Temperature Augmentation in Compact Solar Thermal System

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Abstract: ***In solar thermal concentrators using thin metallic reflector sheet as the concentrator surface, the fraction of net solar radiative heat absorbed by the collector is dissipated to the surrounding without use through it's exposed surfaces & the supporting structure. A simple compact solar thermal device with the recovery of solar radiative heat absorbed by the concentrator is discussed here for it's effect on thermal performance. The concentrator is placed on a spiral housing of heat exchanger pipes at the insulated rear end of the collector with it's focal image at the aperture plane with a glass cover is studied here.***

Keywords: Polygeneration, Insolation, Focal Image, Sensible heat

1.0 Introduction

Conventional paraboloid dish concentrator uses thin metallic reflector sheet, synthetic stretchable reflecting membrane, glass mirror facets and other such modern improvised reflecting materials. As referred in Figure1:, a paraboloid dish surface is developed by the integration of a few lunes of thin metallic reflector sheets geometrically prepared by Gore's method to get the maximum possible point focus at it's aperture plane eliminating possible surface error. This component is placed in a spiral housing of heat exchanger pipes at the rear surface of the collector with an insulated cover & the whole assembly is pivoted on a hollow cylindrical support through another short cylinder for necessary manual orientation for tracking. The receiver at the aperture is placed in the same support of the glass cover to reduce the extra supporting structural weight. The aperture glass cover is expected to serve the purpose in the same way as in case of a flat plat collector besides protection from weathering to sustain good reflectivity.

The effect of heat recovery components & insulation is investigated through enhanced temperature rise in the heat exchanger water and air temperature in the enclosed volume bounded by the insulated cover & the rear surface of the metallic concentrator. Developing a compact solar thermal design of reduced weight & cost with maximum possible heat accumulation per unit aperture area with waste heat recovery is the motivation behind this study.

Early in 1989, a study conducted by Chen Xiaofu at el.[1] to develop the most popular point focusing solar cooker in China to accumulate maximum solar flux, compensating intensity loss due to the inclination of solar altitude angle. For a shorter focal length image formation with a concentration ratio of higher rim angle was studied by Kenef S, Schmidt at el. [2] & a two stage optical design of concentrator (TERC) with variable focal length was proposed by Robert P. Friedman at el.[3]. N.D. Koushika at el.[4] proposed for a deep dish collector design with ideal image formation where cavity receiver performance was investigated.

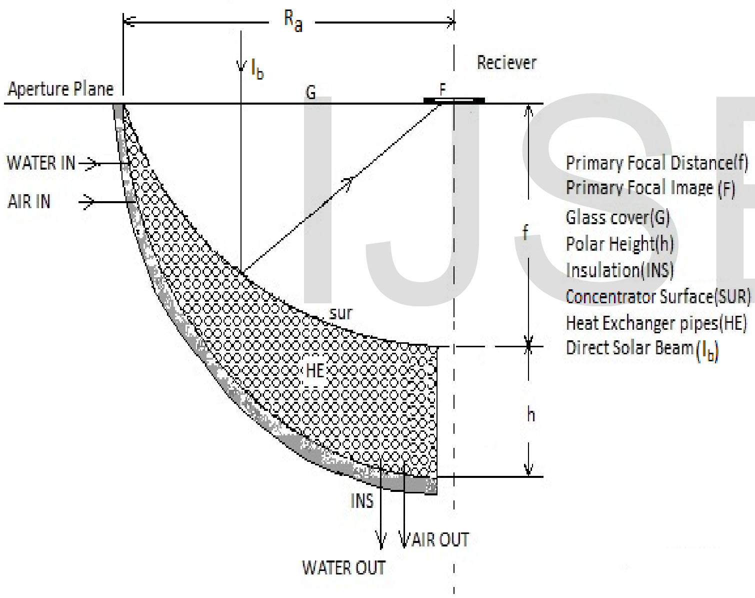
Regarding effective concentrator surface development, Aluminium-polymer-laminated steel reflector, suggested by Maria Brogren at el.[10] & the test report study on at the Jet Propulsion Laboratory, California, USA, and Sandia National Laboratories, Albuquerque, New Mexico[6] on glass mirror facets etc discussed about the effects of specific weight of the reflector, non retention of optical property even as using of any protective layer (e.g. polyethylene terephthalate) on aerial exposure. In using glass mirrors, delamination crack & weight, rigidity to deform were spotted as major drawbacks in the above study. Increasing of local concentration ratio by increasing rim angle beyond 80^0 affects the width of focal image & distortion as depicted by Evan at el.[7]. In our proposed model, the focal image formed at the aperture plane subtends a rim angle beyond maximum limit of 80^0 giving rise to a focal image of distorted wider periphery, but improvement of the image profile without compromising the higher concentration ratio is another objective of our study. In this study the aforesaid investigations are considered.

2. Model performance with graphical analysis.

2.1 Bench model results:

The bench model described earlier, was tested on sunny days at Guwahati (North East India) with Φ(Latitude) = 26.1838° N (Altitude = 91.7633 E) with variable ambient conditions and the results were analyzed accordingly.

T_a = Surrounding (ambient) temperature(^{0} c)
T_{wo} = Outlet temperature of water in the heat exchanger(^{0} c)
T_{hao} = Outlet temperature of air (^{0} c)
T_f = Receiver temperature at the focal point(^{0} c)
C_p = Specific heat of water at constant pressure (KJ/Kg.^{0}K)
A_a = Aperture area of the collector (m^2)
R_a = Aperture radius (m)
I_b = Radiative solar flux (W/m^2)
h_f = Sensible or liquid heat of water per kg of mass on preheating by the heat recovery component (KJ/kg)
dh = ($H-h_f$),The net heat required to bring liquid heat to the saturation point at constant pressure per kg of mass (KJ/kg)
H = The enthalpy of water at saturated temperature (100^{0}c) under atmospheric pressure i.e 419.1(KJ/kg)



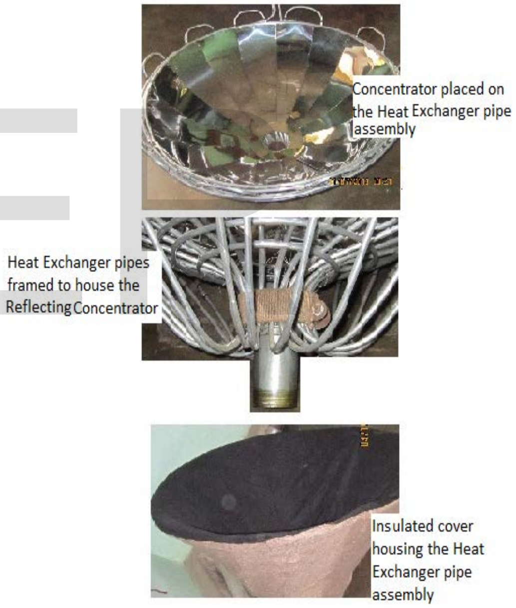


Figure 1(a): **Geometrical design of the system** Figure 1(b): **Experimental bench model**

Block diagram showing Temperature status of the proposed model.

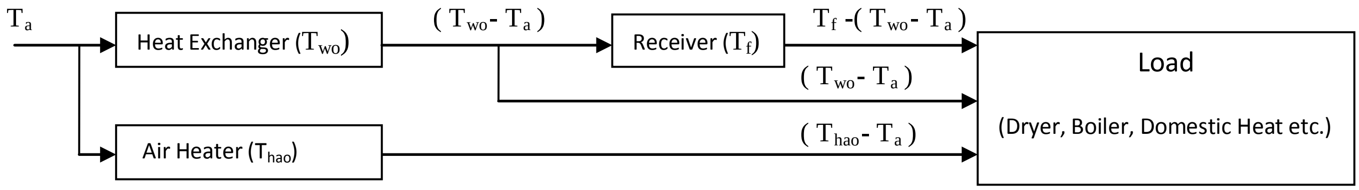


Figure 2:

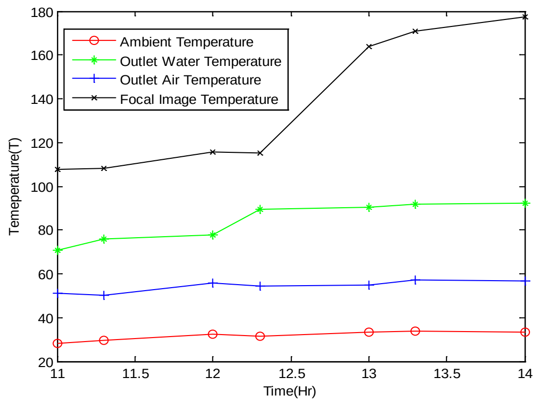
As in the Figure1:, thin steel sheet of high reflectivity is used for the concentrating surface and aluminium pipes for the heat exchanger. The efficiency of the system may be expressed as $\eta = \left[\frac{\sum mC}{I_b A_a}\right]$ [dT/dt] where $\left[\frac{\sum mC}{I_b A_a}\right]$ is constant for a particular thermal system with an average radiative solar intensity, considering $\sum mc$ as the summation of the products of respective mass & specific heats interacting heat transfer. Therefore the system efficiency under transient condition may be considered as the function of the rate of temperature rise only & temperature rise is the dominant factor for the efficiency of the system. The heat transfer to the specific load may be a drying unit using hot air, process heat using hot water or steam. Very often only the latent heat is consumed for multiple utility. Under such situation a single heating system may be envisaged where variable heating facilities with multiple qualitative & quantitative measures can be achieved for several processes. Several applications like Milk Pasteurization, Crop Drying, Food Processing, Textile, laundries, Domestic Heat, Washing & Cleaning, Community Cooking etc need process heat in the temperature range of 30^0c to 250^0c.The heat accumulation rate at the focal point may fulfill the aforesaid demand but it will be a standalone mode for a particular intensity of solar radiation. Therefore as stipulated in the figure2: , the convective heat from the hot surfaces of the exchanger pipes acquired by the air entrapped in the space bounded by the collector rear surface & the insulated cover is enhanced by the glass cover at the aperture in the same way that of a single cover flat plate collector. The water in the heat exchanger is preheated by the aforesaid heat recovery system up to some extent for reducing the net heat required for saturation. After achieving the saturation temperature, the residual heat accumulated by the receiver at the focal point will give out the necessary quality of steam under regulated thermal conditions at a higher rate of delivery.

2.2 Bench Model Experimental Results:

Measuring tools used are:(i)Digital Thermometer: Range:-200 to 1000 ^{0} c (ii) Infra Red Thermometer (TESTO Make, UK). All parameters are for 10 minutes for stagnation in every 30 minutes interval.

Table1:

Time	*Date*	T_a	T_{wo}	T_{hao}	T_f	T_{hao}/T_a	T_{wo}/T_a	*Ambient Conditions*
11.00 hrs	*25-04-13*	*28.20*	*70.80*	*49.00*	*107.8*	*1.74*	*2.51*	*wind flow*
11.30 hrs	*25-04-13*	*29.40*	*76.00*	*50.00*	*108.00*	*1.70*	*2.59*	*wind flow, sunshine interruption*
12.00 hrs	*25-04-13*	*32.40*	*78.00*	*50.00*	*115.60*	*1.54*	*2.41*	*wind flow, sunshine interruption*
12.30 hrs	*25-04-13*	*31.50*	*89.70*	*55.00*	*115.00*	*1.75*	*2.84*	*wind flow, cloudy*
13. 00 hrs	*25-04-13*	*33.50*	*90.50*	*56.00*	*163.90*	*1.67*	*2.70*	*clear sky, wind flow*
13.30 hrs	*25-04-13*	*34.00*	*91.80*	*56.50*	*170.70*	*1.66*	*2.70*	*clear sky, minimum wind*
14.00 hrs	*25-04-13*	*33.50*	*92.70*	*57.70*	*177.20*	*1.72*	*2.78*	*clear sky, minimum wind*
11.00 hrs	*26-04-13*	*28.9*	*81.50*	*51.00*	*100.80*	*1.76*	*2.82*	*wind flow*
11.30 hrs	*26-04-13*	*28.4*	*90.00*	*50.30*	*93.00*	*1.77*	*3.17*	*wind flow, sunshine interruption*
12.00 hrs	*26-04-13*	*33.40*	*91.30*	*56.00*	*115.10*	*1.68*	*2.73*	*wind flow, unsteady focal image*
12.30 hrs	*26-04-13*	*32.50*	*90.40*	*54.40*	*118.00*	*1.67*	*2.78*	*wind flow*
13.00 hrs	*26-04-13*	*33.00*	*89.70*	*55.00*	*141.80*	*1.66*	*2.72*	*clear sky, wind flow*
13.30 hrs	*26-04-13*	*34.00*	*92.00*	*57.00*	*170.60*	*1.68*	*2.70*	*clear sky, moderate wind*
14.00 hrs	*26-04-13*	*33.8*	*92.80*	*56.90*	*175.10*	*1.68*	*2.74*	*clear sky, minimum wind*



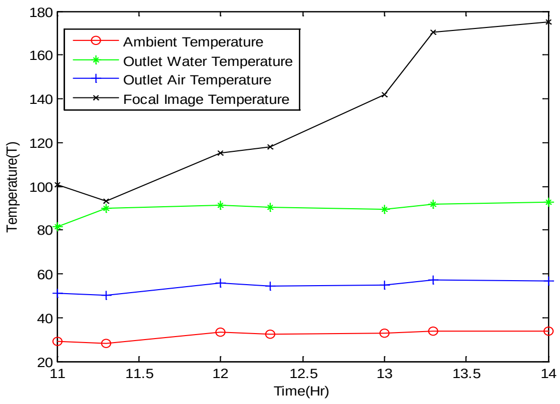
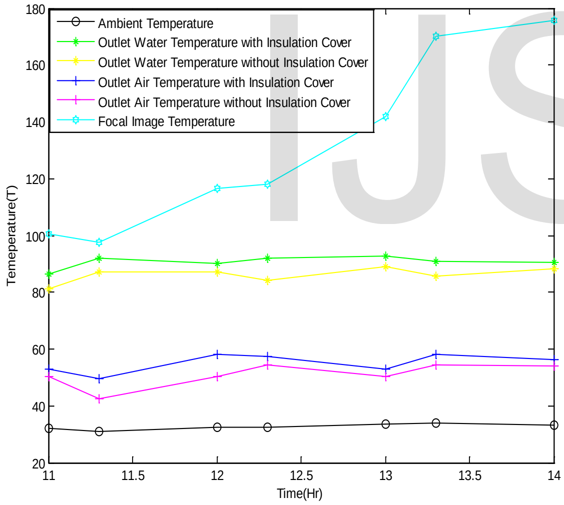


Figure 3(a): Temperature -vs- Time on 25-04-13

Figure 3(b): Temperature -vs- Time on 26-04-13

Table 2:

Time	T_a	T_{wo1}	T_{hao1}	T_{wo2}	T_{hao2}	T_f	h_f	*dh*	*Remarks*
11.00 hrs	*32.50*	*86.50*	*53.00*	*Temperature reading*		*100.80*	*363.0*	*56.1*	
11.30 hrs	*31.00*	*92.00*	*49.40*	*with the rear insulator*		*97.00*	*385.4*	*33.7*	*All readings taken*
12.00 hrs	*32.00*	*90.30*	*58.00*	*cover in place*		*115.10*	*379.0*	*40.1*	*on 21-05-13 with*
12.30 hrs	*32.00*	*92.00*	*57.40*			*118.00*	*385.4*	*33.7*	*an average climatic*
13.00 hrs	*33.00*	*92.80*	*53.00*			*141.80*	*389.0*	*30.1*	*condition as earlier*
13.30 hrs	*34.00*	*91.00*	*58.00*			*170.60*	*381.1*	*38.0*	*with higher solar*
14.00 hrs	*33.00*	*90.60*	*56.40*			*175.10*	*379.0*	*40.1*	*intensity,,*
11.00 hrs	*32.00*	*Temperature reading*		*81.20*	*50.20*	*100.00*	*340.0*	*79.1*	
11.30 hrs	*31.00*	*without the rear*		*87.00*	*42.40*	*98.00*	*364.3*	*54.8*	
2.00 hrs	*33.00*	*insulator cover*		*87.30*	*50.40*	*118.10*	*364.6*	*54.5*	
12.30 hr	*33.10*			*84.30*	*54.50*	*118.00*	*352.0*	*67.1*	
13.00 hrs	*33.80*			*89.00*	*50.50*	*142.00*	*372.7*	*46.4*	
13.30 hrs	*34.00*			*85.60*	*54.50*	*170.00*	*359.0*	*60.1*	
14.00 hrs	*33.60*			*88.30*	*54.20*	*176.30*	*370.0*	*49.1*	



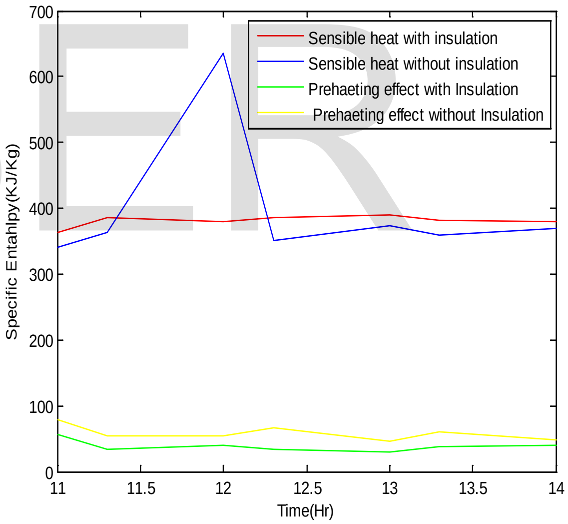


Figure 4(a): Temperature -vs- Time

Figure 4(b): Enthalpy rise -vs- Time

Comparative graphical representation on Temperature & Enthalpy Rise with & without rear insulation

Comparative statement on average temperature readings:

Date	Average Temperature Readings(^{0}c)						Remarks
	T_a	T_{wo}	T_{hao}	T_f	T_{wo}/T_a	T_{hao}/T_a	
25-04-13	31.8	84.2	53.4	136.8	2.65	1.68	With rear collector surface insulation
26-04-13	32.0	89.6	54.3	130.6	2.80	1.69	With rear collector surface insulation
21-05-13	32.5	90.7	55.0	132.0	2.84	1.72	With rear collector surface insulation
21-05-13	32.9	86.1	51.0	132.0	2.70	1.60	Without rear collector surface insulation

3.0 Observations:

(i)From the temperature-time curves of the bench model experiment at Figure3(a): & Figure3(b):, it is found that there is always an increase in temperature for outlet air & water, sharing the absorbed heat by the reflector sheet. The 7% rise in average temperature in heat exchanger water using rear collector surface insulation predicts the opportunity reparation of convective heat loss. .
(ii)In reference to the Figure 4(a): , the rise in temperature with insulation is higher than without insulation of the rear end of the collector.
(iii)The preheating effect of water in the heat exchanger with the rise in sensible heat from the heat recovery unit with insulation is higher than without insulation of the rear collector surface. Further it may be seen that less heat is needed for achieving the saturation point at constant atmospheric pressure with insulation. As a result the supply rate of steam, hot water, hot air etc will be more.
(iv)The ratio of outlet water temperature to the ambient temperature is found higher than that of the hot air to ambient temperature which can be explained due to the variation of effective heat transfer surface area and higher conductive heat transfer rate to the water than that of air due to convective and small extent of radiative heat transfer to the air.

4.0 Discussion: It seems that the fraction of the absorbed solar irradiative heat flux shared by the air & water can be regulated by improvising the effective surface area of the heat exchanger pipes & that of the air passage. The flow rates were not regulated for air & water, rather some steady, instantaneous observations were made. Therefore after saturation point, the qualitative observation of evaporation is beyond the scope of this study. The receiver design for regulating the parameters will be much easier to get necessary quality of steam as per available maximum temperature.

5.0 Conclusion:

As expected, the recovery of absorbed heat by the reflector sheet through conduction at the recovery unit i.e. heat exchanger assembly, as a supplement to the receiver to increase the rate of thermal output which is the most affirmative result of this study. The saturation temperature augmentation on preheating the water by the heat recovery system makes it possible to increase the latent heat absorption rate from the focal image temperature to provide the necessary input to a load at a higher rate where the latent heat is used as the process heat. System works as a Polygenerative system giving out three products simultaneously at a time.

6.0 Future scope:

An assembly of a few such modular dish concentrators to a single sun tracking system is also feasible and such an array of assembly is expected to increase the ratio of generating capacity to land surface area. The increased rate of heat generation at the receiver of the proposed model may also be used for intermittent & diffusive solar radiation in some area experiencing frequent cloud. This can also be implemented in parabolic trough concentrator. This study has sufficient scope, further to develop a most efficient compact, handy & optimized design of solar thermal system increasing the effective heat absorption by water more than air. Reduced volume &weight to use a PLC controlled, fully automatic sun tracking system will definitely improve the system.

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