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Progress in enhancement of CO_2 absorption by nanofluids: A mini review of mechanisms and current status

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ABSTRACT

Nanotechnology is a new technique which is widely applied in several energy systems. The novel process of CO_2 absorption or conversion enhancement using nanofluids receives significant attention in recent decades. A comprehensive literature review on CO_2 absorption enhancement by nanofluids is here compiled. This present review covers the nanofluids preparation methods, enhancement mechanisms, and the enhancement factors of the gas-liquid system. The nanofluids parameters and fluid flow rates effects on the enhancement of CO_2 absorption are discussed and highlighted. Moreover, this review indicates that the CO_2-nanofluids system is a promising technique for gas pollution control. However, a lot of future works are needed to increase the absorption behavior and performance of the nanofluids as well as reduce the energy consumption during the capture process.

1. Introduction

A novel technology to decrease energy costs associated with CO_2 capture is to use external and renewable energy sources. Absorption is a widely used method for reducing CO_2 concentration in industrial applications and human activities. The solvents are the main factor to the evaluation of the CO_2 absorption performance [1–4]. Using nanofluids as the solvents for CO_2 capture could greatly improve the absorption rate of CO_2 and then reduce the energy consumption issues [5]. For instance, CO_2 capture and sequestration (CCS) recovery by the gas hydrate formation process using nanographene oxide (NGO) nanofluids is a good way to decrease the energy and cost consumptions [6].

Choi was first to propose the concept of nanofluids which are novel materials and dispersed nanometer-sized (1–100 nm) materials (including nanofibers, nanoparticles, nanorods, nanosheet, nanowires, nanotubes, or droplets) into the base fluid (water soluble or non-water soluble liquids) [7]. Fig. 1 visually compares the different examples of micrometer, millimeter, and nanometer [8]. The nanoparticles could be oxide, metallic, non-metallic, ceramics, mixture of various nanoparticles (hybrid nanoparticles) and even nanoscale liquid droplets [9–11]. They are advantageous in enhanced thermal diffusivity and conductivity, viscosity, and convective heat transfer coefficient in comparison with base fluids. Meanwhile, they have a greater specific surface area between the fluids and the particles in nanoscale [12]. Even adding a small amount of nanoparticles in the solutions could significantly improve the thermal efficiency, stability, and mass and heat transfer efficiency [13]. Thus, it is no surprise that the use of nanofluids is getting much more attention among academics and engineers for developing advanced systems.

In the 1960s and 1970s, some works [14–16] have reported the gas absorption by slurries containing fine particles, which indicated

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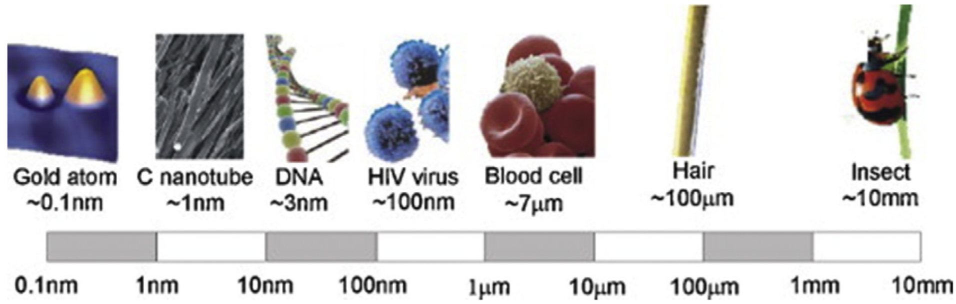

Fig. 1. Examples of different length scales. Reproduced with permission from Ref. [8].

that this technique showed a great potential in gas removal fields such as SO_2, O_2, etc. After the definition of nanoparticles in the 1990s, a lot of researchers [17–22] started to employ nanoparticles into the CO_2 absorption process. Park and Lee [17] examined the CO_2 absorption characteristics using aqueous colloidal SiO_2 with diethanolamine (DEA) solutions inside a flat-stirred vessel. The Korean team has also studied various types of nanofluids for CO_2 absorption such as Fe [23], SiO_2 [19,24], Al_2O_3 [24], carbon nanotube (CNT) [23,25], etc. The nanoparticles either metallic or non-metallic have been widely employed in the experimental and theoretical studies [26,27].

Although there are some review papers published in the heat and mass transfer of nanofluids in the advanced energy systems [28–33], the area of gas absorption using nanofluids has not been reviewed yet. The aim of this review paper is to summarize the very recent work related to CO_2 absorption enhancement by nanofluids, and introduce the fundamentals and enhancement factors in the CO_2 absorption process in details. In this paper, the preparation methods of nanofluids is first discussed including one step, two steps, and other technologies. Then, the existing enhancement mechanisms of the membrane enhancement process are studied and compared in details. Furthermore, the effects of different influence factors on the CO_2 absorption enhancements are illustrated. Finally, the concluding remarks and future directions for nanotechnology applications in CO_2 absorption are given.

2. Preparation of nanofluids

Nanoparticles play a crucial role in the enhancement of the nanofluids properties. Generally, there are different methods for the preparation of nanofluids which are described in the following sub sections [34–36].

2.1. One step method

One step method (single-step method) is direct evaporation and condensation of the nanoparticles in the base solutions at one time [37]. VEROS (vacuum evaporation to a running oil substrate) approach is a main one step method for nanofluids preparation. It provides high purity, and good dispersion and suspension behaviors. Choi [38] prepared Cu–H_2O nanofluids using an improved low-pressure gas evaporation method (see Fig. 2) and the average nanoparticle size was around 10 nm. As depicted in this figure, the solid material is first heated and evaporated inside a low-pressure container, and then the vapor of the raw material is cooled down by the swirling liquid film and settled in the base fluid. This method is mainly used for preparing metal nanofluids. Zhu et al. [39] proposed an efficient one-step chemical approach for preparing Cu nanofluids in ethylene glycol from reaction under microwave irradiation. This method showed a great potential in other metallic

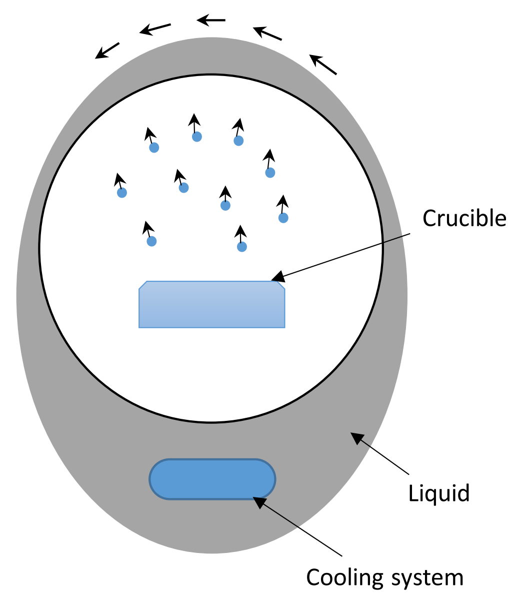

Fig. 2. Schematic of nanofluids preparation using a low-pressure gas evaporation method.

nanofluids synthesis. Sahu et al. [40] used an innovative micro-electrical discharge machining (μ-EDM) approach to synthesize Cu nanofluids, and a novel ultrasound technology for measuring the concentration of the nanofluids.

The submerged arc nanoparticle synthesis system (SANSS) is another effective method for the process of suspension nanoparticles preparation. As shown in Fig. 3, the system includes a pressure unit, a cooling unit, a control unit, an isothermal unit and a heating source [41]. Lo et al. [42] successfully employed this technique for fabrication and characterization of Ag nanofluids and the mean particle size was around 12.5 nm. They also made CuO nanoparticles with a mean secondary particle size of 49.1 nm [43] and Ni nanoparticles with a 10 nm average particle size [44]. Some researchers [45,46] used the improved submerged arc methods to produce more stable nanofluids.

Moreover, the laser ablation technique is also applied for preparing nanofluids [47–49]. Ag nanoparticles synthesized by this technology in 4 g poly vinyl alcohol (PVA) solutions (3.99 nm) had a smaller mean particle size than those synthesized in deionized water (9.99 nm) [47]. Gold (Au) nanoparticles were obtained by a new technology of pulsed laser ablation in liquids (PLAL). This method provides references for nanofluids preparation directed at the applications of solar energy [49]. Other one step approaches adopted for nanofluids preparation are plasma discharging method [50] and microwave irradiation [51].