Chemical Engineering Journal 490 (2024) 151424

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Review

Insights into the adsorption of CO_2, SO_2 and NO_X in flue gas by carbon materials: A critical review

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ARTICLE INFO

Keywords:
Carbon material
CO_2
SO_2
NO_X
Adsorption
Flue gas

ABSTRACT

The acceleration of industrialization has led to extensive emissions of air pollutants, resulting in a series of environmental pollution and climate warming issues. Carbon materials, known for their low manufacturing cost, good plasticity, stable chemical properties, and strong adsorption capacity, are considered one of the most promising materials for adsorbing pollutants in flue gases. Research on carbon material adsorbents has been extensively conducted thus far. This review systematically summarizes the simultaneous adsorption and removal of CO_2, SO_2, and NO_X by carbon materials in flue gas systems, with elaborate discussions on their adsorption capacity, adsorption mechanisms, critical factors affecting adsorption capture, and recent innovative advancements. Additionally, relevant information including carbon material classification, physical–chemical properties, and their modification methods is also briefly covered. Finally, the challenges and future research inspirations for carbon material sorbents in flue gas systems are outlined. The aim of this review is to highlight the development of carbon material solid sorbents for the simultaneous adsorption of air pollutants in flue gases.

1. Introduction

With the rapid development of the global economy, considerable acceleration in the industrialization process has been witnessed, inevitably resulting in heightened resource consumption and environmental pollution. Environmental pollution and climate warming are significantly driven by the emission of flue gas from fossil fuel combustion, which elevates the concentration of alkaline and acidic gases in the atmosphere [1]. The consequential increase in the concentration of acidic and alkaline gases exerts a notable impact on the global climate environment [2]. CO_2, SO_2, and NO_X, originating from various industrial sources such as power plants, steel mills, coking plants, refineries, petrochemical facilities, natural gas processing plants, and waste incineration plants, are typical air pollutants. NO_X serves as a major precursor of particulate matter and ozone, contributing to photochemical haze, reduced visibility, and ozone depletion. SO_2 can be oxidized to form sulfuric acid mist or sulfate aerosols, which are important precursors of environmental acidification [3]. CO_2 is one of the most important greenhouse gases, and the large annual CO_2 emissions cause the global temperature to continue to rise [4]. Fig. 1 illustrates the emissions of CO_2, SO_2, and NO_X in China from 2017 to 2021, showcasing the substantial yearly emission volumes, with CO_2 emissions persistently on the rise. Although there is an annual decline in SO_2 and NO_X emissions, overall emission levels remain high. Consequently, urgent measures are imperative for controlling the emissions of CO_2, SO_2, and NO_X.

Fig. 2 shows the different methods currently available for treating SO_2, NO_X and CO_2 in flue gases. Traditional methods for the removal of SO_2 from flue gas include wet processes employing calcium or sodium compounds (such as $Ca(OH)_2$, $CaCO_3$, Na_2CO_3, and $NaHCO_3$), semi-dry flue gas desulfurization [6], and dry flue gas desulfurization technologies [7]. The limestone-gypsum method for SO_2 adsorption is widely used but necessitates a large amount of limestone feedstock, resulting in the generation of significant quantities of low-quality gypsum with limited resource utilization, leading to excessive solid waste pollution. For nitrogen oxides removal in flue gas, the most commonly used and mature technologies are selective catalytic reduction (SCR) [8] and selective non-catalytic reduction (SNCR) [9]. However, SCR and SNCR methods for NO_X treatment are associated with disadvantages such as high investment costs and strict temperature requirements, as well as demanding technical specifications. In order to effectively control CO_2 emissions, carbon capture and storage technology (CCS) has rapidly developed [10]. Nowadays, one of the most widely used carbon capture

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https://doi.org/10.1016/j.cej.2024.151424
Received 21 January 2024; Received in revised form 21 March 2024; Accepted 16 April 2024
Available online 18 April 2024