Journal of Chemical and Pharmaceutical Sciences www.jchps.com ISSN: 0974-2115

EXPERIMENTAL PERFORMANCE STUDY OF PARABOLIC DISH CONCENTRATOR WITH CYLINDRICAL CAVITY RECEIVER BY VARIABLE MASS FLOW RATE OF WATER

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ABSTRACT

Design of solar parabolic dish concentrator for low cost solar water heating system was proposed in this model. In this project a small scale Aluminum cylindrical solar receiver with spherical cavity was installed at the focal point of the dish. There are variable factors played in the model which increasing the water temperature running through such receiver. These variables include parabolic reflector shape, reflector diameter, parabolic dish concentrator rim angle, parabolic dish reflectivity, parabolic dish concentrator optical error, solar dish tracking error, receiver aperture area, receiver material, effect of wind speed to the receiver, receiver spherical diameter, Inlet temperature of water and mass flow rate through the receiver. All these variables considered in this paper. In this system a medium temperature of 350 degree Celsius (stagnation temperature) was obtained at the mid-day of recording. These medium temperatures however have many disadvantages in terms of heat loss from the receiver, especially radiation heat loss. Concentration ratio of 63 with a rim angle of 45 degree, and 1 degree tracking error are used in this paper. Receiver efficiencies are shown in terms of mass flow rate, receiver spherical diameter, maximum receiver surface temperature and inlet temperature of the working fluid. An overall solar to heat efficiency of between 45 % and 70 % is attainable for the solar collector using the open cavity receiver.

Keywords: Solar receiver, open cavity receiver, Tubular liquid receiver, solar water heating system

INTRODUCTION

The concentrated solar thermal energy system is an option that clearly contributes to increase the energy density of the solar radiation which conducts us to the possibility of using absorbers with small surfaces. Since the objective is to convert the concentrated solar energy into useful work. A lot of research is carried out on designing new water heating systems or improving the performance of existing ones. The receiver is built cylindrically by aluminium materials which forward the heat quickly, so that all the solar rays concentrated at center without shadow. During evaluation stage manual tracking is used which allows for effective collecting and concentrating of the incoming solar irradiation. The parabolic dish concentrator (PDC) receives direct solar radiation approximately 800 W/m2 of global (Total) solar insolation, which is concentrated and reflected to the receiver. The incoming radiation from the sun is concentrated on to the receiver which increases the operating temperature of the system significantly and subsequently increases the efficiency of the conversion. There is a need of research on low cost parabolic dish solar water heater in view of Life of solar water heating systems

1. High temperature materials
2. Development of optimized geometric designs
3. Conversion efficiencies
4. The floor space area availability for such solar water heating systems
5. Cost of conversion, installation and maintenance of such system.
6. Skills required for operation and maintenance
7. Maximize absorptance, minimize heat loss
8. High reliability over thousands of thermal cycles
9. Direct vs Indirect heating

LITERATURE SURVEY

Hussain Al-Madani studied a batch solar water heater in Bahrain which consisted of an evacuated, cylindrical glass tube. Side-by-side testing of prototypes resulted in a maximum temperature difference between the inlet and outlet of the cylindrical batch system of 27.8°C with a maximum efficiency of 41.8%.

Tripanagnostopoulos and Souliotis experimented on optimizing an integrated storage-collector batch solar water heater that contained two cylindrical tanks and a compound parabolic concentrator made of aluminum mylar glazed with an iron oxide and black matte absorbing surface. A simpler batch solar water heater has been investigated by Akuffo. The integrated storage- collector unit was a rectangular galvanized steel box with a total storage capacity of 90L. "Angle iron" was used to support the edges and prevent buckling and jute fiber was used for insulation. This design achieved a maximum temperature of 45°C by 4:30pm and provided 30°C water at 5:30am the next day. Daily ambient peak temperatures exceeded 37°C.

Nahar studied a separated storage-collector system. Nahar found that this system can produce 60.6º C water at 4:00pm and 51.6ºC water the next morning. The overall efficiency of this system was determined to be 57%.

Zerrouki et al. studied a similar separated storage- collector system Algeria. The maximum temperature was observed to be 57ºC starting from an initial temperature of 17ºC at 7:00am.

DESCRIPTION OF SYSTEM USED

The system consists of a parabolic dish of 3.0 m diameter. It is made up of glass mirrors & supported with locally manufactured cast iron stand. At focus a cylindrical aluminium receiver with internal water flow is fitted & it is coated with black paint at the cavity face and the total receivers are insulated by wool. The diameters of cavity receivers are 0.40 m. A water inlet pipe and exit pipe are fixed at the top. Inlet & outlet pipes are made of high temperature & pressure aluminium tube are attached to receiver. Inlet water flow is controlled by using inlet valve & hot water at outlet is collected in insulated tank. Thermocouples are used to measure the temperatures of inlet & outlet water and receiver surface temperature. Wind speed is measured by using anemometer & solar radiation by using Pyranometer.

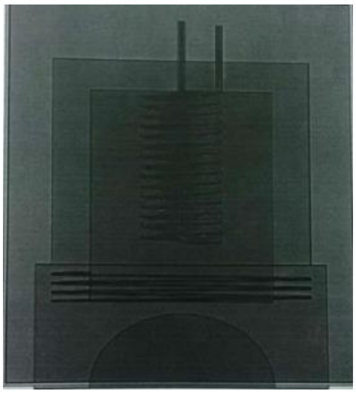

Figure 1. Assembly of Cavity Receiver Figure 2. Receiver machined from Aluminium Bar

Table 1. Parameters of system used for experimentation

Name of component	Dimension
Diameter of Parabolic dish	3.0 m
Thickness of mirror of Parabolic dish	2mm
Reflectivity of Parabolic dish	0.98
Depth of Dish	0.50 m
Focal length of dish	1.125 m
Surface area of parabolic dish collector	11.6 m2
Aperture area of parabolic dish collector	1.54 m2
Diameter of receiver	0.40 m
Surface area of receiver	0.4536 m2
Effective length of receiver	0.60 m
Thermal conductivity of Aluminium	197(W/m k)
Density of Aluminium	2.7(gm/cm3)
Melting point of Aluminium	660(°C)
Specific gravity of Aluminium	2.55
Absorptivity-transmitivity product of Aluminium (dull face)	0.65

EXPERIMENTAL PROCEDURE

The schematic diagram of the experimental set- up is shown in Figure.1. It consists of a cavity receiver supported by support stand. The receiver is kept vertically upright with respect to the horizontal. The cold water circulated in the receiver has been supplied from a water tank of 10 litre capacity. The working fluid is circulated through the receiver tubes by gravity. A rotameter at inlet, measures the mass flow rate of cold water entering the receiver. The cold water is circulated at constant inlet temperature through the receiver. The temperatures of the fluid in the tube at four locations (including the outlet) are measured using thermocouples. The flow is kept constant for the complete period of an experimental run. The system is operated under open loop condition as the water exiting from the receiver is not circulated back to the inlet cold water supply tank. The hot water is stored in an insulated tank near the outlet. The wind speed measurements are taken at a fixed location near the parabolic dish collector plane. The wind may be in the direction normal to the receiver & also the direction of the wind may be parallel to the receiver.

All the measuring instruments used in the experiments are calibrated. The working fluid is cold water and on experiment inlet temperatures varies between 26°C and 33°C. For each test, the inlet fluid temperature is measured using thermocouple. The working fluid will enter in and exit from the receiver. This is to ensure that the highest temperatures are at the top of the cavity receiver and lower temperatures near the concentrator. The solar radiations, tube temperatures and the fluid temperatures are measured at intervals of half hour and the experiment is continued till the solar radiation is available at sufficient intensity. The thermal losses are estimated at steady state. For the experiments with black coated receiver, the region outside the cavity is surrounded by a downward facing cylindrical glass enclosure

Table 2. Experimental Measurements & calculations at mass flow rate ṁ= 0.0075 kg/s

Assumed solar radiation on Horizontal surface (W/m²)	Tin (°C)	Tout (°C)	Tamb (°C)	Receiver Temp. (Tr) (°C)	Wind speed Avg m/s	Optical Energy Captured by Receiver (W)	Overall heat loss coefficient (W/m²°C)	Total heat Loss (W)	Useful heat gain by Water (W)	Collector Efficiency (%)
800	26	45	31	66.75	3.80	606.94	7.87	66.28	540.66	68.73
800	26	49	31	73.00	4.65	730.28	8.97	88.75	641.53	67.78
800	27	52	32	82.00	4.03	797.65	8.18	96.37	701.29	67.84
800	28	53	32	84.25	5.38	841.00	10.13	124.80	716.20	65.71
800	29	48	32	85.75	5.13	679.48	10.16	128.74	550.74	62.54
800	30	57	32	95.75	4.43	955.67	8.53	128.21	827.46	66.81
800	30	57	32	113.25	5.63	988.58	10.91	208.93	779.65	60.85
800	31	57	33	127.00	6.25	1032.21	12.48	276.42	755.79	56.50
800	31	57	32	120.50	6.60	1020.59	12.69	264.78	755.81	57.14
800	32	59	32	98.75	5.80	984.22	10.49	165.06	819.16	64.22
800	32	57	31	102.25	6.10	933.49	11.08	186.07	747.42	61.78
800	33	53	31	79.00	4.98	722.38	9.11	103.11	619.28	66.15
800	33	50	31	74.25	5.23	621.40	9.58	97.63	523.77	65.04

While measurements with mass flow rate of 0.005 Kg/s receiver is covered with cylindrical glass cover of thickness 2 mm. This helps to reduce heat losses from receiver.

Table 3. Experimental Measurements & calculations at mass flow rate ṁ = 0.0050 kg/s

Solar radiation on Horizontal surface (W/m²) Assumed	Tin (°C)	Tout (°C)	Tamb (°C)	Average Receiver Temp. (Tr) (°C)	Wind speed Avg m/s	Optical Energy Captured by Receiver (W)	Overall heat loss coefficient (W/m²°C)	Total heat Loss (W)	Useful heat gain by Water (W)	Collector Efficiency (%)
800	26	42	31	56	2.725	475.35	6.23	36.69	438.66	71.20
800	27	51	31	76	3.7	674.30	7.47	79.28	595.02	68.09
800	28	54	32	80.75	4.25	725.42	8.24	94.69	630.73	67.09
800	29	50	32	65.75	5.175	590.40	9.33	74.25	516.15	67.46
800	30	56	32	104	5.525	819.35	10.64	180.63	638.72	60.15
800	30	64	33	114. 25	3.8	956.64	7.89	151.16	805.48	64.97
800	31	60	33	107	4.275	825.32	8.57	149.49	675.83	63.18
800	31	48	33	63.25	4.25	455.69	7.94	56.61	399.08	67.58
800	32	50	33	60.25	5.2	500.98	9.04	58.07	442.91	68.22
800	32	51	34	62.25	3.875	547.26	7.17	47.77	499.49	70.43
800	33	61	33	67	6.025	812.97	9.94	79.67	733.30	69.60
800	33	64	33	73.25	5.2	862.62	8.63	81.90	780.72	69.83
800	32	64	33	71	4.275	821.91	7.20	64.50	757.41	71.11
800	32	63	32	67.25	3.1	738.68	5.41	44.94	693.73	72.47
800	31	57	32	62	4.475	618.26	7.52	53.16	565.10	70.53

Journal of Chemical and Pharmaceutical Sciences www.jchps.com ISSN: 0974-2115

RESULTS AND DISCUSSION

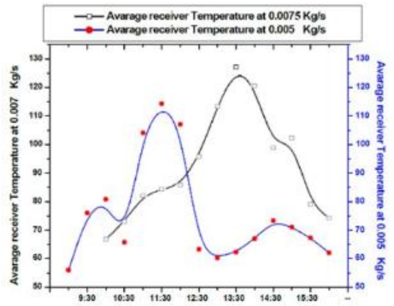

Figure 3. Variation of average receiver temperatures throughout the day

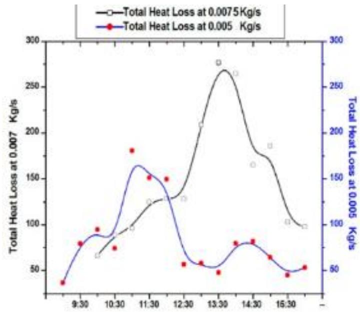

Figure 4. Variation of Total Heat losses throughout the day

Fig. 3 shows Variation of average receiver temperatures throughout the day. It was observed that average receiver temperature is affected by solar radiation & wind velocity at instant. Receiver temperature increases in afternoon as solar radiation increases. With decreased flow rate (0.005 Kg/s) of water & receiver covered with glass cover, receiver temperature must increase as compared to higher flow rate (0.0075 Kg/s) & no glass cover on receiver. But it has also been observed that decreased solar radiation does not allow receiver temperature to increase as expected. Average receiver temperatures of 920C & 750C have been achieved with flow rates 0.0075 Kg/s & 0.005 Kg/s respectively. It has been found that there is decrease of 18 % in receiver temperature with reduced flow rate. Due to wind velocity at instant as flow rate of water reduces heat loss from receiver surface increases.

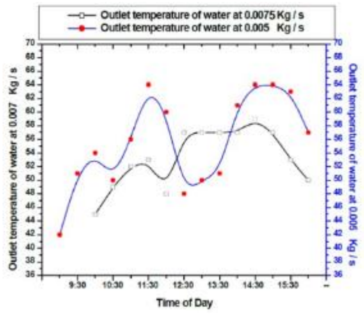

Figure 5. Variation of outlet temperatures of water throughout the day

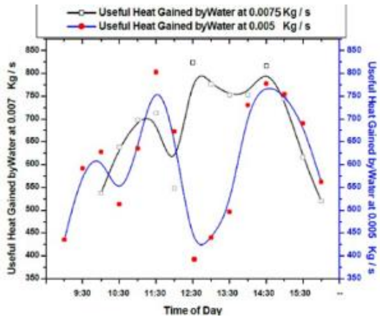

Figure 6. Variation of useful heat gained by water throughout the day

Fig. 4 indicates Variation of total heat losses throughout the day. As explained earlier, an average receiver temperature is affected by solar radiation & wind velocity at instant similarly total heat losses at instant also affected by solar radiation & wind velocity. With decreased flow rate (0.005 Kg/s) of water & glass cover, it is found that heat loss also get reduced as compared to higher flow rate (0.0075 Kg/s) & no glass cover on receiver. Average heat loss of 148W & 83W has been achieved with flow rates 0.0075 Kg/s & 0.005 Kg/s respectively. It is found that there is decrease of 43 % in average heat loss when receiver is covered with glass cover.

From Fig. 5 it is clear that, with reduced flow rate of water, the temperature of water coming out of receiver get increased as compared to higher flow rate. As receiver temperature increases, outlet water temperature also increases. As compared to flow rate of 0.0075 Kg/s, there is average rise of 4% in outlet water temperature of water with flow rate of 0.005 Kg/s & receiver covered with glass.

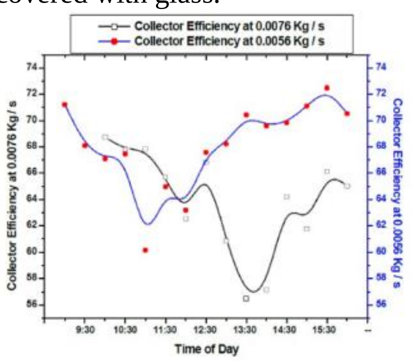

Figure 7. Variation of Collector Efficiencies throughout the Day

Journal of Chemical and Pharmaceutical Sciences www.jchps.com ISSN: 0974-2115

Fig. 6 shows Variation of useful heat gained by water throughout the day. Useful heat gained by water depends on solar radiation, receiver temperature & wind velocity at instant. From Fig. 6, it is clear that water gained 11% more heat at flow rate of 0.0075 kg/s. but when flow rate has reduced to 0.005 kg/s & receiver covered with glass, rate of heat loss from receiver get reduced. Also there is increase in outlet water temperature & system performance. Collector efficiency is again a function of parameters such as solar radiation, surface reflectance, receiver absorbance, atmospheric conditions, & wind velocity. Fig. 7 shows variation of collector efficiencies throughout the day. It is observed that there is rise of 4.19 % in efficiency of collector with flow rate of 0.0075 kg/s and receiver covered with glass.

CONCLUSION

An experimental and numerical study of Parabolic solar Dish collector water heater with receiver has been conducted. General comparison between the parabolic solar dish collector water heater and common models such as flat plate and evacuated tube collectors demonstrated that parabolic solar dish collector water heater is a good alternative for flat plate and evacuated tube water heaters and could be applied effectively. Therefore, the developed model can be considered for designing commercial parabolic solar dish collector water heater. Proposed system is aimed at saving conventional energy sources and environment too. Such objectives are important parts towards the development of self-sufficient sustainable homes in rural as well as urban areas. When receiver is covered with glass cover, system performance gets enhanced. Measure findings from experimentation have been listed.

1. There is rise of 4.19 % in efficiency of collector with flow rate of 0.0075 kg/s & receiver covered with glass.
2. There is average rise of 4 % in outlet water temperature of water with flow rate of 0.005 Kg/s & receiver covered with glass.
3. Heat losses are also reduced as compared to higher flow rate (0.0075 Kg/s) & no glass cover on receiver. There is decrease of 43 % in average heat loss when receiver is covered with glass cover
4. There is decrease of 18 % in receiver temperature with reduced flow rate.

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