gas selectivity [8]. Nevertheless, the cost is correspondingly higher than that of other classical materials. Comprehensively considering cost, adsorption capacity and thermal stability, AC is one of the most suitable aspirants for CO_2 capture, which is inexpensive and insensitive to moisture with a high surface area [9]. Adsorption isotherm curve and reaction heat of AC have been ensured by various researchers [10,11]. The clear thermal properties are quite helpful to understand adsorption phenomenon, which could be used for system design and optimization of CO_2 capture. Except for selection of adsorbent, different operation methods i.e. thermal adsorption cycles also determine the performance of CO_2 capture.

Through the variation of temperature or pressure, approaches to adsorption CO_2 capture could be classified into pressure swing adsorption (PSA) and temperature swing adsorption (TSA). PSA operates adsorption process at a pressure higher than atmosphere value while vacuum swing adsorption (VSA) is defined when adsorption process proceeds at atmospheric pressure and desorption happens under a low

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Nomenclature

Activated carbon	AC
CCS	carbon capture and storage
E	exergy (kJ)
H	reaction heat (kJ^{-1}·kg^{-1})
MOF	metal organic framework
m	mass (kg)
P	pressure (Pa)
PSA	pressure swing adsorption
Q	heat (kJ)
q	CO_2 adsorption capacity (kg^{-1}·kg^{-1})
Re	recovery
T	temperature (°C)
TSA	temperature swing adsorption
VSA	vacuum swing adsorption
W	work (kJ^{-1}·kg^{-1})
WC	working capacity (kg^{-1}·kg^{-1})
y	CO_2 concentration

Greek letters

η	efficiency
ψ	percentage

Subscripts

ad	adsorption
CO_2	carbon dioxide
c	cooling
con	condensation
de	desorption
ex	exergy
H	high temperature
h	heating
hr	heat recovery
i	ideal
L	latent heat
l	low temperature
max	maximum
min	minimum
r	real
re	reactor
S	shaft work
s	sensible
sat	saturation

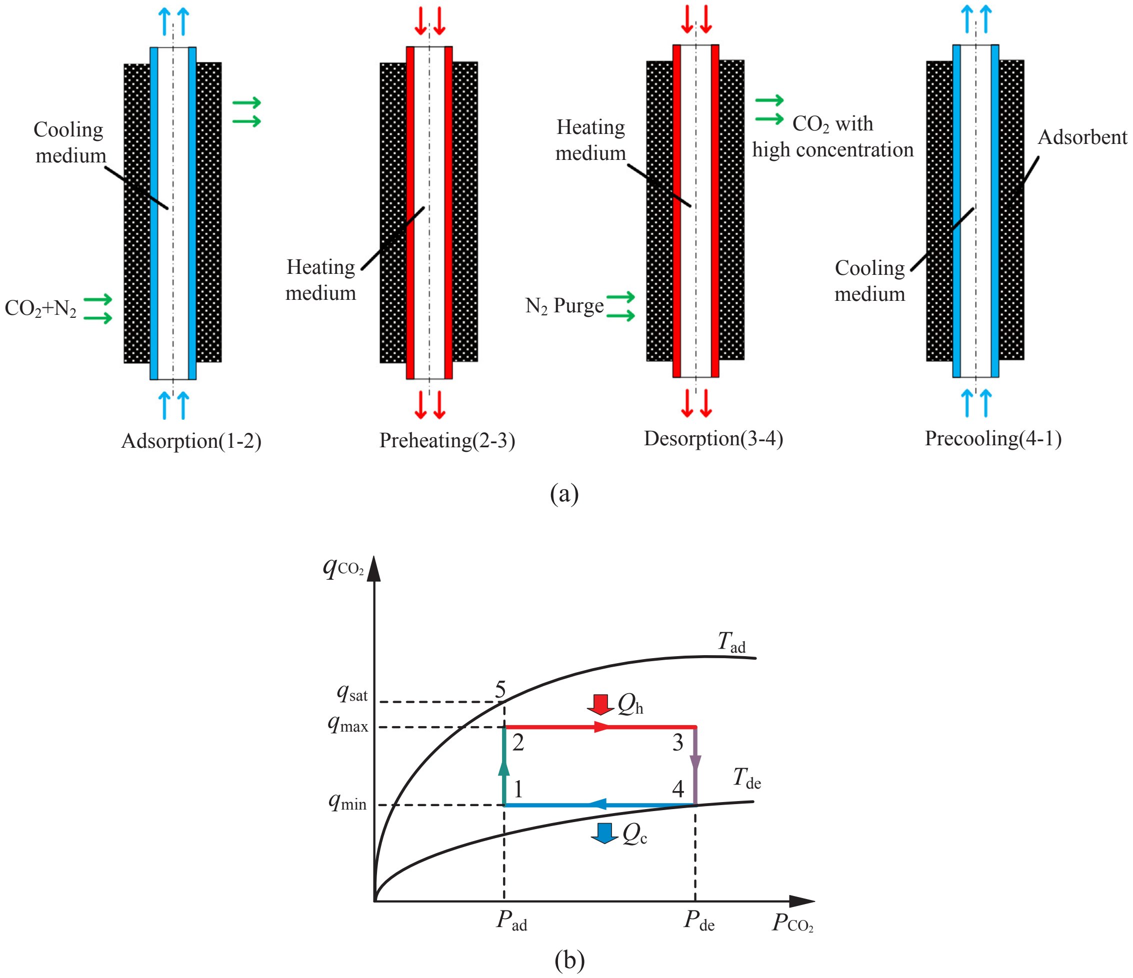

Fig. 1. Schematic diagram for 4-step TSA cycle (a) process schematic; (b) adsorption isotherm diagram.