Applied Energy 203 (2017) 412–421

Contents lists available at ScienceDirect

Applied Energy

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

CO_2 capture performance of a novel synthetic CaO/sepiolite sorbent at calcium looping conditions

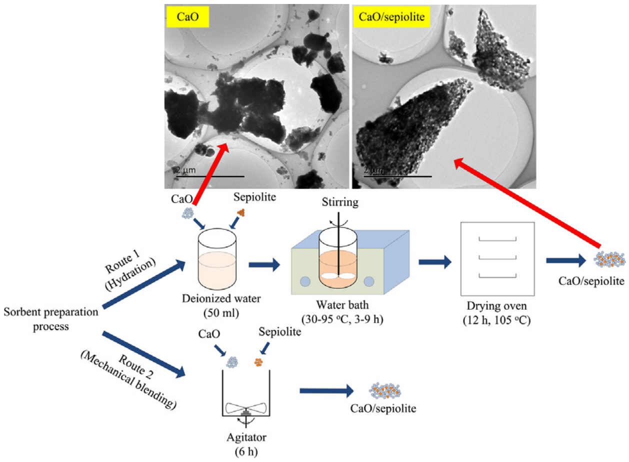
Jiewen Shi[a], Yingjie Li[a,*], Qing Zhang[a], Xiaotong Ma[a], Lunbo Duan[b], Xingang Zhou[c]

[a] School of Energy and Power Engineering, Shandong University, Jinan 250061, China
[b] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, Southeast University, Nanjing 210096, China
[c] State Grid Shandong Electric Power Research Institute, Jinan 250002, China

HIGHLIGHTS

- A novel synthetic sorbent was fabricated from CaO and sepiolite by hydration.
- Hydration temperature has an important effect on CO_2 capture by CaO/sepiolite.
- MgO and Ca_2SiO_4 are formed in calcined CaO/sepiolite for hydration at 95 °C.
- MgO and Ca_2SiO_4 improve sintering resistance of CaO/sepiolite during cycles.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 March 2017
Received in revised form 30 May 2017
Accepted 15 June 2017

Keywords:
Sepiolite
CaO
Hydration
Calcium looping
CO_2 capture

ABSTRACT

A novel synthetic sorbent was fabricated from CaO and sepiolite by the hydration and its CO_2 capture performance was investigated during the calcium looping cycles. The effects of the sorbent preparation conditions including preparation method, hydration temperature, hydration duration and sepiolite content on CO_2 capture by synthetic CaO/sepiolite sorbent were examined in a dual fixed-bed reactor. The results showed that CaO/sepiolite possesses higher CO_2 capture capacity than original CaO. CO_2 capture capacity of CaO/sepiolite after 10 cycles is 39% and 56% higher than those of hydrated CaO and original CaO, respectively. The hydration temperature has an important effect on CO_2 capture by CaO/sepiolite during the preparation. When the hydration temperature is 95 °C, the obtained CaO/sepiolite exhibits the highest cyclic CO_2 capture capacity, because the good supports such as MgO and Ca_2SiO_4 are formed in the calcined CaO/sepiolite at 95 °C, which can improve the sintering resistance of CaO during the cycles. However, these supports are not found in the calcined CaO/sepiolite at the other hydration temperatures. In addition, CaO/sepiolite possesses more porous structure, larger surface area and pore volume, compared to hydrated CaO and original CaO. After the 1st calcination, the volume of pores in 10–100 nm in diameter of CaO/sepiolite is much higher than those of hydrated CaO and original CaO, respectively, which facilitates CO_2 capture of the sorbent. CaO/sepiolite appears promising as an effective and low-cost CO_2 sorbent at calcium looping conditions.

---

* Corresponding author.
E-mail address: liyj@sdu.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.apenergy.2017.06.050
0306-2619/

1. Introduction

Worldwide, 30 billion tons of CO_2 are emitted into the atmosphere annually, with 40% from the coal-fired power plants [1]. Currently, as one of the most effective ways to solve the issue of lots of CO_2 emission from the coal-fired power plant, carbon capture and storage (CCS) has been adopted by the Intergovernmental Panel on Climate Change of the United Nation (IPCC) as the most crucial technological exploration to realize the goal of reducing the emission of greenhouse gases by 2050 [2–6]. Calcium looping, that is, the calcination/carbonation looping of calcium-based sorbent is considered to be one of the most potential CO_2 capture technologies for the industrial application [7–9]. It is reported that CO_2 capture capacities of calcium-based sorbents decrease gradually with the number of calcination/carbonation cycles due to the sintering of the sorbents [10–12]. Thus, the recent research has been laid on how to improve cyclic CO_2 capture performances of the calcium-based sorbents and enhance its sintering resistance [13–16].

Some methods have been used to improve CO_2 capture capacities of calcium-based sorbents, such as use of organic acids for the modification of sorbent [17,18], use of inert materials with high sintering resistance as supports of CaO [19–22], use of additives [14,23–25], pelletization [26], thermal pretreatment [27], discontinuously adding HCl in the carbonation step [28], prolonged carbonation [29] and hydration treatment [30,31], etc. Among these methods, adding the inert material as supports in calcium-based sorbent is an efficient method, producing the high-active synthetic sorbents with large surface area, high porosity and high sintering resistance. Al_2O_3 [32], ZrO_2 [19], CeO_2 [33], MgO [20,34–36], Y_2O_3 [37], MnO_2 [35,38], TiO_2 [39], CuO [40] and Nd_2O_3 [41] can be used as good supports. It should be noted that the preparation of the synthetic sorbents increases the cost. A compromise should be made between improving the sorbent performance and increasing its cost [8]. Chen et al. [42] used attapulgite as a support for calcined limestone, the carbonation conversion of the obtained synthetic sorbent contained 15 wt.% attapulgite after 20 cycles was 128% higher than that of the calcined limestone. Wang et al. [43] used the acid-leaching of metakaolin as a support to prepare the synthetic $CaO/Ca_{12}Al_{14}O_{33}$ sorbent and they found that under the severe calcination conditions (calcination at 950 °C under 100% CO_2), the carbonation conversion of the synthetic sorbent was 4 times as high as that of untreated CaO after 25 cycles. Li et al. [44] fabricated the synthetic sorbent with rice husk ash and CaO by hydration during the specific preparation process (hydration duration of 8 h, hydration temperature of 75 °C and SiO_2/CaO molar ratio of 1.0) and they found the maximum CO_2 capture capacity was 0.45 g/g after 20 cycles, which was twice as high as that of original CaO. Manovic et al. [45] prepared $CaO/Ca_{12}Al_{14}O_{33}$ sorbent by the calcium aluminate cement and CaO under 900 °C and the formation of $Ca_{12}Al_{14}O_{33}$ improved the sintering resistance the sorbent during long-term cycles. Chen et al. [46] produced a novel synthetic sorbent using fly ash and calcined limestone by hydration method, which exhibited higher CO_2 capture capacity than that of calcined limestone due to the formation of supports such as $CaSiO_3$ and $Ca_{12}Al_{14}O_{33}$ in the sorbent. Ma et al. [47] prepared the synthetic sorbent from carbide slag, aluminate cement and by-product of biodiesel by combustion method and they reported that the sorbent could achieve a CO_2 capture capacity of 0.62 g/g after 10 cycles, which was 2.2 times as high as that of carbide slag. Sanchez-Jimenez et al. [48] reported a synthetic sorbent fabricated from calcium nitrate and nanostructured silica by impregnation, which retained high CO_2 capture capacity during 50 cycles. Tian et al. [49] used steel slag and CaO by sol-gel method to prepare a synthetic sorbent and its CO_2 capture capacity was twice as high as that of CaO. Wang et al. [50] added 5 wt.% diatomite into limestone to produce a synthetic sorbent by mechanical mixing and they pointed out that after calcination under an air atmosphere at 1000 °C, Ca_2SiO_4 was generated in the synthetic sorbent, which improved CO_2 capture capacity and sintering resistance of the sorbent. Valverde et al. [51] and Wang et al. [34] both thought that MgO in the calcined dolomite provided the inert skeleton, which was a good support to improve the sintering resistance and maintain cyclic stability of the sorbent.

Sepiolite is a natural mineral clay, the price is about $43–110/t according to its quality [52], which has been widely applied in the building materials, cosmetics, mineral feed, catalysts, detergents and paper, etc. At present, the total reserves of sepiolite amounted to more than 8000 million tons in the world, which is widely distributed in Spain, China, United States, France, and so on [53–56]. As a clay mineral with a unit cell formula $Si_{12}Mg_8O_{30}(OH)_4(OH_2)_48H_2O$ [57,58], sepiolite contains a continuous two-dimensional tetrahedral sheet, however, it differs from other layer silicates in that they lack continuous octahedral sheets. Due to the structural morphology, the considerable attentions have been paid to sepiolite which is used as sorbent for organics, as support for catalysts, and so on [59,60]. For example, Liu et al. [61] used TiO_2 and CaO to prepare a new type of TiO_2/sepiolite composite to enhance the ability of photocatalytic elimination of formaldehyde by using the structural characteristics of sepiolite nanofibers, such as strong adsorption and high porosity. However, sepiolite as a support of CaO has never been reported in the calcium looping technology. Therefore, it is promising to use the structural morphology of sepiolite as a support to improve CO_2 capture performance.

In this work, a novel synthetic CO_2 sorbent was proposed, which was prepared from CaO and sepiolite by the hydration. CO_2 capture performance of the synthetic sorbent, i.e. CaO/sepiolite, was investigated at the calcium looping conditions. The effects of preparation method, hydration temperature, hydration duration and sepiolite content in CaO/sepiolite on the CO_2 capture by CaO/sepiolite were examined in a dual fixed-bed reactor. Also, the microstructures of the synthetic sorbent during the cycles were detected for better understanding its CO_2 capture performance.

2. Experimental

2.1. Preparation of sample

Calcium oxide (CaO ≥ 99.0% purity, size < 0.125 mm, Tianjin Kermel Chemical Reagent Co., Ltd., China) and sepiolite (sampled from Xiangtan in Hunan Province, China and sieved to size <0.125 mm) were used to prepare the synthetic sorbent. The chemical components of the sepiolite detected by X-ray fluorescence (XRF) are shown in Table 1.

To study the influence of different production methods on the CO_2 capture performance of the synthetic CaO/sepiolite sorbent, two preparation routes were adopted: the hydration and the mechanical blending, as presented in Fig. 1. The hydration rout is shown as follows: a certain amount of sepiolite and 1 g CaO were added to a beaker with 50 ml deionized water. The mixture was put into a thermostatic magnetic stirrer to stir for the different durations (1, 3, 6 and 9 h) under different hydration temperatures (30, 65 and 95 °C). The various sepiolite contents in CaO/sepiolite were specified as 5 wt.%, 8 wt.%, 10 wt.%, 12.5 wt.%, 15 wt.% and 20 wt.%, respectively. Then the beaker was placed in a drying oven for 12 h at 105 °C, and then the CaO/sepiolite sorbent by hydration was obtained. To examine the influence of sepiolite and hydration of CaO on the CO_2 capture behavior of the synthetic sorbent, the cyclic reaction performance of the hydrated CaO was also studied. The hydrated CaO was prepared according to route 1 as shown in Fig. 1, except for the addition of sepiolite.