Journal of CO_2 Utilization 23 (2018) 179–199

Contents lists available at ScienceDirect

Journal of CO_2 Utilization

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

Review article

CaO-based CO_2 sorbents: A review on screening, enhancement, cyclic stability, regeneration and kinetics modelling

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ARTICLE INFO

Keywords:
Carbon dioxide
Sorbents
Metal-based
Calcium oxide
Kinetics modelling

ABSTRACT

This article reviews current developments in metal-based sorbents for carbon capture with emphasis on calcium oxide. A broad overview of carbon dioxide capture with metals in various forms including oxides, hydroxides, carbonates and zirconates is presented. Based on the findings from comparative assessments of these sorbents, CaO appears to be the best solid sorbent for CO_2 capture at high temperatures, and its numerous advantages are discussed in this work. For this reason, a detailed review has been conducted for calcium oxide, which works as a sorbent at temperatures up to 700 °C through carbonation, and desorbs CO_2 above 700 °C by calcination of $CaCO_3$ at atmospheric pressure. A review of studies on kinetics modelling of CO_2 capture with CaO-based sorbents is also included in this work. Decay in activity caused by sintering and attrition is identified as the greatest challenge with CaO-based sorbents. This work also focuses on the available techniques for enhancing performance and cyclic stability. Reactivation of the sorbents by hydration and reduction in decay rate by doping with inert supports and synthetic sorbents are reviewed. Additionally, the use of biomass resources (waste animal shells) as competitive sources of $CaCO_3$ is discussed in this work. The review concludes with recommendations for future studies in carbon capture and sequestration.

1. Introduction

The world is witnessing a rapid growth in population and energy consumption, and is faced with the responsibility of minimizing greenhouse gas emissions. There is a consensus in the scientific world that climate change is a serious issue, with CO_2 emission being one of the prime contributors. This has led to international policies and agreements like the Kyoto protocol and the Copenhagen Accord [1]. Fossil-fuelled power plants are major contributors among anthropogenic sources of CO_2 emissions. Power plants account for more than 33% of the total CO_2 emission globally [2,3], and a coal-powered 500-MW plant can generate approximately 3 million tons/year of CO_2 [4,5]. Although alternative energy sources do not contribute to carbon emissions directly, they are intermittent sources of energy. Furthermore, hydrogen is still considered as fuel for the future and currently, it is produced mostly from fossil fuels, which contributes to CO_2 emissions. It, therefore, appears that fossil fuels are likely to remain as the major source of energy for mankind for the time being [6]. As research progresses on how to shift attention from fossil fuels, carbon capture technologies enable continual usage of fossil fuels, while decreasing CO_2 emission, and thus mitigating climate change. Reduction in CO_2 emission may be achieved in three ways: reduction of energy consumption through the use of energy efficient systems, reduction in carbon intensity by the application of alternative energy sources, and reduction in emission by carbon capture and sequestration (CCS) technologies [7].

Considering their cost-effective performance in reducing carbon emissions, CCS technologies have received significant attention in recent times. The most common industrial technology for CO_2 capture from gas streams is amine-based absorption. However, it is limited to low temperature (40–150 °C) applications [8], requires significant cost and high energy for regeneration [9,10], is susceptible to equipment corrosion and may produce a hazardous waste stream [11]. Although microporous and mesoporous materials like activated carbon, zeolite, and carbon fibre can also capture CO_2 at low temperatures, they are ineffective above 300 °C [12,13]. This limits their applications in processes like gasification for syngas/hydrogen production, where the effluent gases can be more than 500 °C. The use of activated carbon and zeolite, in that case, may require cooling and additional costs. This limitation of application at high temperatures can be solved with the use of alkaline metal-based sorbents for CO_2 capture. Hydrotalcite-like compounds (HTLC) can also be used for CO_2 sorption. Nonetheless,

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https://doi.org/10.1016/j.jcou.2017.11.012
Received 18 July 2017; Received in revised form 21 November 2017; Accepted 27 November 2017
Available online 06 December 2017
2212-9820/