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A COMPARATIVE REVIEW OF NH_3-H_2O AND H_2O-LiBr BASED VAPOR ABSORPTION REFRIGERATION SYSTEMS

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ABSTRACT

The vapor absorption refrigeration (VAR) system is gaining importance due to its ability to reduce energy wastage and utilize available energy resources efficiently. This system also provides an adequate substitute for traditional refrigerants such as Hydrochlorofluorocarbons (HCFCs) and Chloro-fluorocarbons (CFCs). However, ozone depletion and global warming problem might be reduced using this system. The primarily used environment-friendly VARS is a mixture of NH_3-H_2O and LiBr-H_2O. The working principle of the VARS is heating and pressure difference during evaporation and condensation process in a reverse heat engine. In this article, various parameters which can affect the efficiency of NH_3-H_2O and LiBr-H_2O VARS system are reviewed and compared. From the review, it can be concluded that the COP of LiBr-H_2O based system was always better than NH_3-H_2O based VAR system. Also, the COP of multiple effect VAR system was higher than the single effect VAR system.

KEY WORDS
Vapor absorption refrigeration system, NH_3-H_2O, H_2O-LiBr, refrigerant, working fluid

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INTRODUCTION

The process of heat flow from the low-temperature system to high-temperature one by the aid of some external means is referred as refrigeration. There are ample applications based on this process such as refrigerators, freezers, cryogenics system, air conditioner etc. At present, it has a substantial impact on the lifestyle of the human race. Absorption refrigeration is a process in which some heating source is always required to provide necessary cooling comfort. The heating source might be direct or indirect heating type powered by the energy extracted from solar, gasoline or other non-conventional energy resources. The essential property of the refrigerant used for the refrigeration system is an extremely low boiling point which must be less than -18 °C. In case of an absorption refrigeration system, only heat input is required for converting vapors to liquid. Therefore, the only moving part in this type of system is refrigerant itself. The refrigerants used in this type of system are NH_3 and H_2O mostly. The vapor absorption refrigeration (VAR) system primarily utilizes low-grade thermal energy such as waste heat or solar power for running the cycle. Additionally, the working fluids employed in this system is natural and does not harm the environment in any capacity, unlike traditional refrigerants [1]. Therefore, the vapor absorption refrigeration system is eco-friendly and providing a similar level of cooling efficiency as produced by the compression refrigeration system. A regular depletion of the ozone layer has grown concern for environmental protection worldwide [2]. The use of hydrocarbons as a refrigerant in the various refrigeration system had a significant contribution to global warming. Some commonly used hydrocarbons as a refrigerant such as CFC-12, HCFC-22, HFC-134a, HFC-161, R502, R404A, R507 etc. have relatively high ozone depletion potential [3, 4]. Moreover, research on new processes working on natural refrigerant has been intensified recently. The focus was also shifted from traditional to renewable energy resources and need to have been grown to utilize the low-grade energy for the refrigeration purpose. Moreover, research on natural refrigerant-based refrigeration system has been intensified recently. The focus has also been shifted from traditional to renewable energy resources. The process optimization is kept on improving for the utilization of low-grade energy which is assisting in higher energy efficiency [1, 2, 5].

In this article, a comprehensive review of the performance of commonly used natural refrigerants i.e. NH_3 and H_2O in VAR system is summarized. The effect of several parameters on the performance of the VAR system is also reviewed. This paper also compiles various procedures used to enhance the coefficient of performance (COP) of NH_3-H_2O and LiBr-H_2O absorption cycle.

VAPOR ABSORPTION REFRIGERATION SYSTEM

The working principle of the vapor absorption refrigeration system is the existence of a necessary pressure gradient between the vaporization and condensation processes. The working fluid released heat to the environment when condensed under high pressure. Whereas, in the case of evaporation, the heat is absorbed from the medium or surrounding and vaporized under low pressure. The cooling effect is produced during the evaporation process. This technique is adopted widely for the utilization of available conventional and unconventional energy resources efficiently [1]. It assisted in terms of minimizing the energy wastage and replacing the traditional refrigerant (HCFCs CFCs etc.) with more environmental friendly working fluids. Using this technique not only prevented ozone layer depletion but also reduced greenhouse warming. The NH_3-H_2O working fluid is the only environment-friendly mixture utilized currently for refrigeration purpose. The applications of VAR system is divided into two ranges i.e., above and below 10°C. The commonly used working refrigerant-absorbent fluid pair of VAR systems for above and below

10°C temperature range applications are H_2O-LiBr and NH_3-H_2O, respectively. The H_2O-LiBr fluid pair could not be used for extremely low-temperature applications owing to the crystallization tendency of LiBr. At extremely low temperatures the miscibility of LiBr and H_2O is poor and phase separation will take place. The selection of absorbent for VAR system was done on the basis of their ionic nature. The fluid with ionic nature has good solubility in different natural refrigerants along with low volatility. Besides the advantages, the high circulation ratio and viscosity of such type of fluids require high pumping power consequently poor absorber efficiency. This problem might overcome if water is used as a co-solvent. Various works have explained theoretically and experimentally the significance and viability of different working fluid operated VAR system processes in terms of its performance and cost-effectiveness. The work explained the process and performance optimization of NH_3-H_2O and H_2O-LiBr working fluid pairs are summarized in forthcoming sections [2].

NH_3-H_2O VAR SYSTEM

NH_3-H_2O refrigerant-absorbent pair is frequently used in an absorption refrigeration system from the starting onwards. This pair is stable in a broad range of working temperature and pressure. NH_3 possess high latent heat of vaporization, and extremely low freezing temperature (-77°C) resulted in an improved performance at low-temperature applications [6]. A rectifier is required in the cycle owing to the volatile nature of both the fluids to fetch the maximum performance from the system. Some disadvantages of the pair are colossal pressure, toxicity, and corrosion behavior towards Cu and its alloys [7]. A simple block diagram of a simple NH_3-H_2O VAR system is shown in [Fig. 1].

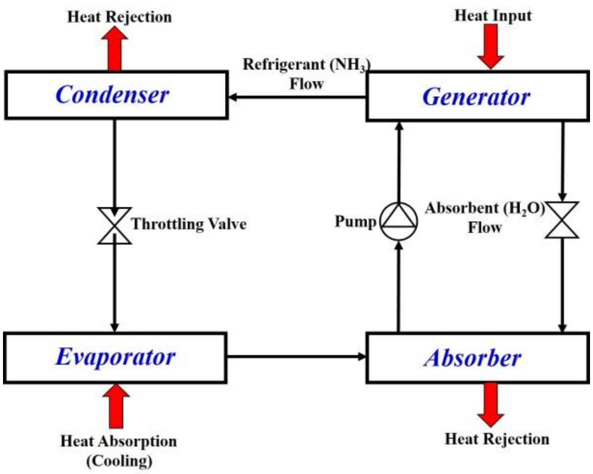

Fig. 1: Block diagram of NH_3-H_2O refrigeration system [10].

Ramesh et al. [8] investigated the performance of NH_3-H_2O vapor absorption system with shell and helical coil type of solution heat exchanger. They observed that the tube side heat transfer coefficient was higher than the shell side. Also, the Nusselt number of tube side was four times higher than the shell side. Lee et al. [9] added Al_2O_3 nanoparticles and carbon nanotubes in pool type NH_3-H_2O VAR system and studied the performance. They noticed 0.02 vol% Al_2O_3 nanoparticles addition exhibited optimum performance. Raghuvanshi and Maheshwar [10] studied the performance of NH_3-H_2O VAR System using the first law of thermodynamics. The COP decreases with higher generator, condenser and absorber temperatures whereas; it increases if the effectiveness of heat exchanger increases. Du et al. [11] worked on a prototype of the air-cooled two-stage NH_3-H_2O solar VAR system for residential use. The prototype performed smoothly and steadily with a COP range of 0.18-0.25. Kim et al. [12] examined the effect of surfactants such as 2-ethyl-1-hexanol, n-octanol, and 2-octanol on the bubble type NH_3-H_2O vapor absorption system. The absorption performance was improved by 4.81 times after the addition. Kang and Kashiwagi [13] quantified the impact of n-octanol (heat transfer additive) addition on Marangoni convection in NH_3-H_2O absorption process. They observed that the increased heat transfer additive concentration improved the driving potential of absorption resulted in high Marangoni convection. Therefore, the absorption performance of NH_3-H_2O VAR system improved significantly. Fernández-Seara and Vázquezan [14] obtained improved COP of NH_3-H_2O VAR system with an inefficient solution heat exchanger and higher pressure drop between evaporator and absorber. Sieres and Fernández-Seara [15] judged the effect of distillation column in small capacity NH_3-H_2O VAR system using numerical analysis. The use of stripping section in the distillation column improved the COP values up to an absolute limit thereafter no improvement was proclaimed. Khaliq and Kumar [16] compared the exergy destruction for NH_3-H_2O and LiBr-H_2O working fluid in a single effect VAR cycle. Considerably high exergy destruction was inscribed for NH_3-H_2O than the LiBr-H_2O solution. The exergy loss mainly occurred in the generator and absorber. With the increase of absorber temperature, exergetic efficiency improved notably. Rogdakis and Antonopoulos [17] proposed a new work producing cycle for NH_3-H_2O VAR system and compared its performance with the Rankine cycle. For all the conditions, the proposed cycle exhibited better efficiency than the Rankine cycle. Jawahar and Saravanan [18] examined the performance of an air-cooled modified NH_3 based generator absorber heat exchange (GAX) absorption cooling system. The optimum cooling capacity was reported when the generator and evaporator temperatures were 120°C and 2°C, respectively.

H_2O-LiBr VAR SYSTEM

H_2O-LiBr refrigerant-absorbent pair was first used in a VAR system in around 1930. A schematic diagram of a simple H_2O-LiBr VAR system is exhibited in [Fig. 2]. There is no need of rectifier in this system as LiBr is non-volatile and H_2O owns a high heat of vaporization. The use of H_2O, as a refrigerant, limits its application above 0°C temperature and require vacuum for smooth functioning. The presence of LiBr in an excessive amount makes the solution more susceptible to crystallization. This problem might get solved if the salt such as $ZnBr_2$, $ZnCl_2$ etc. is added to the working fluid. The COP of this system is always better than the NH_3-H_2O couple. This system is only used to generate air conditioning effect [19, 20]. Saravanan and Maiya [21] did the performance analysis of H_2O–LiBr VAR system operated by the bubble pump. They recorded the highest COP of 0.5 when the boiler temperature was 85°C and absorber and condenser temperatures were more than 40°C. Asdrubali and Grignaffini [22] evaluated the performances of H_2O-LiBr VAR system in various circumstances. They found acceptable efficiency of the machine when the input temperature was as low as 65-70°C. This result indicated that the same device could be driven by solar power. Kang et al. [23] studied the heat and mass transfer rate of H_2O-LiBr falling film absorption process with the addition of Fe or CNT nanoparticles. The mass transfer rate was higher with CNT nanoparticles added working fluid resulted in improved absorption performance of the system. Arora and Kaushik [24] developed a computational model for performance analysis of single and double effect LiBr-H_2O VAR systems. Although the COP and exergetic efficiency increased with the increase of generator temperature, the higher absorber, condenser and evaporator temperatures decreased the same in both the system. The highest amount of irreversibility was recorded in the absorber. Kim et al. [25] did the simulation of the compressor-assisted triple-effect H_2O-LiBr absorption cooling cycles. The corrosion is the main problem with LiBr based triple-effect absorption cooling system. They proposed a new four compressor-assisted H_2O-LiBr cooling system and observed no danger of corrosion with LiBr working fluid. The 1.5-effect H_2O-LiBr cycle based absorption system exhibiting increased sensitivity towards the change of absorption temperature, consequently the generation temperature will alter [26]. Domínguez-Inzunza et al. [27] compared the performance of H_2O-LiBr operated single, half, and double effect VAR systems. The minimum and maximum COP was observed with half and double effect VAR system, respectively. The maximum COP of complex designed double effect VAR system was 1.48.

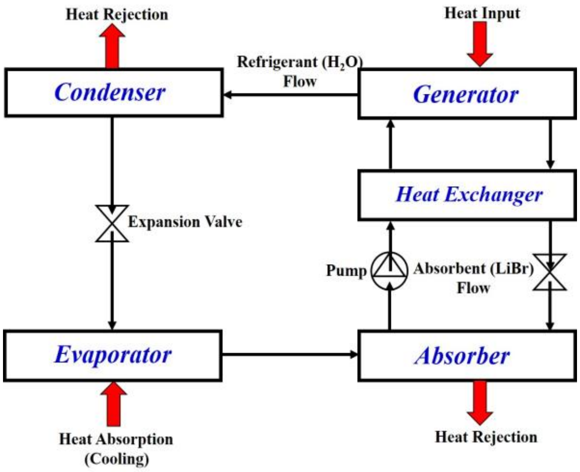

Fig. 2: Block diagram of H_2O-LiBr refrigeration system [24].

VARIATION IN COP

The value of a coefficient of performance (COP) of a refrigeration and air conditioning unit is determined by the ratio of heat absorbing ability of evaporator to the total power supply to the unit. The COP is inversely proportional to the operating cost of the unit. Therefore, a higher COP translated into the lower operating cost. Several efforts have been made to improve the COPs of the compression or absorption refrigeration systems. The COP is varied with the choice of a refrigerant-absorbent pair, single stage or multiple stage operation, generator temperature, absorber temperature, con-denser temperature and various operating pressures. A list of COPs reported in literature considering multiple parameters are listed in [Table 1]. It was observed from the table that H_2O-LiBr couple is providing better COP than NH_3-H_2O couple. The multi-stage operation exhibited improved COP than the single-stage operation. It was even touching the value of 1.9 in case of triple effect cycle for predefined generator, absorber and condenser temperature.

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Table 1: The COP values at different parameters and working pairs

S. No.	Working Fluid	Operation Type	Generator Temp (°C)	Evaporator Temp (°C)	COP	Cooling Capacity (kW)	Year	Ref
1	NH_3-H_2O	Single effect	100	-5	0.6160			[28]
	NH_3-$LiNO_3$	Single effect	100	-5	0.6247		1998	
	NH_3-NaSCN	Single effect	100	-5	0.6390			
2	R1234yf/[hmim][Tf2N]	Single effect	90	5	0.363	100		[29]
	R1234ze(E)/[hmim][Tf2N]	Single effect	90	5	0.426	100	2017	
	H_2O-LiBr	Single effect	90	5	0.805	100		
	NH_3-H_2O	Single effect	90	5	0.737	100		
3	NH_3-H_2O	Air-cooled two-stage	85	8	0.18-0.25	2	2012	[30]
4	H_2O-LiBr	Single effect	60-190	4-10	0.73-0.79	300	2009	[31]
	H_2O-LiBr	Double effect	60-190	4-10	1.22-1.42	300		
5	NH_3-H_2O	Single effect	100	10	0.646	1112	2005	[32]
	H_2O-LiBr	Single effect	100	10	0.833	2502		
6	H_2O-LiBr	Single effect	90	5	0.770		2007	[33]
7	H_2O-LiBr	Single effect	87.8	7.2	0.7609		2009	[34]
	H_2O-LiBr	Double effect	140.6	7.2	1.26			
8	H_2O–LiBr	Single effect	90	5	0.76			[35]
	NH_3–H_2O	Single effect	90	5	0.54		2010	
	NH_3–$LiNO_3$	Single effect	90	5	0.55			
9	NH_3–H_2O	Single effect	121.1	-11.2	0.47	10.51	1996	[36]
10	H_2O–LiBr	Double effect	85-170	2.5-10	1.32-1.39		2000	[37]
11	H_2O–LiBr	Single effect	60-225	4-10	0.73-0.79	300		[38]
	H_2O–LiBr	Double effect	60-225	4-10	1.22-1.42	300	2010	
	H_2O–LiBr	Triple effect	60-225	4-10	1.62-1.90	300		
12	H_2O–LiBr	Single effect	65-85	5	0.467-0.644	2	2007	[39]

CONCLUSION

In this article, a comparison of VAR systems based on NH_3-H_2O and H_2O-LiBr working fluid was carried out. The literature regarding the same was reviewed and summarized. NH_3-H_2O pair can be used in refrigeration as well as air conditioning applications whereas; the H_2O-LiBr pair can be used in air conditioning applications only. The problem of crystallization of absorbent and the freezing tendency of a refrigerant at extremely low temperature constrained its use in refrigeration applications. The addition of efficient heat exchanger designs and/or surfactant or heat transfer additive in working liquid enhanced the COP in NH_3-H_2O based VAR system. The COP of LiBr-H_2O based system was always better than NH_3-H_2O based VAR system. Also, the COP of multiple effect system was higher than the single effect system.

CONFLICT OF INTEREST
None

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FINANCIAL DISCLOSURE
None

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