Absorber Design and Performance in Vapour Absorption Refrigeration System : A Review

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Abstract - *The absorber is a major component of Absorption cycle systems, and its performance directly impacts the overall size, performance, first-cost and energy supplies of these devices. In this paper a review of the main experimental, analytical results and review of different absorber designs reported in absorption refrigeration cycles is presented. It is shown that most of the experimental and analytical work found in the literature has focused on the particularly simplified case of absorption in falling film absorber and bubble mode absorber while there are only few papers on flat plate absorber or slug flow absorber. There are also work on comparison of absorber design for better performance. But there are lesser work available on the effect of heat transfer with increasing circulation rate or absorber temperature.*

Key Words: Vapour absorption refrigeration system, Absorber design, etc.

1. INTRODUCTION

Ammonia–water absorption refrigeration system has drawn increasing attention in recent years. Absorption refrigeration system has much superiority in utilizing industrial waste heat and other low grade heat resources, which is beneficial to environmental protection and energy saving. However, the coefficient of performance (COP) of ammonia–water absorption refrigeration system is relatively low and the equipment is much bigger and heavier than vapour compression system with the same capacity. Many researchers have been conducted on improving the performance of ammonia–water absorption refrigeration.

Absorber is the key equipment in ammonia–water absorption refrigeration system. Absorption enhancement is an effective way to improve the performance of ammonia–water absorption refrigeration. The objective of this paper is to review the significant effort that have been made to develop mathematical, experimental model to analyse the effect of varied operating conditions on the outlet conditions.

1.1 Absorber in vapour absorption refrigeration cycle

Vapour absorption refrigeration cycles produce a cooling effect by removing heat and transferring this heat to a vaporized working fluid called "refrigerant". An absorption cooling system basically consists of an evaporator, an absorber, a generator, a condenser, an heat exchanger and requires two fluids: the refrigerant and an absorber solution. In the absorption cooling cycle the working fluid undergoes a phase change in the condenser and evaporator, and the absorbent solution, a change in concentration in the generator and the absorber.

The refrigerant flows into the evaporator, where it evaporates at a reduced pressure and temperature, taking heat from environment . The refrigerant vapour from the evaporator is absorbed at low pressure into the concentrated absorber solution in the absorber. A quantity of heat is released as much as the refrigerant vapour is absorbed. This heat is removed by some cooling fluid from the absorber. In the generator, a part of the working fluid is vaporized from the diluted absorber solution by addition of a quantity of heat at high temperature and pressure. The working fluid vapour is condensed at high pressure and temperature in the condenser with removal of heat to the ambient. The working fluid liquid in the condenser is returned to the evaporator through the expansion valve. Then the absorption cycle repeats from the evaporator. Figure 1.0 shows a schematic diagram of the described cycle.

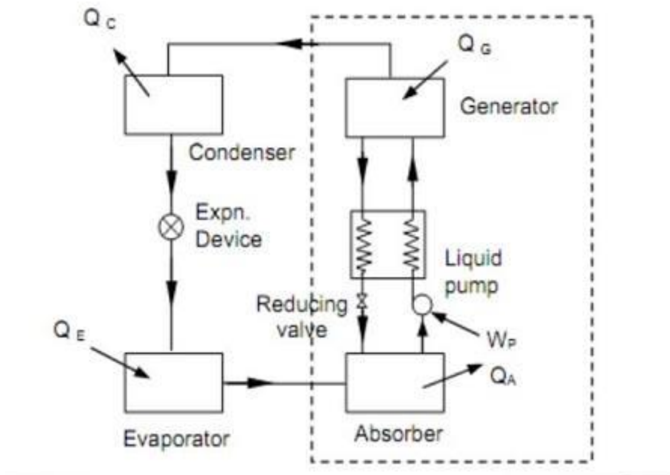

Fig 1. Schematic diagram of vapour absorption refrigeration system

2. Literature review

There are lots of work done in the absorber design and its effectiveness. In some papers they have design the absorber and noted down the effect of various inlet conditions on the outlet parameters. On analysis of these papers we have divided the papers in three section mainly : experimental, theoretical and review papers. In case of experimental review we have included only those papers which has used some experimental set-up to derive a result. In case of theoretical review we have included those papers which has prove some findings through analytical ways using equations. In case of review paper it includes all the review work done on the absorber design and performance.

2.1 Experimental review

In case of falling film its seen that vapour absorption is increased by film inverting design and by establishing magnetic field in same direction as falling film [17,7]. Increase in solution flow rate increases absorber heat duty, overall heat transfer coefficient and solution heat transfer[9].

In flat plate heat transfer coefficient decreases with increase in Reynolds number and in case of flat sheet hydrophobic membrane should be as thin as possible and pore diameter should be in between 0.3µm and 0.1µm[15].

In counter current slug flow absorber the absorption length decreases with increasing the weak solution flow rate and with decreasing the gas flow rate and with increase of thermal heat transfer performance of the coolant side[4].

In bubble mode absorber the decrease in temperature and concentration leads to decrease in region of gas absorption. When ammonia vapour was injected flux were in the range of 0.0025–0.0063 kgm^{-2}s^{-1}, the solution heat transfer coefficient varied between 2.7 and 5.4 kW m^{-2} K^{-1}, the absorber thermal load from 0.5 to 1.3 kW[20]. Absorber heat load increases with circulation ratio and absorber temperature increase whereas decreases with generator temperature. Absorber heat transfer effectiveness increases with generator temperature increase whereas decreases with circulation ratio[27]. Absorption rate achieved with micro-finned tube is 1.7 times higher than the smooth tube and absorption mass flux increases when tube diameter is reduced and decreases when tube length is increased[1].

Table -1: Experimental work in Absorber of VAS

AUTHOR /S	DESCRIPTION	YEAR	METHODOLOGY	FINDINGS
Raisul et.al [17]	Performance study of a falling-film absorber with a film-inverting configuratin	2003	Experimental investigation of development of film-inverting design for falling-film absorbers.	About 100% increase in vapour absorption rate is obtained.
Jae-Cheol et.al [3]	A study on numerical simulations and experiments for mass transfer in bubble mode absorber of ammonia and water	2003	Numerical and experimental analysis of a bubble mode absorber.	With the decrease in temperature and concentration the region of gas absorption decreases. Absorption performance of the counter-current flow was superior to that of co-current.
Kim et.al [4]	Development of a slug flow absorber working with ammonia-water mixture: part I—flow characterization and experimental investigation	2003	Experimental investigation of counter-current slug flow absorber of ammonia–water for low solution flow rate.	The absorption length decreases with increasing the weak solution flow rate and with decreasing the gas flow rate and with increase of thermal heat transfer performance of the coolant side.
Kyongmin K. and Siyoung J. [6]	Effect of vapor flow on the falling-film heat and mass transfer of the ammonia/water absorber	2004	Effect of the vapour flow direction on the absorption heat and mass transfer has been investigated for a falling-film helical coil absorber for solution concentrations of (3, 14,	Heat and mass transfer is deteriorated in the counter-current flow. The effect of vapour flow direction decreased with increasing concentration of

			and 30%).	ammonia solution.
Jesus et.al [20]	Experimental study of an ammonia–water bubble absorber using a plate heat exchanger for absorption refrigeration machines	2009	Experimental analysis in which ammonia vapour was injected in bubble mode into the solution.	Flux were in the range of 0.0025–0.0063 $kgm^{-2}s^{-1}$, the solution heat transfer coefficient varied between 2.7 and 5.4 kW m^{-2} K^{-1}, the absorber thermal load from 0.5 to 1.3 kW.
Niu et.al [7]	Experimental study on ammonia-water falling film absorption in external magnetic fields	2010	Experimental analysis to investigate the effect of magnetic fields of different intensities and different directions.	The magnetic field with the same direction as falling film enhances the absorption, and the magnetic field with the direction against falling film weakens the absorption.
Harikrishnan et.al [22]	Investigations on heat and mass transfer characteristics of falling film horizontal tubular absorber	2011	Experimental investigation of heat and mass transfer characteristics of absorber for refrigerant, R134a absorbed by R134a-DMAC	Heat and mass transfer coefficients increases by higher solution flow rate decrease in the generator heat input increase

			solution.	in concentration of R134a.
Lee et.al [9]	Measurement of absorption rates in horizontal-tube falling-film ammonia-water absorbers	2012	Experimental investigation of Heat and mass transfer in a horizontal-tube falling-film ammonia-water absorber.	The absorber heat duty, the overall heat transfer coefficient, and the solution heat transfer coefficient were found to increase with increasing solution flow rate.
Cesar et.al [12]	Heat and mass transfer in a bubble plate absorber with $NH_3/LiNO_3$ and $NH_3/(LiNO_3 + H_2O)$ mixtures	2013	Experimental test for the absorber characterization at different operation conditions.	For both binary and ternary mixtures, the mass absorption flux, heat transfer coefficient, sub-cooling and mass transfer coefficient increase as the solution flow rate increases.
Suresh M. and Mani A. [27]	Heat and mass transfer studies on a compact bubble absorber in R134a-DMF solution based vapour absorption refrigeration system	2013	Experimental investigations of heat and mass transfer characteristics of Tetrafluoroethane (R134a) in Dimethyl formamide	Absorber heat load increases with circulation ratio and absorber temperature increase whereas decreases with

			(DMF) solution in a compact bubble absorber.	generator temperature. Absorber heat transfer effectiveness increases with generator temperature increase whereas decreases with circulation ratio.
Carlos A, Mahmoud B and Manel V [1]	Effect of advanced surfaces on the ammonia absorption process with $NH_3/LiNO_3$ in a tubular bubble absorber	2014	Experimental investigations are done to analyze the effect of surface enhancement using smooth tube and an internally micro-finned tube.	Results show that the absorption rate achieved with the micro-finned tube is up to 1.7 times higher than with the smooth tube and absorption mass flux increases when tube diameter is reduced and decreases when tube length is increased.
Tommaso et.al [13]	Modelling and experimental validation of a tube-in-tube refrigerant cooled absorber	2015	Experimental investigations for predicting heat and mass transfer and pressure	Higher the load at the RCA, the better the model accuracy. A deviation of 0-20%

			drops occurring inside a tube-in-tube refrigerant cooled absorber (RCA).	has been found for the calculation of pressure drop in the annulus.
Dominguez-Inzunza et.al [14]	Experimental assessment of an absorption cooling system utilizing a falling film absorber and generator	2016	A parametric study of coefficients of performance and cooling capacities at different operating conditions.	It was seen that the coefficients of performance increased with the increase of the generator temperature and decreased with the increase in the temperature of the cooling water supplied to the condenser and absorber.
Delphine et.al [16]	Modeling and experimental study of an ammonia-water falling film absorber	2016	A numerical and experimental study to analyse the heat and mass transfers that take place in a plate heat exchanger used as absorber.	The comparison between experimental and numerical results in terms of temperature, mass flow rate and concentration in the liquid solution at the outlet of the absorber shows a maximal

				relative error of 1 % is observed.
Delphine et. al [2]	Experimental and numerical study of a falling film absorber in an ammonia-water absorption chiller	2017	An experimental and numerical study of heat and mass transfer in a falling film absorber is determined.	The model is validated with experimental data and a maximal relative error of 15% is observed between experimental and numerical results.
Berdasco M, Coronas A. and Valles M. [15]	Theoretical and experimental study of the ammonia/water absorption process using a flat sheet membrane module	2017	A hydrophobic micro-porous membrane contactor was proposed and studied experimentally and analytically as an absorber for an ammonia/water absorption cycle.	The model, the hydrophobic membrane should be as thin as possible and the pore diameter between 0.03µm and 0.10µm.

2.2 Theoretical review

For packed bed absorber a bed height less than 0.7 m guarantees absorption efficiency better than 91%[11]. Local absorption rate of the bubble mode was always higher than that of the falling film and Bubble absorption is more efficient for low solution flow rates[18,19]. In slug flow absorber the heat and mass transfer coefficient at the frost flow region is higher than that at the slug flow region[5]. In vertical tubular absorbers absorption process progresses rapidly in the churn and in the slug flow regions but slows down in the bubbly flow and absorption process occurs slowly from the first to the last tube row[21,28]. In counter-current vapour flow absorber interface temperature is always greater than the bulk liquid temperature and absorption rate increases as the coolant inlet and solution inlet temperatures decrease, and as the coolant flow rate increases[29]. In bubble absorber the reduction in coolant inlet temperature significantly enhances the mass transfer rates[8,25]. In falling film the absorber heat duty, the overall heat transfer coefficient, and the solution heat transfer coefficient were found to increase with increasing solution flow rate and that the influence of released differential heat of solution within the bulk is relatively small[25,26]. For a membrane-based absorber the porosity and pore diameter of the membrane and the solution channel width should be maximum and solution channels depth, the thicknesses of the membrane and of the wall separating the solution and the cooling water and also the cooling water channels depth should be minimum[30].

Table -2: Theoretical work in Absorber of VAS

AUTHOR/S	**DESCRIPTION**	**YEAR**	**METHODOLOGY**	**FINDINGS**
Selim A. M and Elsayed M. M [11]	Performance of a packed bed absorber for aqua ammonia absorption refrigeration system	1999	A mathematical model is used to predict the performance of the bed at various design and operating conditions.	The results shows that changing the bed pressure and/or the vapour inlet temperature have negligible effect on the performance of the bed. A bed height less than 0.7 m guarantees absorption efficiency better than 91%.
Yong et. al [18]	Analytical investigation of two different absorption modes: falling film and bubble types	2000	Parametric analysis is used to evaluate the effects of heat and mass transfer areas on the absorption rate for falling film and bubble modes.	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.
Kim et.al [5]	Development of a slug flow absorber working with ammonia–water mixture: part II—data reduction model for local heat and mass transfer characterization	2003	The study deals with a data reduction model for clarifying experimental results of a counter-current slug flow absorber for significantly low solution flow rate.	The heat and mass transfer coefficient at the frost flow region is higher than that at the slug flow region.
Jose et.al [21]	Ammonia–water absorption in vertical tubular absorbers	2005	A detailed analysis of the heat and mass transfer processes in a co-current vertical tubular absorber.	The absorption process progresses rapidly in the churn and in the slug flow regions but slows down in the bubbly flow.
Nitin G and Yogi G [29]	Analysis of a counter-current vapor flow absorber	2005	A analytical investigation of a combined heat and mass transfer process in a counter-current ammonia–water based absorber.	The interface temperature is always greater than the bulk liquid temperature. In addition, the liquid-side heat transfer resistance is negligible and

				absorption rate increases as the coolant inlet and solution inlet temperatures decrease, and as the coolant flow rate increases.
Jose et.al [28]	Analysis of an air cooled ammonia–water vertical tubular absorber	2007	A detailed analysis of an ammonia–water vertical tubular absorber cooled by air.	The results show that the absorption process occurs slowly from the first to the last tube row according to the air flow direction and the length of the tubes increases from the first row to the last one.
Castro et.al [19]	Comparison of the performance of falling film and bubble absorbers for air-cooled absorption systems	2009	A parametric study has been done on two air-cooled absorber falling film flow and bubble flow models are validated with experimental data.	Bubble absorption is more efficient for low solution flow rates.
Ruander C and Vinod N [8]	Heat and mass transfer characteristics of a constrained	2011	A study of absorption of ammonia vapour bubbles into a	Results indicate that the reduction in coolant inlet

	thin-film ammonia-water bubble absorber		constrained thin-film of ammonia-water solution is presented.	temperature significantly enhances the mass transfer rates in both absorber geometries.
Sangso et.al [25]	Measurement of absorption rates in horizontal-tube falling-film ammonia-water absorbers	2012	Heat and mass transfer in a horizontal-tube falling-film ammonia-water absorber was investigated.	The absorber heat duty, the overall heat transfer coefficient, and the solution heat transfer coefficient were found to increase with increasing solution flow rate.
Mittermaier et.al [26]	A numerical model for combined heat and mass transfer in a laminar liquid falling film with simplified hydrodynamics	2014	A numerical analysis describing heat and mass transfer of an absorbing or desorbing laminar liquid film flowing over a vertical isothermal plate.	It is found that the influence of released differential heat of solution within the bulk is relatively small and mass transfer rate during absorption is higher than during desorption.
Venegas et.al [30]	Parametric study of operating and design variables on the performance of a membrane-based absorber	2016	A simulation of plate-and-frame micro-channel H2O-LiBr absorber using a micro-porous membrane as contactor between the vapour and the solution is done.	The porosity and pore diameter of the membrane and the solution channel width should be maximum and solution channels depth, the thicknesses of the membrane and of the wall separating the solution and the cooling water and also the cooling water channels depth should be minimum.
Mehdi et.al [10]	A detailed study on simultaneous heat and mass transfer in an in-tube vertical falling film absorber	2017	A numerical model of a vertical in-tube falling film absorption heat exchanger utilizing NH3–H2O is developed.	Results shows the main resistances for heat and mass transfer are ones between gas and interface and majority of the gas gets absorbed by the film in the top segments of the pipes.

2.3 Review paper

Maximum work on available on simplified case of absorption in laminar vertical film which has the wettability problem, Adiabatic absorber reduces the size and cost of machines whereas Bubble type absorbers are more efficient[24,31]. The correlations for $LiBr-H_2O$ and NH_3-H_2O

Absorption Refrigeration in falling film and heat and mass transfer enhances as the Reynolds number is increased. And in lithium-bromide there were divergences between theoretical studies[32].

Table -3: Review work in Absorber of VAS

AUTHOR /S	DESCRIPTION	YEAR	METHODOLOGY	FINDINGS
Jesse D. K. and Srinivas G. [24]	A critical review of models of coupled heat and mass transfer in falling-film absorption	2001	It reviews the significant efforts that researchers have made to mathematically model the coupled heat and mass transfer phenomena that occurs during falling film absorption.	Most work found is on the simplified case of absorption in laminar vertical films of water-lithium bromide.
Jonathan I and Rosenberg J. R [31]	Performance of Different Experimental Absorber Designs in Absorption Heat Pump Cycle Technologies: A Review	2014	It provides a review of the literature on absorber design and its performance in absorption cycles.	Falling film absorbers has wettability problem. Adiabatic absorber reduces the size and cost of machines. Bubble type absorbers are more efficient.
Beethoven et.al [32]	A Critical Review of Heat and Mass Transfer Correlations for LiBr-H_2O and NH_3-H_2O Absorption Refrigeration Machines Using Falling Liquid Film Technology	2017	It review the heat and mass transfer correlations in the falling film absorber technology, in ammonia-water and lithium bromide-water.	In ammonia-water absorption processes, the heat and mass transfer enhances as the Reynolds number is increased. And in lithium-bromide there were divergences between theoretical studies.

3. CONCLUSIONS

The absorber is the most important component of absorption machines, in general, its performance impacts directly in the size and energy supply of all absorption devices. There are lots of work done in the field of effect of absorber design on heat and mass transfer and there are ways to increase the heat and mass transfer by adopting certain design and inlet flow conditions. There are also work on comparison of absorber design for better performance. But there are lesser work available on the effect of heat transfer with increasing circulation rate or absorber temperature.

- Experimental review

We have included papers from 2003-2017. There have been a literature gap of 5 years in between where mainly theoretical work was carried out. Majority of works were done on falling film absorber and bubble mode absorber while there are only few papers on flat plate absorber or slug flow absorber. Falling film absorber is the most common absorber but it has a wettability problem and bubble mode absorber provides better heat and mass transfer coefficient and thus making it more efficient.

- Theoretical review

We have considered papers from 1999-2017. There is no any significant literature gap which means the work is continuously being carry on. In this field significant work are carried on each absorber to increase its efficiency and performance. Numbers of work are carried on to visualise the effect of different design parameter on heat and mass transfer. But they do not show the effect of varying mass flow rate on the heat and mass transfer.

- Review papers

There have been hardly few literature review on the design and performance of absorber. we have only 3 which are published in 2001, 2014 and 2017 in which two are on heat and mass transfer coefficient in falling film absorber and one is on performance of different absorber designs. It means that this is the regions were significant work is required to make the further investigation area to be defined.

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