Design of Solar Refrigeration System using Parabolic Solar Collectors & Electrolux Refrigeration System

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ABSTRACT

The design of energy systems becomes more important due to limitations of fossil fuels and the environmental impact during their use. Energy systems are complex as they involve in economic, technical and environmental factors. This presents a detailed description of a new solar-based refrigeration system using Electrolux systems (NH3-H2O, Hydrogen). This paper presents modeling and simulation of a solar absorption cooling system. In this paper, the modeling of a solar-powered, single stage, absorption cooling system, using a parabolic dish solar collector and NH3-H2O, Hydrogen, is done. All the calculations regarding the designing of solar powered vapour absorption system is done in this paper. The effects of hot water inlet temperatures on the coefficient of performance (COP) are studied. Performance of the solar collector has been studied at different time periods during a day time has been studied in respect of ambient temperature & Collector Fluid Temperature. Refrigerating effect using solar energy and electrical energy has been compared. It has been built and tested in the solar laboratory of the Jaypee University, Guna. The unit can produces cold air even for rainy and cloudy days and the COP (cooling energy/solar energy) ranges between 5 and 8% and a daily mean ambient temperature between 38 and 50^{0}C.

Index Terms: **Solar refrigeration system, Electrolux System, Coefficient of Performance, Achieved inlet temperature of cabin, Collector Fluid Temperature**

I. INTRODUCTION

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 ×1011 MW which is much larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on the continuing basis. This makes it one of the most promising of the unconventional energy sources. In the Electrolux system the energy input is given in the form of the heat. This heat can be from the excess steam from the process or the hot water. The heat can also be created by other sources like natural gas, kerosene, heater etc. though these sources are used only in the small systems. Thus we had provided the heat with the help of solar collectors.

II. EXPERIMENTATION

II.I. PARABOLIC SOLAR COLLECTOR

The main components are:

1. Absorber Tank
2. Parabolic Dish
3. Tilting mechanism
4. Frame Stand
5. Reflector

II.II. WORKING OF A SOLAR POWERED ELECTROLUX REFRIGERATION SYSTEM:

The unit consists of four main parts - the boiler, condenser, evaporator and absorber. The unit can be run on electricity, solar or gas. The unit charge consists of a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at the room temperature for which the unit is designed. When heat is supplied to the boiler system, bubbles of ammonia gas are produced which rise and carry with them quantities of weak ammonia solution through the siphon pump. This weak solution passes into the tube, whilst the ammonia vapour passes into the vapour pipe and on to the water separator. Here any water vapour is condensed and runs back into the boiler system leaving the dry ammonia vapour to pass to the condenser. Air circulating over the fins of the condenser removes heat from the ammonia vapour to cause it to condense to liquid ammonia in which state it flows into the evaporator. The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia and lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the food storage space, as described above, thereby lowers the temperature inside the refrigerator.

The mixture of ammonia and hydrogen vapour passes from the evaporator to the absorber. Entering the upper portion of the absorber is a continuous trickle of weak ammonia solution fed by gravity from the tube. This weak solution, flowing down through the absorber comes into contact with the mixed ammonia and hydrogen gases which readily absorbs the ammonia from the mixture ,leaving the hydrogen free to rise through the absorber coil and to return to the evaporator. The hydrogen thus circulates continuously between the absorber and the evaporator. The strong ammonia solution produced in the absorber flows down to the absorber vessel and hence to the boiler system, thus completing the full cycle of operation. The liquid circulation of the unit is purely gravitational. Heat is generated in the absorber by the process of absorption. This heat must be dissipated into the surrounding air. Heat must also be dissipated from the condenser in order to cool the ammonia vapour sufficiently for it to liquefy. Free air circulation is therefore necessary over the absorber and condenser. The whole unit operates by the heat applied to the boiler system and it is of paramount importance that this heat is kept within the necessary limits and is properly applied.

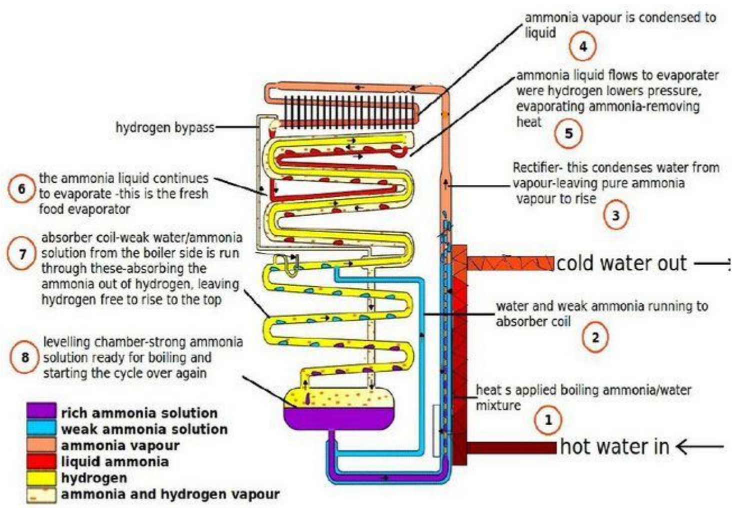

Fig. Electrolux System Working

III. DESIGN CALCULATIONS:

III.I. DESIGNING OF A SOLAR COLLECTOR:

1. DESIGN CONSIDERATIONS:

The structure of the reflector can be divided into two parts as (a) the shell- the supportive structure & the living area exposed to sun.

(a) The shell must be strong to withstand various environmental factors like wind, seasons, etc., to maintain its required shape. This shape decides efficiency of the whole system supported by selective lining.

(b) The lining of the parabolic surface plays major role on overall efficiency of the system. In fact, achieving near 100% smooth and uniform surface is advised to avoid spreading of beam due to micro-roughness/undulations. For doing so, coating with aluminium foil with minimum 80-85% reflectivity is recommended. Even silver coating of the source reflectivity will do the job. However, aluminium having lighter thermal conductivity may constitute to the heat losses due to conduction .To avoid this very thin foil is recommended to minimize the losses.

2. DESIGN SPECIFICATIONS:

The following design specifications have been taken into account for the construction of parabolic dish collector:

- Solar constant I_{SC} = 1369 W/ m^2
- Extraterrestrial Radiation (I_0) = 1398 W/m^2
- Geographical Location of Guna :

Latitude: 24.6500 N

Longitude: 77.3167 E

The part of solar radiation that reaches the surface of the earth without being scattered , absorbed or reflected is direct radiation ant it's the most intense. the intensity at the direct radiation reaching the surface at earth is a function of time at the day, latitude location and declination angle. To calculate the direct radiation reaching the earth surface as a function of time & the day, for a location (γ) with the sun at declination (δ).

Let,

Z-Zenith angle (the zenith angle is an angle measured from z-axis in spherical coordinate denoted z_φ in this work, it is also known as polar angle and colatitudes.

γ- Latitude of location at Guna (latitude γ=24.6500)

δ-declination angle

In March and September declination angle becomes 0^o, in December it is -23.45^o and in June it is 23.45^o here the declination angle is taken as zero.

t – hour angle of sun

t = 15(ST-12) where ST → local solar time

We take at 12 o'clock in the afternoon. We get,

t = 15(12-12)

t = 0

Hour angle for a particular location on the earth is zero when sun is straight overhead, negative before local noon and positive in afternoon. In one 24 hour period the solar hour angle changes by 360 degrees, in that time to changes from -90 to +90.In solar noon it is 0 and this is taken in calculation

Iz - direct normal radiation

Isc – extraterrestrial solar radiation constant

Ih - horizontal radiation

Here s and c are climate graphically determined constants. The **zenith angle** is calculated thus

Cos z = sinγs inδ + cosγ cosδ cost

= sin(24.6500) sin(0) + cos (24.6500) cos(0) cos(0) = 0.41707 x 0 + 0.908872489 x 1 x1=0.908872489

Z = $\cos^{-1}$(0.908872489)

Z = 24.65^0

The **Intensity of the solar radiation** after passing through the atmosphere is calculated thus,

$I_z = I_{sc}\, e^{-c(\sec z)s} = 1353\, e^{-0.357(1/\cos 24.65)0.678} = 1353 e^{-0.266314585}$ = **1048.925325 W/m^2**

This is the value of the direct radiation on a normal surface and it is the maximum value possible. In practice only systems using full tracking mechanisms can collect this radiation.

The value of **radiation on a horizontal surface** is calculated thus:

I_h $=I_z\cos z$ = 1048.925325 x 0.908872489 = **953.3393709 W/m²**

Calculation of reflector area :

In the Electrolux refrigeration system the ammonia is used as a re frigerant. In this system the strong ammonia solution in the generator is heated by applying external source. Here the generator tube is heated by hot water from the solar collector. When the heat is applied the ammonia vaporizes from the ammonium hydroxide solution. In normal conditions or in atmospheric pressure, the ammonia vaporizes in -33^0C. Here the system is in pressure of 10 bars. Then the temperature required to vaporize the ammonia is 25^0C. So there will be a temperature more than 25^0C is required to vaporize ammonia. When the temperature increases, more ammonia will vaporize and the cooling will be accelerated. There is a tube arrangement given in the generator to transfer the heat from the solar collector to the generator tube. 85^0C to 90^0C temperature is required in the generator tube for the proper working of the system. Assume the temperature difference generator tube and water to be $10\text{-}15^0$C

The temperature over 100^0C is needed in the absorber tank of the collector. The area of the reflector is obtained from all the quantity of heat to boil water to steam.

Heat required boiling 1Kg of water

$Q = m \times c \times \Delta T = 1 \times 4200 \times (100-32)$ **= 285600 J**

C – Specific heat of water= 4200 J/Kg K

Heat required vaporizing half the water content in vessel

$Q = M \times L = 0.5 \times 2.26 \times 10^6$

=**113000 J**

Heat loss due to free convection across the surface of the absorber, from the top of the absorber is given by

$P_{top} = a_t(kN_d \Delta T/h_p)$

Where, a_t is the base area of the absorber

H_p is the height of absorber

ΔT is the change in temperature

k is the thermal conductivity

$\Delta T = Ts - Ta$

Where, Ts is the temperature of the generated steam

Ta is the ambient temperature

For turbulence at the hot bottom of absorber,

$Nu = 0.14\ \xi^{0.33}$

Where ξ is obtained from the equation,

$\xi/d^3\Delta T= 5.8x10^7$

(Absorber diameter d_a= 0.2m, height h =0.32m)

Rayleigh number ξ for the top is

$\xi_{top} = 5.8x10^7 x d^3 \Delta T$

$= 5.8x10^7 x(0.2)^3 x(100-32)= 3.1557x10^7$

And, Nusselt Number (Nu)

$Nu = 0.14 \times (3.1577 \times 10^7)^{7.033} = 41.764$

Heat loss at absorber top,

$P_{top}=r^2kNu(Ts-Ta)/hp$ =0.0314x0.027x41.764x68/0.32

(Where,k = 0.027W/mk of air at 32^oC)

=7.5289 W

Convective heat loss from the side of the tank ,

$P_{side} = \pi\ d\ h_p\ k\ Nu\ (Ts-Ta)/h_p$

The applied Nu for the vertical side of the tank due to laminar condition is:

$Nu = 0.56\ (\xi_{size})0.25$

The dimension of the side (r/d): $.\xi = \xi_{top}\ x\ (r/d)^3 = 3.1552x10^7x(0.1/0.2)^3$

$= 3944000$

Then,

$Nu = 0.56x(3944000)^{0.26}$

$= 24.96$

Heat loss from the side of the absorber,

$\mathbf{P_{side}} = \pi\ d\ h_p\ k\ Nu\ (Ts\text{-}Ta)/h_p$

$= 3.142x0.2x0.32x0.027x24.96x68/0.32$

= **28.80W**

Total convective heat loss in W

$\mathbf{P_c} = P_{top} + P_{side}$

= 7.5289 + 28.8 = **36.32 W**

To power over a period of 1 hour

$P_h = 285600 + 1130000/360 = 393.2\ W$

Power needed to heat

$P = P_c + P_h$

= 36.32 + 393.2 =**429.52 W**

The value of radiation on the horizontal surface is $953.3393W/m^2$

This is the maximum value of solar irradiation, but it can't be used,

Lets take $I_h = 750\ W/m^2$

$I_t = P\ x\ I_h$

(P –reflectivity of the Aluminum sheet with chromium coating)

$I_t = 0.9x750 = 675\ W/m^2$

The **area of the reflector** needed

$A = P/I_t = 429.52/675 = \mathbf{0.635\ m^2}$

The depth is taken as 0.25 m

h = 0.25 m

Therefore, **Focal length**

$F = d^2/16h$

$F = 0.9^2/16\ x\ 0.25$

F = 0.2025 m

Using the equation $x^2=4\ ay$, we can plot the shape of the parabola (here a is the focal length).divide the section into 16 segments and find out the value of x and y, finally join these points and we can find out the shape of the parabola.

X	Y
-0.45	0.25
-0.3938	0.1914
-0.3375	0.1406
-0.2813	0.0977
-0.225	0.0625
-0.1688	0.0352
-0.1125	0.0156
-0.0563	0.0039
0	0
0.0563	0.0039
0.1125	0.0156
0.1688	0.0352
0.225	0.0625
0.2813	0.0977
0.3375	0.1406
0.03938	0.1914
0.45	0.25

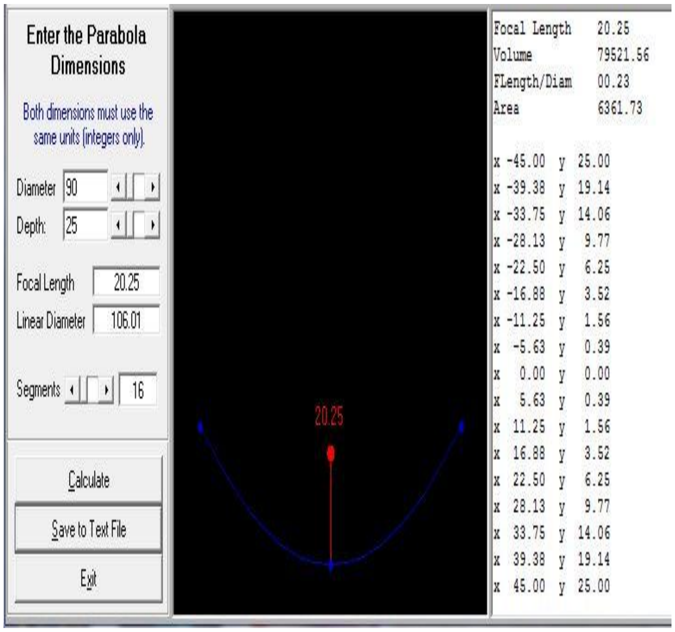

Fig.: Plotted Parabola

III.II. DESIGN OF AN ELECTROLUX SYSTEM

1. CONDENSOR

A condenser is a heat exchanger in which de-superheating of high temperature vapour changes the phase from vapour to liquid and sub-cooling of condensate occurs.

Factors affecting Condenser Capacity

Condenser capacity is the ability of the condenser to transfer heat from the hot water vapour refrigerant to the condensing medium.

1. Material: higher the ability of a material to transfer heat, smaller will be the size of condenser.
2. Amount of contact: by controlling the amount of contact between condensing medium and condenser surface, the condenser capacity can be varied.
3. Temperature difference: with increase in temperature difference, condenser capacity increases.

Air-cooled condensers: In these condensers, air removes heat by either natural convection or forced convection circulation. These type of condensers are made of steel, copper and aluminium tubing provided with fins.

Condenser:

Length = 29cm

Diameter = 1.4cm

Plated fin:

Length = 7cm

Width = 5cm

Thickness = 0.5m

2. EVAPORATOR:

An evaporator is any heat transfer surface in which a volatile liquid is vaporized for the purpose of removing heat from a refrigerated space or product and also cooling its own coils. It is also called chiller, freezer, or cooling coil depending upon its application. Following are the some important factors which affects the heat transfer capacity of an evaporator:

1. Material: The material to be used for the construction of an evaporator should be good conductor of heat and be not affected by the refrigerant. Iron and steel can be used with all common refrigerants. Brass and copper are used with all refrigerants except ammonia. Aluminum should not be used with Freon. The material we used in our project for the purpose is mild steel.
2. Temperature difference: The temperature difference between the refrigerant within the evaporator and the product to be cooled plays a

significant role in the heat transfer capacity of an evaporator.

3. Velocity of refrigerant: With the increase in velocity of refrigerant the overall heat transfer coefficient also increases, but increased velocities leads to greater loss of pressure in the evaporator.
4. Wall thickness of the evaporator coil: It has a slight effect on the total heat transfer capacity because the evaporators are usually made from highly conductive materials.
5. Contact surface area: The contact surface available between the walls of evaporator coil and the medium being cooled is an important factor which affects heat transfer capacity

3. GENERATOR & BUBBLE PUMP:

The input heat is given to the generator. Heat input to the generator is used for two purposes: to vaporize and separate ammonia from the liquid, and to stimulate the pumping effect through the pump-tube. When heat is supplied to the generator, bubbles of ammonia gas are produced from the ammonia-water mixture. The ammonia bubbles rise and lift with the weak ammonia-water solution (weak in ammonia) through the bubble pump lift tube. The weak solution is sent to the absorber, while the ammonia vapour rises to the condenser.

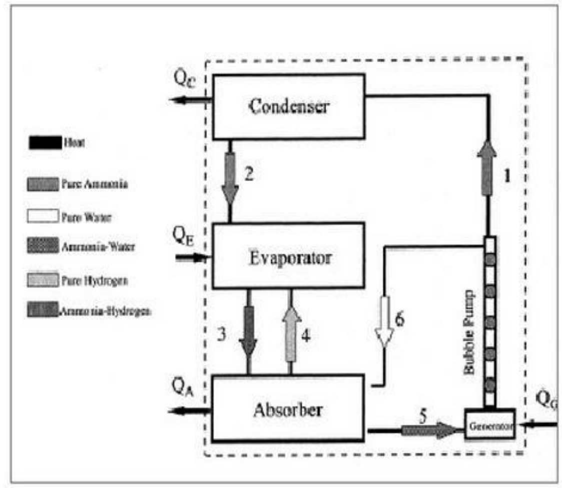

Fig. Bubble Pump

4. ABSORBER VESSEL:

The absorber vessel is used to store the ammonium hydroxide solution which is partially filled. This has the following dimensions:

Length = 12.5cm

Diameter = 5.8cm

IV. EXPERIMENTAL SETUP:

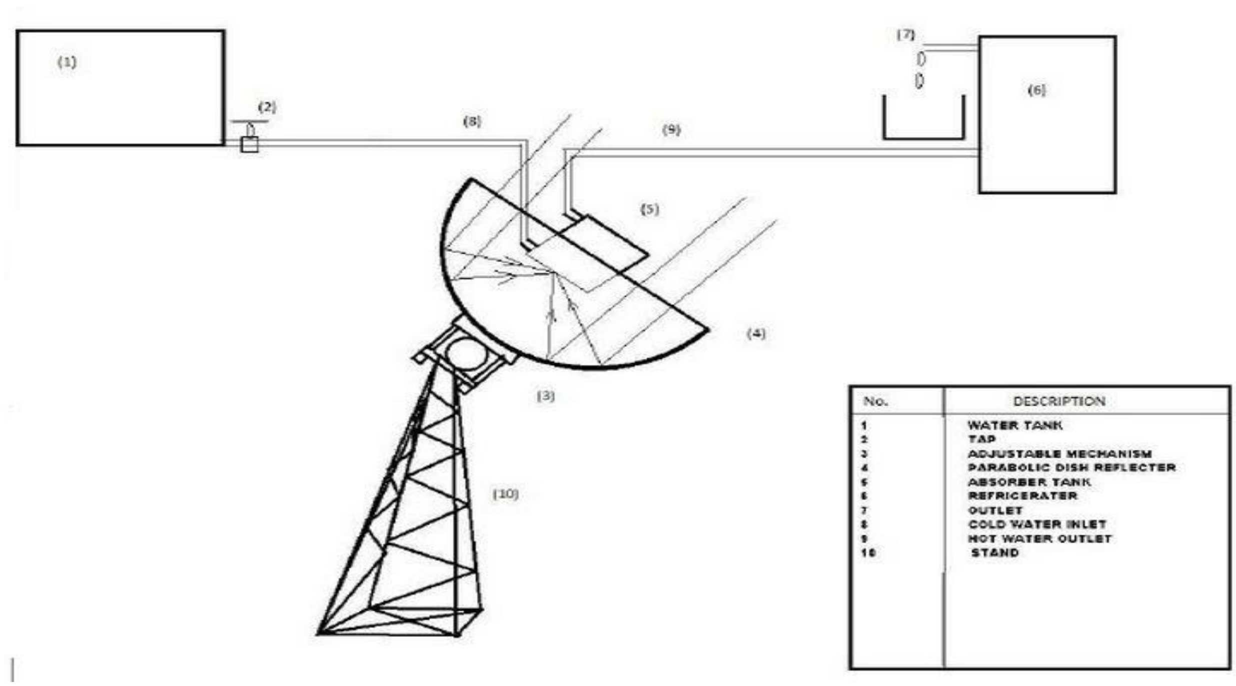

Fig. : Experimental Setup

The schematic diagram of the solar refrigeration setup is shown. Initially arrange the components as shown in figure. The absorber tank is placed on the focal point of the collector; this is because in the focal point we get the maximum temperature. The refrigerator is placed a height of 3 feet from the solar collector. This is because of the heat transfer is take place by natural convection and conduction. Open the water tap and fill the absorber tank with water. When water in the absorber tank is heated, its density will decrease. Then the low density water will move to the higher levels and high density cold water will flow to the lower levels. The hot water makes contact to the generator tube and the heat is exchanged to the generator then the water cools. The high density cold water moves to the absorber tank and low density hot water moves up and the process continues. Open the water tap from the tank over a time period to maintain the water level, because some amount of water will loss in the form of vapour. Also we need to track the collector to gain maximum amount of sunlight. The tracking is done by turning the collector to face the sun. There is a tracking mechanism in the collector stand to adjust the collector. There are also thermocouples are placed in the evaporator and the generator tube to measure the temperature.

HEAT TRANSFER MECHANISM:

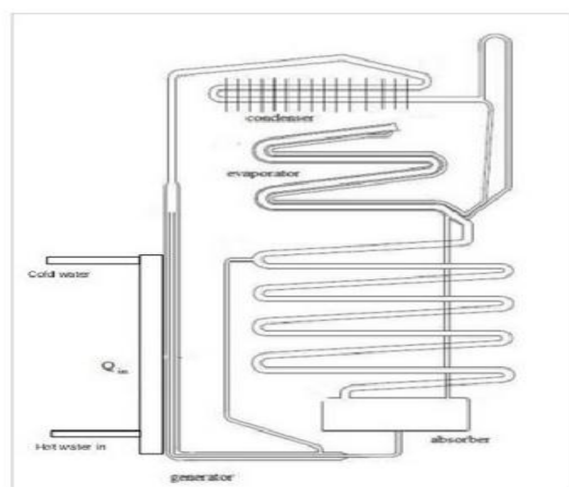

Fig: Heat Transfer Mechanism

In this project we used solar heat to heat the generator tube instead of the electric heating coil. Replace the electric heater from the system and place a heat exchanging mechanism to transfer heat from hot water to the generator .cut a copper pipe of 3cm diameter over a length of 25cm. Drill 2 holes of 1cm diameter and

23cmdistance. Fix two copper pipes of 1cm diameter to the holes by soldering. Seal the two ends of the pipe by welding a metal sheet over it. Check the specimen for leakage by pumping water through it. Then fix the specimen to the generator tube by winding copper wire over them. The arrangement is shown in figure.

V. RESULTS & CONCLUSIONS

We have chosen a sunny day to conduct the experiment. On 15-5-2013 we arrange the experimental set-up at 8:30 morning. We have tracked the collector periodically and take the temperatures using thermocouples.

PERFORMANCE OF THE SOLAR COLLECTOR

Local time hour	Ambient Temperature (^{o}c)	Collector Fluid Temperature (^{0}c)
9:00	38	40
10:00	38	47
11:00	39	52
12:00	40	65
13:00	41.5	75
14:00	42	87
15:00	42	87
16:00	40	86

Table: Performance of the solar collector

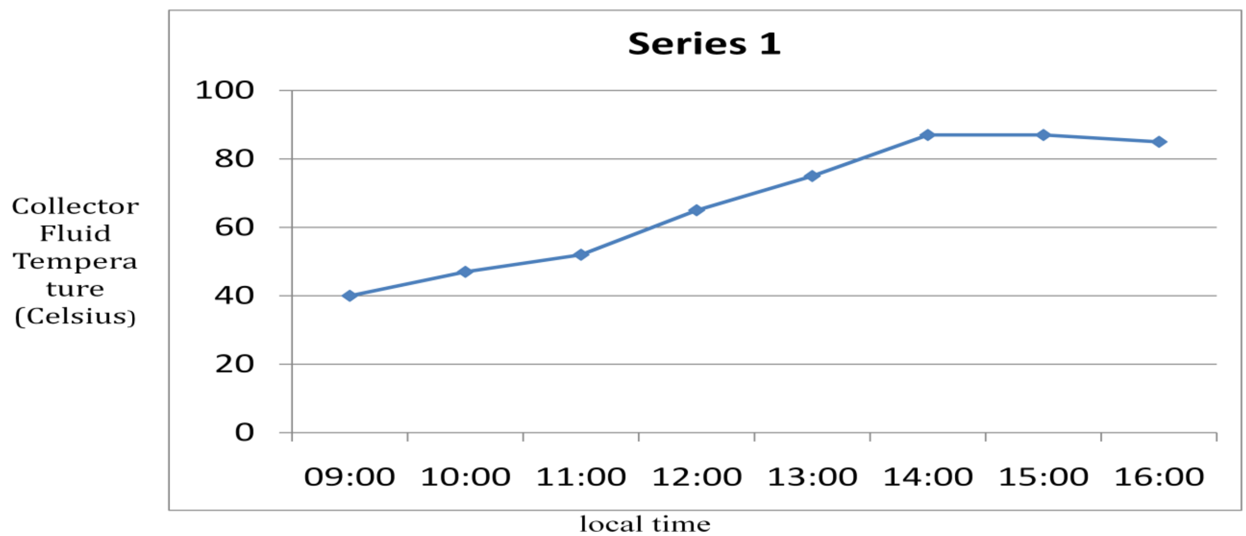

Fig.: Graph between local time and collector fluid temperature

REFRIGERATING EFFECT WHEN SOLAR ENERGY IS USED

Assuming the fridge is empty with only air inside to obtain the maximum temperature drop. After doing the experiment considering the reflector area of 0.635m^2, temperature of air inside the cabin was reduced to 18^{o}C .The refrigeration effect was found to be

- Volume of cooling cabin = 40 liters.
- Volume of air inside the cabin = 0.04 m^3
- Density of air = 1.15 Kg/ m^3 (at sea level, 30^{o}c)
- Initial temperature of air inside the cabin (T_0) = 30^{o}C
- Final temperature of air inside the cabin (T_f) =18^{o}C

REFRIGERATING EFFECT WHEN ELECTRICAL ENERGY IS USED

The refrigerator is electrically heated by using a heating coil. Where a temperature about 140 ^{0}C reached in the generator tube and the refrigeration effect is increased.

- Volume of cooling cabin = 40 liters.
- Volume of air inside the cabin= 0.04 m^3
- Density of air = 1.15 Kg/ m^3 (at sea level, 30^{o}c)
- Initial temperature of air inside the cabin (T_0) = 30^{o}C
- Final temperature of air inside the cabin (T_f) =8^{o}C

CONCLUSION & FUTURE SCOPE

The future of solar refrigeration seems to be a very promising and no doubt will find it’s place in future industrial applications. The major limiting factor at present if; the shape of energy so as to make it available whenever it is required, for example at nights and extended cloudy days when we cannot attain a high enough temperature and refrigeration. Modifying the design of solar collector for wide acceptance angle and making generator tubes with material of higher thermal conductivity. Proper installation is also required to get the desired effect. In the present scenario of energy shortage this system will be most welcoming.

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