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Review on absorption enhancement of aqua ammonia systems

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ABSTRACT

This paper reviews the absorption enhancement of the aqua ammonia systems by various technologies like mechanical treatment, chemical treatment and nanotechnology. By using mechanical enhancement we can reduce size of the absorber by 48.7%, by using chemical treatment the absolute absorption can be increase by 8% than pure water. And the nano-solution is more effective than pure solution. However, the combined treatment with both surfactant and nanoparticles is recommended to improve the absorption performance for practical applications.

Introduction

The absorption refrigeration using binary mixture ammonia and water is considered as an alternative to the Vapour compression refrigeration systems which causes the environmental problems like ozone layer depletion and global warming[1,4,6].The absorber is the most critical component in the absorption refrigeration system in which both heat transfer and mass transfer occurs simultaneously[3,8].

Types of Enhancement

Mechanical Treatment

In the ammonia-water absorption systems, falling film heat transfer and bubble type heat transfer have been recommended to enhance heat and mass transfer performances. Thin falling film heat transfer mode provides relatively high heat transfer coefficients and is stable during operation. However, falling film heat transfer modes have wettability problems and need good liquid distributors at the inlet of the liquid flow. Bubble type heat transfer provides not only high heat transfer coefficients but also good wettability and mixing between the liquid and the Vapour. However, bubble type heat transfer does not require Vapour distribution rather than liquid distribution. Generally, Vapour distribution is easier to accomplish than liquid distribution [2].

Figure 1. shows the profile of the total absorption rate for the falling film and bubble modes. The local absorption rate increases gradually in the falling film mode, which is due to the mass transfer resistance is dominant within the effective mass transfer region in the liquid flow while both heat and mass transfer resistances are considerable in the Vapour flow. For the bubble mode, however the local absorption rate is the highest near the vapour inlet, decreases suddenly at the length of 5.0 cm, and increases again gradually along the length. The local absorption rate of the bubble mode is always higher than that of falling film mode. This is mainly due to the larger mass transfer area, a better mixing between liquid and Vapour and the higher heat transfer coefficients from the bubble mode than those from the bubble mode than those from the falling film mode. Due to this reasons the bubble absorption mode has about 48.7% smaller size of heat exchanger than the falling film mode.

Table 1. Characteristics of the falling film and bubble modes [2]

Heat Transfer Mode	Falling Film Mode	Bubble Mode
Configuration	Horizontal tube bundle vertical tubes	Packed type plate HX
Interfacial area	Small	Large
Heat transfer area	~Interfacial area	Smaller than interfacial area
Mixing	Poor	Excellent
Wettability	Critical	Excellent
Liquid Distributor	Yes	No
Vapour Distributor	No	Yes
Flooding	Yes for counter, No for concurrent	Yes
Heat and mass transfer	Liquid and Vapour	Liquid and Vapour
Compactness	Good	Excellent

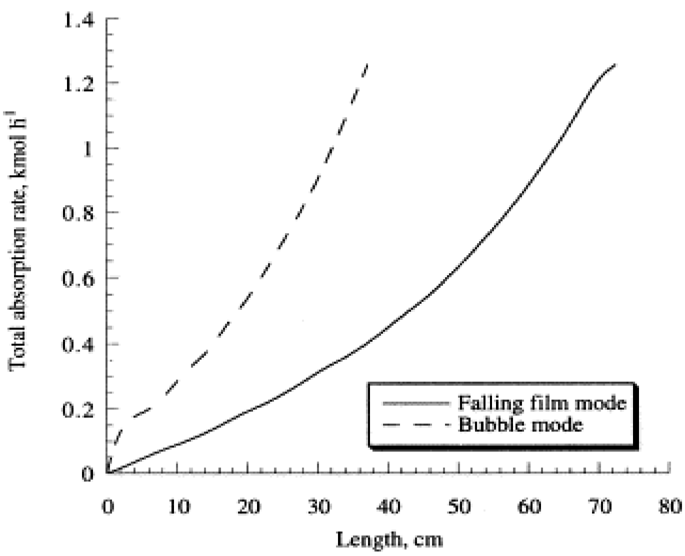

Figure 1. Total absorption rate profile for falling film and bubble modes [2]

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Chemical Treatment

The chemical treatment methods are the addition of surface active agents into the working fluids. In the falling film type absorber, the surface tension of the working fluids with surfactants is reduced significantly, so their wettability which influences the heat and mass transfer performance can increase. Moreover, the addition of surfactant causes the interfacial turbulence, which lead to a higher heat and mass transfer performance. This interfacial turbulence is induced by the gradient of surface tension, which is called Marangoni convection [6].

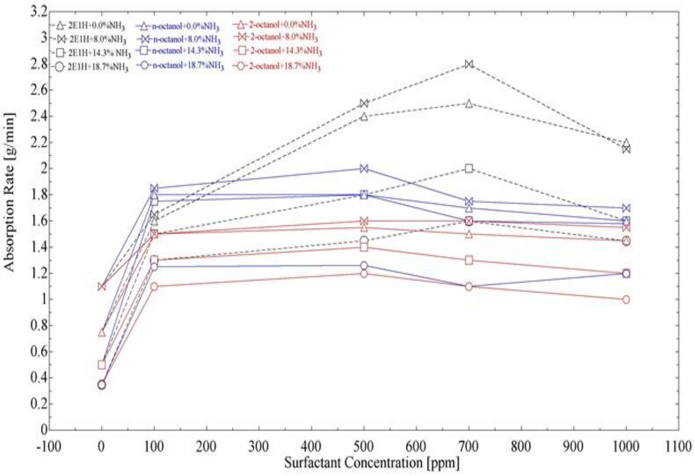

Figure 2. Absorption rates with Surfactants [3,6]

Figure 2 shows the absorption rates with respect to surfactants concentration for 2-ethyl-1hexanol (2E1H), n-octanol and 2-ctanol. The absorption rates with all considered surfactants are higher than those without any surfactant. In case without any surfactants, the absorption rate decreases with increasing ammonia concentration of initial solution. This is because the absorption potential due to variation of Vapour pressure of ammonia solution with surfactant. That is, the effect of surfactant for 8.0% solution than that for pure water.

Figure 3 and 4 shows the bubble behavior for the 8.0% ammonia solution without any surfactants, and with 2E1H 700ppm. The bubble size with surfactant is larger than that without any surfactants. The next bubble strongly affects the behavior of former bubble in the case with surfactants.

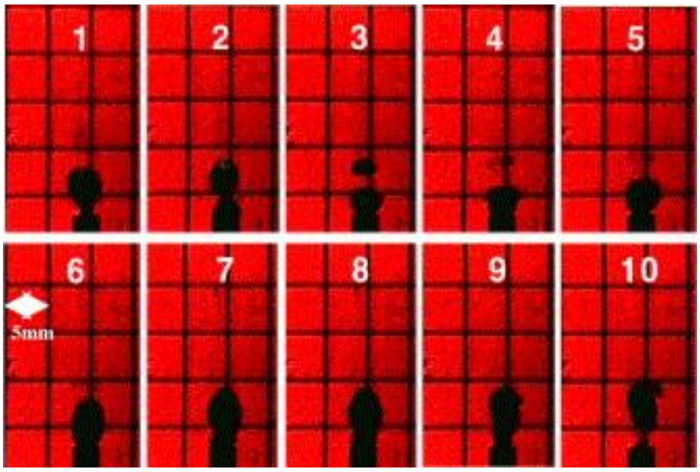

Figure 3. Bubble behavior without surfactants [6].

Nanotechnology

Nanofluid is defined as solid/liquid mixture where Nano sized particles of which diameter are under 100 nm are stably suspended in the base fluid. The binary nanofluid is defined as the nanofluid in which the base fluid is a binary mixture such as ammonia/water. It cannot only solve the problems such as sedimentation, cohesion and corrosion which happen conventionally in heterogeneous solid/ liquid mixture with millimeter or micrometer particles, but also increase the thermal performance of base fluids remarkably [1,3,4,5,8,9].

Synthesis of Nanofluids

Generally two major methods are used for the production of nanofluids

Single step technique: Nanoparticles manufacturing and nanofluid preparation are done in this method. the drying, storage, transportation and dispersion of nanoparticles is avoided. Thus the agglomeration of nanoparticles is minimized and the stability of the nanoparticles is increased. This method is used for the production of nanofluids in large scale [9].

Two step technique: Dry nanoparticles are first produced, and then they are dispersed in a suitable liquid host. But as nanoparticles have a high surface energy, aggregation and clustering are unavoidable and will appear easily. Afterward, the particles will clog and sediment at the bottom of the container. Generally, ultrasonic equipment is used to intensively disperse the particles and to reduce the agglomeration of nanoparticles. In addition chemical surfactants are mostly used to improve the stability of the nanofluids [1,3,4,5,8,9,10].

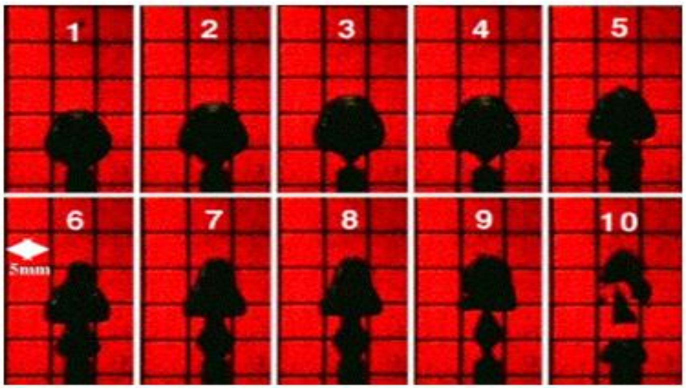

Figure 4. Bubble behavior with 700ppm 2E1H [6].

Mass transfer in nanofluids

Bubble type absorption system: Fig. 5. shows the schematic diagram of bubble absorption equipment. The absorber is connected with a tee valve. The ammonia Vapour is discharged to the water in a tank through the tee valve when its flow rate is adjusted, the tee valve is switched and the ammonia Vapour enters the absorber through the orifice at the bottom of the absorber. The flow rate of the ammonia Vapour is measured by the gas flow meter. The electronic balance is used to measure the mass of this system before and after the absorption.

Falling film absorption system: Fig. 6. shows the schematic diagram of the falling film absorption setup. it contains mainly NH_3 vessel, container of solution, falling film absorber, constant flow controller and sub-system of cooling water. The material used for the cover and body are transparent to visible the absorption process. The thermocouples and pressure transmitter are controlled by a real time data acquisition system. And to weigh the initial and final mass of this system a highly accurate electronic balance is used.

Data Reduction

By measuring absorption time and mass of the test section, the absorption rate can be easily calculated as follows

$$m_{abs} = \frac{m_{fin} - m_{ini}}{t_{abs}} \qquad (1)$$

When nanoparticle or surfactants are added to the solution, the ammonia absorption rate may be changed. In order to analyze the effect on absorption rate, the effective absorption ratio is defined as

$$R_{eff,abs} = \frac{m_{abs,bn}}{m_{abs,bf}} \quad (2)$$

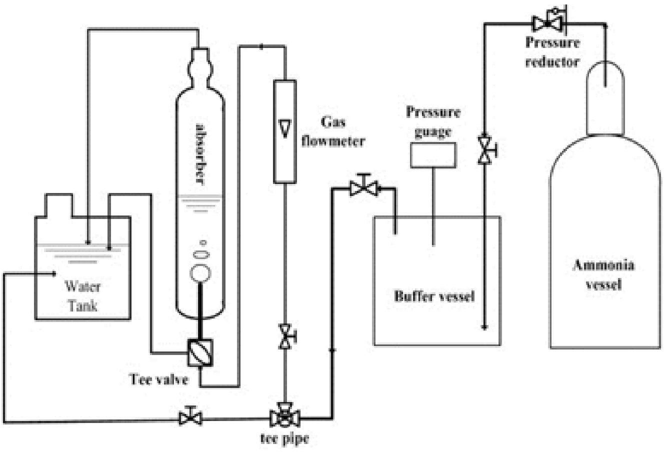

Figure 5. Experimental setup for bubble absorption [8]

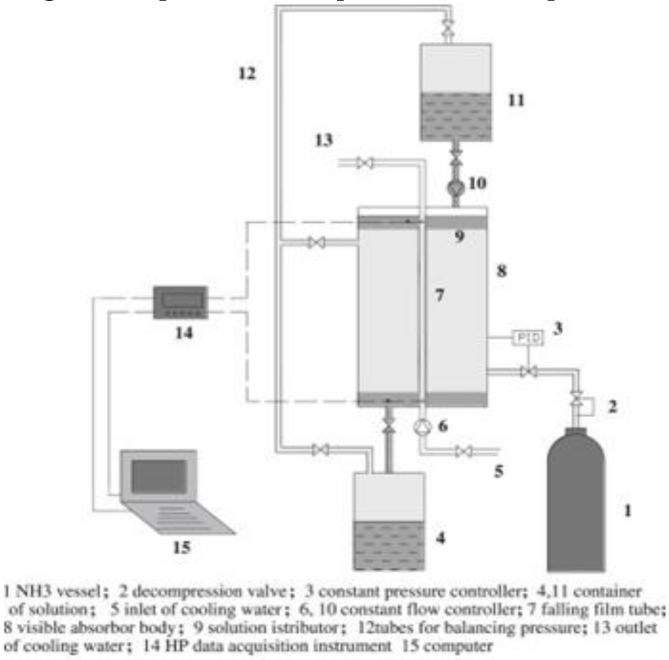

Figure 6. Experimental setup for falling film absorption [5]

The physical meaning of the effective ratio is the effectiveness of the binary nanofluid for absorption enhancement. If Reff,abs is larger than 1.0 it can be said that the binary nanofluid enhances the absorption performance [3].

Kim et. al [3] studied the absorption enhancement of ammonia-water with chemical and nanoparticles. He used Cu, CuO and Al_2O_3 nanoparticles and 2E1H, n-octanol and 2-octanol as chemical surfactants. He got 700ppm 2E1H enhanced the absorption rate to 4.8 times than without surfactants. For binary nanofluid with 0.1 wt% Cu nano-particle, the absorption rate enhanced to 3.21 times. Furthermore, the absorption rate with both 2E1H and Cu nano-particle is improved to 5.32 times.

Pang et. al [7] used the mono silver particle is use to enhance the absorption rate of the Ammonia-water mixture. And from his experiment clearly implied that the mass transfer during Ammonia-water bubble absorption process is always enhanced, and it increases more when the coolant is applied to the process.

Lee et. al [4] is studied the effect of CNT and Al_2O_3 particles on NH_3 /H_2O performance. He used the concentration and constituents as the key parameters. He concluded that the absorption rate of the 0.02 vol% CNT is 16% higher than those without nanopartices. And for 0.02 vol% Al2O3 is 18% higher than those without nanoparticles.

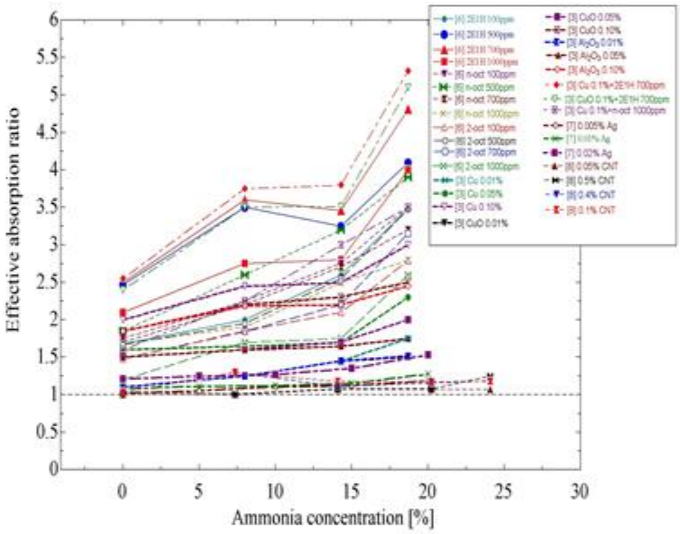

Figure 7. Effective absorption ratio in Bubble type absorption

Xuehu Ma et. al [8] investigated the bubble absorption performance of the CNTs- ammonia binary nanofluid experimentally. The experiment result shows that effective absorption for 0.4 wt% CNT have 1.8 times higher than those without nanoparticles at 25 wt% ammonia concentration.

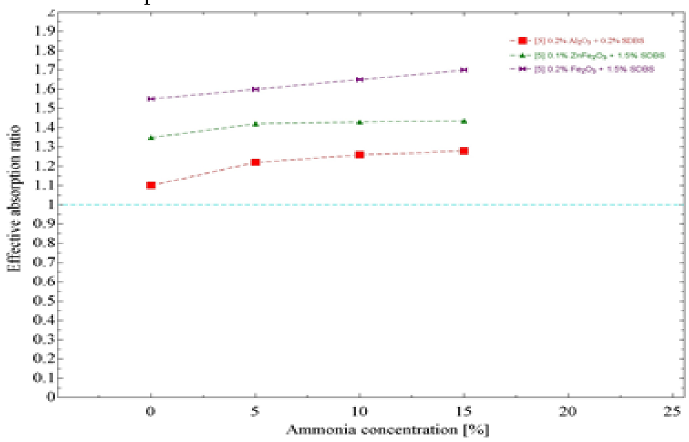

Figure 8. Effective absorption ratio in falling film type absorption.

Yang et. al [5] studied the enhancement of ammonia-water falling film absorption by adding Al_2O_3,Fe_2O_3 and $ZnFeO_4$ nanofluids. He used the SDBS as the surfactants. The effective absorption ratio can be increased by 70% and 50% with Fe_2O_3 and $ZnFe_2O_4$ nanofluid when the initial ammonia mass fraction is 15%.

Conclusion

The local absorption rate of the bubble mode is always higher than that of the falling film mode due to the larger mass transfer area, a better mixing and the higher heat transfer coefficients from the bubble mode. The bubble absorption mode has about 48.7% smaller size of heat exchanger than the falling film mode. The addition of surfactants enhances the absorption performance during the bubble absorption process. The maximum effective absorption ratio is 4.81 when 2E1H is added 700ppm to 18.7% ammonia solution. The effective absorption ratio increases with increasing initial ammonia concentration. It implies that the nanoparticles and surfactant have more significant effects on the mass transfer performance in the higher ammonia concentration ranges than that in the lower concentration ranges. The mass transfer enhancement by nanofluids is attributed to two main reasons, the enhanced heat transfer and gas bubble breaking. The absorption performance can be improved by adding either surfactants or nanoparticles. However, the combined treatment with both surfactant and nanoparticles is recommended to improve the absorption performance for practical applications.

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