RESEARCH ARTICLE

SAMRIDDHI Volume 15, Issue 1, 2023 Print ISSN: 2229-7111 Online ISSN: 2454-5767

Investigations on Solar Powered Vapour Absorption Refrigeration based Air Conditioning

Onkar Singh*, Sandeep K. Rai, Ravindra K. Ambikesh

Mechanical Engineering Department, Harcourt Butler Technical University, Kanpur, Uttar Pradesh, India

Abstract

A solar-operated vapor absorption refrigeration cycle is environment-friendly refrigeration system that holds the potential to be used for refrigeration and air conditioning systems. Such a system requires a solar concentrator to run the vapor absorption refrigeration cycle using LiBr-H_2O-based refrigeration/air conditioner for small capacity applications. With the solar-powered pumping process, this refrigeration system becomes completely free from electricity requirements. However, the limitations of all time solar radiation availability, low-pressure maintenance requirement of the LiBr-H_2O system, low efficiency, and low COP as compared to other vapour compression refrigeration based air conditioning system are the key deterrents. In the present study, the modeling and analysis of various components used in the proposed arrangement of solar vapor absorption refrigeration - air conditioning system has been carried out to improve the performance It is seen that altering the geometrical property of the bubble pump, as well as heat input through a solar concentrating collector, use of hydrogen as a third fluid increases the rate of evaporation which in turn increases the cooling effect as well as COP of the cycle. At 54% concentration of LiBr and 4.5kW heat input, the COP of the proposed layout is found to be 0.61.

Keywords: Solar refrigeration, Vapour absorption, Air conditioning, Solar concentrator.

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology (2023); DOI: 10.18090/samriddhi.v15i01.15

Introduction

The increasing atmospheric temperature is gradually challenging the sustainability of life due to global warming. Changing climatic conditions appear to be a consequence of the technological advances made at the cost of nature. This has resulted in excessive carbon emissions, ozone layer depletion, etc., which are disastrous for human beings. The increase in air conditioning requirements and refrigeration needs due to rising temperature are endangering the environment through CFC emissions from vapor compression refrigeration systems. The vapor absorption refrigeration cycle run on environment-friendly refrigerants can help mitigate the adversities created by the most vapor compression refrigeration cycle. The smaller energy requirements to run the vapour absorption refrigeration cycle for its operation make it further suitable in respect to the continually increasing energy requirements. The possibilities of utilizing renewable energy for getting refrigeration effects from less energy incentive cycle are explored by researchers worldwide. Solar energy availability in abundance motivates to attempt to have solar powered refrigeration cycle and using it for refrigeration/air conditioning purposes. In this context, the present work is undertaken to investigate the solar-powered vapor absorption refrigeration cycle that can be used for low-capacity air conditioning applications.

Pioneering work carried out in this regard is detailed herein. Rahman *et al.*[1] performed an analysis in which he replaced the compressor by a generator, absorber and pump to produce 300 watt load at 23°C having cycle coefficient of performance 0.51. Sokhansefat *et al.*[2] performed parametric analysis of cycle having collector area 55m^2 and storage tank capacity 1m^3 through which solar performance enhanced by 28%. Sharawi *et al.*[3] improved system performance by reducing the collector size and storage tank capacity of 5kW chiller. Solano-Olivares *et al.*[4] compared the Commercial Air Conditioning system with Solar Air conditioning which results in saving emission of 80% global warming potential as carbon footprint.[5] Shelton *et al.*[6] developed a model which optimizes a Bubble Pump that runs the refrigeration cycle against gravity, having a Bubble pump tube diameter between 2 mm to 6mm to obtain maximum efficiency of the cycle.[7] Bi Yuehong *et al.*[8] studied that collective use of a Parabolic trough collector (PTC) and 3-Phase accumulator with Solar Absorption Refrigeration improves

Corresponding Author: Onkar Singh, Mechanical Engineering Department, Harcourt Butler Technical University, Kanpur, Uttar Pradesh, India, e-mail: onkpar@rediffmail.com

How to cite this article: Singh, O., Rai, S.K., Ambikesh, R.K. (2023). Investigations on Solar Powered Vapour Absorption Refrigeration based Air Conditioning. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology,* 15(1), 116-121.

Source of support: Nil

Conflict of interest: None

the efficiency of Parabolic Trough Collector i.e. 67.5%.[9] Cheng *et al.*[10] that the efficiency of the refrigeration cycle may get influenced by 2 or 3 times with change in solution concentration and absorbent variety and solar steam-based system having photo thermal material that localize the heat at the evaporation surface that helps in low loss of energy.[11] Benhmidene *et al.*[12] studied the comparison between the homogeneous model of void fraction and vapor quality for pumping ratio 0.216 and void fraction 0.9, the optimum heat flux is between 5 to 10 kW/m^2. Zaho *et al.*[13] observed that the photovoltaic air conditioner's economic performance totally depends on the self-consumption ratio and solar radiation amount. Aman *et al.*[14] compared that LiCl-H_2O having higher efficiencies as compared to LiBr-H_2O since LiCl-H_2O working pressure is high while LiBr-H_2O has crystallization constrain, which results in efficiencies of LiBr-H_2O and LiCl-H_2O as 0.46 and 0.56 respectively. Paurine *et al.*[15] studied the design and operation of thermo gravity pump which operates by low-grade energy i.e.temperature range of 75°C - 85^{o}C to obtain COP of range 0.72 . Ezzine *et al.*[16] studied an experimental investigation on diffusion absorption having 2 fluids (Hydrocarbon, i.e., C_4H_{10} / C_9H_{20}) as working fluid to obtain temperature range between -10 °C to 10 °C . Chaves *et al.*[17] studied 3 fluid refrigeration system i.e., ammonia-water-hydrogen having 14 distinct subparts for investigation , which shows a deviation of 2.5°C in a generator as well as 0.7°C in condenser for source power 80W. Anand *et al.*[18] studied the performance analysis of steam powered absorption refrigeration system. Aman *et al.*[19] studied the dimensional (geometrical) analysis of bubble pump to enhance the performance of bubble pump operated diffusion absorption refrigeration system, which results in 79% efficiency at start of slug flow regime. Also, the Bubble operates in turbulent conditions. Jemaa *et al.*[20] studied commercial Diffusion absorption for calculating overall heat transfer coefficient theoretically as well as experimentally, whose value resides between 0.2W/°C , so 35W-45W power is necessary for heating elements. Zohar *et al.*[21] Comparative analysis of with/without condensate cooling before evaporator entrance results in enhanced COP by 14–20% without condensate cooling at evaporator temperature 15°C. Bellos *et al.*[22] did study on efficiency of mechanical compression absorption cooling throughout the year based on solar system. Also did an economic as well as environmental impact study. Kilic *et al.*[23] studied the efficiency of LiBr-H_2O cooling system such that its efficiency is highest at higher generator temperature. Solano-Olivares *et al.*[24] studied the air conditioning system runs on fossil fuel also studied that solar equipped system reduces global warming by 80%. Soltani *et al.*[25] did experimental study on conversion of conventional air conditioner to solar air conditioner, also for absorption cooling - crystallization is major concern at high temperature range.

Based on the literature review, the solar powered vapour absorption cycle based refrigeration system calls for improving its effectiveness and devise it in useful form for being utilized for small capacity air conditioning needs of premises. Therefore, this study is carried out considering solar parabolic concentrator for running the vapour absorption cycle on Lithium Bromide – Water as working fluids for it.

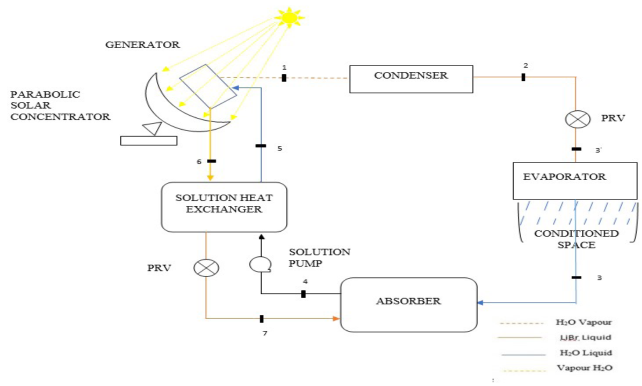

Figure 1: Schematic layout of solar air conditioner

Experimental Setup

The schematic of the studied arrangement for solar air conditioner after assessing various study of different technological solutions for low capacity cost effective solar air conditioners is given in Figure 1. This layout for a solar air conditioning system design is inclusive of the considerations for greenhouse gas emission reduction, ease of the availability of components and fabrication for making it cost effective.

LiBr – H_2O is used for getting the refrigeration effect in the evaporator section between states 3' and 3. The room unit of air conditioner is installed between these states i.e. evaporator section. From state 3, the water should enter the absorber where LiBr will be entering into it. The concentrated LiBr-H_2O solution is sent to solution heat exchanger from where it goes to generator. Heat concentrated from solar collector falls on the generator from which water vapours enter the condenser at state 1 and condensate coming out at state 2 enters the expansion valve where the pressure is lowered and water enters evaporator at state 3'. The absorber operates at lower pressure and the pumping of a concentrated liquid mixture of LiBr and H_2O is realized from state 4 to solution heat exchanger and then to the generator at state 5. The weak solution leaves the generator at state 6 to return to the the solution heat exchanger from where it is expanded upto absorber pressure and enters at state 7.

The schematic layout of solar air conditioner has been used to arrive at the dimensional details of all components used in it for the refrigeration capacity needed for the 0.5 Ton air conditioner. The principal governing equations used for mathematical modeling based on energy considerations are as under.

Generator Modelling

Mass balance

$$\dot{m}_5 = \dot{m}_1 + \dot{m}_6$$

Energy balance

$$\dot{Q}_{gen} = \dot{m}_1 h_1 + \dot{m}_6 h_6 - \dot{m}_5 h_5$$

Condenser Modelling

Mass balance

$$\dot{m}_1 = \dot{m}_2$$

Energy balance –

$$\dot{Q}_{cond} = \dot{m}_1 h_1 - \dot{m}_2 h_2$$

Evaporator Modelling

Mass balance

$$\dot{m}_2 = \dot{m}_3 + \dot{m}_8$$

Energy balance

$$\dot{Q}_{evap} = \dot{m}_3 h_3 - \dot{m}_2 h_2 - \dot{m}_8 h_8$$

Absorber Modelling

Mass balance

$$\dot{m}_8 + \dot{m}_4 = \dot{m}_7 + \dot{m}_3$$

Energy balance

$$\dot{Q}_{abs} = \dot{m}_3 h_3 + \dot{m}_7 h_7 - \dot{m}_4 h_4 - \dot{m}_8 h_8$$

Cycle Performance

In this setup, the only input energy is in form of solar energy through a bubble pump, so the

coefficient of performance (COP),

$$\text{COP} = \frac{DESIRED\ EFFECT}{ENERGY\ INPUT} = \frac{\dot{Q}_{evap}}{\dot{Q}_{gen}}$$

Based on the estimations carried out here, the brief description of the components of experimental set up created for solar air conditioning based on LiBr-H_2O vapour absorption refrigeration System is given ahead along with details of materials, and dimensions.

Generator

Generator is used for vaporization of refrigerant using heat available from solar collector. This is made up of steel and withstands the pressure at which refrigerant mixture is charged in it. The other details are given in Figure 2.

Details – Length : 0.4 m, Breadth : 0.4 m, Height : 0.4 m, Material used : Mild Steel

Solar Collector

Parabolic dish collector is used for capturing heat from the solar radiations. The generator is placed at the focus of the collector for carrying out the processes inside utilizing the heat available. The details of parabolic dish collector are as given in Figure 3.

Details – Diameter: 1.5 meter, Material used: Aluminium base with stainless steel taping

Figure 2: Generator

Condenser

Condenser has been got fabricated using copper tubes and suitable fins made up of aluminium. The condenser details are given alongwith Figure 4.

Details: Length:0.4 m, Breadth: 0.10 m,Height: 0.35 m, Material used: Copper(tubing), Aluminium (fins)

Evaporator

Evaporator is shown in Figure 5. It performs the function of creating cooling effect that cools the air being circulated in conditioned space. It has steel body and copper tubing.

Details: Length :1.2 m, Breadth: 0.65 m, Height : 0.4 m The material used : Steel (body), Copper (tubing), Aluminium (fins)

Absorber

Absorber facilitates the return of refrigerant from evaporator and mixing to get the refrigerant mixture suited for being sent to absorber. Figure 6 shows the details of absorber facbricated for this experimental study.

Figure 3: Solar Collector

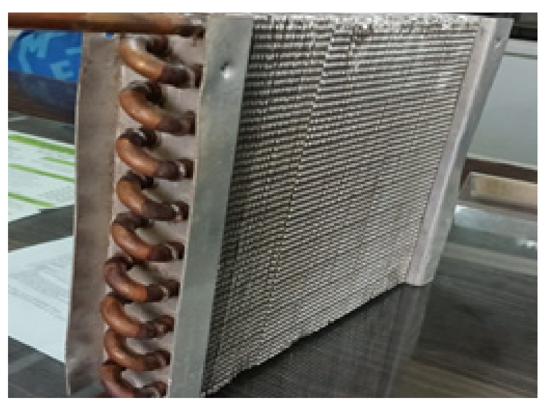

Figure 4: Condenser

Figure 5: Evaporator

Details: Length :0.4 m, Breadth:0.4 m, Height :0.4 m, Material used: Mild steel

Complete Setup

The components that are required for running the refrigeration cycle and indoor room unit were assembled. The outdoor unit included the solar collector, generator, condenser, absorber, pump that are connected with suitable piping. The room unit included evaporator and fan inside it along with controls. Figures 7, 8, and 9 are showing the outdoor unit installed on the roof and Figure 10 demonstrates the indoor room unit.

Figure 6: Absorber

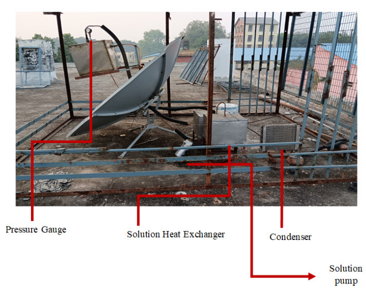

Figure 7: Left side view of Setup

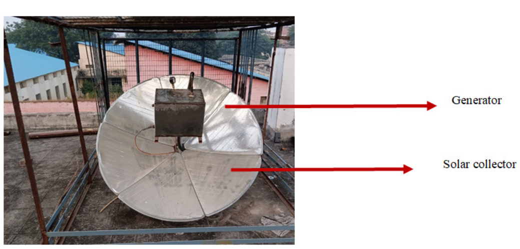

Figure 8: Front view of setup

Figure 9: Pipe arrangement

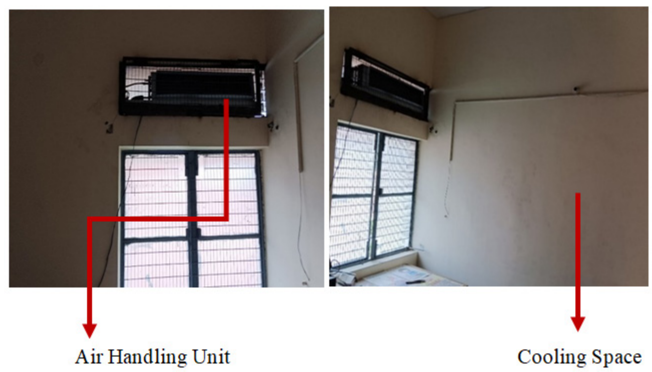

Figure 10: Indoor setup

Results and Discussion

The experimental set up assembled on roof top has been considered for study and the major outcome from the study is presented here. The input parameters considered for the results analysed are given in Table 1.

Variation of Cooling Effect (Qevap) with respect to different Heat Generation (Qgen) at 50% LiBr concentration

Figure 11 shows the effect on variation of cooling effect (Qevap) with respect to different Heat generation at 50% LiBr concentration in solution. The cooling effect (Qevap) keeps increasing as the amount of heat generation from solar collector to bubble pump increases. The cooling effect (Qevap) is directly dependent on mass flow rate of strong solution, which is dependent on volumetric flow rate of vapour refrigerant that depends upon the amount of heat generation from solar collector. As the heat generation increases, the strong solution's mass flow rate increases, resulting in an increase in the cooling effect. At 2.5kW of heat generation, the cooling effect obtained is 1.54kW which is the minimum on the other hand, at 5kW of heat generation, the cooling effect obtained is 3.07kW which is the maximum in this range. The above graph has the values of heat generation taken in 0.5kW interval in range of 2.5 to 5kW to get following cooling effect 1.54 kW, 1.84 kW, 2.14 kW, 2.45 kW, 2.76 kW, 3.07 kW, respectively.

Table 1: Input parameters

S. No.	*Parameters*	*Values*
1	Solar Collector Diameter	1.5 meter
2	Solar Intensity	4.5 kWh/m^2/day
3	Effectiveness of Solar Collector	90%
4	Pressure of Generator	0.0567 bar
5	Pressure of Condenser	0.0567 bar
6	Pressure of Evaporator	0.0102 bar
7	LiBr Concentration	50%
8	Pressure Reducing Valve efficiency	90%
9	Temperature of Generator	70°C
10	Temperature of Condenser	35°C
11	Temperature of Evaporator	7°C
12	Temperature of Absorber	40°C
13	Temperature of Ambient	25°C
14	Specific volume of weak solution	0.00011m^3
15	Specific volume of strong solution	0.0474m^3

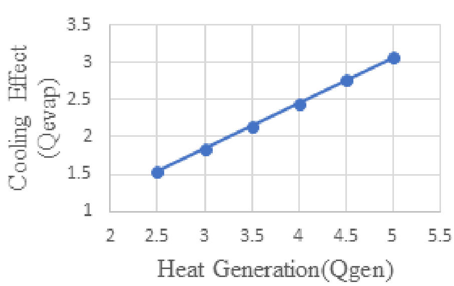

Figure 11: Variation of Cooling Effect (Qevap) with respect to different Heat Generation (Qgen) at 50%LiBr concentration

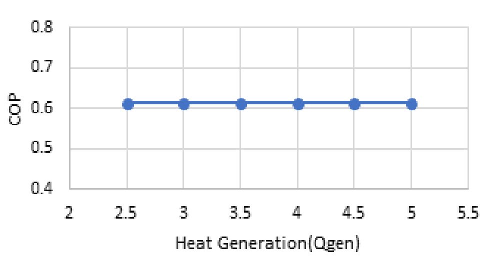

Figure 12: Variation of COP with respect to different Heat Generation (Qgen) at 50%LiBr concentration

Variation of COP with respect to different Heat Generation (Qgen) at 50% LiBr concentration

Figure 12 shows the effect on variation of COP with respect

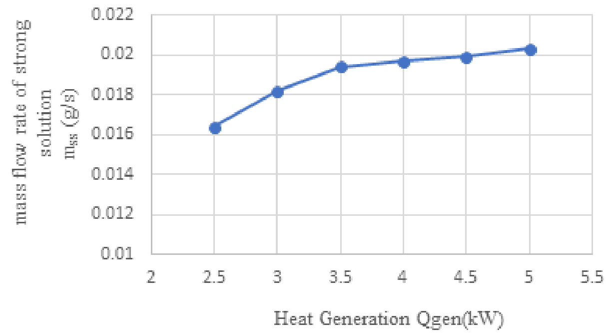

Figure 13: Variation of mass flow rate of strong solution with different heat generation value at 50% LiBr concentration

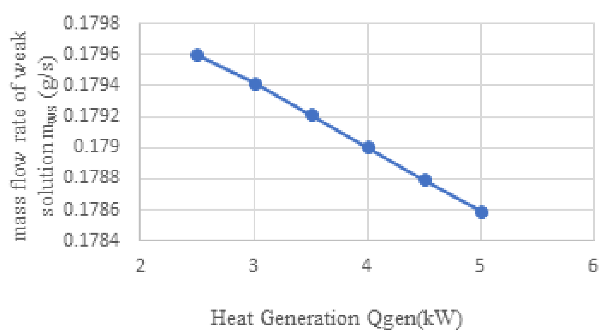

Figure 14: Variation of mass flow rate of weak solution with different heat generation value at 50% LiBr concentration

to different heat generation at 50% LiBr concentration in solution. It is seen that on increasing the value of heat generation from solar collector, the COP of the setup is obtained as constant i.e., 0.61. The reason behind the constant nature of graph is that COP is ratio of Qevap to Qgen. Both values are directly dependent on mass flow rate of the strong solution (m_{ss}). So upon increasing the heat generation rate, the mass flow rate starts to increase, affecting both parameters equally in ratio. This results in obtaining the ratio constant. The heat generation values are taken in an interval of 0.5kW in range of 2.5kW to 5kW to get the COP 0.61, respectively.

Variation of mass flow rate of strong solution (m_{ss}) with respect to different heat generated at 50% LiBr concentration

Figure 13 shows the variation of strong solution mass flow rate with respect to different heat generation values. Since increasing heat generation, the mass flow rate of strong solution starts to increase because heat generation is responsible for the volumetric flow rate of vapour refrigerant.

Variation of mass flow rate of weak solution (m_{ss}) with respect to different heat generated at 50% LiBr concentration

Figure 14 shows the variation of weak solution mass flow rate with respect to different heat generation values. Upon increasing heat generation, the mass flow rate of strong solution starts increasing and the weak solution flow rate droops down.

Conclusions

The results demonstrate that the cooling effect (Qevap) starts to increase with an increase in heat generation (Qgen). The COP of setup is independent of few parameters. On increasing the heat generation value, mass flow rate of the strong solution starts to increase while mass flow rate of the weak solution starts to decrease at a nominal rate. For enhanced efficiency of the whole system, it is also proposed to equip solar dish collectors with a tracking system for proper tracking of solar radiations. Pressure variation at the evaporator may give a different rate of evaporation, which affects the COP of the setup could be attempted. Also, the energy storage with the setup is a better idea for getting the refrigeration effect throughout the day.

Acknowledgment

Authors gratefully acknowledge the funding received from the Council of Science and Technology U.P. under the research project titled “Development of low capacity and cost-effective solar air conditioner”.

References

[1] Rahman, S., Said, Z., & Isa, S.(2020). Performance evaluation and life cycle analysis of new solar thermal absorption air conditioning system. *Energy Reports,* 6, 673-679.

[2] Sokhansefat, T., Mohammadi, D., Kasaeian, A., & Mahmoudi, A.R. (2017). Simulation and parametric study of a 5-ton solar absorption cooling system in Tehran. *Energy Conversion and Management*, 148, 339-351.

[3] Sharawi, V., Kosmopoulos, P., & Papadopoulos, A. (2016). Solar cooling system using concentrating collectors for office buildings: A case study for Greece. *Renewable Energy*, 97, 697-708.

[4] Solano–Olivares, K., Romero, R., Santoyo, E., Herrera, I., Galindo–Luna, Y., Rodríguez Martínez, A., Santoyo-Castelazo, E., & Cerezo, J. (2019). Life cycle assessment of a solar absorption air conditioning system, *Journal of Cleaner Production*, 240, 118206.

[5] DeVault, R C, Marsala, J, & TECOGEN, Inc., Waltham, MA. Ammonia-water triple-effect absorption cycle. United States.

[6] Shelton, Sam, Stewart, Susan, Erickson, D., & Schäfer, Laura. (2002). Bubble Pump Design for Single Pressure Absorption Refrigeration Cycles. *ASHRAE Transactions*, 108, 867-876.

[7] Mohammadi, K., Efati Khaledi, M. S., & Powell, K. (2019). A novel hybrid dual-temperature absorption refrigeration system: Thermodynamic, economic, and environmental analysis. *Journal of Cleaner Production*, 233, 1075-1087.

[8] Bi, Y., Qin, L., Guo, J., Li, H., & Zang, G. (2020). Performance analysis of solar air conditioning system based on the independent-developed solar parabolic trough collector. *Energy*, 196, 117075.

[9] Shelton M, Chahbani MH, Guizani A. (2008). Feasibility of solar absorption air conditioning in Tunisia. *Building and Environment*, 43,1459-1470.

[10] Cheng, F., Wu, Y., & Li, X. (2020). Research on regeneration performance of the solar steam method for absorption air-conditioning system. *Applied Thermal Engineering*, 178, 115576.

[11] Balghouthi, M., Chahbani, M., & Guizani, A. (2012). Investigation of a solar cooling installation in Tunisia. *Applied Energy*, 98, 138-148.

[12] Benhmidene, A., Hidouri, K., Chaouachi, B., Gabsi, S., & Bourouis, M. (2016). Experimental investigation on the flow behaviour in a bubble pump of diffusion absorption refrigeration systems. *Case Studies in Thermal Engineering*, 8, 1-9.

[13] Zhao, B., Li, Y., Wang, R., Zhao, Z., & Taylor, R. (2018). A universal method for performance evaluation of solar photovoltaic air-conditioner. *Solar Energy*, 172, 58-68.

[14] Aman, J., Henshaw, P., & Ting, S-K D. (2018). Bubble-pump-driven LiBr-H_2O and LiCl-H_2O absorption air-conditioning systems. *Thermal Science and Engineering Progress*, 6, 316-332.

[15] Paurine, A., Maidment, G., Eames, I., & Missenden, J. (2012). Development of a thermo-gravity pumping mechanism for circulating the working fluids in a novel LiBr–H_2O vapour absorption refrigeration (VAR) system. *Applied Thermal Engineering*, 47, 25-33.

[16] Ben Ezzine, N., Garma, R., Bourious, M., Bellagi, A. (2010). Experimental studies on bubble pump operated diffusion absorption machine based on light hydrocarbons for solar cooling. *Renewable Energy*, 35, 464–470.

[17] Chaves, F. D., Moreira, M. F. S., Kouryc, R. N., Machado, L. & Cortezc M. F. B. (2019). Experimental study and modeling within the validation of a diffusion absorption refrigerator. *International Journal of Refrigeration*,19, 30033-30037.

[18] Anand, S., Gupta, A., Anand, Y., & Tyagi, S. (2016). Use of process steam in vapor absorption refrigeration system for cooling and heating applications: An exergy analysis. *Cogent Engineering*, 3, 1160639.

[19] Aman J., Henshaw P., & Ting D.S-K. (2018). Performance characterization of a bubble pump for vapor absorption refrigeration systems. *International Journal of Refrigeration*, 58-69.

[20] Jemaa, R., Mansouri, R., Boukholda, Ismail., Bellagi. (2017). Experimental characterization and performance study of an ammonia–water–hydrogen refrigerator. *International Journal of Hydrogen Energy*, Volume 42, Issue 13, 8594-8601.

[21] Zohar, A., Jelinek, M. , Levy, A., & Borde, I. (2007). The influence of diffusion absorption refrigeration cycle configuration on the performance, *Applied Thermal Engineering*, 27, 2213–2219.

[22] Bellos, E., Tzivanidis, C., & Tsifis, G. (2017). Energetic, Exergetic, Economic and Environmental (4E) analysis of a solar assisted refrigeration system for various operating scenarios, *Energy Conversion and Management*, 148, 1055-1069.

[23] Kilic, M., & Kaynakli, O. (2007). Second law-based thermodynamic analysis of water-lithium bromide absorption refrigeration system, *Energy*, 32, 1505-1512.

[24] Solano–Olivares, K., Romero, R., Santoyo, E., Herrera, I., Galindo–Luna, Y., Rodríguez Martínez, A., Santoyo-Castelazo, E., & Cerezo., J. (2019). Life cycle assessment of a solar absorption air conditioning system. *Journal of Cleaner Production*, 240, 118206.

[25] Soltani, M., Ansari, M. & Taghavi, S.M. (2006). Designing and building a solar absorption chiller. *Journal of Air Conditioning Refrigeration*, 17, 67–82.