Investigation on an Intermittent Absorption Refrigeration prototype powered by Solar Irradiation

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ABSTRACT

In this study, a design and fabrication of intermittent solar absorption refrigeration unit was performed at Hillah city in Iraq(32.4^o, 44.4^o). The absorption solar unit consists of parabolic trough concentrator (PTC) was used as solar rays mirror reflector with aperture area of 2 m^2 , carbon steel pipe inside a vacuum glass envelop with a diameter of 1.5 in as tubular receiver, condenser, storage tank, evaporator. The aqua ammonia solution(NH_4OH)is used as working fluid with different concentration (25%, 30%, 35%, 40%). The validity and visibility of the unit were evaluated by measurements of pressures and temperatures at different parts of the unit during a year from May month 2014 to July month 2015. The maximum pressure and temperature is found to be 12 bar and 120^{o}C respectively. The coefficient of performance was in the range of 0.01-0.09.

Key words: Solar, Refrigeration, Absorption

الخلاصة

في هذه الدراسة ,تم انجاز تصميم وبناء منظومة تبريد امتصاصية تعاقبية في مدينة الحلة في العراق(44.4^o) (32.4^o). الوحدة الشمسية الامتصاصية تتكون من مركز على شكل حوض قطع مكافئ يستخدم كمرآة عاكسة للأشعة الشمسية بمساحة فتحة 2 م^2, انبوب من الحديد الكربوني داخل غلاف زجاجي مفرغ من الهواء بقطر 1.5 انج يعمل كمستلم انبوبي. يستخدم محلول هيدروكسيد الامونيوم كمائع تشغيل بتركيز مختلف (25%,30%,35%,40%). تحقيق ووضوح الوحدة قيم من خلال قياسات للضغوط ودرجات الحرارة خلال سنة من شهر ايار 2014 الى شهر تموز 2015 . اقصى ضغط ودرجة حرارة وصل ال 16 بار و 150 درجة سيليليزية. معامل الاداء كان يتراوح من 0.01 الى 0.09.

Nomenclature

A Area ……………….……m^2
Cp heat capacity ………………..kJ/kg.K
Coefficient of performance..……
CPC Compound parabolic concentrator..
G Solar radiation …………………..…W/m^2

m Mass …………………………….……kg
PTSC Parabolic trough solar concentrator…
Q_R Heat received from solar radiation….MJ
Qev Cooling capacity…..……………….MJ
t Time……..………..……………..……s

H solar insolation …………………….MJ/m^2 V volume…………………………………m^3

h_{fg} Latent heat of evaporation for NH_3….kJ/kg v Specific volume ……………………m^3/kg

1. INTRODUCTION

Energy shortage is sum of all fears in our earth on base of experts that sources of fossil fuel will be depleted in next 50 years**[1]**.It is a fact that the countries development and welfare states depend on energy so researchers are increasingly focusing on renewable energy sources. Another panic reason for concentration on renewable energy is global warming due to rise in global temperature (about 0.6 ^oC) according to UN governmental panel on climate change who also warned that the temperature may further increase by 1.4-4.5 ^oC **[2]**. The issue remains of seeking an alternative to fossil fuel before deplete or destroyed the earth. Solar energy can provide cheap and clean energy for cooling and refrigeration applications all over the world. Solar refrigeration has become more attractive for cooling and refrigeration purposes. Absorption is the process in which a substance assimilates from one state into a different state. These two states create a strong attraction to make a strong solution or mixture. The increase of heat in a solution can reverse the process **[3]**. The first evolution of an absorption system began in the 1700s.It was observed that in the presence of H_2SO_4 (sulfuric acid), ice can be made by evaporating pure H_2O (water)within an evacuated container. In 1810,it was found that ice could be produced from water in a couple of vessels connected together in the presence of sulfuric acid. As the H_2SO_4 absorbed water vapor (to reduce heat), ice formed on the surface of water. Sorption refrigeration systems have annexed a lot of interest due to their zero ozone attrition, so it is have favorabls of being environmentally zero impact. Using of natural refrigerants such as ammonia, water, methanol, etc. it will be zero global warming(GWP). No moving parts, low –grade of heat requirement, less noise, low initial cost . All that will add fortuitous over the exiting vapor compression systems**[4].**

Aqua-ammonia vapor absorption refrigeration systems which operate such that the generation of ammonia vapors takes place at the daytime only and the production of cold utilizing the generated ammonia vapors takes place at the night time only are known as intermittent-based operation systems. The operation of the system is approximately the same as that of the continuous operation system except that in such systems, both the generation and absorption processes take place intermittently in the same vessel. Similarly, both the condensation and evaporation take place intermittently in the same heat exchanger. The water cooling system designed for this system works on the thermo siphon. Different types of collector are used to concentrate the solar heat on the receiver unit(Generation/Absorption unit G/A). Rivera et al. 2003**[5]** presents a theoretical performance of an intermittent absorption refrigeration system with compound parabolic concentrator(CPC) and NH_3-$LiNO_3$ as working pair fluid. They found that the maximum temperature was 120^oC and the coefficient of performance was 0.15-0.4 and the efficiencies were satisfactory the simplicity of the system. Moreno et al.2012**[6]** performanced an experimental comparison between binary working fluid (NH_3/$LiNO_3$)and ternary working fluid (NH_3/$LiNO_3$/H_2O) by using a compound parabolic trough (CPC). They found the coefficient of performance of ternary working fluid was up to 24% higher than those obtained with the binary mixture. The presence of water with refrigerant liquid form a problem during the expansion process due to choking phenomena so, Sun**[7]** analyzed the performance of refrigeration systems operating with ammonia/water, ammonia/lithium nitrate, and ammonia /sodium thiocyanate mixtures. It was found that the ammonia/lithium nitrate, and ammonia /sodium thiocyanate mixtures were suitable alternatives to ammonia/water absorption systems. The important purpose of solar absorption unit is working in the rural area and desert area where no electricity grid is found, so Hammad et al 2000**[8]** made a steel sheet cabinet 0.6*0.3*0.5 m, the cabinet was intended to store vaccine in the remote desert area with suitable temperature and using solar powered aqua ammonia solution. The coefficient of performance (COP) was found 0.65 with refrigeration effect period of 8 hours.

The most common cycles are NH_3-H_2O and H_2O-LiBr that have served as standards for comparison in studying and developing new cycles and new refrigerant. Abdulateef et al 2008**[9]** used thermodynamic properties to simulate three cycles NH_3-H_2O, NH_3_LiNO$_3$, and NH_3-NaSCN. The purpose from this simulation was to compare the performance of three operating working fluid pairs. The results show that the NH_3_LiNO$_3$ and NH_3-NaSCN cycles give better performance than NH_3-H_2O, because of no requirement for analyzer and rectifier. Different solar sources are used as power for refrigeration absorption units, Sierra et al 1993**[10]** used a solar pond to power an intermittent absorption refrigerator with NH_3- H_2O solution . It was reported that generation temperatures as high as 73 ^oC and evaporation temperatures as low as -2 ^oC could be obtained. The thermal COP working under such conditions was in the range of 0.24-0.28. De Francisco et al 2002**[11]** developed and tested a prototype of 2kW NH_3-H_2O absorption system in Madrid for solar powered refrigeration in small rural operations. The test results showed that unsatisfactory operation of the equipment with COP lower than 0.05. In Mexico a theoretical study of an intermittent absorption refrigeration system carried out by Rivera et al 2003**[12]**. The designed system was driven by a compound parabolic concentrator (CPC) operated with ammonia –LiNO$_3$. The results showed that in typical Mexico weather, it was possible to produce up to 11.8 kg of ice with a thermal COP between 0.15 and 0.4 depending on the generation and condenser temperatures. Bulgan (1995) **[13]** optimized the aqua-ammonia absorption refrigeration system (ARS) in the light of the first law of thermodynamics. The system consisted of an evaporator, a generator, a condenser, a pump, expansionvalves and two heat exchangers. A theoretical model was developed for the ARS. The coefficient of performance (COP) was maximized for various evaporator, condenser and absorber temperatures. Li et al. 2002 **[14]** published an experimental study on the dynamic performance of a flat-plate solar solid-adsorption refrigerator for ice making operating with activated carbon/methanol. The experimental results showed that this machine could produce 4-5 kg of ice after receiving 14-16 MJ of solar radiation with a surface area of 0.75 m^2, while producing 7-10 kg of ice after receiving 28-30 MJ of solar radiation with a surface area of 1.5 m^2. Hildbrand et al. 2004 **[15]** reported the results of the performance of an adsorptive solar refrigerator built in Yverdon-les-Bains, Switzerland operating with the adsorption pair silicagel water. Cylindrical tubes functioned both as the absorber system and the solar collector. The condenser was air-cooled and the evaporator contained 40 L of water that could freeze. The results showed that the gross solar coefficient of performance defined by the authors varied between 0.1 and 0.25 with a mean value of 0.16 .

From above a strenuous efforts were exerted for validity, feasibility, modification and improvements in the weather conditions of researcher country. Therefore in the present study a design , fabrication, experimental and theoretical prediction for solar insolation is achieved in Iraq. He study used ammonia as refrigerant due to its thermodynamic properties**[16]**

2.SYSTEM DESCRIPTION

The solar powered absorption refrigeration prototype was designed and fabricated to operate with the aqua ammonia (NH_4OH) for a maximum capacity of 1 kg of ice/day for experimental purposes. It consists of a condenser, a storage tank, an expansion valve, by pass a capillary tube, an evaporator and a parabolic trough concentrator(CPC) as shown in **Fig.1** The CPC reflector was made out of an stainless steel sheet with a reflectance value of 0.85. The tubular receiver covered with a black paint with an emittance range from 0.28 to 0.5 and an absorptance range from 0.88 to 0.94 the other specifications show in **table 1.** The tabular receiver rounded by glass envelop to reduce the convection effect. As water evaporates at the operating conditions, a rectifier is necessary in the system. The system operated solely with solar energy and no other moving parts were required. The condenser consisted of a heat exchanger composed of a helicoidally carbon steel coil , immersed in a water tank. The water inside the condenser is continuously circulated to control the temperature of the cooling water for experimental purposes. The coiled cylindrical storage tank had a capacity of 0.5 L. Two expansion devices used : a capillary tube and an ordinary valve with 1.5 mm hole diameter. Only one of these expansion devices was used at a time during the evaporation process. The capillary tube is recommended because it permits the automation of the evaporation process. The evaporator was made from carbon steel inside an insulated chest as shown in **Fig. 2.**

During the day, the aqua ammonia solution in the generator/absorber was heated by the solar radiation incident on the CPC until it reached the saturation temperature. Then the ammonia is partially evaporated from the solution. The ammonia vapor goes a water cooled condenser, where it is condensed and then it is stored in the storage tank. At night, the temperature and pressure in the generator-absorber decreases because of the decrease of the ambient temperature. In this way, the pressures are inverted in the components in a natural way. The liquid ammonia passes through the expansion valve decreasing its pressure and temperature, producing the refrigeration effect in the evaporator. Then it returns to the generator-absorber where it is absorbed by the weak solution starting the cycle again.

3.CALCULATION PARAMETERS

Five main parameters were used in order to evaluate the performance of th experimental system: (i) the amount of ammonia produced in the generator, (ii) the insolation, (iii) the solar radiation incident on the CPC, (iv) the cooling capacity and (v) the solar coefficient of performance. The amount of ammonia produced in kg is the ratio between the storage tank volume to saturated specific volume of ammonia liquid as following:

$$m_{NH_3} = \frac{V_{storage\ tank}}{v_{L_{NH3}}} \tag{1}$$

The solar irradiation is the sum of the product of the solar radiation and time:

$$H = \sum_{i=1}^{n} G_i\ t \tag{2}$$

The energy incident on the CPC is calculated as:

$$Q_R = \sum_{i=1}^{n} G_i\ tA \tag{3}$$

The cooling capacity is the sum of latent heat and sensible heat at sub cooling state:

$$Q_e = m_{NH_3}(h_{fg} + C_P\Delta T) \tag{4}$$

4.EXPERIMENTAL RESULTS & DISCUSSION

4.1. Variation of temperatures and pressures

In order to experimentally evaluate the solar refrigeration system operation , more than 120 tests run are carried out during the year. However, only 50 tests were taken in account because of cloudy, dusty skies periods(Normally longer than two hour). During the experimental test the pressure and temperature are the main parameters ,the pressure is logged every 60 seconds and the temperature is logged every 600 seconds. The temperatures and the pressure are measured experimentally with change of incident solar radiation(S_{module}) on parabolic trough concentrator. The efforts of experimental work are presented in the **figs 3-12**. The figures show the behavior of the temperatures and pressures for different parts of the solar unit. The figures are performed for the summer and winter months during the year. It can be seen from **figs 3-12** that the pressure increase with increment of the solar radiation. The maximum pressure and temperature occur at maximum solar radiation at almost the midday. The maximum pressure and temperature reached to over 12 bar and 120 ^{o}C respectively during summer season and this is matched with the maximum load at this season. During the cold months as December , January, February, that the maximum pressure reaches to 4.5 bar . Also the temperature of generator($T_{G/A}$)is more than the vapor solution temperature, since the generator represent the source of heating to the solution

After the incident solar radiation decreasing the pressure and temperature will decrease too almost after 12.00 pm. So the system should be shutdown to prevent any lose in the pressure (pressure drop).

4.2 Effect of Concentration

The concentration is an important parameter for the unit performance, due to the increasing in the concentration means a lot of releasing ammonia vapor. In the study different solution concentration used for tests (25%,30%,35%,40%). **Fig. 13** shows the maximum pressure reached in the cylindrical receiver against solution temperature in the generator unit. It can be observed that the pressure increases rapidly with the increment of the solution temperature and concentration. The increment in the concentration leads to increase in the ammonia vapor liberated. **Fig. 14** shows that the liberation of ammonia vapor occurs at low temperature when the solution concentration is high , while the low concentration needs higher temperature to liberate ammonia vapor . **Fig. 15** shows that the pressure of generator is higher at high concentration due to the larger ammonia vapor liberated as shown in **fig.16**. The figure shows the relation between concentration and mass of ammonia vapor produced. It can be observed that the amount of ammonia vapor increases with increasing the concentration. This increasing in mass produced depends on energy received by the CPC and solution concentration.

4.3. Experimental coefficient of performance

The coefficient of performance depends on concentration as well as the pressure achieved in the unit base on the ammonia vapor is completed condensation (saturated liquid at environment temperature). The refrigeration effect(cooling capacity) occurs at night, when the environment temperature reaches to saturated ammonia liquid temperature. High pressure for ammonia liquid (refrigerant) means high saturated temperature, then sensible heat will add with latent heat of evaporation to increase the coefficient of performance. **Figure 17** shows the coefficient of performance(COP) for the solar intermittent system operating with aqua ammonia solution. Different solution concentrations had been tested in the experimental study (25%,30%,35%,40%). It can be observed that the higher performance is obtained at higher concentrations due to large ammonia vapor produced. The high concentration gives more ammonia released and high pressure difference between evaporator and condenser. In any refrigeration system the coefficient of performance increases with increasing the pressure difference between evaporator and condenser(or generator). **Figure 18** shows the effect of increasing pressure on the increasing of COP. High pressure in unit leads to high latent heat for evaporation after expansion valve.

5. CONCLUSIONS

In this study a novel solar intermittent refrigeration system for ice production was developed and designed with aqua ammonia solution to match with Iraqi weather conditions. The natural refrigerant (ammonia) is suitable for intermittent absorption refrigeration unit, due to high latent heat for evaporation. It is obvious that the solar irradiation satisfies the unit requirements. The parabolic trough concentrator (PTSC) is suitable for intermittent absorption refrigeration unit, due to the high temperature and pressure can be obtained during the day. The high pressures and temperatures present during all months suitable for unit operation. The condenser unit can be neglected at low ammonia amount used, due to high pressure performed during the operation. The amount of aqua ammonia used can be increase for present study (more than 10 kg) due to large aperture area for PTSC. So the coefficient of performance will be increase with increase of released ammonia. The environment temperature have important role in intermittent absorption unit for saturated conditions purpose for ammonia liquid. The expansion device is more efficient than the capillary tube due to the change in the inlet pressure for ammonia liquid in different seasons and days.

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Table (1): overall dimensions for collector unit

Item	Value/type
Collector aperture area	2 m^2
Aperture width	106 cm
width to focus ratio	4.6
Rim angle	41^o
Receiver diameter	1.5 in.
Mode of tracking	Manual seasonal adjustment
Geometric Concentration ratio	7

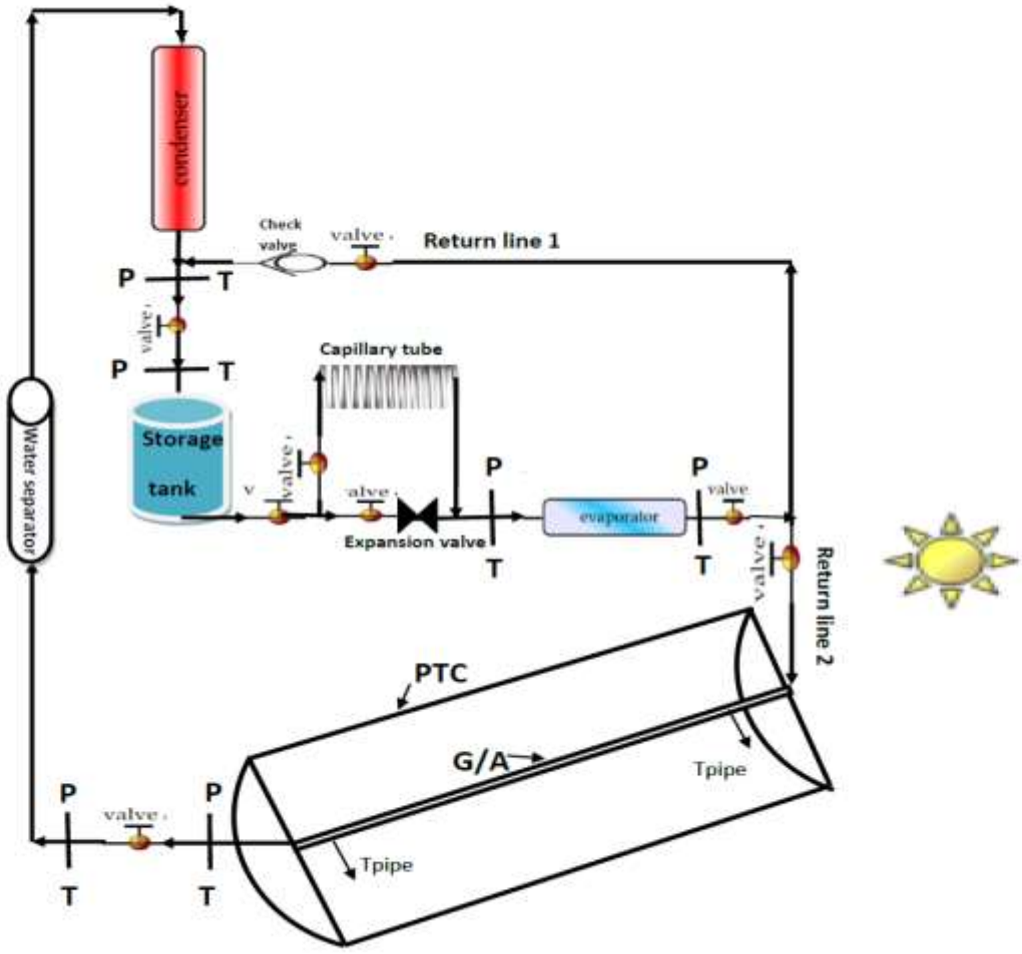

Figure (1): Schematic of solar powered intermittent absorption unit

Figure (2): a photograph of the solar absorption refrigeration module

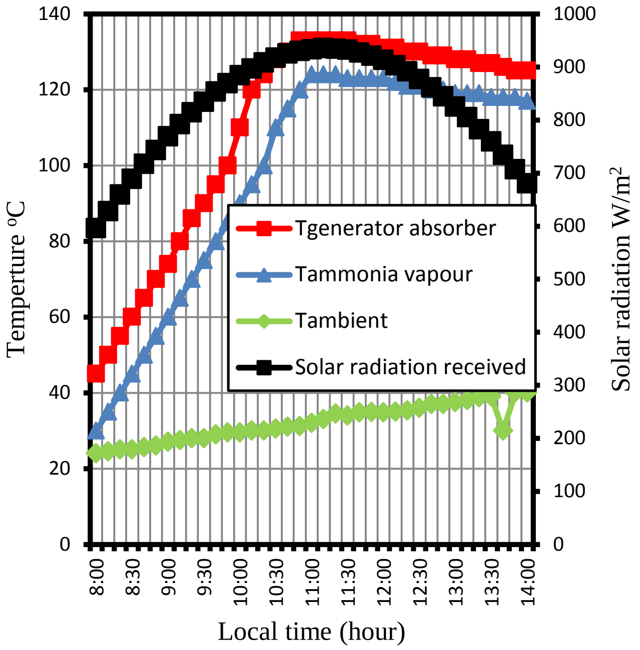

Figure 3 Development of generator, ammonia vapour,ambient temperture and solarradiation received with time in sunny day June.2014

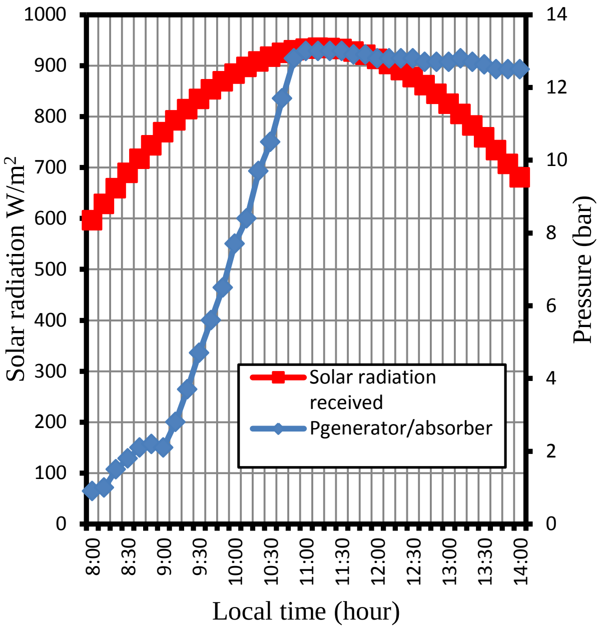

Figure 4 Development of generator pressur and solar received with time in sunny day June.2014

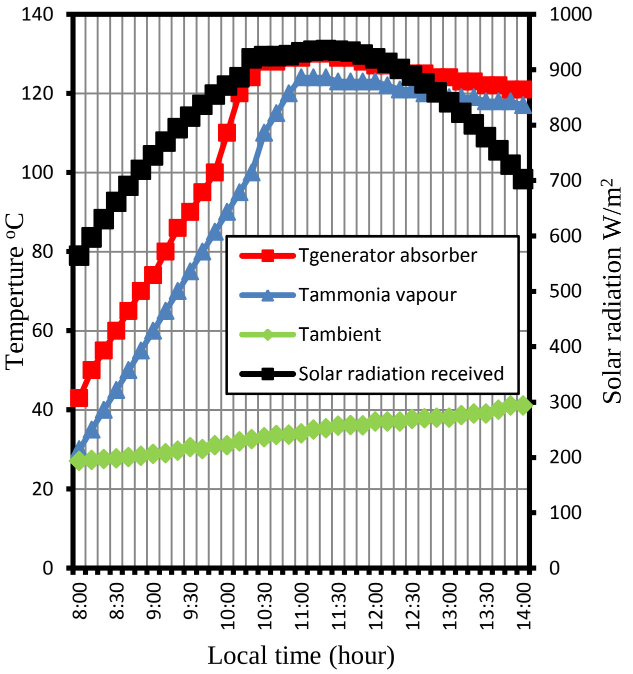

Figure 5 Development of generator, ammonia vapour,ambient temperture and solar radiation received with time in sunny day July.2014

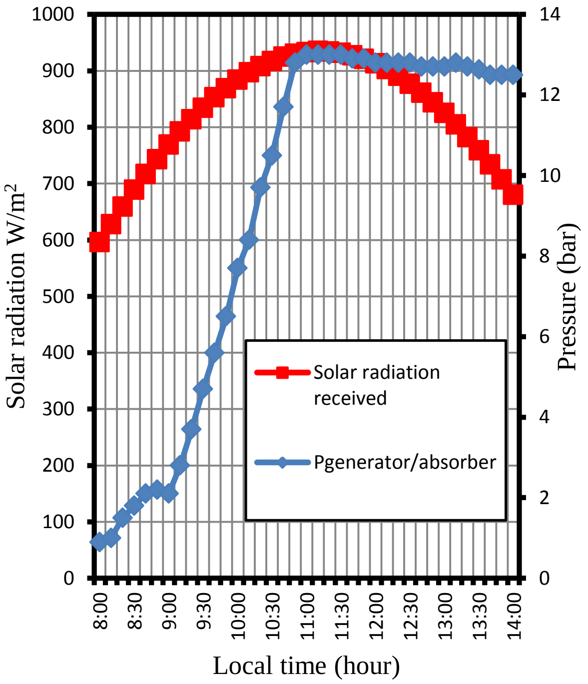

Figure 6 Development of generator pressur and solar received with time in sunny day July.2014

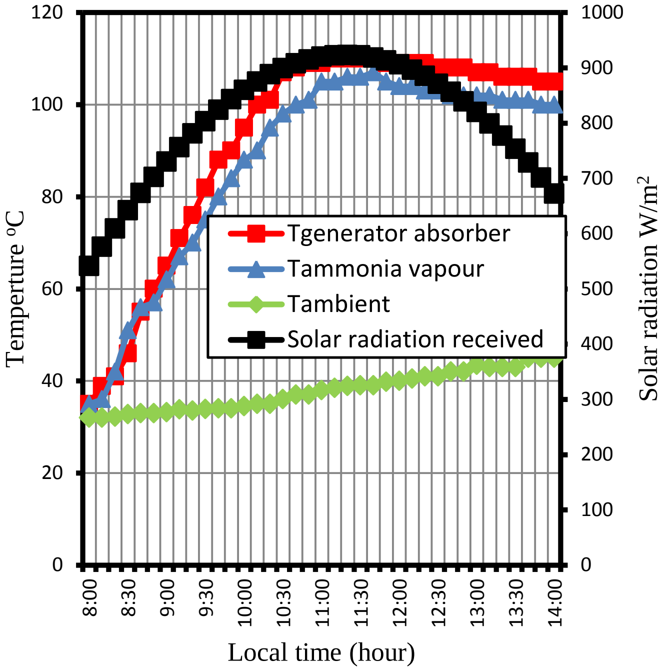

Figure 7 Development of generator, ammonia vapour,ambient temperture and solar radiation with time in sunny day Aug.2014

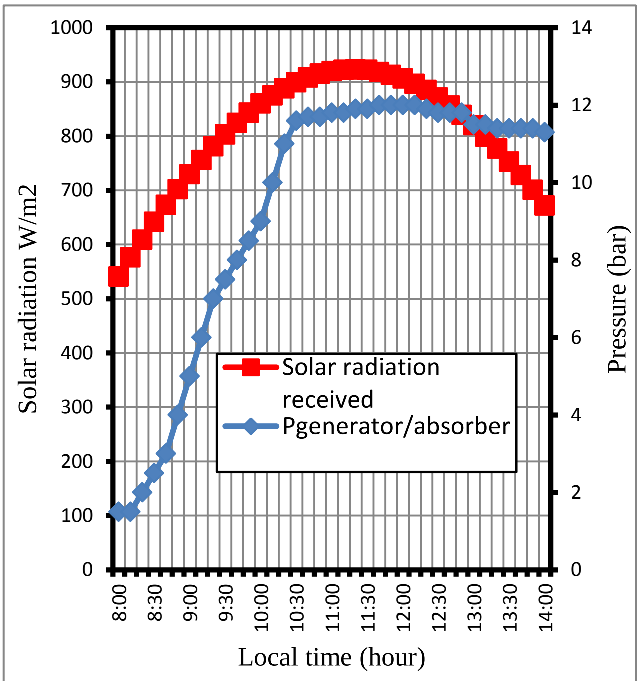

Figure 8 Development of generator pressur and solar received with time in sunny day August.2014

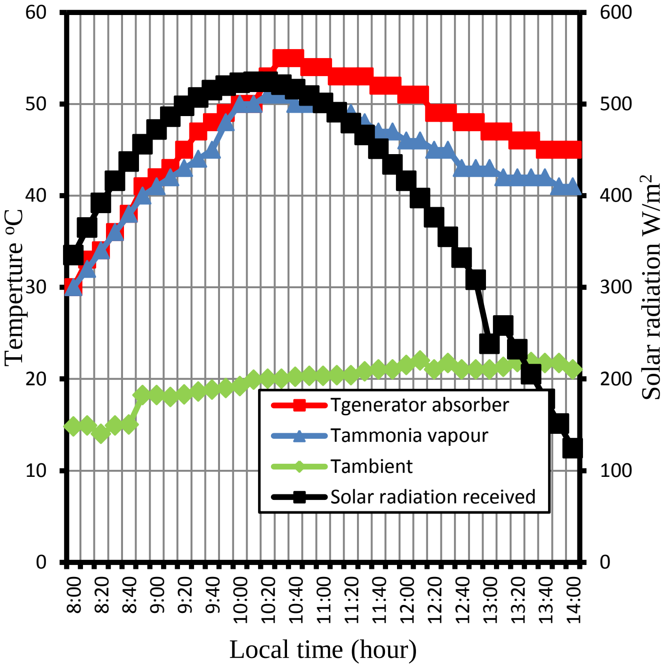

Figure 9 Development of generator, ammonia vapour,ambient temperture and solar radiation with time in sunny day Nov.2014

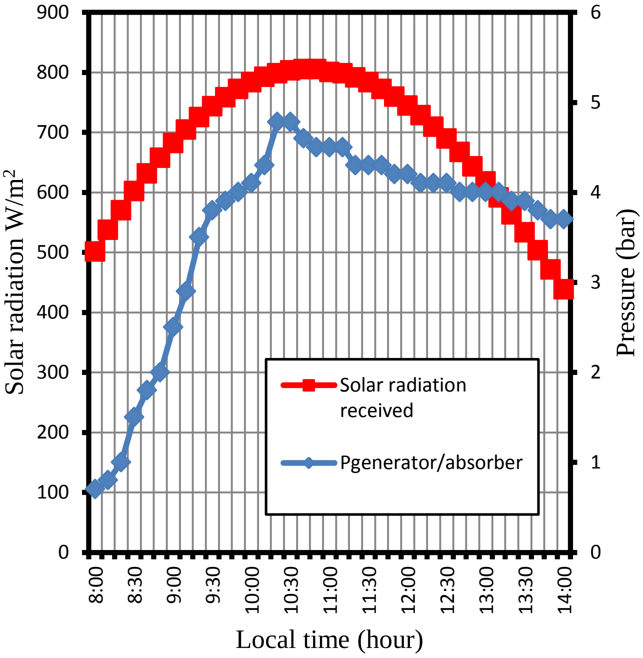

Figure 10 Development of generator pressur and solar received with time in sunny day Nov.2014

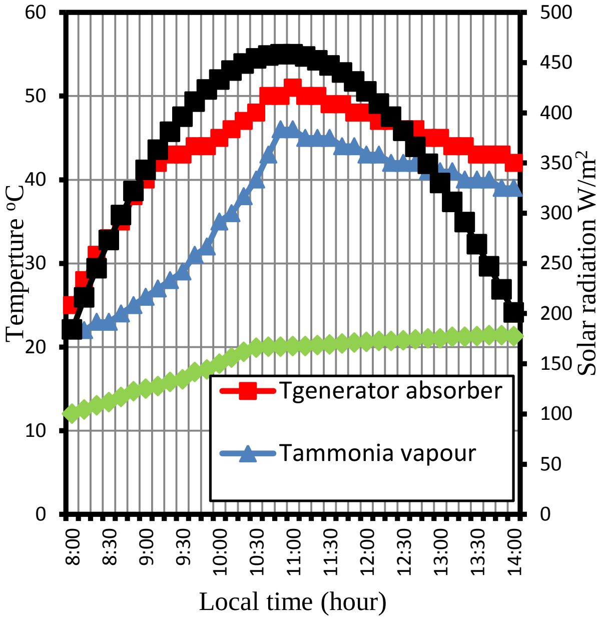

Figure 11 Development of generator, ammonia vapour,ambient temperture and solar radiation with time in sunny day Dec.2014

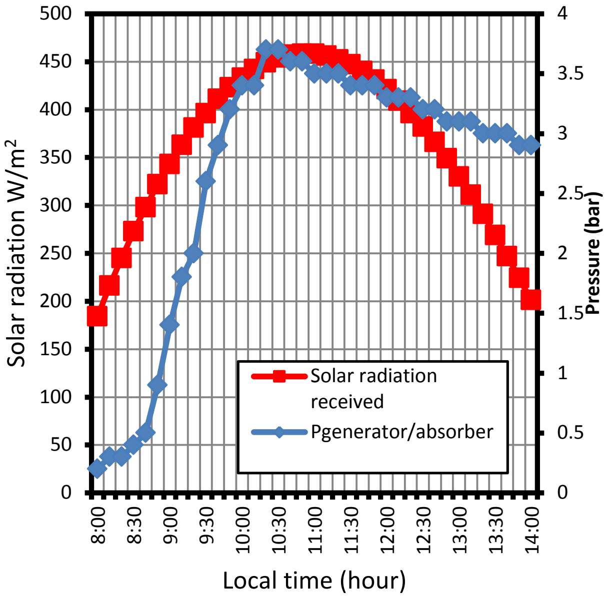

Figure 12 Development of generator pressur and solar received with time in sunny day Dec.2014

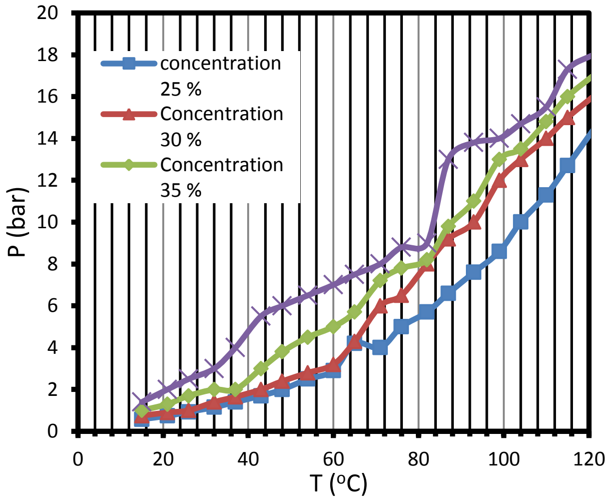

Figure 13 Total pressure versus temperture of solution

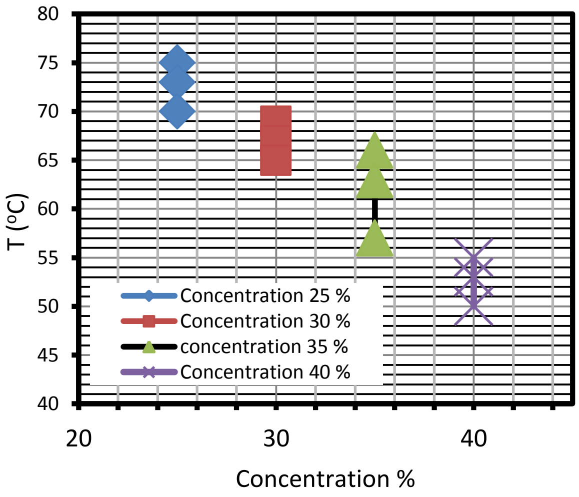

Figure 14 Initial generation temperture (°C)

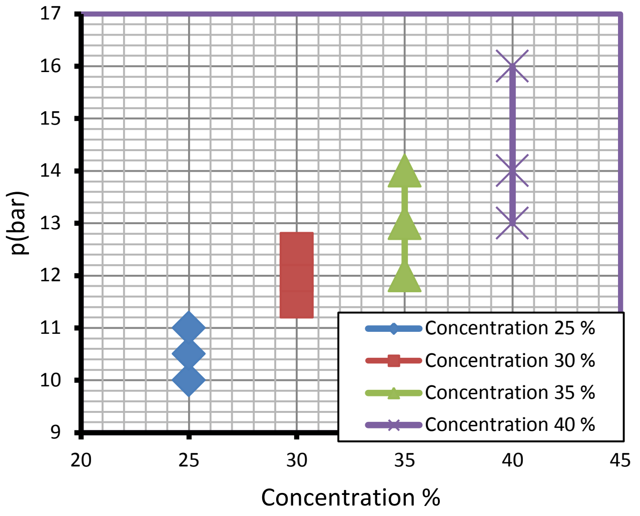

Figure 15 Generator/ Absorber Operating pressure (bar)

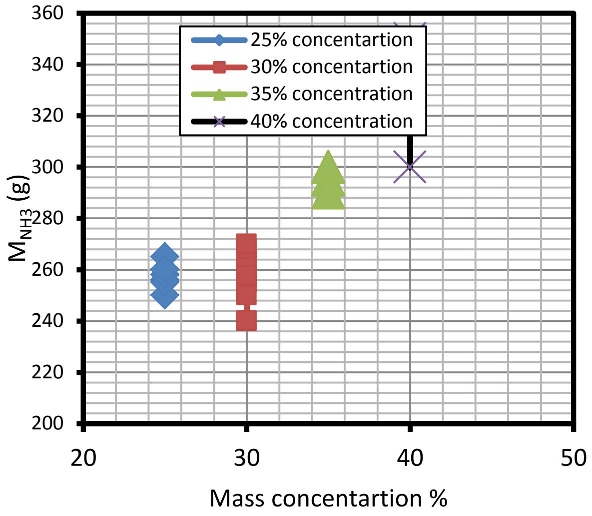

Figure 16 Mass of ammonia produced during the generation process

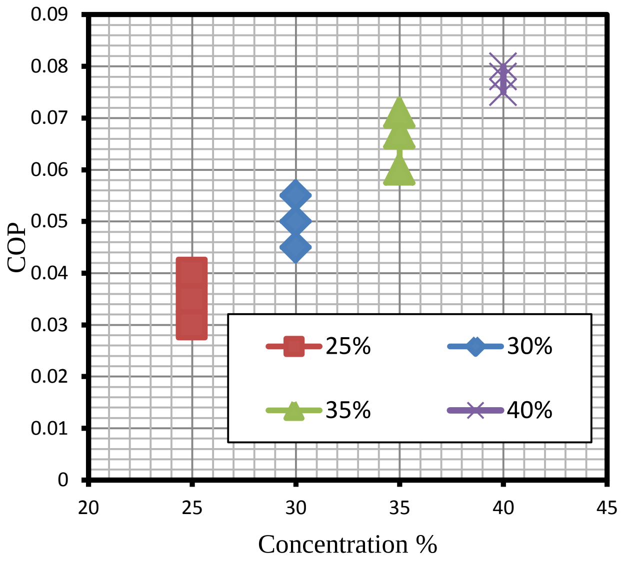

Figure 17 Coefficient of Performance (COP) for different concentration

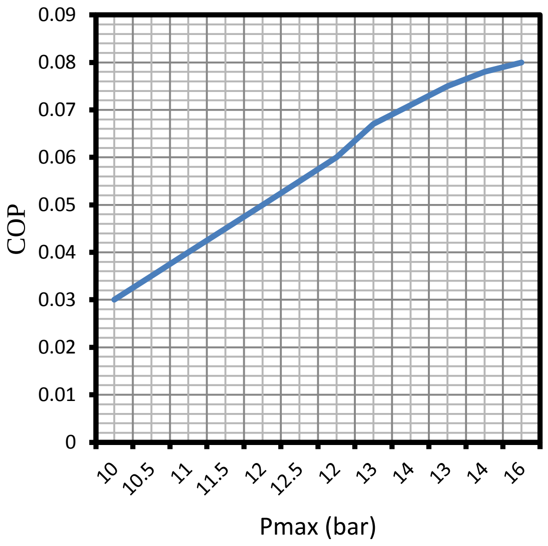

Figure 18 Coefficient of performance versus generator pressure