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THE USE of DIRECT SOLAR ENERGY in ABSORPTION REFREGERATION EMPLOYING NH_3 – H_2O SYSTEM

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ABSTRACT

This work was conducted to study the coefficient of performance for solar absorption refrigeration by using direct solar energy using aqueous ammonia 0.45 mass fraction (ammonia – water).The experiments were carried out in solar absorption system .The system consisted of solar collector generator (0.25 m × 0.25 m × 0.04m) and condenser cooled by a water bath followed by liquid receiver and evaporator. The results showed that the maximum generator temperature was (92° - 97°) during June 2009, and the minimum evaporator temperature was (5°C - 10°C) for aqua ammonia system.. It was, also, found that the coefficient of performance, cooling ratio and amount of cooling obtainable increased with increasing maximum generator temperature and pressure. While the minimum evaporator temperature and concentration decreased with increasing maximum generator temperature and pressure. The coefficient of performance was (0.1096 - 0.2396).

Keyword: Solar Energy, Absorption Refrigeration

INTRODUCTION

In the developing countries there is a growing interest in refrigeration for food preservation. Especially in rural areas, simple solar refrigerators working independently, i.e. not being provided with electrical energy, would be very valuable. Mechanical refrigerators powered by solar cells are available, but are too expensive [1].

In Iraq the climate features high temperature in summer season and high solar radiation. The director beam solar radiation in north of Iraq is (5 – 6 kw.hr/m^2) and in the middle and south is (6 – 6.5 kw.hr/m^2) and (6.5– 7 kw.hr/m^2) respectively [1].These two conditions helping to use solar energy for:

- Solar heating
- Solar refrigeration and air conditioning
- Solar desalination
- Solar food drying
- Solar photovoltaic
- Solar furnaces

A solar refrigeration system consists of two components, a solar power units and a refrigeration unit. The solar power unit is based on either of two basic concepts, i.e. flat plate collectors or focusing collectors [2].

Flat plate collectors are flat blackened surfaces to absorb direct and diffuse solar radiation. Transparent cover and back insulation may be provided to reduce or control heat loss from the plate. On the plate, absorbed solar energy is converted to a desired form of energy, usually heat, and means are provided to remove that energy, usually as heated water or air. Flat plate collectors are generally suitable for operation in a fixed orientation.

The refrigeration unit can be either a continuous or an intermittent absorption system. The intermittent absorption refrigeration is preferred .The intermittent refrigeration cycle has two major operations, regeneration and refrigeration .Regeneration is the process of heating the refrigerant and absorbent fluid to drive off the refrigeration vapour and condense the vapour in a separate container.Refrigeration takes place when the liquid refrigerant vaporizes; producing a cooling effect around the evaporator .The refrigerant is reabsorbed by the absorbent [2].

The first absorption refrigeration system was developed by Ferdinand Carre in 1860 [3]. This was the first heat operated absorption system and consists of an evaporator, condenser, generator, pump, and absorber. This unit was designed to operate with ammonia as the refrigerant and water as the absorbent.

In the University of Wisconsin, Williams [4] built a small food cooler in 1957 intended for use in underdeveloped rural areas. Ammonia-water and R-21-glycol ether were used as working solutions. This study showed that refrigeration can be achieved by the use of intermittent absorption refrigeration cycles. Although performance is limited by the characteristics of the intermittent cycle, the simplicity of the system accounts for the low temperature obtained in the evaporator. Finally, the study showed that ammonia-water has a superior performance over R-21-glycol ether in an intermittent refrigeration system .

Chinnappa (1962) built a simple intermittent refrigerator operated with a flat-plate collector. An ammonia-water solution was used as the working fluid. While it has been generally expected that the flat-plate collector would be more suitable for the lower temperature of generation required in air conditioning, tests in the investigation by Chtnnappa (1962) indicated that it is possible to use a flat-plate collector incorporated with the generator to produce refrigeration at a temperature as low as -12°C. It is noted that ice can be produced in this refrigerator at one kg a day per 0.7 m^2 of solar collecting surface. Results in this investigation were not spectacular, but they showed that a simple intermittent refrigerator using a low temperature heat collecting device such as the flat-plate collector can achieve cooling [5].

The first major project on an all solar absorption refrigeration system was undertaken by Trombe and Foex (1964)[6]. Ammonia-water solution is allowed to flow from a cold reservoir through a pipe placed at the focal line of a cylinder-parabolic reflector. Heated ammonia-water vaporized in the boiler is subsequently condensed in a cooling coil. The evaporator is a coil surrounding the container used as an ice box. The cylindro-parabolic reflector measured 1.5 m'. In the prototype trials, the daily production of ice was about 6 to 4 kilograms of ice per square meter of collecting area for four-hour heating. The design by Trombe and Foex is very promising and should be studied further although modifications may be necessary on the solar collector, boiler, and condenser.

Farber (1970)[7] has built the most successful solar refrigeration system to date. It was a compact solar ice maker using a flat-plate collector as the energy source. It was reported that an average of about 42,200 kJ of solar energy was collected by the collector per day and ice produced was about 18.1 kilograms. This gave an overall coefficient of performance of about 0.1 and 12.5 kilograms of ice per m^2 of collector surface per day.

Swartman and Swaminathan (1971) [8] built a simple, intermittent refrigeration system incorporating the generator-absorber with a 1.4 m^2 flat-plate collector. Ammonia water solutions of concentration varying from 58 to 70 percent were tested. Tests were relatively successful; evaporator temperatures were as low as -12°C, but due to poor absorption, the evaporation rate of ammonia in the evaporator was low.

Staicovici [9] made an intermittent single-stage H_2O-NH_3 solar absorption system of 46 MJ/cycle (1986). Solar collectors heat the generator. Installation details and experimental results were presented. The system coefficient of performance $(COP)_{system}$ varied between 0.152 and 0.09 in the period of May–September. Solar radiation availability and the theoretical (COP), also applicable to the Trombe-Foex system, were assessed. Reference was made to evacuated solar collectors with selective surfaces. Actual $(COP)_{system}$ values of 0.25–0.30 can be achieved at generation and condensation temperatures of 80°C and 24.3°C respectively.

In 1993 Sierra, Best and Holland [10] made a laboratory mordent of absorption refrigeration. Using ammonia - water solution at 52 % concentration by weight and the total weigh is 38 kg. this system was operated intermittently using this heat source .A heat source at temperature no higher than 80 °C was used to simulate the heat input to an absorption refrigeration from solar pond .In this system the temperatures of generator was as high as 73 °C and evaporator temperatures as low as -2 °C . Tap water was used to remove the heat generated from the condensation of the ammonia vapor and the absorption of the refrigerant in the water. The temperature of the tap water was near the ambient laboratory temperature of 28 °C. The COP for this unit working under such condition was in the range 0.24 to 0.28 .

In 2000 Hammad and Habali [11] made a steel sheet cabinet of 0.6 m x 0.3 m face area and 0.5 m depth. The cabinet was intended to store vaccine in the remote desert area, away from the electrical national grid. A solar energy powered absorption refrigeration cycle using Aqua Ammonia solution was designed to keep this cabinet in the range of required temperatures. The ambient temperatures reached about 45 °C in August. A computer simulation procedure was developed to study the performance and characteristics of the cooling cycle. The simulation included MATLAB computer programs for calculation the absorption cycle. In this system using a cylindrical solar concentrator extended the daily operating time to about 7 h and increased the output temperature up to 200 °C and the range of the COP was between 0.5 to 0.65 .While the temperature which gives optimum condition (of COP =0.65)was 120 °C. For this study a solar absorption refrigeration unit was constructed. The

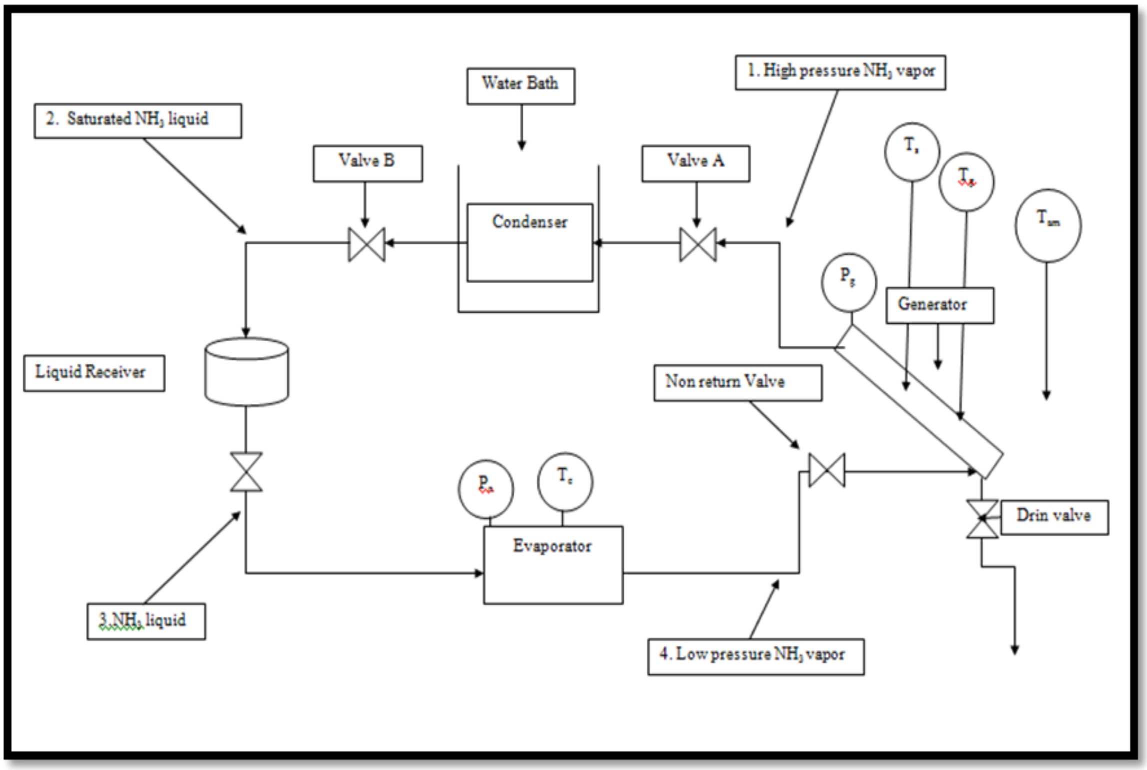

Fig. 1 Schematic diagram of the equipment used

working fluids employed was aqueous ammonia (25wt% NH_3 – H_2O) .The system was operated during the months of June and July (2009) for a period of 8 hours per day (8 am to 4 pm).

Assessment of the system is by determining the following relevant parameters:

- Cooling obtainable
- Cooling ratio
- Solar coefficient of performance (C.O.P).

EXPERIMENTAL WORK

Apparatus

The systems consist of generator. It was fabricated from 2 mm thick stainless plate (316) painted black to improve on it's solar radiation absorbing capabilities. The section is rectangular and the dimensions are (25 cm x 25cm x 5 cm) and at 20° inclined angle. The volume is 2.5 liters. Steel was used because other nonferrous material like copper and brass are attacked by ammonia. All side of the generator were insulated except the solar side. The second part of the system is the condenser which consists of a small coil (1cm diameter and 20 cm length 0.2 cm thickness) was immersed in cold water bath after that the receiver follows the condenser .The benefit of receiver is to collect liquid condensate outside of the condenser. And the evaporator is stainless steel pipe 1cm diameter and 10 cm length 0.2 cm thickness (Fig 1).

Experimental procedure

During the regeneration, valve A is open and valve B is closed(Fig. 1), and the strong solution in the generator being heated by the flat-plate collector producing vapor at a high pressure, the weak solution returns from the top to the bottom of collector. The vapor in the top header collector is mainly ammonia because water has a much lower volatility than ammonia. The ammonia vapor passes into the condenser which is immersed in a cold water bath to keep it cool, the pressure is uniform throughout the system. When heating stops at 14:30 PM (maximum generators temperature and pressure) valve A is closed and the vapor pressure in the generator drops. The concentration in the generator is now less than it was before regeneration, after that valve B was opened. The condenser now functions as the evaporator. Ammonia vaporizes due to the pressure difference between the generator and evaporator. The vaporization of ammonia absorbs heat from the surroundings of the evaporator, thus producing the refrigeration effect. Ammonia vapor from the evaporator passes through the pipe and taken to the bottom of the collector so that the incoming vapor bubbles through the solution thus facilitating absorption in it. Refrigeration continues until all the liquid ammonia in the evaporator has vaporized. A full cycle of operation has now been completed. The temperature and pressure of the evaporator and absorber were recorded every 5 minutes .

While the ambient, solution and generator temperature and the generator pressure were recorded at 30 minutes intervals.

Results of experiments are given in table (1) in the appendix.

DISCUSSIONS

Variation of Temperatures and Pressure with Time in Regeneration Cycle

Fig. 2 shows the variation of generator (T_g), solution (T_{so}), ambient (T_{am}) temperature with time (t). The average mean generator temperature (T_{gavr}) was between (61.5 to 66.7 °C).The maximum generator temperature ($T_{gmax)}$ for five runs was between (92 to 97 °C) this maximum temperature recorded at 02:30 PM because the sun at this time is vertically to collector . In the same figure the pressure variation with time it also shown .Initial pressure was for five runs (average) 2.4 bar and reached to maximum pressure(Pg) at 02:30 PM .The maximum pressures was about 12.9 bar for generation cycle, as a result of heating the generator and closing the exiting valve of the generator. And return to initial value after complete absorption cycle.

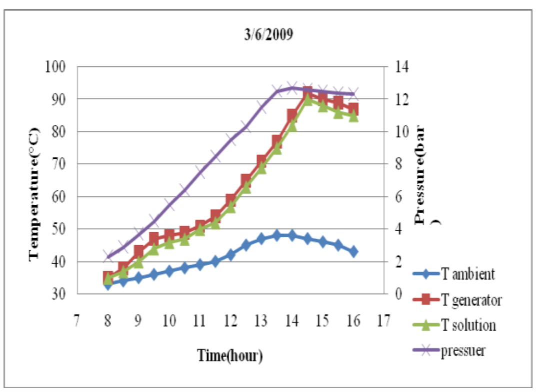

Fig.2 Variation of generator, ambient and solution temperature and generator pressure with time (NH_3-H_2O)

Variation of Temperatures and Pressure with Time in Refrigeration Cycle

Fig.3 shows the variation between evaporator (T_e), absorber (T_{ab}) temperature and evaporator (P_e), absorber (P_{ab}) pressure with refrigeration time. In this figures the evaporator temperature was about (30 to 35 °C) and pressure (10.4 to 10.7 bar). At this stage the temperature of surrounding more than evaporator temperature causing transfer of heat from surrounding to evaporator. The minimum evaporator temperature was (5 to 10 °C) for five runs. At these temperatures liquid ammonia was evaporated and evaporator pressure dropping to initial pressure (2.4 to 2.7 bar). Liquid ammonia was evaporated at (5 to 10 °C) and enter to absorber .The condition was (25 °C) and (1.7 bar) the vapor of ammonia absorbed in absorber the temperature of absorber increases to (32 to 34 °C) because the absorption is exothermic. The pressure in absorber at the end of refrigeration cycle equal to evaporator pressure.

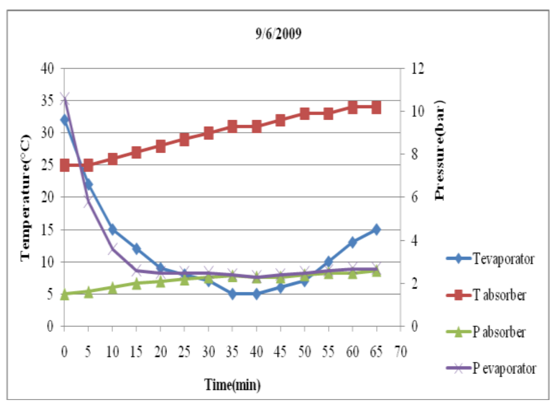

Fig.3 Variation of temperature and pressure in the evaporator and absorber with time (NH_3-H_2O)

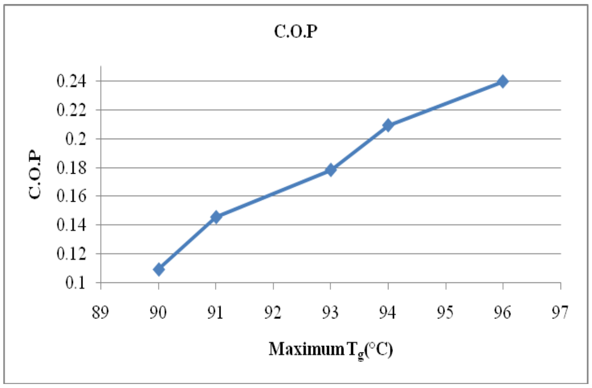

Fig.4 Effect of maximum generator temperature on C.O.P (NH_3-H_2O)

Effect of Maximum Temperature on C.O.P

Figs.4 and 5 shows the effect of maximum temperature and pressure on C.O.P For five runs it was found the C.O.P increases with maximum generation temperature and pressure .This is because the quantity of NH_3 evaporated increases with increasing maximum generation temperature.

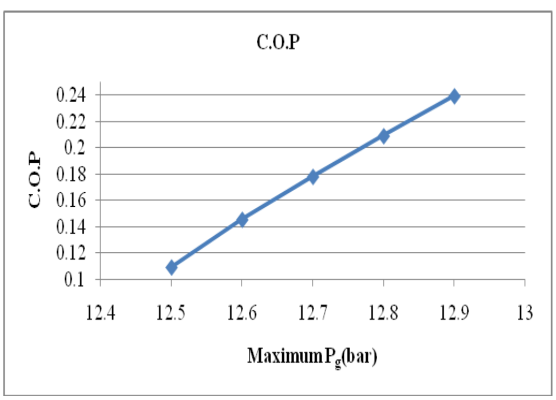

Fig.5 Effect of maximum generator pressure on C.O.P (NH_3-H_2O)

Effect of maximum generator temperature and pressure on evaporator temperature

Fig. 6 shows the Effect of maximum generator temperature and pressure on evaporator temperature. The minimum evaporator temperature (Temin) decreases with increasing maximum generator temperature and pressure.

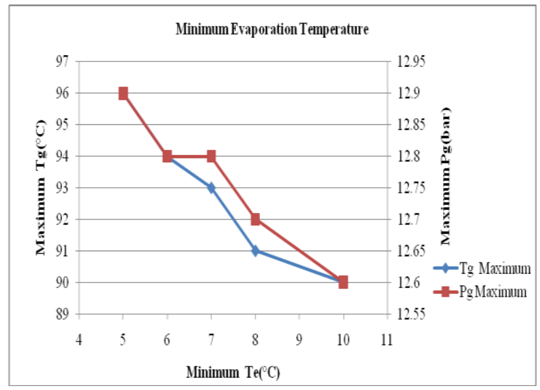

Fig.6 Effect of maximum generator temperature on evaporator temperature (NH_3-H_2O)

CONCLUSIONS

The following conclusions could be drawn from the present research during the months of June and July (2009),

1. The maximum generator temperature was found to be 97 °C.
2. The range of C.O.P for the aqueous ammonia system was (0.1096 - 0.2396).
3. The range of minimum evaporator temperature was (5°C - 10°C).
4. Cooling ratio and cooling obtainable increases with increasing maximum generator temperature and pressure.
5. The Final concentration decreases with increasing maximum generator temperature and pressure.

NOMENCLATURE

C.O.P	Coefficient of performance	T_{am}	Ambient temperature
P_{ab}	Absorber pressure	Te	Evaporator temperature
P_e	Evaporator pressure	T_{emin}	Minimum evaporator temperature
P_g	Generator pressure	T_g	generator temperature
t	Time	T_{gavr}	Average generator temperature
T_{ab}	Absorber temperature	T_{gmax}	Maximum generator temperature
T_{gmean}	Mean generator temperature		
T_{so}	Solution temperature		

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APPENDIX

Table 1 Summary of Experimental Results for Aqueous Ammonia System[13].

		Date June 2009				
	Day	3	9	11	14	22
Regeneration	Units					
Initial mass of solution	gm	1000	1000	1000	1000	1000
Initial mass concentration	_	0.45	0.45	0.45	0.45	0.45
Initial solution temp	°C	35	34	35	34	33
Max solution temp	°C	90	96	93	94	91
Max generator Pressure	bar	12.5	12.9	12.7	12.8	12.6
Incident solar radiation	KJ	532	532	532	532	532
Heat to collector plate	KJ	148.4	241.58	194.75	222.71	176.62
Mean generator temp	°C	62.5	65.5	63	64	62
Condenser temp	°C	30	30	30	30	30
Final concentration	_	0.42	0.38	0.41	0.39	0.4
Refrigeration						
NH_3 evaporated	gm	51.7	113	88.3	98.3	67.8
Min evaporator temp	°C	10	5	8	6	8
Cooling obtainable	KJ	58.32	127.47	94.95	111.35	77.59
Cooling ratio	_	0.3929	0.5275	0.4875	0.4999	0.4393
Solar C.O.P	_	0.1096	0.2396	0.1784	0.2093	0.1458