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Visual experimental research on bubble absorption in a vertical tube with R124–DMAC working pair

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ABSTRACT

Visual experimental investigations were carried out on a vertical co-current glass tube absorber to observe the behavior of the R124 (2-chloro-l,l,l,2,-tetrafluoroethane)–DMAC (N′,N′-dimethylacetamide) bubble absorption process and study the effects of different operating conditions on absorption performance. The results show that the refrigerant vapor flow rate, absorption solution flow rate, concentration, temperature and nozzle orifice diameter significantly affect the flow pattern and absorption height. As the vapor flow rate, absorption solution concentration and temperature, and nozzle orifice diameter increases, the absorption height increases. As the absorption solution flow rate increase, the absorption height reduces. Under the conditions of a large refrigerant vapor flow rate, high solution inlet concentration and temperature, three kinds of flow pattern, namely churn, slug and bubbly flow, can be simultaneously observed in the absorption tube.

1. Introduction

Compression refrigeration systems are widely used in automotive refrigeration systems, which consume a large amount of fuel oil for automobile air conditioning. It was reported that automobile air conditioning systems consume about 10% of engine rated power and average fuel oil consumption increases about 18% when driving the automobile with air conditioning in operation [1]. In addition, the huge amount of waste heat needs to be ejected into environment from automotive engines. To recover high temperature waste heat from automotive engines, an absorption–compression hybrid refrigeration cycle (ACHRC) driven by exhaust gases and power from vehicle engines was proposed to reduce fuel oil consumption for automotive refrigeration systems [2]. The cycle comprises two sub-cycles. One is the absorption refrigeration sub-cycle (ARSC) driven by exhaust gases and the other is the compression refrigeration sub-cycle (CRSC) driven by power. Working pairs in the cycle is the mixture of R124 (2-chloro-l,l,l,2,-tetrafluor oethane) and DMAC (N′,N′-dimethylacetamide).

There are many specific technical requirements for the waste heat refrigeration system for automobile application, such as, the system should be compact and light and can either be installed separately or together to fit the narrow space of automobiles, the system should be cooled by air directly and the system should function normally whenever the vehicle runs under any standard road condition such as bumping, slanting, swinging, speeding up or slowing down. As a result, the absorber, a key equipment of the ACHRC, is specifically designed as an air-cooled vertical fin-tube bubble absorber that replaces the conventional fall-film absorber, which is showed in Fig. 1. Advantages of the bubble absorption allow it to be applied in special working conditions like automobiles and ships.

Up until now, research on bubble absorption in the absorption refrigeration field mainly focused on the ammonia–water absorption process. Ferreira et al. [3] performed experiments for ammonia–water absorption in a vertical bubble absorber both with and without heat removal. The model used to calculate simultaneous heat and mass transfer processes was developed, which can give a first indication about the methods for prediction of the absorption process. An interactive procedure to design vertical tubular bubble absorbers for ammonia–water absorption refrigeration systems was presented.

Kang et al. [4–6] analyzed a combined heat and mass transfer for an ammonia–water absorption process and evaluated the effects of heat and mass transfer areas on absorption rates for two different absorption modes, falling film and bubble, via the parametric analysis method. It was found from the study that the local absorption rate of the bubble mode was always higher than that of the falling film model leading to about 48.7% smaller size of the heat exchanger for the bubble mode compared to the falling film mode. They then set a visual experimental system to investigate bubble behaviors and the effect of key parameters on

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Nomenclature

ACHRC	absorption–compression hybrid refrigeration cycle
ARSC	absorption refrigeration sub-cycle
CRSC	compression refrigeration sub-cycle
DMAC	N′,N′-dimethylacetamide
DMETEG	Dimethylether tetraethyleneglycol
DMF	Dimethylformamide
HCFCs	hydrochlorofluorocarbons
HFCs	hydrofluorocarbons
t	temperature, °C

ammonia–water bubble absorption performance in pool. A correlation used to calculate the interfacial area in design of ammonia–water bubble absorber was presented. In following studies, they developed an experimental mass transfer correlation coefficient for ammonia–water bubble absorption.

Castro et al. [7] developed two type models, falling film and bubbly flow, of air-cooled ammonia–water absorber for air-conditioning and refrigeration in a mobile application taking advantage of exhaust gases of the engine. The parametric study results confirmed that the performance of the bubble absorber is better in both cases.

Lee et al. [8] performed an experimental analysis of ammonia–water bubble absorption in a plate-type absorber. The results were converted into dimensionless numbers to elucidate heat and mass transfer performance of ammonia–water bubble absorption. In following research, Lee et al. [9] performed both the numerical and experimental analyses in the bubble absorption process and estimated the region of vapor absorption by two analyses. It was found that the model simulation and experimental analyses yield similar results. The authors concluded that the given numerical model can be applied to design a bubble mode absorber.

Kim et al. [10,11] first investigated a counter-current ammonia–water absorber with slug flow in vertical tube and confirmed that the slug flow absorber operated well at significantly low solution flow rate conditions by experiment. The flow pattern of absorption process was observed by visual experiment and the local heat transfer rate was measured by varying the main parameters. A data reduction model for clarifying experimental results was then proposed to obtain the local heat and mass transfer coefficients on the liquid side. The result indicated that the local heat and mass transfer coefficients on the liquid side of the absorber are greatly influenced by flow patterns.

Fernández-Seara et al. [12] developed a mathematical model to explore ammonia–water absorption process in a vertical tubular absorber cooled by air. The churn, slug and bubbly flow pattern experimentally forecasted in this type of absorption processes were considered. The influence of design parameters and operating conditions on the absorber performance was investigated by numerical simulation. The noteworthy results were presented and commented on in the paper.

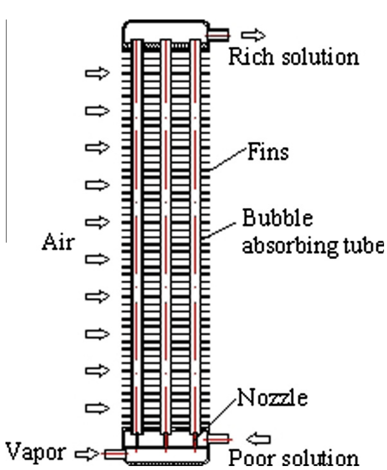

Fig. 1. Structure of the air cooling bubble absorber.

Cerezo et al. [13–15] first carried out an experiment to investigate the ammonia vapor bubble absorption process in a corrugated plate heat exchanger model NB51. The effect of the absorber operating conditions on the most significant efficiency parameters was analyzed. It was found from the research that solution and cooling flow rates positively affect the absorber performance with pressure increasing, but solution and cooling temperatures negatively affect the absorber performance with the concentration increasing. A mathematical model for ammonia–water bubble absorbers was then developed and compared with experimental data using a plate heat exchanger. A sensitivity analysis was also carried out on selected operation parameters on the absorber thermal load and mass absorption flux. The comparison between experimental and simulation results were acceptable with the maximum difference being 11.1% and 28.4% for the absorber thermal load and the mass absorption flux, respectively. In a subsequent research, they developed a mathematical model to analyze the absorption process in a bubble absorber with NH_3–H_2O, NH_3–$LiNO_3$ and NH_3–NaSCN as working pairs using a plate heat exchanger.

Nevertheless, using H_2O–NH_3 solution as working pair, the corrosion, toxicity, flammability and high working pressure under air cooling condition will result in large equipment volume and weight. Hence, considering the safety, volume and weight aspects for automobile driving, the ammonia–water mixture is not suitable for the refrigeration system driven by waste heat from automobile engines. Some organic working pairs with non-toxic or low toxic capabilities, nonflammable or low flammability can however be applied into the system. To date, though, there has not been much literature about the bubble absorption process of organic working pairs.

Suresh et al. [16–19] carried out experimental investigations to visualize bubble behavior and effects of vapor flow rate and liquid concentration on bubble characteristics of R134a–DMF (Tetrafluoro ethane – Dimethylformamide) solution in a glass absorber. Bubble behavior was studied in still as well as flowing solution. A correlation for bubble diameter during detachment is presented from the experimental studies, which can be useful for the design of the R134a–DMF bubble absorber. The authors then carried out experimental investigations to study heat and mass transfer characteristics of R134a–DMF solution in a compact bubble absorber which is a plate heat exchanger. A volumetric mass transfer correlation coefficient was obtained by using multi-linear regression analysis.

There are many organic working pairs in which the refrigerants are HCFCs or HFCs, such as R22, R124, and R134a, and the absorbents are chemical solvents, such as DMAC, DMF and DMETEG (Dimethylether tetraethyleneglycol). In accordance with the technical requirements of waste heat refrigeration system for automobiles, the R124–DMAC organic working pair is thought to be more suitable for use in the ACHRC. Under air cooling conditions, the