DESIGN AND ANALYSIS OF SOLAR ELECTROLUX VAPOUR ABSORPTION REFRIGERATION SYSTEM

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ABSTRACT

This paper describes about the utilization of solar energy by concentric collector tracking mechanism for domestic refrigeration purposes. Power of the sun can be efficiently used to harness energy for need for various applications. Different systems are available to collect or utilize the solar energy, but the incident angle of direct radiation keeps changing vis-a-vis the day length. So, we cannot use the solar energy to full extent with the fixed collector. To attain the incident angle nearly perpendicular to the collector, need to deal with the moving collector system. Thus we employed for mechanically operated automatic tracking system which gives ease in operation. An 'Electrolux refrigeration system' used in this present work is a three fluid system namely Ammonia, water & hydrogen. Instead of a compressor it uses low grade energy to run a generator, as opposed to a standard refrigerator. The system was operated on sunny days, the mechanical modifications made to generator accommodate the vapour absorption system and diameter of solar concentric collector was 0.6 m and a lowest cabin temperature of 10.6 ºC was achieved. The maximum C.O.P obtained by solar heat input was 0.78 and the average C.O.P obtained was 0.44.

***Keywords*: Cabin Temperature, Coefficient Of Performance (Cop), Hour Angle, Parabolic Collector, Vapour Absorption.**

I. INTRODUCTION

Solar power is a form of energy that makes use of the world's largest energy source: the sun. More than 99% of the world's available renewable energy is in one way or the other related to solar energy. Because of increasing environmental and climate awareness, the use of solar power has been growing explosively the past few years. It is however expected that technological and economical developments will within 10 years put the price of solar power on par with traditional energy sources.

Sunlight has two components, the "direct beam" that carries about 90% of the solar energy, and the "diffuse sunlight" that carries the remainder - the diffuse portion is the blue sky on a clear day and increases proportionately on cloudy days. As the majority of the energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible. The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel (i) shown in Table 1. In addition, the reflectance (averaged across all polarizations) is approximately constant for angles of incidence up to around 50°, beyond which reflectance degrades rapidly.

i	Lost = 1 – cos i	i	Lost=1 – cos i
0°	0%	23.4°	8.3%
1°	0.015%	30°	13.4%
3°	0.14%	45°	30%
8°	1%	60°	>50%
15°	3.48%	75°	>75%

Table No.1 Percentage of energy loss for given angle 'i'

For example trackers that have accuracies of ± 5° can deliver greater than 99.6% of the energy delivered by the direct beam plus 100% of the diffuse light. As a result, high accuracy tracking is not typically used in non-concentrating PV applications.

Considerable amount of research went into finding of new and alternate energy sources and also for creating means for the efficient utilization of solar energy for cooling was an attractive one, as the demand for cooling is somewhat in tune with the availability of heat. The vapour absorption refrigeration system (VARS), being a heat operated system, is especially suited for refrigeration using solar energy. Several theoretical and experimental studies are going on to improve performance of system.

II LITERATURE REVIEW

Recent work carried out for study and analysis of the vapour absorption refrigeration system based on solar energy as heat input is reviewed as follows:

A.R. El Ouederni [1] A parabolic solar concentrator has been experimentally studied. The experimental device consists of dish of 2.2 m opening diameter. Its interior surface is covered with a reflecting layer and equipped with a disk receiver in its focal position. The temperature in the centre of the disc reaches a value which is about 400 °C. A.K.Ahmed [2]In this research the design and fabrication of solar dish concentration with diameters 1.6m for water heating application and solar steam was achieved .The dish was fabricated using metal of galvanized steel, and its interior surface is covered by a reflecting layer with reflectivity up to(76 %), and equipped with a receiver (boiler)located in the focal position. Water temperature creased up to 80, and the system efficiency increased by30% at mid noon time. Zenis Jesko [3]in this paper it is mentioned that with the increasing use of solar collectors the variety of constructions of solar collectors in order to improve its' efficiency gets wider. Wherewith, for the last time there are originated a large amount of modifications of solar collectors. To establish a solid classification of solar collectors the following research has been done. It is stated, that the basic constructions are kept the same, but new modifications of them are arisen up. In these paper classifications of all the collectors is given. Hossein Mousazadeh, Alireza Keyhani [4] in this paper different types of sun-tracking systems are reviewed and their cons and pros are discussed. The most efficient and popular sun-tracking device was found to be in the form of polar-axis and azimuth/elevation types. Siw Meiser [5]in this paper the analysis of the parabolic trough concentrator is done. The mirror shape accuracy is obtained it is explained in detail in this paper. Also the analysis of collector is also done which is also explained in detail which is relevant to our project data. P.Naidoo, T.I. van Niekerk [6] the aim of this research project is to test the solar-to-thermal energy efficiency of a tracking line-focus parabolic trough solar collector (PTSC). This is determined by measuring the temperature rise of water as it flows through the receiver of the collector when it is properly focused. Given the varying demands of different operating regimes required for proper operation of the solar collector, different modes of control will form an integral part of the project to optimize tracking accuracy and thereby thermal efficiency as well. Rohit Agarwal [7] in this research the Gear train operating system with the help of potential load is employed to rotate the solar concentrator with the movement of the sun. The comparison between the “Mechanical Solar Tracking System” and “Electro-Mechanical Solar Tracking System” shows that it consumes zero energy from the produced energy and thereby, increasing the overall efficiency by 5 to 8%. It can be concluded that “Mechanical Solar Tracking System” is more efficient than “Electro-Mechanical Solar Tracking System”. K Karthik [8] in this paper primary focus is on utilizing solar energy for domestic refrigeration purposes. Vapour absorption system was successfully run using hot water as source of heat obtained from a solar collector of area $0.64m^2$.A lowest cabin temperature of 8°C was achieved for a mini fridge of 40L capacity. The testing conditions were a sunny day and the duration of testing was 9 hours. The C.O.P obtained was 0.1675. The tonnage of the system was computed as 0.0164TR.

Nomenclature

i	angle between incoming light and panel	I_{sc}	solar constant
Q	total heat required at solar collector	Q_2	heat loss from pipe
Q_1	maximum power required to generator	R	overall resistance of pipe
U	overall heat transfer coefficient	I_0	extra-terrestrial radiation
ΔT_m	log mean temperature difference	f	focal height
$h_{o\ oil}$	heat transfer coefficient of olive oil	V_s	swept volume
$h_{ammonia}$	heat transfer coefficient of ammonia	Q	flow rate
δ	declination angle	r	radius of collector
t	hour angle	$\emptyset$	latitude of location

III DESIGN OF SOLAR COLLECTOR SYSTEM

3.1 Design of Generator Heat Exchanger

Note- Several data collected from same setup earlier working on electric heat input of 40 litre capacity.

Q_1= 72Watt

For finding modified generator heat exchanger size use following relations

$Q_1 = UA\Delta T_m$

Minimum temperature achieved at evaporator= -14.2 ≅-15℃

Corresponding generator temperature at inlet = 58.3℃

Corresponding generator temperature at outlet = 81.1℃

Considering ideal generator inlet =90℃

θ_1=10℃

θ_2=26℃ (Minimum condition)

$\Delta T_m = \frac{\theta_1 - \theta_2}{\ln\frac{\theta_1}{\theta_2}} = 16.74$

$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_0}$

$h_{0\,oil}$ = 232.78 w/m^{2}K, $h_{ammonia}$ = 330 w/m^{2}K

D ≅0.04m

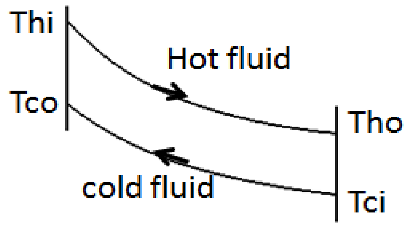

Fig. 1 Counter Flow heat exchanger

3.2 Heat loss from pipe

Standard size available for polyurethane pipe

OD=12 mm

ID= 9 mm

Considering h_∞=5 w/m^{2}k

T_∞ = 30℃

Considering L=6m

$R=R_1+R_2+R_3$

R =1.0987

$Q_2 = \frac{\Delta T}{R} = \frac{(90-30)}{2.5637}$ = 23.43 watt

Considering aperture loss and loss from mechanism which holds absorber is assumed to be 5% - 10% of the reflected intensity.

Loss Q_3 = 450*0.08 = 36 watt.

Total heat required at solar collector

$Q_1 + Q_2 + Q_3 = 72 + 23.43 + 36$

≅ 132 Watt.

3.3 Design of collector

Taking maximum generator temperature as $T_g = 90^0C$

I_{sc} = 1353 W/m^2 (error = ± 1.5 %)

I_0= 1398 W/m^2

Graphical location of Karad where the solar collector was placed.

Latitude = 17.187505 N

Longitude = 74.157496 E

Month of operation is assumed to be March.

$\delta = 0$

t = 0

Direct radiation reaching the surface of earth is a function of time of day, latitude location and declination angle.

Consider a piece of earth that is big rectangle.

γ< 0 (towards east)

γ> 0 (towards west)

$$\cos\theta = \sin\delta\sin\emptyset\cos - \sin\delta\cos\emptyset\cos\beta\cos\gamma + \cos\delta\cos\emptyset\cos\beta\cos\omega + \cos\delta\sin\emptyset\sin\beta\cos\omega + \cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

θ For horizontal Surface called as zenith angle θz

For horizontal surface β = 0

β = 360 (n-81)/364

$\cos\theta z = \cos\delta * \cos\emptyset * \cos\omega + \sin\delta * \sin\emptyset$

Where,

$\cos\theta z = \cos(17.29) * \cos(0) * \cos(0) + \sin(0) * \sin(17.29)$

=0.9548

Intensity of solar radiation

$I_z = I_{sc} * e^{(-c(\sec z)s)}$

Where,

c= 0.357, $s = 0.678$

$I_z = 1353 * e^{(-0.357\left(\frac{1}{\cos 0.95}\right)0.678)}$

=1050.031W/m^2

The value of radiation on horizontal surface is

$I_{h=} I_z \cos\theta z = 1050.031 * 0.9548 = 1002.57$W/$m^2$

So available radiation intensity= 1002.57W/m^2

Assume 50% efficiency due to

1) Variance
2) Collector efficiency
3) Correction in tracking system

This implies solar radiation intensity approx=500W/m^2

Now reflected intensity,

$R_i = 0.9 * 500 = 450W/m^2$

Area required = 132/450 = 0.293 (nearly 0.3m^2)

Assume, h=0.07m

$S=8\frac{\pi}{3}f^2([\{1+(\frac{d}{4f})^2\}^{1.5}]-1)$

$f = \frac{d^2}{16h}$

Putting all calculated values in above equations, we get

f = 0.64m

r = 0.3m

3.4 Design of tracking mechanism

Assumptions made for Design

- The friction between the piston and cylinder surfaces is considered as negligible.
- The load on the collector and tracking system due to the weight of receiver (absorber) is neglected.
- The deviation occurred in the angular motion of collector due to the natural changes like wind force is considered as negligible.
- The extraction and retraction in the cylinder is considered to its maximum value.
- Teeth engagement of gear is considered to be uniform.
- The friction between bearing and shaft is negligible.

We connect the pneumatic cylinder having stroke length 150mm and diameter 50mm.

For that, we use the gears having number of teeth 127 and 30.

So firstly we find the gear ratio,

Gear ratio $=\frac{T2}{T1}$

Gear ratio = 4.233

For 8 hrs, required angle of solar tracking is 150^0

Required angle for Gear $= \frac{150}{GearRatio}$

$= \frac{150}{4.233}$

= 35.43580

$\tan\Theta = \frac{CD}{AD}$

$\tan 17.718 = \frac{75}{AD}$

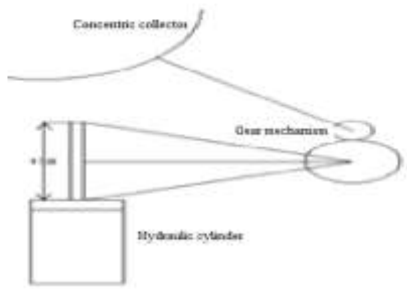

Fig.2 positioning of cylinder

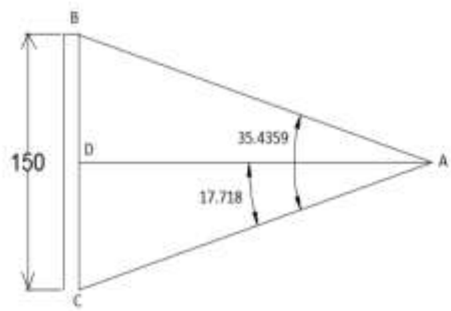

Fig.3 Angular travel by collector

AD = 235mm

We know that stroke length of cylinder is 150 mm.

The piston is designed to travel this length in 8 hours.

We find that piston is to be travelled 150 / 8 = 1.875 mm per hour

$V_s = \frac{\pi}{4} \times d^2 \times L$

$= 294524.31\ mm^3$

$V_s = 0.2945$ litre

For 150^o revolution, we require 8 hr. that means for 8hr, flow of oil = 0.2945 litre.

So we find the flow rate of oil per hour.

$Q = \frac{0.2945}{8} = 0.036$ litre/hr

Note: If we increase the angle of solar tracking the distance of AD will be reduces and vice versa.

That angle can be achieved by using different combination also that means by changing cylinder stroke or by changing gear ratio.

IV EXPERIMENTAL SETUP

On the basis of above design, solar operated Electrolux vapour absorption system with tracking mechanism was being fabricated. Fluid from receiver to generator circulates by natural circulation phenomenon.
Olive oil used as circulating fluid because it is having better thermal properties than other fluid.

Fig. 4 Schematic diagram of experimental set-up

V RESULTS AND DISCUSSION

The experimentation was carried out in order to achieve maximum temperature at the absorber. The required temperature can be achieved by achieving the corresponding hour angle. As the system is completely mechanical, the difference between the actual and theoretical hour angle is also important and we have kept this difference as minimum as possible. Experiments were performed for 6 days during sunny days for 8hrs. Data is being present in terms of hour angle. Fig. 5 revels that absorber temperature is maximum in the range of 40˚-60˚hour angle. Graph shows that first receiver temperature increase and then decreases, this is because of global radiation incident on collector surface. There is more deviation in between 20˚-40˚ hour angle due to inertia effect of solar collector, which affects the performance of tracking mechanism.

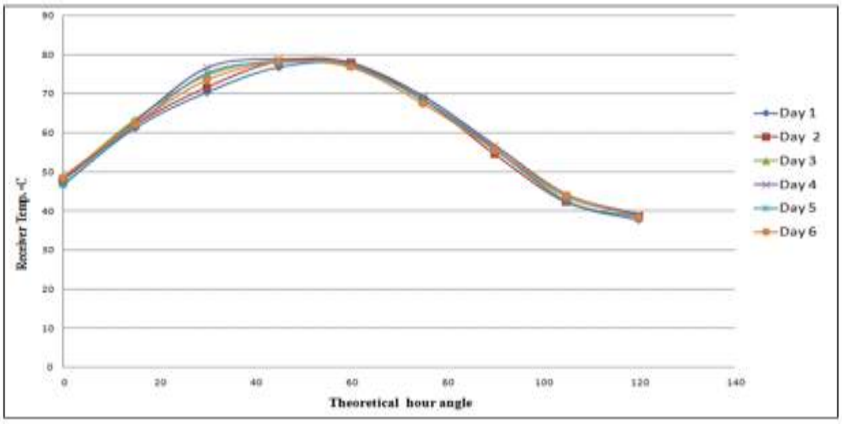

Fig. 5 Graph of Receiver Temperature (^{0}C) vs Theoretical Hour Angle (^{0})

Fig.6 shows the variation of cabin temperature with respect to time. Data was collected for 6 days from 9am to 5 pm at the interval of 1 hr. System takes nearly 1 hr. to steady state working because solar system completely works on natural circulation phenomenon. Lowest temperature achieved was 10.6˚c at about 12-1pm because generator receives maximum temperature at this time. On day 2 the cabin temperature fluctuation is more comparatively to other days, this is due to reason that diffused ration is more during morning time which were measured by Pyranometer. Cabin temperature first decreases and then increase, finally during time 4.30-5 pm cabin temperature nearly reach to ambient temperature.

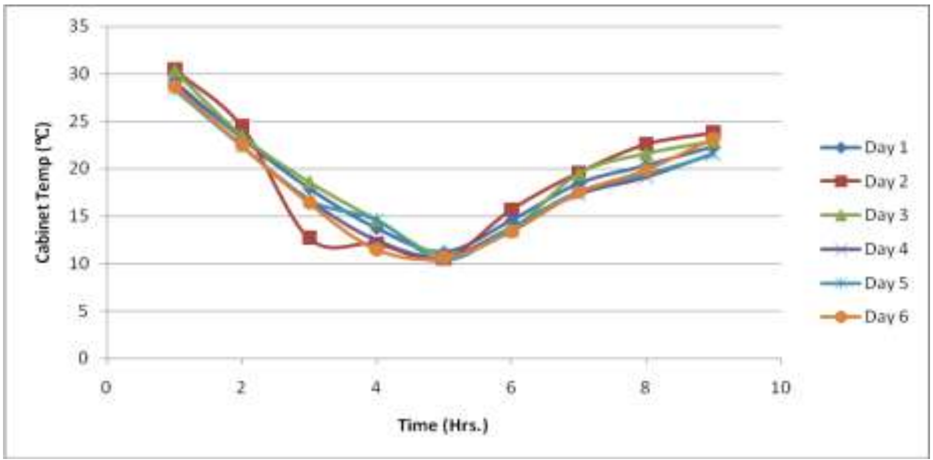

Fig. 6 Graph of Time (Hrs) vs Cabinet Temperature (^{0}C)

As shown in graph below, gives the relation between times in hrs. is independent and coefficient of performance is being dependent not only on time but also on other factor. In solar system it depends on hour angle, solar intensity, tracking mechanism accuracy and time taken to transfer heat from receiver to generator.

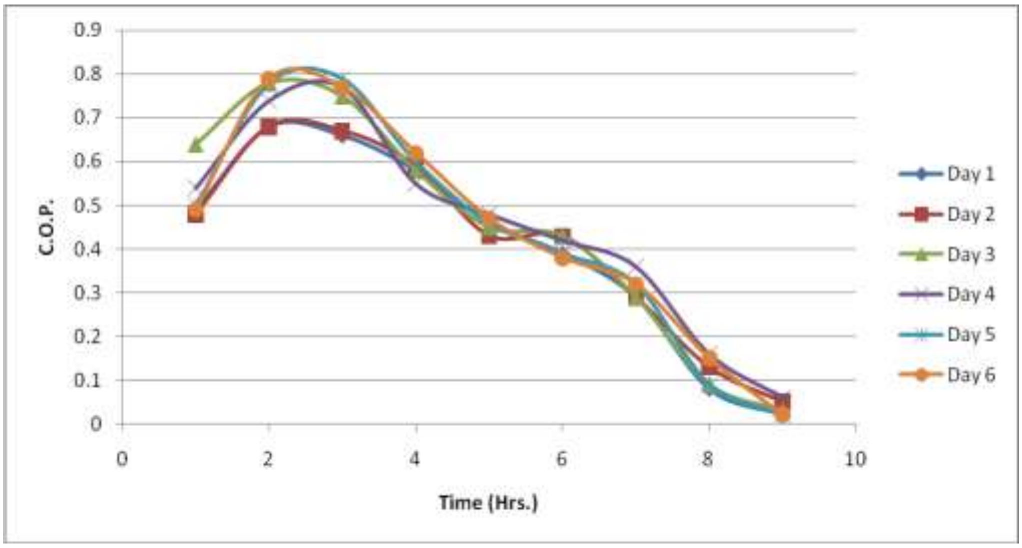

Fig. 7 Graph of Time (Hrs) vs C.O.P. (^{0}C)

In case of absorption system C.O.P. is depend on generator outlet temperature and evaporator temperature which extract heat from cabin. Absorber temperature also affects the system C.O.P. Maximum C.O.P achieved at 2 hrs. after setup was start and it in shows continuously decreasing manner.

VI CONCLUSIONS

The setup was successfully made and the testing was done and vapour absorption system was successfully run using olive pomace oil as source of heat obtained from a solar collector of diameter 0.6 m. 'Mechanical Solar Tracking System' consumes zero energy from the produced energy and thereby increasing the overall efficiency and reduces the losses occurring in the conventional solar concentrating systems. This system is totally mechanical it is environment friendly. The mechanical modifications made to generator accommodate the vapour absorption system and the design of the solar collector was successful and a lowest cabin temperature of 10.6^{0}C was achieved for a mini fridge of 40L capacity. The testing conditions were a sunny day and the duration of testing was 8 hours. The maximum C.O.P obtained by solar heat input was 0.78. The average C.O.P obtained by solar power

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