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Experimental assessment on the solar energy storage by using chemical-looping combustion

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Abstract

This paper put forward a new method that using the perovskite–type oxide ($LaCu_xNi_{1-x}O_3$) as the solar thermal energy storage material which can drop the reduction temperature to below 500°C that parabolic-trough solar collectors could reach. Herein, $LaCu_xNi_{1-x}O_3$(x =0, 0.1, 0.2, 0.3, 0.5) is synthesized and investigated. Besides, the physical and chemical properties of $LaCu_xNi_{1-x}O_3$ are tested by XRD, SEM and BET, and the reactivity and generation are studied through experiments by means of thermogravimetric analyzer (TGA). Experimental results indicate that these five oxygen carriers are of high porosity and this porous structure benefits from doping by Cu at B-site when $LaCu_xNi_{1-x}O_3$ reacts with methane at 350°C, it exhibits great performance such as high reproducibility and good resistance for carbon formation. No obvious sintering is appeared after 30 times multiple redox cycles and $LaCu_{0.1}Ni_{0.9}O_3$ is able to be reoxidized to initial oxidation state.

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Keywords: Perovskite; solar energy; Chemical looping combustion

1. Introduction

Concentrating solar power (CSP) technology has been got rapid development after the energy crisis erupted in the 1970s; however, its intermittence has limited its development and application in the current. So more and more people pay attention on thermal energy storage (TES) technologies. The traditional thermal energy storage technologies include sensible heat storage, latent heat storage and thermochemical storage. Sensible heat TES technology has low volume specific heat capacity will lead to its large equipment for solar thermal energy storing and impede its further development [1]. Latent heat TES technology has large volume specific heat capacity, but has low heat conductivity of PCM [2]. While thermochemical TES involves an endothermic chemical reaction, its

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volume specific heat capacity is larger than sensible TES and latent TES. So the thermochemical TES is the most promising heat storage technology. But, the current chemical reactions used for energy storage generally work at high temperatures (≥800°C), this is a huge challenge for storage containers [3].

Researchers have pointed out [4] that the perovskite-type oxide has unique physical and chemical properties partly due to its structure features. Fernando et al. [5] investigate the performance of La-based perovskites oxides ($La_{1-x}Sr_xMO_{3-y}$ with M=Fe/Co) for reacting with methane. $La_{1-x}Sr_xMO_{3-y}$ synthesized by combustion method and doped by Sr at A-site prevents methane decomposition in CLC process, reported by He and Zhao [6]. Meanwhile this carrier exhibits a high regenerability. However the reduction temperature is 900°C and is too high for using trough-based solar energy.

Based on the superiorities of perovskite-type oxides, this paper intends to study the performance of $LaCu_xNi_{1-x}O_3$(x =0.1, 0.2, 0.3, 0.5) as oxygen carriers for hybrid solar chemical-looping combustion (HS-CLC) with methane at low temperature. The perovskite oxides are prepared via combustion method. To evaluate the properties of these materials, the micro morphology is observed by means of SEM. The specific surface area is measured by BET techniques. And the crystalline phase is identified by XRD. In addition, the temperature –programmed reduction (TPR) experiments are operated to evaluate the react activities on thermogravimetric analyzer. More importantly, the isothermal experiments in which novel oxygen carriers react with methane under low temperature (350°C) are investigated in TGA to reveal the reactivity and regeneration of oxygen carriers.

2. Experimental

2.1 Synthesis of perovskite-type oxides

Perovskite-type oxides were prepared by combustion method. The nitrates and glycine were weighed at a desired stoichiometric ratio and put into a beaker. Deionized water was added to make an aqueous solution. The baker was put on the magnetic stirrer with continuous stirring at 70~80°C to form precursor. The precursor was dried in the air blowing thermostatic oven overnight. Finally, the precursor was calcined 1h under 750°C and then heated to 900°C for 6h.

2.2 Reactivity tests

The capability of all the prepared powders to reversibly deliver and pick up oxygen is tested by successive reduction-oxidation steps in the thermogravimetric experiment which was produced by SHIMADZU corporation. In the reaction process, all gas flow is 20ml/min and the temperature rise rate is 5°C/min.

3. Results and discussion

3.1 Characterization of the oxygen carrier

3.1.1 XRD

The structure of fresh perovskite-type oxides $LaCu_xNi_{1-x}O_3$(x=0, 0.1, 0.2, 0.3, 0.5) are examined by XRD to identify the crystalline phase formed, as shown in Fig 1. From the XRD patterns of five fresh oxides the nine characteristic peaks of perovskite oxides in the range of 20° to 80° can be found, which confirms the formation of the desired monophase crystalline perovskite phases. Compared with $LaNiO_3$, no impurities are identified in the XRD patterns of $LaCu_xNi_{1-x}O_3$, indicating that the second metal Cu is in all cases incorporated in the perovskite structure. By comparing the intensity of the XRD pattern can be found the peak intensity of $LaCu_{0.1}Ni_{0.9}O_3$ is the strongest. With the increase of Cu doping amount, the peak intensity weaken. Since peak intensity shows the crystallinity, the crystallinity of $LaCu_{0.1}Ni_{0.9}O_3$ is the highest.