Analecta Technica Szegedinensia

Vol. 17, No. 1 ISSN 2064-7964 2023

DEVELOPMENT OF A SOLAR-POWERED VAPOUR ABSORPTION COOLING SYSTEM

[1]*Taye Stephen Mogaji*

[1] Department of Mechanical Engineering, Federal University of Technology Akure, School of Engineering and Engineering Technology, P.M.B. 704, Ondo State, Nigeria
e-mail: tsmogaji@futa.edu.ng

ABSTRACT

In this paper, a performance evaluation of a developed Solar-Powered Vapor Absorption Refrigeration (VAR) System using the NH_3-H_2O solution as a working fluid is done. The cooling system has a total storage space of 0.038 m^3 with the capacity to accommodate about 0.04 metric tonnes (40kg) of items, such as cool water and other drinks for human comfort, applicable in rural regions where electricity is unreliable or non-existent. A solar Photovoltaic (PV) panel of 300W, 40 W Direct Current (DC) heating element with a 20A solar controller was designed to power the developed cooling system. Measurements of important operational parameters such as the generator, ambient, evaporator, cabinet and condenser temperatures were studied and measured from the system. Performance evaluation of the system refrigerating capacity was determined in terms of its cooling performance (COP) and the system efficiency ratio (η) based on no load and on load conditions. The system, when tested, has COP of 0.1275 at an average cabinet temperature (Tr) of 9.0 ºC against an average room temperature of 25.8 ºC. Additionally, the system had an overall refrigerating efficiency ratio of 8.25. The performance test results revealed that the developed cooling system performed well in terms of temperature regulation for refrigeration purposes.

Keywords: Vapour absorption, Coefficient of Performance, refrigerating efficiency ratio, Solar-powered, NH_3-H_2O

1. INTRODUCTION

The quest to reduce problems related to environmental issues, such as the so-called greenhouse effect observed from using Vapor Compression Refrigeration (VCR) systems due to CO_2 emission from the combustion of fossil fuels cum required high grade energy (mechanical or electrical) for their operation, have led to more research interest in the development of low grade energy and environmentally-friendly refrigeration system. According to Mali et al. [1], Refrigeration technologies, recognised as one of the outputs of thermal engineering development technology, play an important role in today's industrial applications. As pointed out in the research work of Bangotra and Mahajan [2], Refrigeration is the process of removing heat from an enclosed space or from a substance and moving it to a place where it is unobjectionable. Numerous reports from open kinds of literature revealed that conventional vapour compression refrigerators are the most common and popular method of cooling systems which are effectively powered using electrical energy. It is noteworthy to point out that grid electricity is far from available in many parts of the world today, especially in rural areas. According to Agrouaz et al. [3], Vapor compression air-conditioning systems used in building for human comfort cause a significant consumption of electrical energy in many parts of the world. It is also known that electrical energy remains a scarce commodity in many developing countries, and the effect of its source on the environment is not making the use of cooling systems for human comfort and industrial processes effective. Moreso that the fossil fuel upon which people depend is getting depleted Elyas et al.[4], Moreover, it costs more to explore, making the product cost more by the day. Similarly, Allouhi et al. [5] reported that most vapour compression systems commonly use Chloro-Flouro-Carbon and Hydro-Chloro-Flouro-Carbon refrigerants with a high negative impact on the environment. It is therefore, vital to come up with ideas for energy-efficient and environmentally friendly cooling systems, especially with the aid of exploring the largely untapped solar energy resources available in our environment. Solar energy is a very large inexhaustible source of energy obtained from the sun's radiation. It can be harnessed in multiple ways, such as heat energy by using solar thermal technologies and electrical energy by the use of photovoltaic cells Akinola et al. [6]. To improve

DOI: 10.14232/analecta.2023.1.28-43

energy efficiency in providing thermal comfort for people in hot areas of the world and for providing food preservation facilities, a solar cooling system seems to be an interesting alternative. By taking into consideration the best idea of an absorption cooling system regarding cope with the energy crisis, as pointed out by Meraj et al. [7] cum the fact that the vapour absorption cooling system is environmentally friendly and its operating cost is less compared to that of vapour compressor cooling system as reported in the studies of Aamir *et al*. [8] and Sathiamourtty et al. [9], the absorption system appears to be one of the most promising solar cooling system methods. An absorption refrigeration system is a system that operates based on an absorption process using a heat source such as solar energy to provide the required energy needed to drive its cooling process Sathiamourtty et al. [9]. Experimental and theoretical research on vapour absorption refrigeration has been reported in the previous studies of Aphornratana and Eames [10] and Aphornratna and Sriveerakul [11]. The performance of an absorption refrigeration cycle powered by various sources, namely electricity, LPG (methane) and renewable energy sources, was assessed by Alsaqoor and AlQdah [12]. An ammonia-water absorption cycle was used. The results showed that when the cycle was driven by electricity, the coefficient of performance ranged from 0.694 to 1.032 and the generator temperature hovered between 48.1˚C to 101.5˚C with an average efficiency of 57.1%, and the average coefficient of performance of 0.78 was achieved by the authors. Similarly, in carrying out a performance investigation of a solar absorption refrigeration system, Abdulateef et al. [13], in their study, achieved a COP of 0.6 and a refrigeration capacity of 1.5 tons. Al-Hemiri and Nasiaf [14] conducted studies on the COP for solar absorption refrigeration by using direct solar energy using aqueous ammonia 0.45 mass fraction (ammonia – water). The results showed that the maximum generator temperature was between 92°C and 97°C and the minimum evaporator temperature was between 5°C and 10°C. The coefficient of performance ranged between 0.1096 and 0.2396 was also achieved by the authors. A novel solar-powered vapour absorption refrigeration system was investigated by Velmurugan et al. [15]. The system cooling capacities were found to be between 100W and 180W, with a COP between 0.09 and 0.15. Bajpai [16], in his work, designed, constructed and tested a solar-powered vapour absorption system. The system was powered by hot water coming from a solar flat plate water heater. The generator temperature of 84°C and the theoretical COP of the system were established to be 0.58. On average bases, COP of 0.118 was also obtained experimentally by Mondal et al. [17] in carrying out a performance evaluation of a designed and constructed solar-driven ammonia absorption refrigeration system in their study. Said et al. [18] designed and constructed a solar-powered ammonia-water absorption refrigeration system in Saudi Arabia. The results of the experiments indicated a chiller coefficient of performance (COP) of 0.69 and a cooling capacity of 10.1 kW at 114/23/−2 (°C), representing the temperatures of the generator inlet, the condenser/absorber inlet and the evaporator outlet respectively. A daily average solar collector efficiency of 0.35 with an average daily COP of 1.175, including a solar heat fraction of 0.75 and a solar cooling ratio of 0.44.was achieved in the study of Bangotra and Mahajan [2], who tested a solar cooling plant in Seville, Spain, between 2008 and 2009. Gandhi and Arakerimath [19] developed an aqua-ammonia vapour refrigeration system powered by a parabolic solar dish collector. During system tests, the temperature of the evaporator floated between 7 and 8 degrees Celsius. The average COP of the system hovered between 0.75 and 0.79. The maximum COP of the system hovered between 3 and 3.5. Sharma et al. [20] compared the performance of solar photovoltaic refrigeration systems using two different cycles: vapour compression and vapour absorption. The results showed that in comparison to the vapour compression system, the vapour absorption system took more time to decrease the temperature of the cabinet. In evaluating the effects of generator inlet temperature, the effectiveness of the solution heat exchanger and the pumped mass flow rate on the energetic and exergetic performance of a solar-powered chiller system, Esa et al. [21] carried out energetic and exergetic analysis of Solar-Powered Lithium Bromide-Water Absorption Cooling System. In addition to the fact that the results from their study revealed that an evacuated selective surface collector type has higher efficiency and more useful heat gain than the single and double-glazed collector types, the authors also found that 7.1% of the inlet exergy was lost in the generator which was equivalent to 8.3% of the total exergy loss.

DOI: 10.14232/analecta.2023.1.28-43

In this study, a solar-powered vapour absorption refrigeration (VAR) system is developed, considering the use of ammonia water as the refrigerant-absorbent pair. The research is conducted to instate the unique efficiency of utilising solar photovoltaic (PV) panels in powering a vapour absorption refrigeration (VAR) system. Performance evaluation was carried out to assess the refrigerating capacity of the cooling system in terms of its cooling performance (COP) and the system efficiency ratio (ɳ). The study's finding thus confirmed that in today's world, where energy consumption is ever on the increase, absorption technology powered by renewable energy would be a useful alternative cooling solution.

2. MATERIALS AND METHODS

2.1. Design Considerations

A vapour absorption refrigeration (VAR) system of 40 litres capacity cooling space that can accommodate about 0.04 metric tonnes (40kg) of items such as cool water and other drinks was constructed. To aid easy mobility of the cooling system, a moderately sized box of 450 mm height, 330 mm wide and 255 mm long is constructed in this work

2.2. Determination of Cooling Load Capacity

The total cooling load (Q_{total}) required for the cooling system is estimated by adding the Transmission Load (TL) and the Product Load (PL) of the cooling system given as:

$$Q_{total} = TL + PL \tag{1}$$

Transmission load (TL): This is the sensible heat gain through the walls of the refrigerated space. Transmission load is dependent on the constituent materials that make up the said space and the surface area. Mathematically, it is given as:

$$Q_1 = UA\Delta t \tag{2}$$

Where, Q_1 is the sensible heat gain, W, A is the total surface area of the cooling box, m^2 obtained as 0.07m^2 using Eq. (3), Δt is the difference between external temperature, T_O, °C and temperature of refrigerated space, T_I, °C as presented in Figure 1 and determined as 20 °C using Eq.(4) while U is the overall heat transfer coefficient, W/mK obtained using Eq.(5)

$$A = 2(hwl) \tag{3}$$

$$\Delta t = T_O - T_I \tag{4}$$

$$U = \frac{1}{\frac{1}{h_o} + \frac{L_M}{K_M} + \frac{L_P}{K_P} + \frac{L_R}{K_R} + \frac{1}{h_i}} \tag{5}$$

Where, h_o = 11.6W/m^{2}K and h_i=14.5 W/ m^{2}K are constants extracted from the study of Akintunde and Obadina [22]. L and K are values of thickness and coefficient of thermal conductivity of Mild steel (M), Plastic (P) and Rigid Polyurethane foam (R), respectively, as presented in Table 1.

DOI: 10.14232/analecta.2023.1.28-43

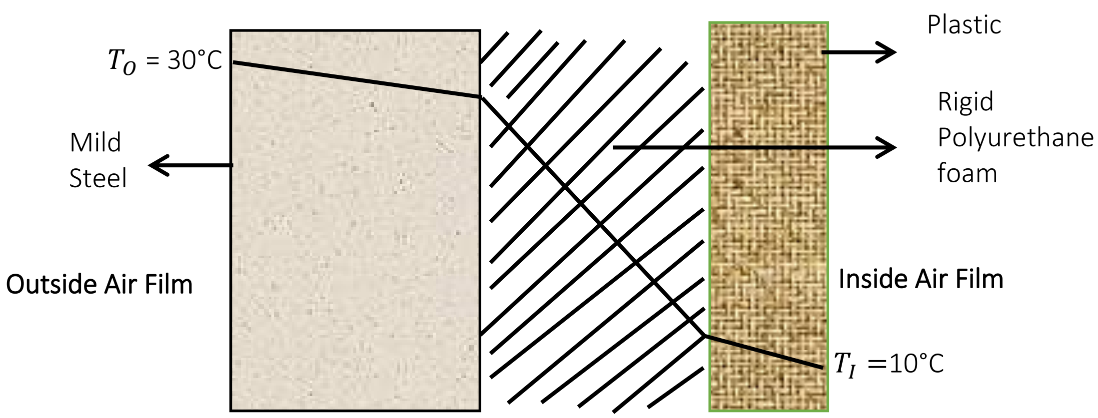

Figure 1. Section through the cabinet wall

Table 1. Properties of Materials for the Refrigeration Wall Design

Material	Thermal conductivity (W/m.K)	Thickness, L (mm)
Mild steel (M)	K_M = 46.5	L_M = 2
Plastic (P)	K_P = 0.035	L_P = 1
Rigid Polyurethane foam (R)	K_R = 0.025	L_R = 38

Implementing the obtained properties of the refrigeration wall materials, the overall heat transfer coefficient U given in Eq. (5) is calculated as 0.5870 W/m^{2}K. Substituting the obtained parameters values in Eq. (1), the sensible heat gain Q_1 is estimated to be 8.2 W

Product load (PL): This is the primary refrigeration load from products kept in the refrigerated space. It includes, most importantly, heat to cool the product from the initial temperature to some lower temperature above the freezing point and is given as:

$$Q_2 = mc_1\Delta t \tag{6}$$

Where, Q_2 is the heat removed, kJ, m is the mass of the proposed product to be stored at a time = 40kg, c_1 is the specific heat of product = 4200 J/(kg.K), Temperature difference, $\Delta t = (30 - 10)^oC$ = *20 ºC*. The heat removed from the stored product using Eq. (6) is calculated as 3360 kJ

Thus, the designed product load of the cooling system for a period of 12 hours is obtained as follows:

$$Q_2 = \frac{mc_1\Delta t}{12hours} \tag{7}$$

It is thus obtained as 77.8 W. Hence, the total estimated cooling load capacity of the cooling system is obtained using Eq. (1) as 86W

2.3. Design of the Vapour Absorption Refrigeration (VAR) System

The total cooling load of 86 W obtained for the system cooling load capacity is considered for designing the VAR system in this work. Presented in Figure 2 is the schematic diagram of a typical VAR system used

DOI: 10.14232/analecta.2023.1.28-43

Analecta Technica Szegedinensia

Vol. 17, No. 1 ISSN 2064-7964 2023

in this study. From the Figure, a strong solution (ss) is a mixture of refrigerant and absorbent; which in this case is ammonia and water, while a weak solution (ws) is ammonia with little traces of water vapour

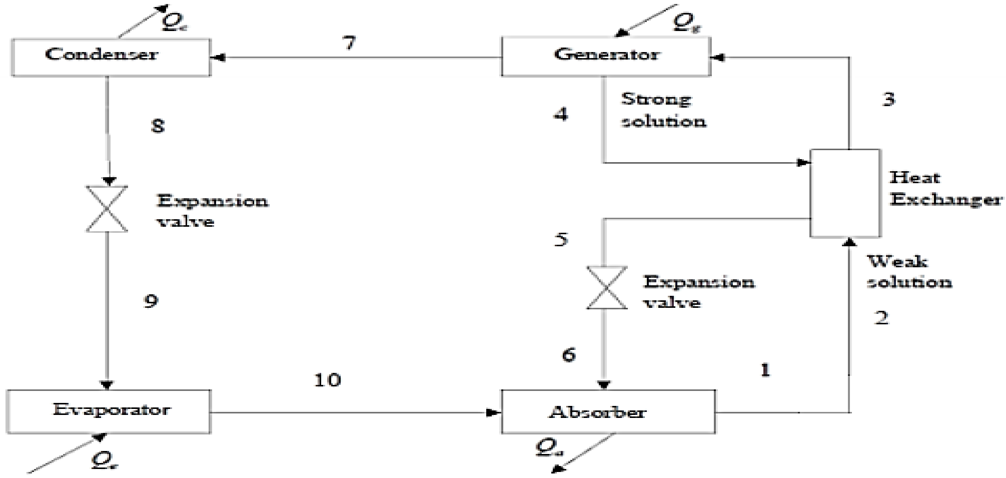

Figure 2. Schematic diagram of vapour absorption refrigeration system

Design of Generator–Absorber: The generator-absorber system was designed by applying the principle of total mass balance given as:

$$m + m_{ss} = m_{ws} \tag{8}$$

Where m is the mass flow rate of refrigerant, kg/s, m_{ss} is the mass flow rate of a strong solution, kg/s, m_{ws} is the mass flow rate of weak solution, kg/s

Thus, the heat transfer at the absorber (Q_a) is calculated considering the total mass balance principle as follows:

$$Q_a = mh_{10} + m_{ss}h_6 - m_{ws}h_1 \tag{9}$$

Where, h_1, h_6, and h_{10} are enthalpies of ammonia at their respective located points as shown in Figure 2

Similarly, heat transfer at the generator (Q_g) is obtained as:

$$Q_g = mh_7 + m_{ss}h_4 - m_{ws}h_3 \tag{10}$$

Where, h_3, h_4 and h_7 are enthalpies of ammonia at their respective points, as shown in Figure 2

Design of the evaporator: By applying the mass balance principle for the evaporator component in this work, as shown in Figure 2, we have:

$$m_9 = m_8 = m \quad \text{(kJ/s)} \tag{11}$$

The heat transfer at the evaporator is thus calculated as follows:

Analecta Technica Szegedinensia
Vol. 17, No. 1 ISSN 2064-7964 2023

$$Q_e = m(h_9 - h_8) \tag{12}$$

Where h_8 and h_9 are enthalpies of ammonia at their respective located points shown in Figure 2.
The surface area of the evaporator, which determines the size of the evaporator component, is calculated using Equation (13) extracted from the study of Bangotra and Mahajan [2] given as follows:

$$A_e = \frac{Q_e}{F_e U_e \theta_{me}} \tag{13}$$

Where θ_{me} is the Logarithmic mean temperature difference (LMTD) *calculated as* 8.3°C using Eq. (14) by taking $T_A = 60°C - 30°C = 30°C$; *and* $T_B = 2°C - 0°C = 2°C$, Overall heat transfer coefficient (U) = 1000 W/m^2 *and* Correction factor (F) = 1

$$\theta_{me} = \frac{\Delta T_A - \Delta T_B}{\ln T_A - \ln T_B} \tag{14}$$

Thus, by using Eqn. (13), A_e is obtained as 0.017m^2
Design of the condenser: Similarly, considering the mass balance principle using Eqn. (15) for the condenser component in this work, according to Figure 2, by taking Overall heat transfer coefficient (U) = 1000 W/m^2 *and* Correction factor (F) = 1 and implementing $T_A = 30°C - 0°C = 30°C$; *and* $T_B = 60°C - 50°C = 10°C$, in Eqn. (13) the surface area of the condenser is calculated as follows:

$$m_7 = m_8 = m \qquad \text{(kJ/s)} \tag{15}$$

Thus, the heat transfer at the condenser is calculated as follows:

$$Q_c = m(h_7 - h_8) \tag{16}$$

$$A_c = \frac{Q_e}{F_c U_c \theta_{me}} \tag{17}$$

Hence, the surface area of the condenser (A_c) is determined as 0.024m^2

2.4. Selection of photovoltaic (PV) solar panel

The photovoltaic (PV) solar panel was selected, assuming that the refrigeration system would run for 12 hours daily. Therefore, for a 86W rated refrigerator, the energy requirement (E_{req}) is calculated as follows:

$$E_{req} = 86W * 12\,hours/day = 1{,}032Wh/day \tag{18}$$

Thus, the PV array size required to store the energy needed from sun radiation while using 5.21 hours per day as sunlight availability for Akure city in Ondo state, Nigeria, as reported by Melodi and Famakin [23] is obtained as follows:

DOI: 10.14232/analecta.2023.1.28-43

$$PV\ array\ size\ needed = \frac{Total\ Energy\ needed\ \ per\ day}{Available\ Sun\ hours\ per\ day} = \frac{1{,}032\ Wh/day}{5.21\ h/day} = 198.08\ \text{Watts} \tag{19}$$

In order to ensure the maximum solar efficiency to run the developed VAR system for use in moderate sunshine weather conditions, a solar power panel with a higher capacity of 300 W is selected in this work.

2.5. Determination of Battery Size

The battery size is obtained as a function of the Ampere rating, and therefore the amount of current to be delivered by the battery is calculated as follows:

$$I = \frac{\text{Total Refrigerator load}}{\text{Battery Voltage}} \tag{20}$$

Where the total refrigerator load is 1,032Wh/day and the Battery Voltage is 12V. Thus, the daily current needed to run the cooling system using Eqn. (20) is obtained as 12 Ah. Based on the estimated daily current needed to run the cooling system in this study, a higher rated battery of 24Ah battery was selected to aid the effectiveness of the system.

2.6. CAD designs and operation of the Solar Powered VAR system

An assembled Isometric view of the cooling system and selected solar equipment are given in Figures. 3 and 4. The designed VAR system efficiency is a function of available sun intensity at a particular point in time. The accumulated energy stored in the 24Ah 12V battery is regulated by a solar controller and effectively powered by a Solar P.V set, the A D.C. Heating Element in the generator unit of the vapour absorption cooling system in operation. Once the Heating Element is adequately heated, the refrigerant in the generator unit begins to vaporise and then flows through the condenser. In the condenser, the refrigerant gives off heat and is converted to liquid. The refrigerant now of low temperature and low pressure enters the evaporator. In the evaporator, the refrigerating effect is produced. The liquid refrigerant gets converted back into vapour once it leaves the evaporator. The refrigerant then gets absorbed by the absorbent in the absorber unit of the cooling system. The mixture of both fluids (absorbent and refrigerant) flows back to the generator by gravity, where the vaporisation of the refrigerant begins again to continue the cycle.

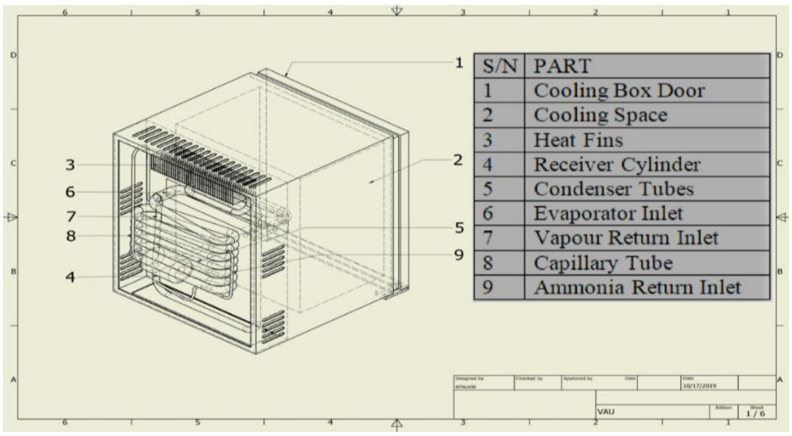

Figure 3. Assembly Drawing of the Solar-Powered VAR System

DOI: 10.14232/analecta.2023.1.28-43

Analecta Technica Szegedinensia
Vol. 17, No. 1 ISSN 2064-7964 2023

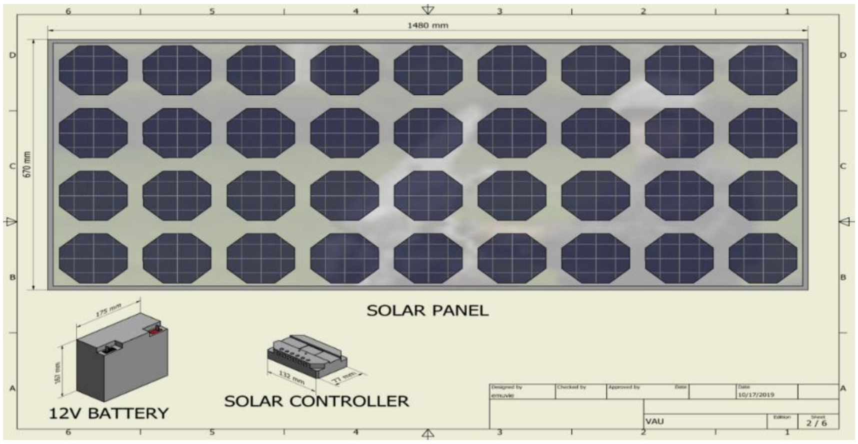

Figure 4. Solar Equipment kits for the VAR System

2.7. Apparatus and experimental Set-Up

The temperature measurements at the generator (Tg), evaporator unit (Te), and condenser unit (Tc) were performed, including the ambient (Ta) and the cabinet temperature (Tr) were also measured by using a digital thermometer as shown in Figure 5. The experiment was carried out using the developed VAR system on no load condition for 2 days. The system was also used on loaded conditions to cool stored products sample for a period of 2 days, as shown in Figure 6. During the testing period condition, five thermometer sensors were placed to measure Tg, Ta, Te, Tr and Tc. The significant difference between testing on load and no load is the substance to be cooled. In this study, the used substance in the experimental no load process is air, while that of on load condition is water. Shown in Figure 7 is the obtained cold water ready for consumption at 9.3°C using the developed VAR system in this study.

Figure 5. Vapour Absorption Cooling System developed under testing period condition

DOI: 10.14232/analecta.2023.1.28-43

Figure 6. Tested bottled Water samples inside the developed VAR System in this study

Figure 7. The temperature of cold water obtained using the developed VAR System in this study

3. RESULTS AND DISCUSSION

Experimental studies were conducted to determine the efficiency of the cooling system. The system was tested over a 2day period respectively on no-load and on load conditions. The following parameters were measured between 8:00 am to 8:00 pm on each testing day: the temperature at the generator (Tg), room temperature (Ta), the temperature at the evaporator unit (Te), the temperature within the cooling cabinet (Tr) and temperature at the condenser (Tc).

3.1. Performance of the Vapour Absorption Refrigeration System without Load

The performance of the developed cooling system was done on no-load conditions for days 1 and 2, respectively. Ambient temperature (Ta), generator temperature (Tg), evaporator temperature (Te), condenser temperature (Tc) and temperature of the refrigerated space (Tr) were all recorded as presented in Tables 3 and 4. The results from Tables 3 and 4 revealed that both recorded Tg and Tc are observed to be increasing with the time changing as expected. This behaviour indicates effective heat rejected out of the cooling system in operation with the aid of the designed/selected condenser component of the developed AVR system in this study. It is also noticed that the cabinet considered in this research experience constant Tr temperature between 25.8°C and 21.4°C for the first five hours of the test achieving the lowest temperature condition of about 5°C at the 10th hour of the test and thereafter maintaining an appreciable drop in temperature for the rest hours of testing the cooling system. The observed appreciable low temperature of the cooling system is a result of the effective functioning of the cooling system generator component unit that peaked up agitatedly to produce the expected vaporise refrigerant from about an average of 160 Tg of the developed cooling system in operation. The observed temperature evolution behaviour of the cooling system is similar to those observed in the study of Sharma et al. [20]. The performance test results revealed that the system performed well in temperature regulation for cooling commodities such as drinking water/beverages. Additionally, the above-freezing point temperature control condition of the AVR system attained in this study will also be profitable for fresh fruit preservation. The achieved above-freezing point temperature result in this work is in agreement with those attained by Akintunde and Obadina [22], who established that storage of farm produce is most effective at a temperature just above the freezing point.

Table 3. Evaluation results for no-load testing for day 1

Clock time	System Temperatures in °C				
	Ambient (T_a)	**Generator (T_g)**	**Evaporator (T_e)**	**Cabinet (T_r)**	**Condenser (T_c)**
08:00	29.1	29.0	25.3	25.8	22.4
09:00	29.1	90.4	25.3	25.8	22.4
10:00	29.1	115.7	25.3	25.8	22.4
11:00	30.2	132.1	25.2	25.8	22.0
12:00	31.7	149.7	24.0	25.4	31.5
13:00	31.6	155.4	19.2	22.3	36.7
14:00	31.8	157.8	15.6	18.2	39.6
15:00	31.5	165.3	11.7	13.7	40.5
16:00	31.9	168.8	8.6	9.8	55.3
17:00	30.2	167.2	6.4	7.8	58.6
18:00	30.1	165.0	4.0	6.7	60.8
19:00	29.4	141.5	6.8	7.2	47.4
20:00	29.1	120.6	12.2	8.4	41.6

DOI: 10.14232/analecta.2023.1.28-43

Table 4. Evaluation results for no-load testing for day 2

Clock time	System Temperatures in °C				
	Ambient (T_a)	Generator (T_g)	Evaporator (T_e)	Cabinet (T_r)	Condenser (T_c)
08:00	29.4	29.1	25.0	25.8	22.8
09:00	29.4	90.3	25.0	25.8	22.8
10:00	29.4	114.0	25.0	25.8	22.8
11:00	30.1	131.6	24.9	25.8	22.8
12:00	31.6	147.5	24.3	25.8	32.6
13:00	31.7	158.7	19.4	20.6	38.4
14:00	32.0	162.2	16.3	18.2	43.7
15:00	32.4	168.5	10.5	12.1	43.9
16:00	32.1	168.6	8.4	11.2	54.6
17:00	30.6	167.2	5.2	6.5	59.1
18:00	29.7	166.3	3.8	4.7	61.8
19:00	29.2	139.6	6.4	7.8	50.6
20:00	28.5	118.2	10.2	8.7	42.0

3.2. Performance of the Vapour Absorption Refrigeration System with LOAD

The performance of the developed cooling system on load was evaluated over two days using drinkable bottled water, as shown in Figure 6. The recorded cooling system temperature values during the testing period are shown in Tables 5 and 6, respectively. The results from tables 5 and 6 revealed recorded optimum temperatures that occurred at tenth hour of testing the cooling system for both the evaporator and condenser unit. As shown in table 5 it can be noticed that the lowest temperature values of 8.7°C and 9.3°C were recorded respectively within the refrigerated space of the developed VAR system in this work. This typical behaviour is similar to that observed in the study of Mogaji [24]. Generally, it can be noted that the developed solar-powered Vapour Absorption Refrigeration System functions quite reliably during the day. Additionally, this behaviour indicates that the cooling system performed well in terms of temperature regulation above freezing point and could also be a useful storage system for preserving fresh fruits from waste, especially in many rural regions where electricity is unreliable or non-existent.

DOI: 10.14232/analecta.2023.1.28-43

Table 5. Evaluation results for load testing for day 1

Clock time	System Temperatures in °C				
	Ambient (T_a)	Generator (T_g)	Evaporator (T_e)	Cabinet (T_r)	Condenser (T_c)
08.00	29.3	28.2	25	26.1	23.9
09.00	29.3	91.6	25.2	26.1	23.9
10.00	29.3	112.9	25.2	26.1	23.9
11.00	30.1	128.5	25.2	26.1	24.2
12.00	31.6	150.0	24.6	25.4	30.7
13.00	31.7	151.8	19.7	21.3	36.7
14.00	31.9	166.0	18.4	18.6	40.6
15.00	31.9	169.4	12.3	12.5	48.7
16.00	31.9	170.1	11.1	10.8	52.5
17.00	30.1	175.6	10.6	10.1	54.6
18.00	30.1	171.1	8.9	8.7	58.4
19.00	29.4	154.6	11.4	11.6	53.4
20.00	28	132.7	13.6	13.8	47.5

Table 6. Evaluation results for load testing for day 2

Clock time	System Temperatures in °C				
	Ambient (T_a)	Generator (T_g)	Evaporator (T_e)	Cabinet (T_r)	Condenser(T_c)
08:00	28.6	28.4	24.0	25.1	24.0
09:00	28.6	87.5	24.0	25.1	24.2
10:00	28.6	109.6	24.0	25.1	24.6
11:00	29.1	125.4	24.0	25.0	24.6
12:00	30.0	146.7	24.0	25.0	30.0
13:00	30.0	150.0	19.7	20.2	35.4
14:00	30.0	163.4	17.5	18.9	39.3
15:00	30.5	170.8	13.2	14.5	45.6
16:00	30.6	171.1	10.8	12.6	53.0
17:00	29.8	172.7	10.2	11.4	55.8
18:00	29.6	171.0	9.1	9.3	59.7
19:00	29.2	162.4	11.5	11.9	55.5
20:00	28.2	148.5	13.9	14.3	47.6

DOI: 10.14232/analecta.2023.1.28-43

Analecta Technica Szegedinensia
Vol. 17, No. 1 ISSN 2064-7964 2023

3.3. A comparison of the pattern of temperature changes of load and no-load conditions of the developed cooling system

Analysing the effect or impact of load on the cooling performance behaviour of the system, the average temperature evolution observed for two days in conducting tests using the developed cooling system under no-load and loaded conditions is presented in Figure 8. The result from this Figure revealed that the system Tg on no-load peaked earlier by about fourth hours compared to when the system was loaded. This behaviour is due to more heat needed in the generator to produce effective vaporised refrigerant in the system to aid the cooling process of the stored products. It is also observed that the temperatures of the Te and Tr followed a similar pattern maintaining appreciable low temperature conditions sufficient enough to cool/preserve the stored products as expected. This behaviour indicates the occurrence of annular flow pattern condition of the working fluid, thus aiding the high evaporation process through the thin film thickness of the working fluid on the tube's internal surface, as pointed out in the study of Mogaji et al. [25] resulted into an appreciable low temperature above freezing point ranging between 5.70 ºC and 9.0 ºC for both no-load and load tests condition of the tested cooling system respectively. The Tc and the Ta for both load and the no-load test showed a comparable trend depicting increment with the time changing. The evolution of the temperature remained almost constant for the first four hours of the test, indicating the occurrence of stratified flow pattern condition of the working fluid. It also notices an appreciable temperature increase with the time changing from the fifth hour of the test. This behaviour indicates the occurrence of intermittent to annular flow patterns as observed in the study of Kanizawa et al. [26], thus aiding the effective heat rejection function of the designed condenser component of the developed cooling system in this study.

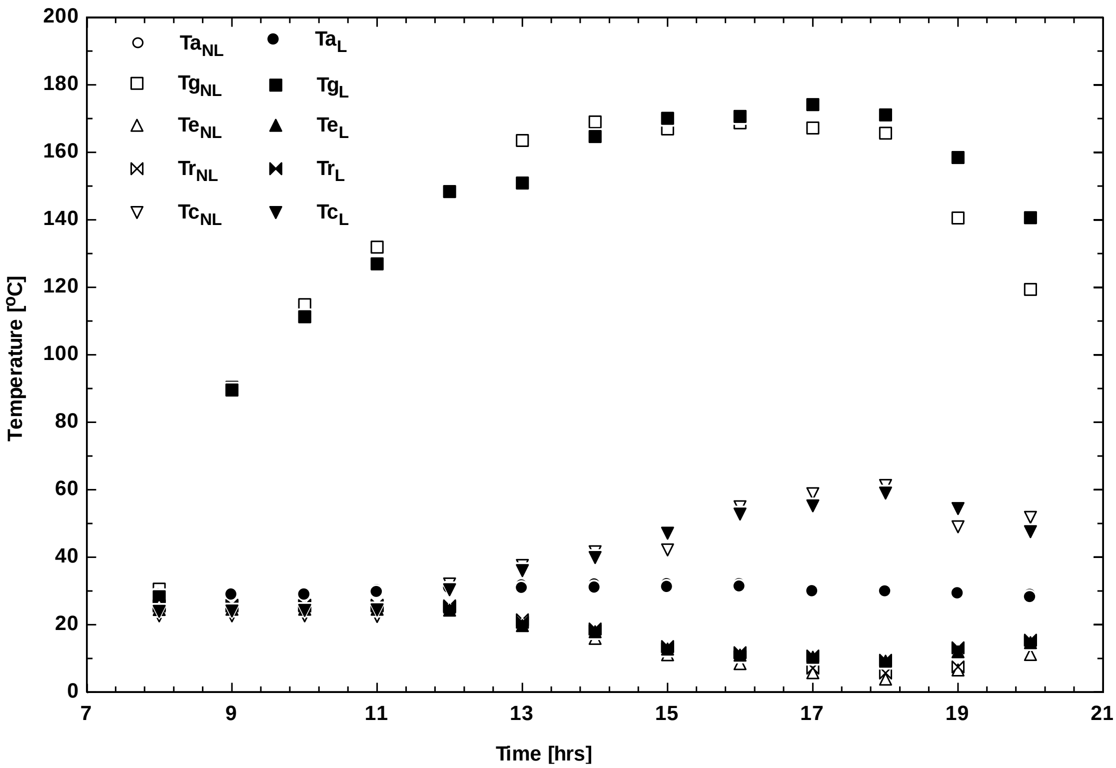

Figure 8. Patterns of temperature evolution during no-load and load conditions of the developed cooling system. (The subscripts NL and L indicate no-Load and Load conditions of the tested cooling system)

DOI: 10.14232/analecta.2023.1.28-43

3.4. Performance evaluation of the developed VAR system

Performances of the developed VARS systems are evaluated based on the experimental data obtained. The evaluation of the developed solar-powered refrigeration systems is characterised by their refrigerating effect in terms of their cooling performance (COP) and the system efficiency ratio (η). In this work, the mean COP for the system on no-load tests and that on load tests are estimated as 0.1164 and 0.1275, respectively, using Eq. (21). Similarly, the mean system efficiency ratio (η) is defined as the ratio of the coefficient of performance of the cooling system to the Carnot coefficient of performance (**COPc**) of the system is determined as 71.56% and 82.47% for the system on no-load tests and that on load tests respectively by applying Eq. (22). These values were calculated by applying the mean temperature evolution results displayed in Figure 8. The obtained cooling performance (COP) value for the cooling system in this study is similar to those observed in the study of Mondal et al. [17]. It is interesting to point out that the COP value in this work is low compared to the COP value achieved in the study of Akinola et al. [6]. Akinola et al. [6] worked on the Development of a Solar-Powered Mobile Refrigerator, a Vapor Compression operated cooling system (VCR). This result is expected due to the fact that the developed cooling system in this study is a heat-operated cooling system. However, considering the efficiency of the system, the obtained performance efficiency in this study is similar to that achieved in the study of Akinola et al. [6].

$$COP = \frac{T_e}{T_g} \tag{21}$$

$$\eta = \frac{COP}{COP_c} \tag{22}$$

Where the term Carnot coefficient of performance (COP_c) in Eq. (22) is obtained using Eq. (23).

$$COP_c = \left(\frac{T_g - T_a}{T_g}\right)\left(\frac{T_e}{T_c - T_e}\right) \tag{23}$$

4. CONCLUSIONS

In this study, solar-powered vapour absorption refrigeration system was developed, and its performance was evaluated. The cooling system underwent tests on load and no-load in liew of validating its cooling capacity. These tests revealed that this system is capable of cooling water to about 9°C, indicating that solar power can be used effectively to power a vapour absorption refrigerating system. It was found that the cooling system experience a constant Tr of 25.8°C for the first five hours of the test and thereafter maintained an appreciable temperature drop for the rest of the testing period. The performance test results revealed that the system performed well in terms of temperature regulation for refrigeration purposes, such as drinking water/beverages for human comfort. Moreso, the needed above-freezing point storage temperature condition required for effective preservation of fresh fruits, thus preventing excessive chilling or freezing injury effect on stored items usually observed in using the commonly VCR system refrigerating space was also achieved by the developed VAR system at the mean Tr of 9 °C. Generally, it is observed that the Vapour Absorption Refrigeration System developed in this work functions quite reliably during the day. This research opens a new window into utilising a renewable energy source (Solar energy) to provide eco-friendly solutions in refrigerating drinkable commodities and preservation means for waste fresh fruits, especially in many rural regions where electricity is unreliable or non-existent.

DOI: 10.14232/analecta.2023.1.28-43

CONFLICT OF INTEREST

The author declares no conflict of interest.

.

ACKNOWLEDGMENT

The author would like to acknowledge the assistance of the Refrigeration and Air Conditioning Unit of the Department of Mechanical Engineering, Federal University of Technology Akure, in supplying the equipment used in the present study. The technical support (experimental data acquisition) given to this investigation by Mr Ohwovoriole, Emuvie Adonaye is also appreciated and deeply recognised.

REFERENCES

[1] Mali, S. S., Wagh, .M.M., Shinde, N. N.: Review Of Design Of Single Effect Solar Powered Vapour Absorption Air Conditioning System International Journal of Advance Research In Science And Engineering, .2(7) (2013), 44-52

[2] Bangotra, A.,Mahajan, A.: Design Analysis of 3 TR Aqua Ammonia Vapour Absorption Refrigeration System, International Journal of Engineering Research & Technology (IJERT), 1(8) (2012), 1 – 6.

[3] Agrouaz, Y., Bouhal, T., Allouhi, A., Kousksou, T., Jamil, A., Zeraouli, Y.: Energy and parametric analysis of solar absorption cooling systems in various Moroccan climates, Case Studies in Thermal Engineering, http://dx.doi.org/10.1016/j.csite.2016.11.002

[4] Elyas, R., Alireza, G., Iman, H. N., Morteza, S. :Spray Characteristics Comparison of Different Fuels Injected from a Diesel Injector, International Journal of Engineering & Technology, Vol. (2021),1-10

[5] Allouhi, A., Kousksou, T., Jamil, A., El Rhafiki, T., Mourad, Y., Zeraouli, Y.: Economic and environmental assessment of solar air-conditioning systems in Morocco. Renewable and Sustainable Energy Reviews, 50(2015), 770-781.

[6] Akinola, A. O., Mogaji, T. S., Adewole, K. A.: Development of a Solar-Powered Mobile Refrigerator, International Journal of Emerging Technology and Advanced Engineering, 5(9) (2015), 1-6.

[7] Meraj, Md., Emran K. M., & Rashid I.: Analysis of Single Effect Vapor Absorption Refrigeration Cycle, International Journal of Science and Research, 5(5) (2015), 755-758

[8] Aamir., S., Ikram K., Abdul,G. M., Aakash, D. A., Tahwer H.:Thermodynamic Analysis of Combined Vapor Compression and Vapor Absorption Refrigeration System, ,Mehran University Research Journal of Engineering & Technology, 36(3) (2017), 733-740.

[9] Sathiamourtty, A.,Ashok, K., Pavanan, B.:Thermodynamic Analysis of Vapour Absorption Refrigeration Cycle Using Different Working Fluids, International Journal of Applied Engineering Research 15(9) (2020), 911-917.

[10] Aphornratana, S., Eames I.W.: Thermodynamics analysis of absorption refrigeration cycles using the second law of thermodynamics method, International Journal of Refrigeration; 18 (1995), 244-452.

[11] Aphornratna S., Sriveerakul T.:Experimental studies of a single-effect absorption refrigerator using aqueous lithium-bromide: Effect of operating condition to system performance, Experimental Thermal and Fluid Science; 32(2007),658-669.

[12] Alsaqoor, S., AlQdah, K.S.:Performance of a Refrigeration Absorption Cycle Driven by Different Power Sources, Smart Grid and Renewable Energy, 5(2014), 161 – 169.

[13] Velmurugan, V., RajaBalayanan, S.R., Surendhra Babu, K. & Sakthivadivel D.:Investigation of a Novel Solar Powered Absorption Refrigeration System with Solar Point Collector,' Research Journal of Chemical Sciences, 1(7) (2011), 51- 56

[14] Abdulateef, J., Alghoul, M., Zaharim, A. & Sopian, K.: Experimental Investigation on Solar Absorption Refrigeration System in Malaysia Proceedings of the 3rd WSEAS Int. Conf. on RENEWABLE ENERGY SOURCES, (2009), 267 – 671.

[15] Al-Hemiri, A.A. Nasiaf, A.D.: The Use of Direct Solar Energy in Absorption Refrigeration Employing $NH_3 – H_2O$ System Iraqi Journal of Chemical and Petroleum Engineering, 11(4) (2010), 13 – 21.
[16] Bajpai, V.K.: Design of Solar Powered Vapour Absorption System, Proceedings of the World Congress on Engineering, 3 (2009)
[17] Mondal, A., Didarul Alam, M.D., Islam, M.A.: Design and Construction of a Solar Driven Ammonia Absorption Refrigeration System, International Journal of Scientific and Research Publications, 5(10) (2015), 51 – 56.
[18] Said, S.A.M., Spindler, K., El-Shaarawi, M.A., Siddiqui, M.U., Schmid, F., Bierling, B. Khan, M.M.A.: Design, construction and operation of a solar powered ammonia–water absorption refrigeration system in Saudi Arabia International Journal of Refrigeration, 62 (2016), 222 – 231.
[19] Gandhi, A., Arakerimath, R.R.: Solar Vapour Absorption Cooling System Using parabolic dish Collector, IOSR Journal of Mechanical and Civil Engineering, 13(2) (2016), 9 – 13.
[20] Sharma, N.K., Singh, H., Sharma, M.K. Gupta, B.L.: Performance Analysis of Vapour Compression and Vapour Absorption Refrigeration Units Working on Photovoltaic Power Supply, International Journal of Renewable Energy Research, 6(2) (2016), 39-48.
[21] Esa D. K., Achmad Chafidz, O. Phillip A., Jamel Orfi, A.H., Fakeeha, A. S.:Energetic and Exergetic Analysis of Solar-Powered Lithium Bromide-Water Absorption Cooling System, Journal of Cleaner Production (2017), doi: 10.1016/j. jclepro.2017.03.060
[22] Akintunde, M.A., Obadina, R.B.: Development of a Refrigeration System for Storage of Pepper and Tomatoes International Journal of Applied Engineering Research, India, 6(23-24) (2011), 2561 – 2574.
[23] Melodi, A.O., Famakin, S.R.:Assessment of solar PV-grid parity in Akure, South-West Nigeria Journal of Engineering Trends in Engineering and Applied Sciences, 2(3) (2011), 531 – 536.
[24] Mogaji, T. S.: Development and Performance Evaluation of a Micro Controller Based Refrigeration Control System Using Fresh Fruits, Journal of Engineering Research and Development Vol. 2 (2019), 120-134.
[25] Mogaji, T.S., Kanizawa, F.T., Bandarra Filho, E.P., Ribatski, G.: Experimental study of the effect of twisted-tape inserts on flow boiling heat transfer enhancement and pressure drop penalty. International Journal of Refrigeration, Vol. 36 (2013), 504-515
[26] Kanizawa, F.T., Mogaji, T.S., Ribatski, G.: Evaluation of the heat transfer enhancement and pressure drop penalty during flow boiling inside tubes containing twisted tape inserts, Applied Thermal Engineering, Vol. 70 (2014), 328- 340.

DOI: 10.14232/analecta.2023.1.28-43