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Experimental investigation on enhancement of ammonia–water falling film generation by adding carbon black nanoparticles

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ABSTRACT

This paper presents a falling film generating apparatus for testing the ammonia vapor generation amount and the generation rate with or without carbon black (CB) nanoparticles. The comparative experiments were based on influence of the concentrations of nanoparticles, surfactant, ammonia–water and hot water temperature. The results show that the ammonia vapor amount can be directly obtained through the test bench. The generation rate of ammonia vapor can be improved by adding the matched mass fraction of carbon black (CB) and proper volume fraction of emulsifier OP-10. For the base solution of ammonia whose mass fraction ranges from 25% to 40%, the effective generation ratio can be increased by 50% by adding 0.1% mass fraction of CB and 0.1% volume fraction of OP-10. However, only adding the dispersant OP-10 dispersants will produce a certain inhibitory effect on generating ammonia vapor. In order to achieve optimal results, the dispersion stability and whether it can play a positive effect should be taken into account. Combining with the absorption enhancement effect, we know that nanoparticles have great effects on absorption and generation process in ammonia–water absorption refrigeration systems (AARS). Therefore, adding nanoparticles with optimal dispersion stability into ammonia–water to enhance the COP of AARS should have a more promising future for their commercial application.

1. Introduction

With the gradual deterioration of environment and climate, low-carbon economy and sustainable development have become inevitable choices for the future development of human society. Energy conservation, emission reduction and consumption reduction have reached an unprecedented strategic height to human beings. It is an indisputable fact that parts of CFCs refrigerants damage the atmospheric ozone layer and contribute to the greenhouse effect. In 2011, the appearance of Arctic ozone hole alarmed those who use the Freon refrigerants once again. When looking for the alternative refrigerants, ammonia–water re-attracted people's attention for its environment acceptability. The ammonia–water absorption refrigeration system (AARS) has many advantages such as the comprehensive utilization of waste heat, indirect control of environment pollution and no damage to the atmospheric ozone layer. Although there are a lot of studies and improvements on absorption [1], condensation [2] and rectification [3] process in AARS, it has many obvious disadvantages, for example, low thermal coefficient, big scale of equipment, inconvenience on applications. Therefore, improving its COP and miniaturizing the device are two research topics for promoting absorption refrigeration technology.

In 1995, Choi [4] proposed a new concept-nanofluid, nanofluid technology has achieved intense research in the field of engineering thermal physics. The results show that: (1) The viscosity of nanofluids will increase [5]. (2) The effective thermal conductivity of nanofluids will increase [6]. (3) The convective heat transfer coefficient of nanofluids will increase [7]. (4) Mass diffusion coefficient of nanofluids will increase [8,9]. As a result, the rapid development of nanofluids brings vitality to the study of AARS.

Application of nanofluids to AARS is mainly on enhancing absorption process, including the falling film absorption and bubble absorption. In 2007, Kim and Jung [10,11] carried out the bubble absorption experiment by adding Cu and CuO nanoparticles and surfactants into ammonia solution. They found that the absorption rate can be increased to 3.21 times when adding nanoparticles only; While adding nanoparticles and surface active agent at the same time, it can be increased to 5.32 times. However, as we know, both Cu and CuO nanoparticles will react with ammonia to generate the copper ammine ions. Therefore, Cu and CuO nanoparticles are hard to stably exist in ammonia water for a long time, so it is unfit for being applied to AARS. Kang et al. [12], in

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Nomenclature

b	systematic uncertainty
i	generation rate (g s^{-1})
k	thermal conductivity (W m^{-1} K^{-1})
m	mass (g)
N	a number of samples
s	combination of a precision uncertainty
S	sample standard deviation
U	uncertainty

Greek symbols

τ	effective falling film time (s)
ω	fraction (%)

Subscripts

g	ammonia gas
fin	finish(dilute solution mass after generation)
ini	initial(concentrated solution mass before generation)
eff	effective
na	nanofluid
bf	base fluid (ammonia–water solution)
s	surfactant
vol	volume

2007, added carbon nanotubes in the ammonia water for bubble absorption experiment. According to the results, when adding 0.001 wt% of carbon nanotubes, the heat transfer and mass transfer efficiency increased by 20% and 29.4%, respectively. Su and Ma [13] modified the surface of carbon nanotubes and then prepared ammonia nanofluids without the usage of dispersants. They used the ammonia water nanofluid to carry out the bubble absorption experiment, and found that the absorption rate increased first then decreased with the nanoparticles mass concentration increased, and the absorption rate also decreased with the increase of the initial ammonia concentration. Du, Yang et al. [14] made out a stable and dispersive ammonia–water nanofluid, and applied it in the falling film absorption process experiments, founding that, for the 15% mass fraction ammonia–water with 0.1% of SDBS dispersant, the absorption ratio can reach the maximum 1.50 and 1.70, respectively, by adding Fe_2O_3 and $ZnFe_2O_4$.

In summary, the absorption process in AARS in which nanoparticles are applied has been preliminary researched and has achieved a relatively good effect on enhancing the heat and mass transfer coefficient. However, there are few literatures on falling film generation process of ammonia–water with nanoparticles. Meanwhile, many studies reported that the nanoparticles in the boiling heat transfer showed enhanced [15–17] or worsened [18–20] results, but in the flow boiling heat transfer showed excellent characteristics in enhancing the generation process [21,22]. Hence, further experiments are needed to be conducted to demonstrate whether nanoparticles will enhance the generation process in AARS.

Therefore, this paper proposes an ammonia–water falling film generation experimental equipment. Then, a series of comparative experiments have been conducted to study the generation process between ammonia–water and ammonia–water with nanoparticles under different working conditions, namely different nanoparticle concentrations, different dispersant concentrations, different ammonia concentrations as well as different heat source temperatures. The influence factors on the efficiency of ammonia–water generation are studied in detail.

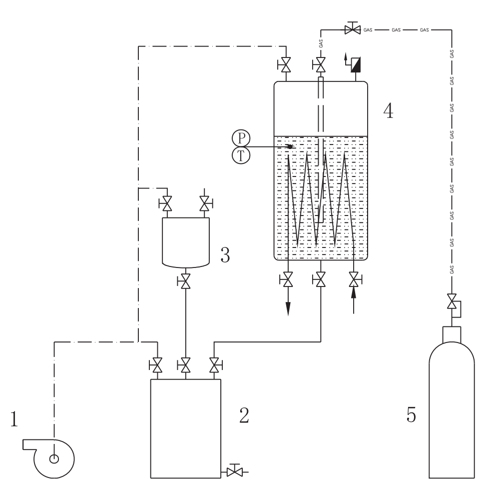
2. Preparation of ammonia–water nanofluid

According to our previous work [23], carbon black(CB) was adopted in the experiments as the testing nanoparticle. CB nanoparticles were produced by oil furnace method with ethylene tar as the raw material. Their size was around 20 nm. Surfactant was OP emulsion(OP-10).

Preparation of high concentration ammonia water solution was conducted in the bubble absorber in our laboratory. The bubble absorber is shown in Fig. 1. The shell of the bubble absorber was made of plexiglass, and the pressure allowed is 0.5 MPa. A stainless steel tube was connected to the bubble absorber with an ammonia vessel. The whole system needs evacuation before the bubble absorption process. During the absorption process, the absorption heat was taken away by the cooling water in cooling coil in time which was installed inside the absorber. The concentration of the ammonia–water solution was obtained by the measured temperature and pressure of the bubbled solution in the stable state, using the property of the saturated solution ammonia water. Therefore, by controlling the internal pressure in bubble absorber, the required high concentration of saturated ammonia water solution could be achieved.

The process for preparing stable high concentration of ammonia–water nanofluid is shown in Fig. 2.

In order to achieve uniform and dispersed ammonia solution, the active agent was added for the surface modification, at the same time, we used the physical method of ultrasonic and mechanical stirring to disperse nanoparticles. Nanofluids were prepared with the optimization method [24]. After two hours of mechanical agitation and 30 min of ultrasonic vibration on the mixing solution, sequentially the stable nanoparticle suspension of ammonia–water nanofluid solution is obtained. After 1 h's standing, when the bubbles were generated by the agitation of



1-vacuum pump; 2-preparation solution container; 3-water-based accumulator; 4-bubble absorber; 5-ammonia vessel.

Fig. 1. Schematic diagram of the experimental system for mixing NH_3/H_2O and nanoparticles bubbling absorber.