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Yazar(lar) (Author(s)): *Engin ÖZBAŞ*

ORCID: 0000-0003-4922-7890

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Experimental Study Of Diffusion Absorption Refrigeration Systems Using Solar Energy

Araştırma Makalesi / Research Article

Engin ÖZBAŞ*

Yeşilyurt Demir Çelik Vocational School, Ondokuz Mayıs University, 55330 Samsun, Turkey

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ÖZ

Bu çalışmada, güneş enerjisi kullanılarak difüzyon soğurmalı soğutma (DAR) sisteminin performansı deneysel olarak araştırılmıştır. Bu amaçla, deneyde ön soğutmalı / ön soğutmasız olmak üzere iki tip sistem kullanılmıştır. Enerji kaynağı olarak güneş enerjisinden faydalanmak amacıyla çalışma akışkanı su olan iki fazlı kapalı tip termosifon tip ısı borusu tercih edilmiştir. Deneyler sırasında; DAR sistemleri ve ısı boruları üzerindeki kritik nokta sıcaklıkları ile birlikte çevre sıcaklığı, DAR sistemleri basınçları ve güneş radyasyonu verileri 06:00-16:00 saatleri arasında kaydedimiş ve her ısı borusu ile 82.5W güneş enerjisi toplanmıştır. DAR1 en düşük buharlaştırıcı giriş sıcaklığına (-14.8°C) 14:40'da ve DAR2 ise 13:55'de -0.9°C'ye ulaşmıştır. DAR1 ve DAR2'nin STK değerleri 0.2362 ve 0.2254 olarak bulunmuştur. DAR1 ve DAR2'de kullanılan ısı borularının verimliliği sırasıyla 0.3677 ve 0.3690 ve ısı direnci değerleri sırasıyla 0.1154W/°C, 0.0828W/°C'dir.

Anahtar Kelimeler: Yayınımlı soğurmalı soğutma, ısı borusu, güneş enerjisi, performans.

ABSTRACT

In this study, the performance of a diffusion absorption refrigeration (DAR) system using solar energy is investigated experimentally. For this purpose, two types of systems with/without sub-cooling are used for the experiment. Two-phase closed thermosyphon type heat pipes using water as the working fluid are used to utilize solar energy as heat source. During the experiments; ambient temperature along with critical point temperatures on DAR systems and heat pipes, DAR systems pressures and solar radiation data are recorded from 06:00 to 16:00 and each heat pipe has collected 82.5W of solar energy. DAR1 has achieved its lowest evaporator inlet temperature (-14.8°C) at 14:40, and DAR2 has reached -0.9°C at 13:55. COP values of DAR1 and DAR2 are found as 0.2362 and 0.2254. Efficiency of the heat pipes used in DAR1 and DAR2 are 0.3677 and 0.3690, and their thermal resistance values are 0.1154W/°C, 0.0828W/°C respectively.

Keywords: Diffusion absorption refrigeration, heat pipe, solar energy, performance.

1. INTRODUCTION

The diffusion absorption refrigeration (DAR) systems were invented by Von Platen and Munters in the 1920s [1]. The disadvantage of DAR, which is used in domestic spaces such as hotel rooms and offices particularly because it offers silent operation, is the quite low coefficient of performance (COP) it has. Its greatest advantage is that it can be run by any source of energy such as electricity, solar power, LPG, natural gas, and waste heat. Two working fluids are used in the DAR system: ammoniac as a cooler and water as an absorber. Additionally, hydrogen or helium is used as auxiliary gas in this system in order to decrease the partial pressure in the evaporator according to Dalton's law. Therefore, there are no moving parts in these systems, and solution cycle is achieved by the bubble pump heated at 150-200°C [2,3,4].

Heat pipes are used in electronic devices, heating and ventilation (HVAC) systems, and some other industrial sectors [5]. Various types of heat pipes are used in thermal applications. One of them is two-phase closed thermosyphon (TPCT) moved by gravitational force [6].

The literature contains a lot of studies carried out to enhance the performance of the DAR system and TPCT separately. In the present study, the possibility of cooling through solar power was experimentally investigated by combining the DAR system, in which ammoniac, water and helium fluids are used, with TPCT, in which water is used as a working fluid. In this way, the usability of solar-powered TPCTs for cooling (besides heating) purposes was investigated.

**Sorumlu yazar (Corresponding Author)*

e-posta : engin.ozbas@omu.edu.tr

2. DAR Systems

2.1. DAR1

The Figure 1 illustrates the DAR1 cooling machine that was invented by Platen-Munters and consists of a generator, a rectifier, a condenser, and an evaporator. When the system is in the steady state, the internal wall of the two-wall generator contains ammonia-water solution, which is also called rich solution.

Its external wall, on the other hand, contains poor solution in a structure that runs down from 1c and leaves its heat to the rich solution in the solution heat exchanger and connects to the absorber through 6. The ammonia gas that separates from the rich solution at 1c enters the condenser region by going through the rectifier to separate from the water on it, if any. The ammonia that liquefies in the condenser goes towards the gas heat exchanger through 3 where it transfers its heat to the

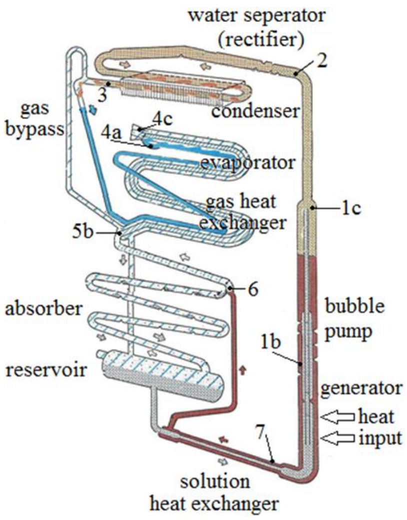

Figure 1. DAR1 [1]

helium gas via sub-cooling and enters the evaporator through 4a. The helium gas that gets heated in the gas heat exchanger and thus has higher concentration in the upper evaporator evaporates the liquid ammonia by decreasing its partial pressure in accordance with Dalton's law. The ammonia starting to evaporate enters the internal wall of the evaporator through 4c of the two-wall evaporator and goes on until the absorber. The ammonia facing the poor solution at 6 is absorbed by water and goes back to the tank as rich solution [2,3,4].

2.2. DAR2

Based on the DAR1 cycle, Zohar et al. [7] investigated the effect of liquid ammonia's entering the evaporator directly with no sub-cooling on the system performance.

As it can be understood from the Figure 2, in DAR2, a certain part of the evaporator has been turned into single wall, and it has been ensured that the liquid ammonia leaving 3 enters the evaporator straightforward with no sub-cooling. The functioning of other parts and liquids in the system is the same as DAR1.

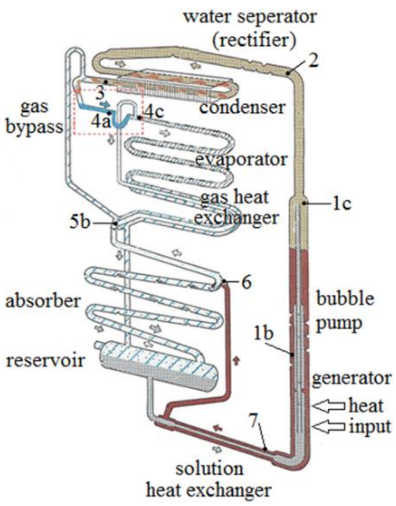

Figure 2. DAR2 [7]

3. TPCT

Two-phase closed thermosyphons (TPCT) are heat pipes with two close-ends 5% to 30% of whose volume is filled with working fluid and in which working fluid exists in both liquid and gas phases simultaneously [8].

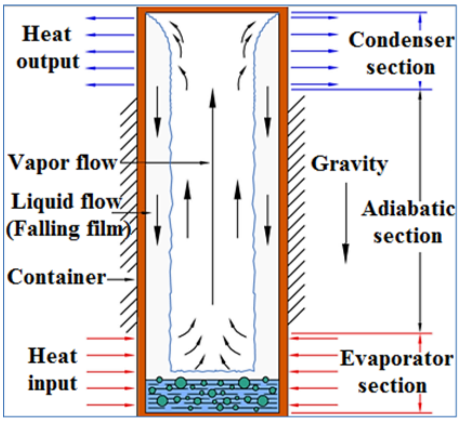

Figure 3. TPCT [9]

TPCT, whose physical mechanism is illustrated in the Figure 3, consists of three sections: evaporator, condenser, and adiabatic section. Owing to the heat it gets from the evaporator section, the working fluid reaches the condenser region by rising from the interior of the pipe in the vapor phase. The working fluid leaves its heat and turns into liquid phase here and completes its cycle by going down to the evaporator section from the pipe surface in the form of film membrane owing to gravity [9].

4. MATERIAL and METHOD

In this study, the effect of using solar power in diffusion absorption refrigeration (DAR) system, which can be run by any heat source, on performance was experimentally analyzed. To this end, solar-powered TPCT type heat pipe was combined with two different DAR systems (i.e. with sub-cooling (DAR1) and without sub-cooling (DAR2).

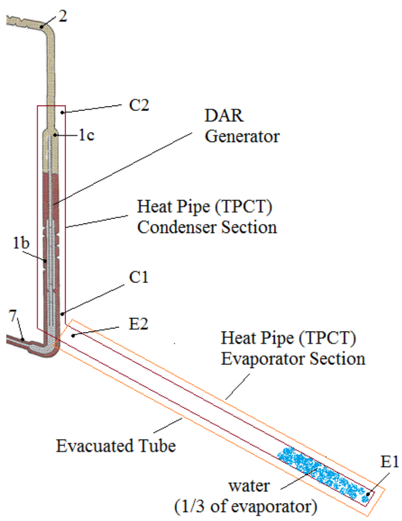

Figure 4. The combination of TPCT with DAR

Figure 4. illustrates the combination scheme of DAR and TPCT. Parabolic reflector was used with evacuated tube in order to reach higher temperatures in the heat pipe filled with water as working fluid at a ratio of 1/3 of the evaporator volume. For the performance calculations of TPCT, thermocouples were fastened through E1 and E2 points in the evaporator section and through C1 and C2 points in the condenser section for measuring temperature.

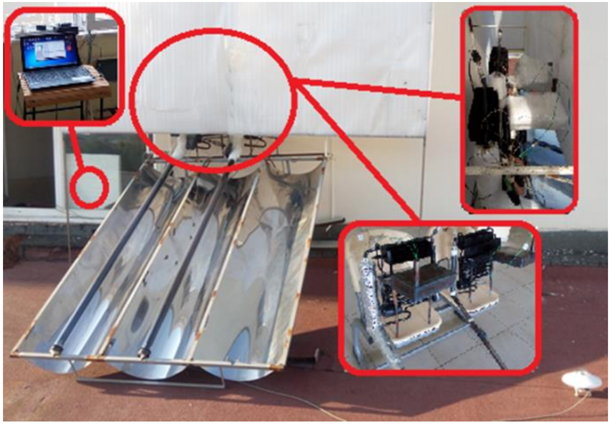

Figure 5. Experimental Setup

Figure 5. presents a general view of the experimental setup. The experiments were carried out under the weather conditions prevailing in Samsun, which is situated on the north coast of Turkey (the exact location at sea level: 41°14'N 36°26'E). The experiments were conducted between 06:00 and 16:00, and K-type thermocouples were used in all the temperature measurements required for analysis. Incident solar radiation was measured via DeltaOhm LP PYRA 02 pyranometer, and the pressure measurements of DARs were carried out via Keller PA-21Y pressure transmitter with ± 0.25 %FS linearity. All the experimental data were gathered at the intervals of one minute. ORDEL UDL100 universal Data Logger with 0.2% accuracy was used for recording.

5. RESULTS AND DISCUSSION

5.1. Experimental analysis

The experiments were carried out under the conditions of Samsun, Turkey. Solar-powered heat pipe placed at 35° slope angle was used as heat source. While temperature and pressure values were calculated for the performance analysis of DAR systems, only temperature values were calculated for the performance analysis of the heat pipe. The data related to the period from 06:00 to 16:00 were taken into consideration for results and calculations.

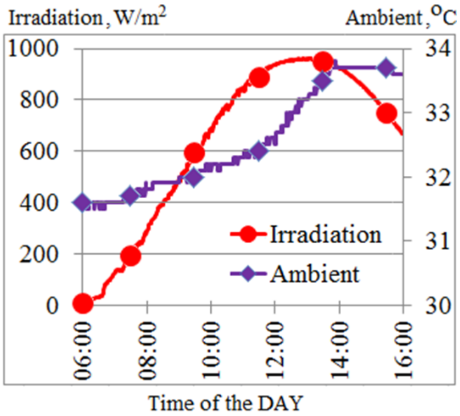

Figure 6. Temporal irradiation intensity and ambient temperature distribution

Figure 6 shows temporal irradiation intensity and ambient temperature distribution. It is evident that irradiation intensity reaches the highest level (i.e. 959.8 W/m2) at 12:55 and starts to fall at 13:15 while ambient temperature varies between 31.5°C and 33.8°C.

Figure 7 shows the temporal system pressure distribution for DAR1 and DAR2. The highest system pressure value is 19.5bar in DAR1 and 21.3bar in DAR2.

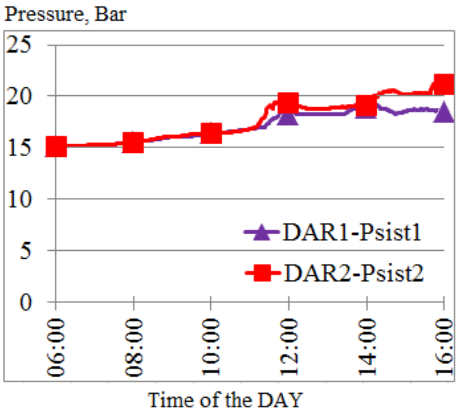

Figure 7. The temporal pressure values of the DAR systems

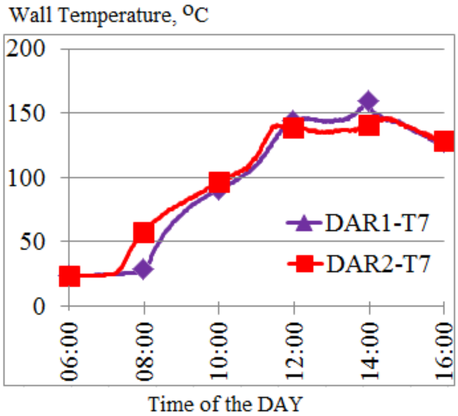

Figure 8. Temperature distribution of the point 7

Figure 8 shows the temporal temperature distribution of the point 7, which indicates the temperature values of the rich solution before entering the generator. The highest value is 160.1°C for DAR1 and 146.0°C for DAR2.

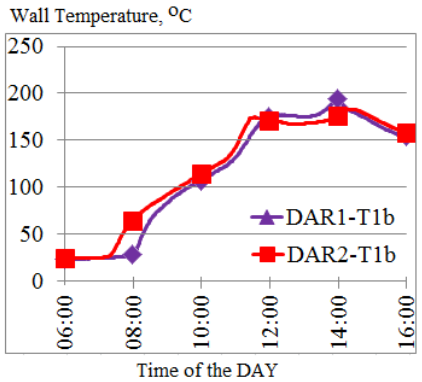

Figure 9. The temperature distribution of the point 1b

The distribution of the temperature values of the rich solution in the generator is seen in Figure 9. The highest temperature values of the 1b point are 195.6°C for DAR1 and 183.1°C for DAR2.

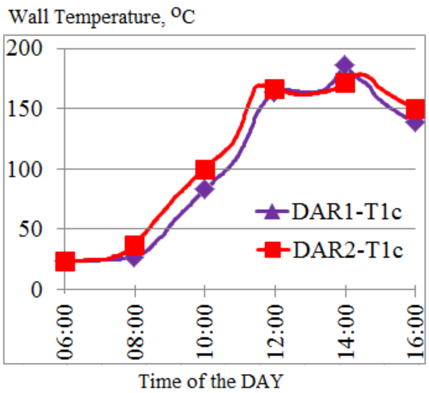

Figure 10. The temperature distribution of the point 1c

Figure 10 shows the temperature distribution of the bubble pump outlet. This measurement value, which also refers to the temperature of the ammonia vapor separating from the rich solution, is 188.4°C in DAR1 and 178.6°C in DAR2.

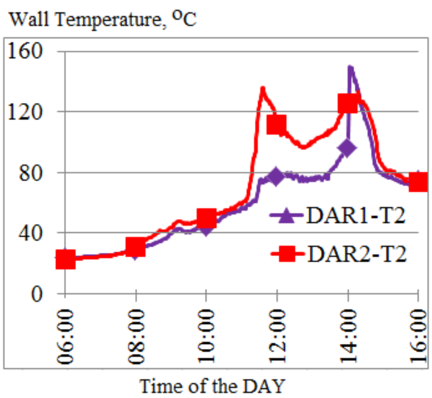

Figure 11. The temperature distribution of the point 2

Figure 11 shows the temperature distribution of the ammonia vapor entering the condenser from the rectifier. It is one of the indicators of cooling taking place in the DAR system. Sudden temperature increase in the point 2 indicates the start of vaporization in the evaporator. Sudden temperature increase of the point 2 took place at 11:36 for DAR2 (i.e. 135.7°C) and took place at 14:05 for DAR1 (i.e. 149.5°C), thereby reaching the highest level.

Figure 12 presents the temperature distribution of the point 3. The highest temperature of the ammonia turning into the liquid phase starting from this point is 54.7°C for DAR1 and 46.7°C for DAR2.

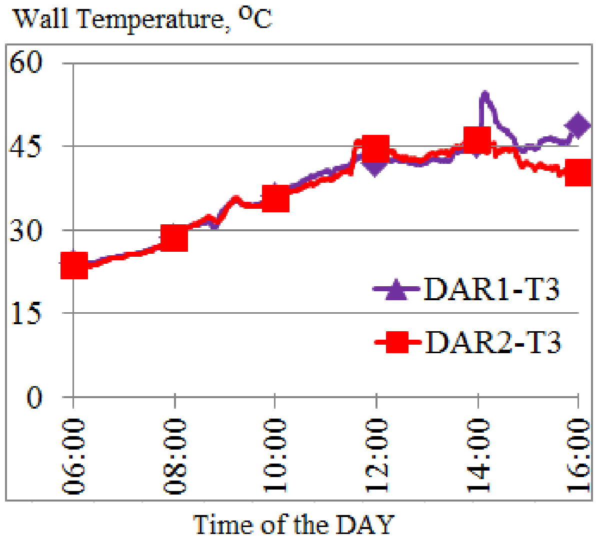

Figure 12. The temperature distribution of the point 3

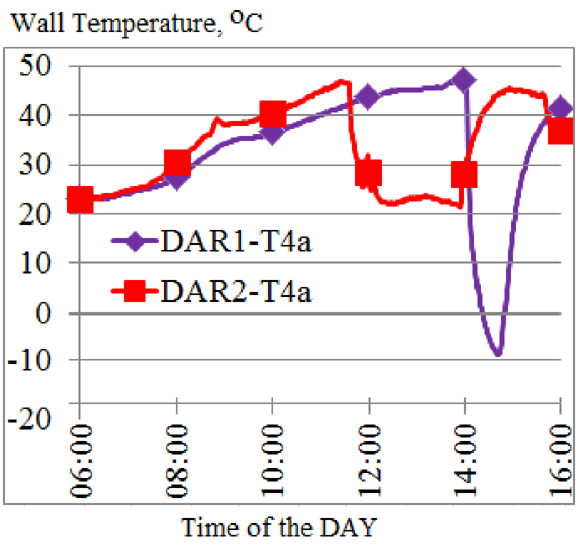

Figure 13. The temperature distribution of the point 4a

Figure 13 shows the temperature distribution of the ammonia coming from the condenser in the liquid phase just before it enters the evaporator. The lowest 4a temperature value was found to be -8.5°C for DAR1 and 21.5°C for DAR2.

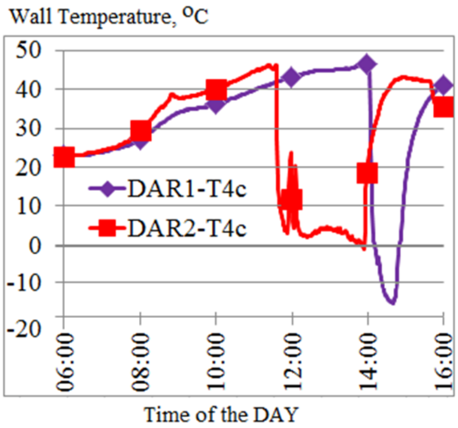

Figure 14. The temperature distribution of the 4c point

Figure 14 shows the temporal temperature distribution of the point 4c where vaporization starts in the evaporator. The fact that irradiation intensity started to decrease at 13:15 and its decrease accelerated after 14:00 caused cooling to be short-time by negatively affecting the systems. Cooling started at 14:05 for DAR1 and took approximately 1 hour whereas it started at 11:36 and finished at around 14:00 for DAR2. The lowest 4c temperature turned out to be -14.8°C for DAR1 and -0.9°C for DAR2.

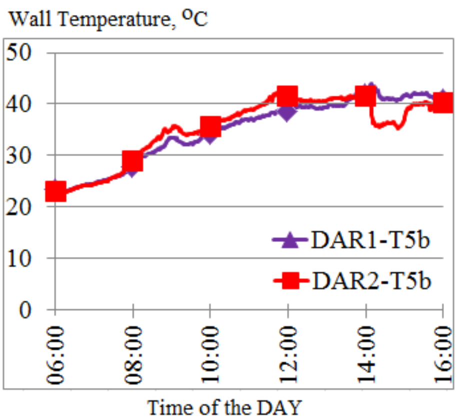

Figure 15. The temperature distribution of the point 5b

Figure 15 shows the temporal temperature distribution of the point 5b. The lowest value was measured to be 23.1°C in DAR1 and 22.8°C in DAR2.

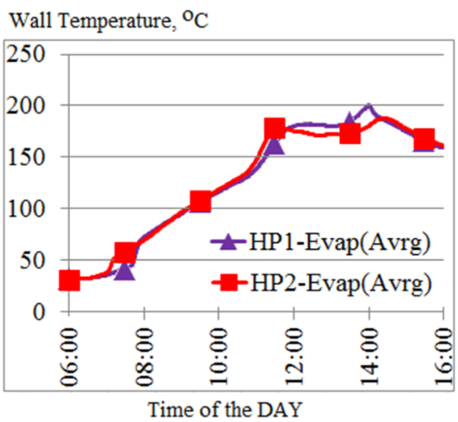

Figure 16. The evaporator temperature (average) distribution of the heat pipes

Figure 16 shows the average evaporator temperature distribution of solar-powered heat pipes used as heat source in DAR systems. HP1 is the heat pipe connected to the DAR1 system whereas HP2 is the heat pipe connected to the DAR2 system. The highest evaporator temperature (average) was measured to be 201.1°C in HP1 and 187.7°C in HP2.

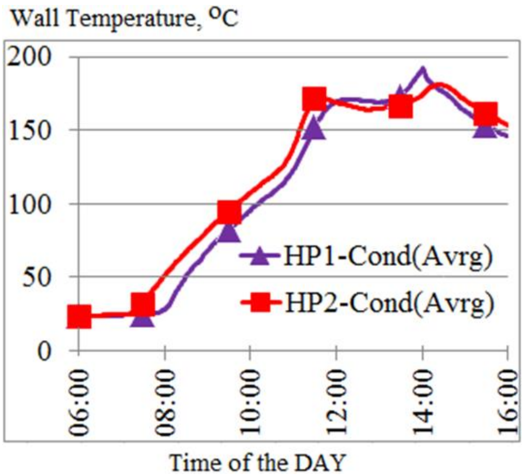

Figure 17. The condenser temperature (average) distribution of the heat pipes

Figure 17 shows the average condenser temperature distribution of the heat pipes. The highest value was found to be 192.0°C for HP1 and 180.8°C for HP2.

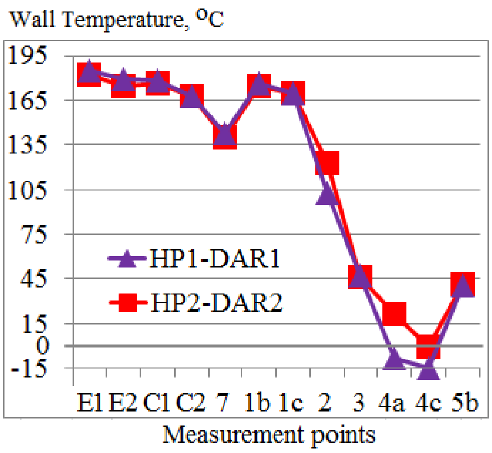

Figure 18. Comparison of measurement points for DAR and HP

The lowest 4c temperature was reached at 14:40 for DAR1 and at 13:55 for DAR2. Figure 18 involves a comparison of the temperatures in all the measurement points for DAR1 and HP1 at 14:40 and the temperatures in all the measurement points for DAR2 and HP2 at 13:55. E1 and E2 refer to the evaporator inlet and outlet temperatures of the heat pipes while C1 and C2 refer to their condenser inlet and outlet temperatures. The points 7, 1b, 1c, 2, 3, 4a, 4c, and 5b are the measurement points of the DAR system. The graph indicates that heat transfer from the heat pipes to the generator is highly successful.

5.2. Theoretical analysis

The temperature values measured in the experiments can be used for theoretical thermodynamic analysis (i.e. calculation of the coefficient of performance [COP] of the system). COP can be calculated with the following formula:

$$COP_{DAR} = \dot{m}_{pr-stm} \frac{\dot{Q}_{evap}}{W_{heater}} \quad (1)$$

In the DAR scheme for $\dot{Q}_{evap}$, the enthalpy values of the evaporator inlet (4c) and outlet (5b) points, h_{4c} and h_{5b}, can be used. In addition, the amount of energy collected by the solar-powered heat pipe used as heat source, $Q_{incident}$, can be written instead of W_{heater}.

$$Q_{incident} = A\int_1^2 I dt \quad (2)$$

where A refers to vacuumed glass tube surface area (m^2) and I refers to the global irradiance (W/m^2). The vacuumed tube used in the experiment has a surface area of 0.1332 m^2.

Equation (3) is obtained when COP_{DAR} is rewritten by using Equation (1) and Equation (2).

$$COP_{DAR} = \dot{m}_{pr-stm} \frac{h_{4c}-h_{5b}}{Q_{incident}} \quad (3)$$

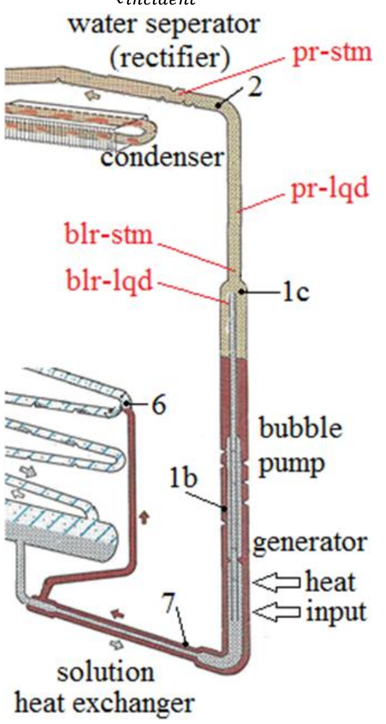

Figure 19. Necessary measurement points for theoretical analysis in DAR

Figure 19 shows the necessary measurement points for COP calculation in the DAR system. Here, the vapor ascending from the outlet of the bubble pump (1c) is represented by (*blr-stm*) whereas the liquid descending is represented by (*blr-lqd*). (*pr-lqd*) refers to the liquid condensing through (blr-stm) in the purifier whereas (*pr-stm*) refers to the pure ammonia vapor entering the condenser from the purifier in the vapor phase. According to the principle of energy conservation, the mass flow of the ammonia-water vapor that flows from the boiler toward the purifier, $\dot{m}_{blr-stm}$, is calculated in accordance with the conservation of mass and energy equations at the outlet of the bubble pump.

$$\dot{m}_{1c} = \dot{m}_{blr-lqd} + \dot{m}_{blr-stm} \quad (4)$$

$$x_{1c} \cdot \dot{m}_{1c} = x_{blr-lqd} \cdot \dot{m}_{blr-lqd} + x_{blr-stm} \cdot \dot{m}_{blr-stm} \quad (5)$$

$$h_{1c} \cdot \dot{m}_{1c} + \dot{q}_{blr} = h_{blr-lqd} \cdot \dot{m}_{blr-lqd} + h_{blr-stm} \cdot \dot{m}_{blr-stm} \quad (6)$$

The mass flow of the pure ammonia vapor that flows to the condenser, $\dot{m}_{pr-stm}$, is calculated based on the conservation of mass equations at the purifier outlet.

$$\dot{m}_{blr-stm} = \dot{m}_{pr-lqd} + \dot{m}_{pr-stm} \quad (7)$$

$$x_{blr-stm} \cdot \dot{m}_{blr-stm} = x_{pr-lqd} \cdot \dot{m}_{pr-lqd} + x_{pr-stm} \cdot \dot{m}_{pr-stm} \quad (8)$$

REFPROP was used in all the calculations concerning the DAR system. The REFPROP software, which simulates the physical and chemical properties of fluid groups, was used in order to determine the mass ratios (x) and enthalpies (h) to be employed in the equations. The amount of energy collected by the heat pipe, $Q_{incident}$, is given in Equation (2). ΔT is the difference between the average vaporizer temperature and the average condenser temperature of the heat pipe. ΔT can be calculated with the following formula:

$$\Delta T = (E1 + E2)/2 - (C1 + C2)/2 \quad (9)$$

The thermal resistances of the pipes used for DAR can be calculated with the formulas (2) and (9) as follows;

$$R = \Delta T / Q_{incident} \quad (10)$$

DAR systems contain a mix of 75% water and 25% ammonia in mass. Accordingly, the amount of heat transferred by the heat pipe to the water in DAR can be calculated based on the change in the temperature of the water going through the generator, its mass flow, and specific heat as follows:

$$Q_{hp} = \dot{m}_w c_{p,w}(T_{1c} - T_7) \quad (11)$$

where m_w is the mass flow of the water in the rich solution (kg/h); $c_{p,w}$ is the specific heat of water (kJ/kg°C); T_7 is the generator inlet temperature of the water in the rich solution (°C); and T_{1c} is its outlet temperature (°C).

Productivity (η) can calculated based on the ratio of the total solar power amount coming onto the heat pipe ($Q_{incident}$) to the amount of the heat transferred by the heat pipe to the tank water (Q_{hp}):

$$\eta = Q_{hp} / Q_{incident} \quad (12)$$

Table 1 presents the values of the DAR1 and DAR2 systems calculated and measured at the moments when the points 4c reach the lowest temperature. It occurred at 14:40 for DAR1 and at 13:55 for DAR2. COP and mass flow ($\dot{m}_{1c}$) were calculated for DAR whereas thermal resistance (R) and productivity (η) were calculated for HP.

Table 1. Calculated and measured valuess

		R	COP	ṁ1c	η	H1	H2	E1	E2
DAR1-HP1	14:40	0,1154	0,2362	0,2580	0,3677	182,0	174,1	176,1	167,7
DAR2-HP2	13:55	0,0828	0,2254	0,2220	0,3690	184,8	179,0	178,2	167,6
		7	1b	1c	2	3	4a	4c	5b
DAR1-HP1	14:40	140,2	174,1	169,7	123,0	46,6	21,5	-0,9	41,5
DAR2-HP2	13:55	143,0	176,2	169,6	103,0	47,0	-8,3	-14,8	40,8

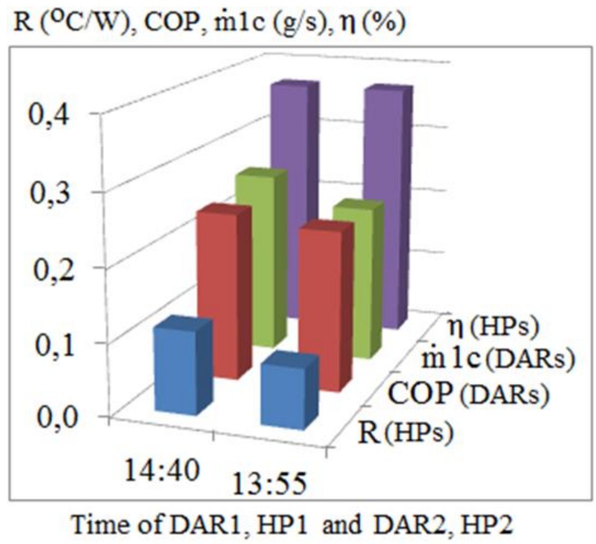

Figure 20. The graph of the values calculated for DAR and HP

Figure 20 presents a graphical representation of the values calculated based on the measurements for DAR and HP at 14:40 and 13:55. Figure 21 presents the distribution of the radiation coming to the heat pipes (incident) and thermal resistance.

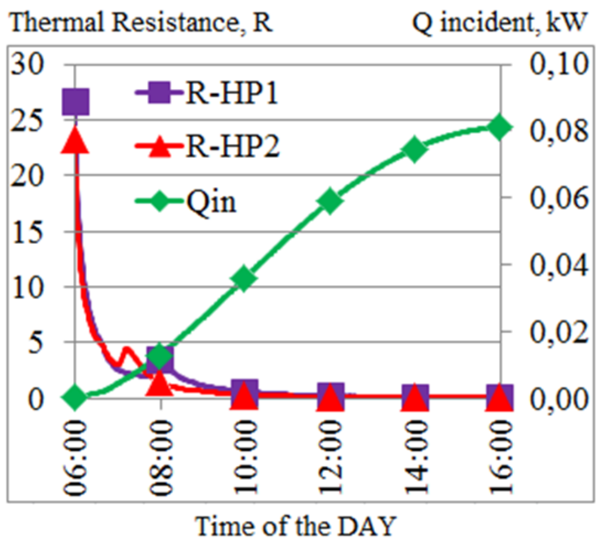

Figure 21. The distribution of the radiation coming to the heat pipes (incident) and thermal resistance

6. CONCLUSION

This study aimed to make an experimental analysis of the performance of the diffusion absorption refrigeration (DAR) system, which can be run by any heat source, with solar power. In this regard, two-phase closed thermosyphon (TPCT) type heat pipers were used to obtain high temperatures. DAR1 and DAR2 systems with and without sub-cooling were tested to understand the effect of solar energy on DAR systems better. Temperature and pressure measurements were evaluated. The performance analyses of DAR1 and the heat pipe connected to it (HP1) and DAR2 and the heat pipe connected to it (HP2) were separately made. In the end, while DAR1 yielded the lowest temperature, DAR2 yielded the longest cooling. Heat transfer was quite successful in HP1 and HP2, which had proper connections to the systems and in which water was used as working fluid. Future studies may focus on earlier and longer working of DAR systems. In this respect, the effects of different working fluids, different ratios, and different angles on DAR systems may be examined in the solar-powered heat pipe used as heat source.

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