A Comprehensive Review on LiBr–H_2O Based Solar-Powered Vapour Absorption Refrigeration System

S. Somesh, Sumit Kumar Shaw and Piyush Mahendru

Abstract Solar energy is used for refrigeration cycle in solar-powered vapour absorption refrigeration (SVAR) systems. The significance and explanation of eco-friendly SVAR system based on LiBr–H_2O are available in the literature. The use of solar power improves the coefficient of performance (COP) of the cycle, and it lies in between 0.27 and 1.20. The improvement in COP makes it suitable for industrial and commercial purposes. It was claimed that, this system is also worthy for the applications operated at or above 0 °C. The use of LiBr as absorbent allows the system to run without expansion valve. Use of water as refrigerant is helpful to keep the operating pressure low in condenser and evaporator. Even if the system works on lower pressure, the COP is not affected. The machine-driven parts are installed in pump housings only. Therefore, the complete operation is smooth, and the system is maintenance-free. This system might not produce any greenhouse gas and considered as a green technology for future. The load variation does not affect the performance of the system too. The use of LiBr provides the flexibility to replace the volatile liquid from the absorbent refrigerant pair. Also, the liquid exiting the generator does not contain absorbent mixed with refrigerant. Therefore, the analyzer and rectifier are absent which simplifies the design and reduce the production cost. The main limitations of this system are crystallization and reduction in efficiency at very low temperatures. In this article, the recent developments in the field of LiBr–H_2O-based SVAR system are reviewed.

Keywords Solar energy · Absorption · Refrigeration · LiBr–H_2O · Vapour absorption refrigeration systems

1 Introduction

The vapour absorption refrigeration (VAR) system comprises of the processes like absorption, condensation, expansion and evaporation. The main refrigerant used in

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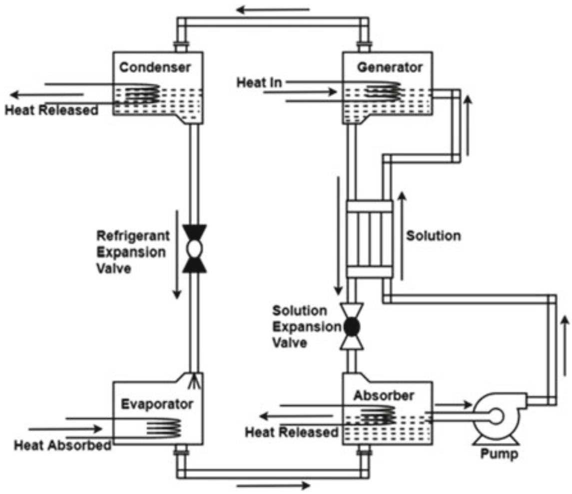
vapour absorption system is NH_3 (ammonia), H_2O (water) or LiBr (lithium bromide). The refrigerant gets condensed and evaporated simultaneously in the condenser and evaporator, respectively. In the evaporator, the evaporation of refrigerant produces the cooling effect by discharging the heat to the surroundings. Vapour compression and absorption are two leading techniques used in the refrigeration systems with varied suction and compression processes of refrigerant. The suction, compression and flow of the refrigerant during refrigeration cycle are carried out by the compressor in the vapour compression system. On the contrary, two devices, i.e. absorber and generator are employed to suck and compress the refrigerant in the vapour absorption system. Also, the flow of the refrigerant was managed by the absorbent in the cycle. Furthermore, the energy input is furnished to the vapour compression and vapour absorption systems is in the form of mechanical work and heat energy, respectively [1]. The use of solar energy for powering the air-conditioning and refrigeration units not only saves the limited fossil fuel reserves but also preserves the environment which is excessively deteriorating due to global warming. Solar energy in the form of sunlight is abundantly available yet a very small percent of that is utilized for the betterment of the human race. Challenges associated with solar energy need to be addressed properly before utilizing it as a primary source of energy in various engineering applications. A thorough literature review indicated that solar power can be employed in absorption refrigeration systems. The present article aims to provide a comprehensive analysis of the progress of solar-powered absorption refrigeration systems.

2 H_2O–LiBr VAR System

In H_2O–LiBr pair, H_2O is used as a refrigerant and LiBr as an absorbent. The main limitation of this system is that it cannot be employed for refrigeration process below 0 °C. However, this system is primarily suitable for air-conditioning purpose only. A schematic representation of H_2O–LiBr VAR system is shown in Fig. 1. At extremely low temperatures, i.e. below 0 °C, the refrigerant used in this system turns into solid. Additionally, the crystallization of LiBr at moderate concentrations is another major issue with the system. This problem mainly arises when the absorber unit is cooled with air cooling system. The absorbent with a blend of salts is used to overcome this issue. Another difficulty with this system is related to the flow because the viscosity of the solution increases at low pressure. A proper design of the equipment might solve this issue to some extent. Apart from the problems, this system provides the advantages like high safety, large volatility ratio, high affinity, excellent stability and tremendous latent heat [2, 3]. Most of H_2O–LiBr VAR machines are at risk of atmospheric air leakage if the unit is improperly maintained or mishandled owing to their low operating pressure. Trouble-free operation of the H_2O–LiBr system is ensured if the crystallization of LiBr is prevented using efficient

Fig. 1 Schematic of a H_2O–LiBr system



concentration control system. The COP of the H_2O–LiBr system is good, although the crystallization problem limits it. The increased mass flow rate of refrigerant in the generator due to high generator temperature resulted in enhanced COP followed by high cooling rate [2, 3].

3 Thermodynamic Analysis of VAR System

The optimization of the first and second law of thermodynamics maximizes the COP and exergy efficiency, respectively. In exergy method, the exergy loss due to irreversibility, and the useful work produced by a substance is calculated. Thermodynamic study of the energy transformation systems is carried out using this powerful tool. Aprhornratana and Eames [4] described the second law analysis of VAR cycle. As per their investigation, the solution circulation ratio has a decisive role in determining the COP of the system. It is required to pay more attention to the performance of evaporator than absorber to improve the overall cycle performance. As crystallization temperature of a solution is fixed, the maximum efficiency can be fetched when it is being operated from low-grade heat instead of high-temperature heat sources. Berlitz et al. [5] discussed the economic aspects of absorption heat pumping equipment operating on H_2O–LiBr. Arora and Kaushik [6] developed a computational model for the parametric analysis of H_2O–LiBr VAR system. The study specified that COP and exergy efficiency increased with higher generator temperatures. An increase in temperature associated with absorber, condenser and evaporator increases the irreversibility of the system. Also, highest irreversibility was proclaimed for the absorber. Asdrubali and Grignaffini [7] simulated and verified the performance of a single-stage H_2O–LiBr absorption machine. Their results indicated that acceptable efficiency could be achieved from the device in 65–70 °C temperature range. Thus, as per findings, solar energy could be used as an energy source for the machine in future. Domínguez-Inzunza et al. [8] examined the performance of various absorption cooling arrangements working with H_2O–LiBr fusion. They observed maximum COP with double effect systems. However, this type of systems is complex. Anand et al. [9] analysed the energy and exergy of H_2O–LiBr VAR plant. They observed maximum exergy loss in the generator. Also, COP of the system increased with higher evaporator temperature. The areas of energy wastage in the system are pointed out in the study as well. Samanta and Basu [10] developed a theoretical model for H_2O–LiBr-based single-stage VAR system and it has been optimized for minimum entropy and maximum COP. They reported that the entropy generation is minimum when the generator temperature is low. Therefore, the absorber has a significant role in enhanced irreversibility in the system. A thermoeconomic analysis based on exergy analysis for H_2O–LiBr VAR system was carried out by Misra et al. [11] and Bereche et al. [12]. This optimization technique assisted in achieving a cost-effective design of VAR system for optimum performance. Further, a higher exergetic cost of the main product is reported for a direct-fired VAR system.

4 Solar-Powered VAR System

Engineering sectors like food processing, air-conditioning, pharmaceutical, etc. require a cooling environment for multiple purposes. The vapour compression systems are largely catering the demands in such type of applications. The focus of the research in the recent time has shifted to develop technologies offering low power consumption, renewable and clean energy resources without compromising the level of comfort [13]. The use of solar power in refrigeration technologies eliminates most of the harmful effect produced by conventional refrigeration machines. On the other hand, the performance of such type of system is mainly dependent on the availability of the solar radiation. Also, it is required to convert solar energy into electricity or heat for powering a refrigeration system. Currently, research is focused on the development and improvement of vapour absorption system driven by solar power. The efficiency of solar photovoltaic (PV) collectors increased marginally (i.e. 10–15%) than solar thermal collectors in the recent past. Also, solar PV collectors bear fairly high initial cost [14, 15]. Therefore, refrigeration technologies are mainly focusing on absorption or adsorption systems utilizing solar temperature. Dieng and Wang [16] presented a review on solar adsorption systems based on fundamental understandings, design parameters and applicability in air-conditioning and refrigeration. This system is able to serve basic cooling requirements in remote locations. Additionally, systems powered by solar energy are noiseless, non-corrosive and environmental friendly. However, this type of system is useful for air-conditioning in vehicles, ice making, medical and food preservation/transportation. Still, this field requires a lot of advancements for competing with the already established vapour compression system. Low specific power and high cost need attention for the development of solar absorption systems. Sumathy et al. [17] proposed a solar cooling system driven at low temperature. The proposed model is a two-stage LiBr absorption chiller. Their results exhibited that the system can run at 60–75 °C, which could be achieved easily by portable solar hot water plant. This type of system is not only efficient but also cost-effective. As per their results, the COP of a two-stage chiller is almost similar to well established single-stage chiller with an approximately 50% cost cutting. Apart from H_2O–LiBr absorption system, a solar-driven carbon (C)–NH_3 refrigeration system with claimed power densities of almost 1 kW cooling for 1 kg carbon is also gaining importance [18]. Renewable and clean energy sources (i.e. solar, wind, biomass, etc.) and their combinations are power packed alternatives for all the energy needs in the refrigeration and air-conditioning industries.

5 Progress of Solar-Powered H_2O–LiBr VAR System

Many researchers have explained theoretically and experimentally the significance of SVAR system using H_2O–LiBr. They have claimed that using solar energy makes the whole process eco-friendly. Additionally, there is no recharging cost of refrigerant which is inevitable in vapour compression system. Arunkumar and Ragavendran [19] stated that through solar energy, the working fluid is able to achieve COP of refrigeration up to 0.7–0.8, and due to considerable COP this can be used not only for domestic purposes but also for industrial purposes. They claimed that this system is useful for those applications where the required temperature is more than 0 °C. Some studies claimed that the expansion valve is not needed in the cycle when LiBr is used as an absorbent. As water is used as refrigerant, the operating pressure in the condenser and evaporator is low. Even if the system works on lower pressure, COP is not affected. The cycle operation is smooth, noiseless, maintenance free and cost-effective. One of the main advantages of the H_2O–LiBr system is that the absorbent is non-volatile. There is no absorbent mixed refrigerant (water) pair leaving generator, and so the analyzer and rectifier can be removed from the system thereby simplifying the design and reducing the cost of production [20].

The year-wise progress of the SVAR system is presented in Table 1. The effect of different type of collectors used to collect solar energy on the efficiency of the system is fetched from the literature and plotted in Fig. 2. From Fig. 2, it could be concluded that the maximum COP of the system is obtained when evacuated tube type collectors were used.

Table 1 Year wise work on solar vapour absorption system based on H_2O–LiBr pair reported in the various literatures

S. No.	Solar thermal technologies	Cooling technologies	Chillers types	COP	Remarks	Ref.	Year
1	Flat-plate collector	Continuous absorption	–	0.07	Storage tank size used is 2.75 m^3 (partitioned into two parts) for 4.7 kW cooling capacity	[21]	2001
2	Flat-plate collector	Continuous absorption	Single-effect	–	Optimized storage tank size is 1 m^3	[22]	2002
	Compound parabolic collector	Continuous absorption	Single-effect	–	Optimized storage tank size is 0.6 m^3		
	Evacuated tube collector	Continuous absorption	Single-effect	–	Optimized tank size is 0.6 m^3		
3	Tube type collectors	Continuous absorption	Double effect	1.2	Additional gas fired heating arrangement used	[23]	2004
4	Integrated compound parabolic concentrating reflector evacuated solar collector (ICPC)		Double effect	1.1	Daily collection efficiencies are 50–55%	[24]	2004
5	Parabolic trough solar collector	Continuous absorption	Single-effect	0.67–0.76	Minimum required collector area is 57.6 m^3 Storage tank capacity should be in between 0.68 and 1.23 m^3	[25]	2008
6	Flat-plate collector	Continuous absorption	Single-effect	0.74	The storage tank size used is 0.8 m^3	[26]	2008
7	Vacuum tubes solar collector	Continuous absorption	Single-effect	0.37–0.81	Absorption chiller with 35.17 kW cooling capacity. Hot and cold water storage tank capacity is 6.8 and 1.5 m^3, respectively.	[27]	2008

(continued)

Table 1 (continued)

S. No.	Solar thermal technologies	Cooling technologies	Chillers types	COP	Remarks	Ref.	Year
8	Flat plate collector	–	Single-effect	0.41–0.66	Absorption chiller cooling capacity is 35 kW	[28]	2008
9	Evacuated tube solar collector	Continuous absorption	Single-effect	0.7	19% energy is provided to the chiller using a LPG-fired backup heating unit	[29]	2008
10	Flat-plate collector	Continuous absorption	Single-effect	0.8	Cooling water temperature should be below 40 °C	[30]	2014
11	Double-glazed flat plate collector	Continuous absorption	Single-effect	0.27–0.85	Required storage tank size is 0.68–1.23 m^3 for 10.39 kW of cooling loads	[31]	2014
12	Compound parabolic concentrators	Continuous	Double effect	0.4–0.5	No cooling tower employed	[32]	2014
13	Flat-plate collector	Continuous		0.77	Design with refrigerant storage is the best suited design for 24 h AC operation	[33]	2015
14	Evacuated tube array	Continuous	Single/double effect	0.69–1.08	The maximum COP was obtained when generator temperature was 120 °C	[34]	2016
15	Evacuated selective surface collector	Continuous	Single-effect	0.7–0.8	Evacuated selective surface collectors are better than single and double-glazed collector	[35]	2017
16	Parabolic trough collectors	Continuous	Single-effect	0.65	Optimal heat source temperature is 95.5 °C	[36]	2018

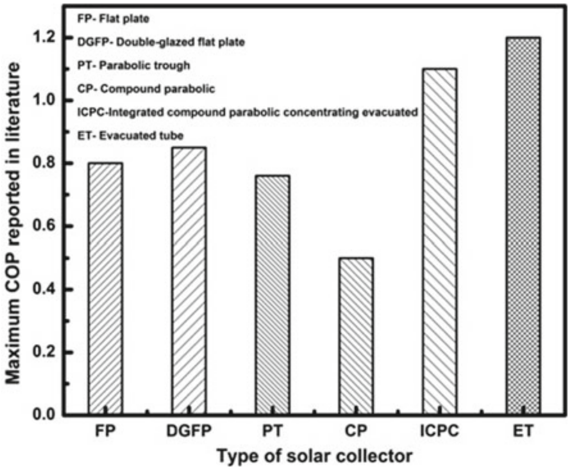


Fig. 2 Reported values of COPs of H_2O–LiBr based VAR system with various solar collectors

6 Conclusions

In this article, a review of the research state on the SVAR systems is presented. From the report, it can be concluded that the SVAR systems could be utilized for generating a broad range of temperatures for refrigeration and air-conditioning by the adoption of renewable energy source. It is an attractive technology that not only able to serve the demands for refrigeration/air-conditioning applications but also meet the requirement for energy conservation and climate protection. As per the review, evacuated tube collectors are able to extract high COP from the system. Absorption systems are more suitable for air-conditioning. Many areas related to SVAR technology is not fully investigated yet. Poor COP and low solar collector efficiency are mainly obstructing the commercialization of SVAR systems from demonstration/prototyping to the final product. However, a lot of research work is still needed for enhancing the heat and mass transfer to improve performances of SVAR systems. Incorporation of more advanced solar energy collectors, innovative optimization/simulation models and use of micro-exchangers could achieve required efficiency from the system.

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