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Modification of a Solar Absorption Refrigerator for Performance Improvement

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ABSTRACT: *A solar absorption refrigerator uses solar energy as a heat source to operate the cooling system. Nowadays, absorption refrigerators displace the vapour compression refrigeratordue to vibration of compressor and unavailability, cost and load shedding of electricity. It mainly consists of a solar energy collector that focuses the solar radiation to generator pipe in which the absorption mixture (calcium chloride and aqueous ammonia) will be heated,and it will release ammonia gas. Distilled ammonia will be generated in the day and reabsorb will occur at night. The gas condenses in the condenser and will drip down into the storage tank, where absorbed ammonia will be collected at the end of the day. As the generator cools at night, the calcium chloride will reabsorb ammonia gas, pulling it back through the condenser coil as it evaporates out of the tank in the insulated box which removes large quantities of heat from the insulated box. The average temperature of the generator increases and a the same timethe evaporatortemperature decreases. As a result, temperature difference between evaporator and generator increase due to an increase of mass flow rate of refrigerant (ammonia gas). Thus more refrigerant is occupied to remove heat from the isolated box during evaporation. So, COP of the solar absorption is increased.*

Keywords *-absorption , COP,calcium chloride and aqueous ammonia, evaporation, solar radiation.*

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I. INTRODUCTION

Solar energy is the cleanest, reliable and available renewable energy source. The nuclear fusion reactions of hydrogen nuclei to helium produced solar energy in the sun. This energy is radiated as light and heat, and transmitted through space as quanta (packet) of energy called photons to the earth. Refrigerators are one of the most energy-consumption apparatus in our life.As pointed out by Coulomb (2007) in his introductory talk at the Second International Conference on Magnetic Refrigeration at Room Temperature (Thermag II), 15% of the total worldwide energy consumption involves the use of refrigeration (air conditioning, refrigeration, freezing, chilling, etc.) [1]. The vapour absorption refrigeration system now become popular than the vapour compression refrigeration system, which requires no external work (compressor) and less effect on ozone layer depletion because of no use of CFC refrigerant. To overcome this problem, the alternative technology such as thermoelectricity [2], adsorption [3], electrochemical refrigeration [4], and magnetic refrigeration [5].William Cullen first demonstrated artificial refrigeration at the University of Glasgow in 1748[6]. The American inventor Oliver Evans, acclaimed as the "father of refrigeration," invented the vapor-compression refrigeration machine in 1805[6]. The heatwas removed from the environment by recycling vaporized refrigerant, where it moved through a compressor and condenser, where it eventually reverted to a liquid form to repeat the process. However, Evans built no such refrigeration unit. In 1834,Jacob Perkins modified Evans' original design, building the world's first refrigerator and filing the first legal patent for refrigeration using vapor-compression[7].The French scientist Ferdinand Carré invented theabsorption cooling in 1858 [8].

Nomenclature			
List of symbols			
COP	coefficient of performance	”	inch
T_A	ambient temperature (°C)		
T_G	generator temperature (°C)	Subscripts	
T_E	evaporator temperature (°C)	A	ambient
Q	heat rate (W)	G	generator
Q_E	evaporator heat rate (W)	E	evaporator
Q_G	generator heat rate (W)	th	theoretical

Though absorption refrigerator is a good alternativeto reduce energy consumption of power sector, ithad some drawback such as COP comparatively low, not suitable for very low evaporating temperature, high heat release to the ambient and required a good knowledge about maintenance. Also, a high load system requires a large area of the solar collector, which means a very high installation cost and a large installation area.

Absorption cooling is done using some working pairs (absorbent/refrigerant). The selection criteria of working pair solely depend on their availability, cost, chemical and physical properties, environmental effect, application area (refrigeration, air conditioning), and mostly on the affinity between them and so forth. The performance and sorting criteria are discussed briefly in Ref [9].

In this project a solar collector collects solar energy to evaporate the refrigerant that flows through the condenser coil, where the refrigerant condenses. The condenser coil is placed inside a water bath. Then condensed refrigerant is collected in a storage tank which is an insulated box and from which temperature will be rejected for cooling operation.

II. ABSORPTION REFRIGERATOR DRIVEN BY SOLAR

The solar-powered absorption refrigerator system is shown in Fig. 1. It consists of an evaporator, a generator-absorber instead of compressor used in vapour compression refrigerator, a condenser and a valve. As a generator-absorber, a compound parabolic concentrator (CPC) with a glass cover is used in the cooling system.In this work, ammonium hydroxide is used as refrigerant and calcium chloride as absorbent. We used a mixture of 25% 325 ml NH_4OH and 100 gm $CaCl_2$.The refrigerant ammonia (R-717) is useful because of its vaporization properties, high energy efficiency and low cost.

Heat is lost by the radiation (collector is not a perfect body) and convection (wind flow) from the generator pipe. A glass plate acts as heat insulator is used to covers the solar collector and generator to prevent the heat flow due to convection. This glass plate of approximately 3 mm thickness allows almost all the incident solar ray to pass through,but it resists the light ray of longer wavelength (radiated heat). Since the reflection surface made by the glass piece is not a perfect parabola, a portion of reflected ray is not incident on the generator pipe. A metallic plate, which reflectivity is approximately close to the glass is used to solve this limitation. However, the metallic plate absorbs some energy to heat up itself. Thus there also would have some loss of incident energy.

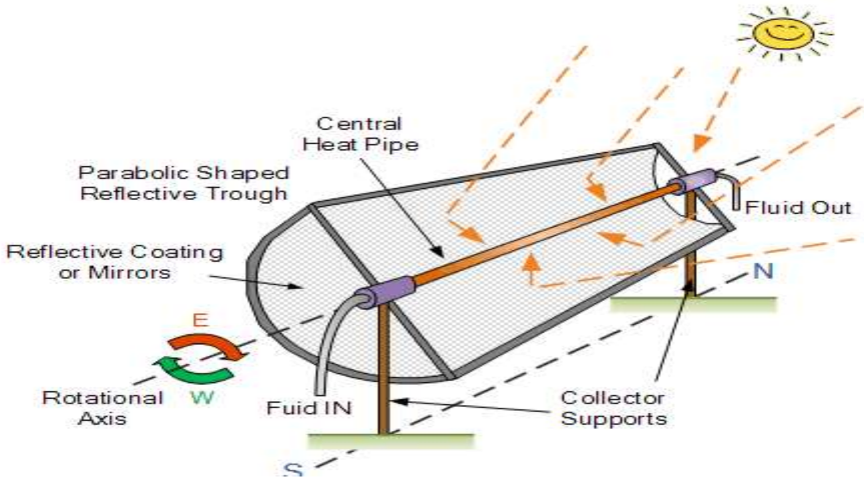


Figure 1: Diagram for a refrigerator by using parabolic trough [10]

The refrigerator will operate according to the following cycle-

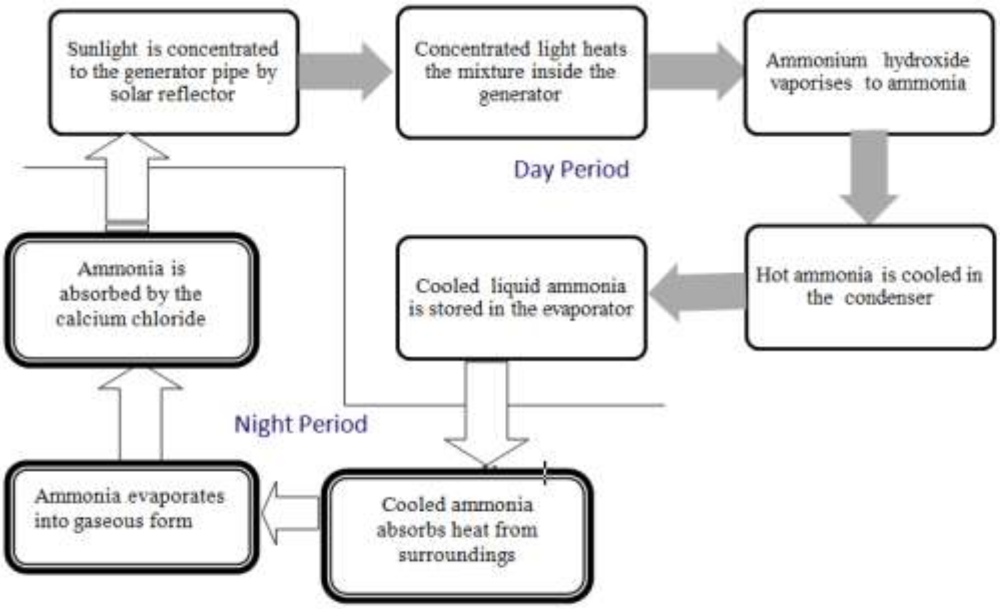


Figure 2: Flowchart of the operation of the refrigerator

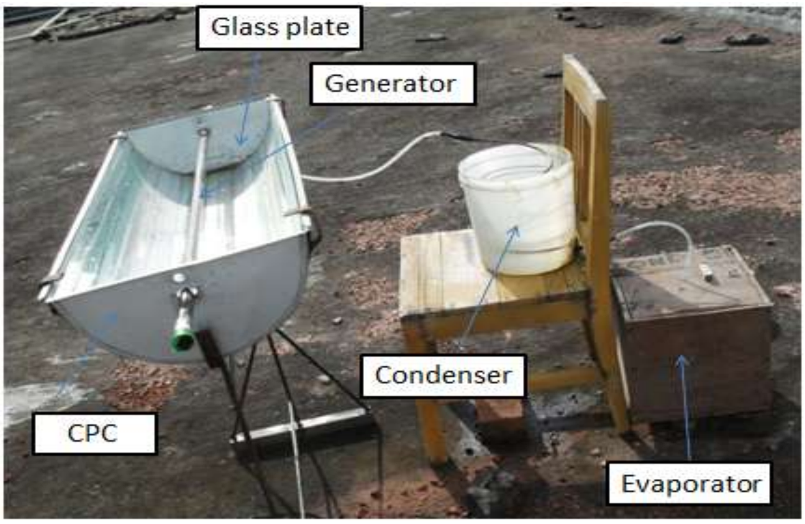


Figure 3: Experimental setup of the solar absorption refrigerator

2.1 Dimension of the experimental setup

- Length of solar collector = 36 inch
- Breadth of the solar collector = 12 inch
- Radius of the bottom = 8 inch
- Length of the generator pipe = 3 foot
- Diameter of the generator pipe = 1 inch
- Length of the condenser copper coil = 15 foot
- Dimension of the metallic plate = (36" x 18")
- Amount of refrigerant mixture = 325 ml 25% $(NH)_4OH$ and 100 gm $CaCl_2$

2.2 Theoretical coefficient of performance and percentage of ammonia stored

It is assumed that the absorption refrigeration system is a perfectly reversible system. According to the first law of thermodynamics, the coefficient of performance of the absorption refrigeration system is given by

$$Cop = \frac{\text{Heat absorbed in evaporator}}{\text{Heat supplied in generator} + \text{Pump work}}$$

As there is no pump work, the overall performance of the system

$$(\mathbf{COP})_{\mathbf{th}} = \frac{Q_E}{Q_G}$$

$$= (\frac{T_E}{T_A - T_E})(\frac{T_G - T_A}{T_G})$$

$$\text{percentage of ammonia stored} = \frac{\text{Measured volume in flask}}{\text{Total volume}} \times 100\%$$

2.3 Efficiency parameters of a solar absorption refrigeration system

- Incident solar ray**:** Incident solar ray is not always the same. It varies from time to time as well as day to day.
- Radiation concentration: A higher concentration of radiation will raise the absorber temperature and as well as increase the COP of the system.
- Flow rate of refrigerant: The vaporization of ammonia increases with the increase of generator temperature. So, the flow rate of ammonia varies continuously.
- Thermal receiver efficiency: The convective and radiation heat losses affect the COP of the refrigerator.
- Impurities inside the flow path:Impurities may enter the flow system of the refrigerator from valve stem packing, piping leaks and thetypical breakdown of ammonia. It may be added during charging the system and through inadequate evacuation
- Fabrication of insulated box:Fabrication of insulated box is difficult.

III. RESULT AND DISCUSSION

Data is collected from 6 AM to 1AM in every hour interval. Performance of the refrigerator is tested two days for the system fabricated previously and for each system including modification. A mercury thermometer and measuring flask are used to measure temperature and storage volume of the liquid respectively.

TableI: Temperature of the different parts fabricated bythe parabolic collector (Day 1- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_A(°C)	Temperature difference (°C)
6:00 AM	40	28	12
7:00 AM	40	28	12
8:00 AM	42	31	9
9:00 AM	49	32	17
10:00 AM	51	33	18
11:00 AM	56	34	22
12:00 PM	60	35	25
01:00 PM	60	35	25
02:00 PM	60	35	25
03:00 PM	57	35	22
04:00 PM	52	34	18

Liquid Ammonia stored at the end of the day = 165ml (50.77%)

TableII: Temperature of the different parts fabricated bythe parabolic collector (Day 1- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	26	29	03
8:00 PM	25	28	03
9:00 PM	23	28	06
11:00 PM	22	27	05
01:00 AM	21	25	04
05:00 AM	22	26	04

Table III: Temperature of the different parts fabricated bythe parabolic collector (Day 2- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
6:00 AM	33	28	05
7:00 AM	38	28	10
8:00 AM	42	30	12
9:00 AM	48	31	17
10:00 AM	53	31	22
11:00 AM	58	33	25
12:00 PM	60	35	25
01:00 PM	60	35	25
02:00 PM	60	36	24
03:00 PM	56	35	21
04:00 PM	54	32	22

Liquid Ammonia stored at the end of the day = 190ml (58.46%)

TableIV: Temperature of the different parts fabricated by the parabolic collector (Day 2- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	26	29	03
8:00 PM	25	28	03
9:00 PM	25	28	03
11:00 PM	22	28	06
01:00 AM	22	27	05
05:00 AM	22	28	06

Table V: Temperature of the different parts fabricated by CPC (Day 1- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_o(°C)	Temperature difference (°C)
6:00 AM	35	28	07
7:00 AM	35	28	07
8:00 AM	38	29	09
9:00 AM	43	30	13
10:00 AM	50	34	16
11:00 AM	56	34	22
12:00 PM	62	36	26
01:00 PM	66	34	32
02:00 PM	68	34	34
03:00 PM	67	32	35
04:00 PM	62	30	32

Liquid Ammonia stored at the end of the day = 220ml (67.07%)

Table VI: Temperature of the different parts fabricated by CPC (Day 1- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	26	29	03
8:00 PM	25	29	04
9:00 PM	23	29	06
11:00 PM	21	28	07
01:00 AM	19	25	04
05:00 AM	16	28	12

Table VII: Temperature of the different parts fabricated by CPC (Day 2- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
6:00 AM	34	28	06
7:00 AM	37	29	08
8:00 AM	37	30	07
9:00 AM	41	30	11
10:00 AM	46	30	16
11:00 AM	48	31	17
12:00 PM	53	33	20
01:00 PM	56	33	23
02:00 PM	66	35	21
03:00 PM	67	33	34
04:00 PM	60	29	31

Liquid Ammonia stored at the end of the day = 220ml (67.07%)

Table VIII: Temperature of the different parts fabricated by CPC (Day 2- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	25	27	02
8:00 PM	25	27	02
9:00 PM	24	26	02
11:00 PM	20	26	04
01:00 AM	19	25	06
05:00 AM	16	27	11

Table IX: Temperature of the different parts fabricated by CPC with a metallic sheet (Day 1- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
6:00 AM	30	28	02
7:00 AM	34	28	04
8:00 AM	34	29	05
9:00 AM	35	29	06
10:00 AM	40	31	09
11:00 AM	46	32	14
12:00 PM	53	35	18
01:00 PM	60	35	25
02:00 PM	69	35	34
03:00 PM	70	32	38
04:00 PM	66	30	36

Liquid Ammonia stored at the end of the day = 280ml (86.15%)

Table X: Temperature of the different parts fabricated by CPC with a metallic sheet (Day 1- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	26	27	01
8:00 PM	25	27	02
9:00 PM	22	27	05
11:00 PM	20	26	04
01:00 AM	18	25	07
05:00 AM	12	26	14

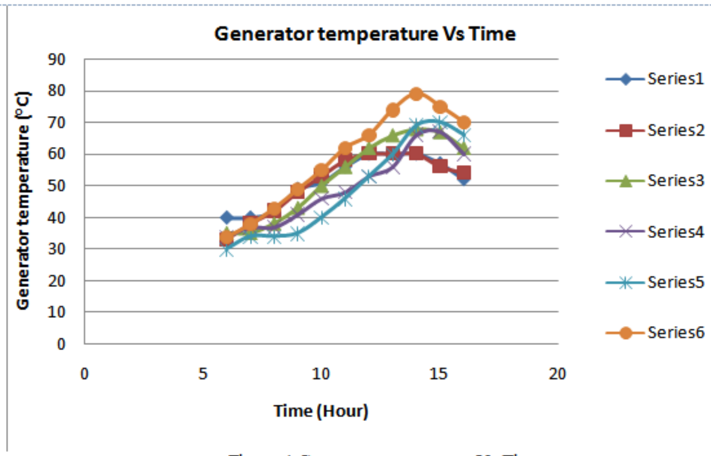
Table XI: Temperature of the different parts fabricated by CPC with a metallic sheet (Day 2- Day period)

Time	Generator temperature T_G(°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
6:00 AM	34	28	06
7:00 AM	38	28	10
8:00 AM	43	29	14
9:00 AM	49	30	19
10:00 AM	55	34	21
11:00 AM	62	35	27
12:00 PM	66	35	31
01:00 PM	74	36	38
02:00 PM	79	35	44
03:00 PM	75	34	41
04:00 PM	70	30	40

Liquid Ammonia stored at the end of the day = 295ml(90.77%)

Table XII: Temperature of the different parts fabricated by CPC with a metallic sheet (Day 2- Night period)

Time	Evaporator temperature T_E (°C)	Ambient temperature T_o (°C)	Temperature difference (°C)
7:00 PM	25	28	03
8:00 PM	21	28	07
9:00 PM	20	27	07
11:00 PM	18	26	08
01:00 AM	17	25	08
05:00 AM	12	27	15



Series 1	parabolic collector (day1)
Series 2	parabolic collector (day2)
Series 3	After using CPC (day1)
Series 4	After using CPC (day 2)
Series 5	After the use of metallic sheet with CPC (day 1)
Series 6	After the use of metallic sheet with CPC (day 2)

Figure 4: Generator temperature Vs Time

By analyzinggraphs, it can be said that with the modification done to a solar collector, it is convenient that the efficiency of solar collector is increased.As a result, the temperature of the generator increases. The temperature of the generator first decreases due to heat absorption by metallic sheet and after sometime heat increased drastically. The more heat rises; more ammonia will be vaporized and stored in an insulated box. From the following figure, it is evident that the stored ammonia is increased after modification due to temperature rise in thegenerator.

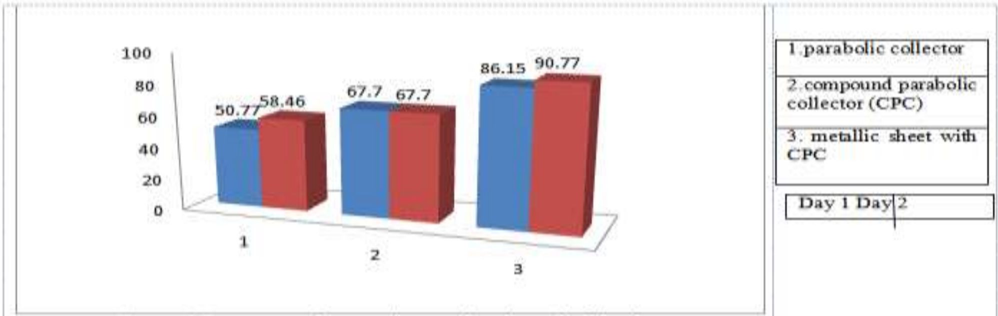


Figure 5:Percentage of ammonia stored at the end of the day

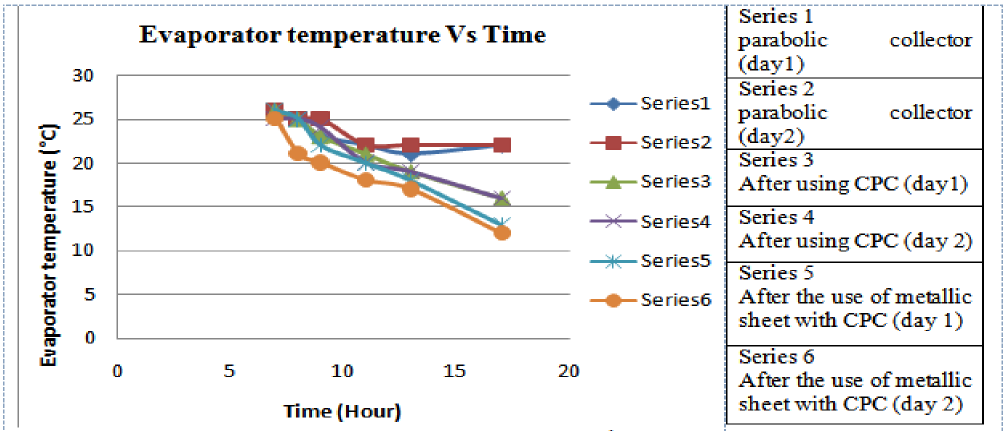


Figure 6:Evaporator temperature Vs Time

With the modification, the temperature decreases gradually from the previous one. When ammonia reabsorbs to the $cacl_2$, it tookthe heat and cooled the evaporator.The lowest temperature of the evaporator is found in case of the use of metallic sheet with CPC due to the maximum amount of stored ammonia. As the evaporator temperature decrease, the COP of the performance also increased.

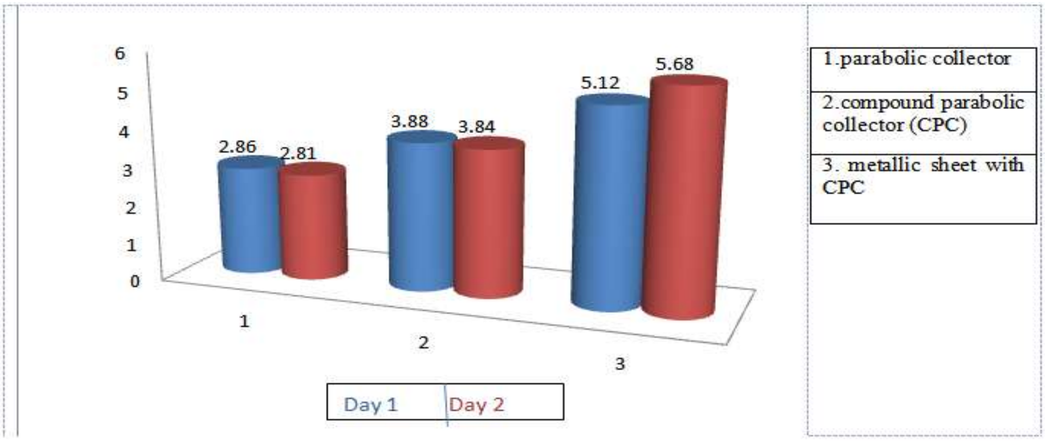


Figure 7:COP of the refrigerator

IV. CONCLUSION

The ultimate aim of this project is to develop a much cleaner cost-effective way of refrigeration, which in turns help to bring down the global warming as well as reduce the power shortage. For further study of the solar absorption refrigerator, a GPS tracked solar system may develop to make sure that solar ray inclined to the surface of the collector is always maximum possible. This project may also help rural people to use solar energy as per refrigeration and also this project may reduce somewhat the consumption of electricity. This project may reveal a new era of using solar energy in various vital issues of ina practical way.

As though the COP and refrigeratingeffect, is increased,but still small in comparison with domestic uses. However, its limitation should be marked, such as- the refrigerant ammonia is a little bit toxic and is somewhat not appreciable for domestic use. Also, it can also be mentioned that there are possibilities to leak ammonia from connecting pipes, generator and evaporator and so forth. In that case, the refrigerator will cause environmental pollution. Therefore precautions should be taken before working on this project. Again it is not suitable for all sort of refrigerant because all refrigerant does not vaporize in such a low pressure.

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