Investigation and Development of Liquid Flat Plate Solar Collector using Concrete as Absorber Plate and its Performance Testing

Sangram Patil*‡, A A Keste**, Ajinkya Sable***

*Department of Mechanical Engineering, Research scholar, Mewar University, Chittorgarh, India

** Department of Mechanical Engineering, MES college of Engineering, Savitribai Phule University Of Pune, Pune, India

*** Department of Mechanical Engineering, Singhad Academy of Engineering, Savitribai Phule University Of Pune, India

(sangramrpatil@gmail.com, aakeste@mescoepune.org, sableajinkya@gmail.com)

‡ Corresponding Author: Sangram Patil, Sr. No 74/1A, A-7, Anant Smurti, Katraj, Pune, India, 411046, Tel: +919763369224, sangramrpatil@gmail.com

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Abstract: In order to increase usage of solar water heater (SWH) for domestic purposes instead of conventional sources of heating water which contribute towards energy crisis, global warming & air pollution, the cost of SWH needs to be reduced which is the major reason for its lesser usage. Hence by keeping the objective of low cost liquidflat plate solar collector, we replace the costliest component of collector, which is the metal absorber plate with the concrete absorber plate.Here the possibility of utilizing building materials (concrete) for making liquid flat plate solar collector, in Pune, has been investigated. Thus 2m X 1m concrete collector is designed, fabricated and tested for various months and for different mass flow rates. It was observed that, the average temperature of hot water collected in rainy season was in the range of 47 ˚C to 57 ˚C, in winter season was 48 ˚C to 59 ˚C and insummer season was 56 ˚C to 80 C˚. Therefore, concrete collector is sufficient to provide required quantity of hot water for domestic purposes. This paper also paves way for possible integration of concrete collector with roof slab. Such integration will also provide comfort temperature zone within the building.

Key words –Liquid flat plate solar collector;passive solar technology; concrete; metal fibers; serpentine tube.

Nomenclature

A_p - Top surface area of absorber plate (m^2)
T_p - Thickness of absorber plate (mm)
K - Thermal conductivity of metal fiber reinforced concrete (W/m-K)
X - Unit mass of metal fibers
K_m - Thermal conductivity of metal fibers (W/m-K)
K_c- Thermal conductivity of concrete (W/m-K)
$\dot{m}$ - Water flow rate (liters/ hour)
D_o - Outer diameter of copper serpentine tube (mm)
D_i - Inner diameter of copper serpentine tube (mm)
W - Spacing between serpentine copper pipes (cm)
h_f - Heat transfer coefficient on inside surface of tube (W/m^2-K)
R_e - Reynolds number for flow in pipe or tube
ρ - Density of water (kg/m^3)
V - Velocity of water (m/s)
μ - Dynamic viscosityof water (Pa-s)
D_H - Hydraulic diameter of pipe
P_r - Prandtl number
C_p- Specific heat of water (J/kg-K)
K_f - Fluid thermal conductivity at bulk temperature (W/m-K)
l_f- Length of flow tube (m)
N_u - Nusselt number
U_L- Overall loss coefficient (W/m^2-K)
F - Plate effectiveness
F' - Collector efficiency factor
F_R - Collector heat removal factor
ɳ - Instantaneous efficiency of collector
Q - Heat absorbed by water (W)
I_p - Incident solar intensity (W/m^2)
T_i - inlet temperature of water (˚C)
T_o - outlet temperature of water (˚C)

1. Introduction

Conventional water heating methodslike burning of fuels, electric geyser, gas geyser, etc.for domestic purposes,contribute to three major threats, which the world is facing today-fossil fuel depletion, environmental pollution and climate change. Thus to tackle with these threats liquid flat plate solar water heater is the best available option for heating water for domestic purposes.

In conventional liquidflat plate-collector systems, metals like copper, aluminum, etc. are used. But metals require a large amount of fossil fuel energy for their production [1].Also this solar system forms a separate unit with high initial cost, acquires large space for its setup and forms dead load on building structure.

A possible alternative by considering above problems is use of concrete collector. Here initial cost is reduced by using concrete absorber plate with metal scrap added, instead of metal absorber plate. For long term considerations this collector could be made integrated with the building slab thus clearing space and eliminating dead loads on building structure. Also by this, a separate investment requirement will be merged into the cost of construction investment, further reducing the cost.

We know that the surrounding temperature is the most important factor of comfort for humans, and in buildings, the roof slab becomes hot by absorbing heat in day time and rejecting this heat inside the building at night time. Due to this characteristic of roof slab, indoor environmental conditions become more uncomfortable to live which leads to increase in energy demand due to usage of fans, air conditioners, cold storage, etc. A building can provide comfortable thermal conditions for the occupants by separating the inside spaces from the outside environment. For this, the building should be designed such that it opens itself to those climatic conditions which are comfortable and closeitselfto uncomfortable climatic conditions. This will ultimately reduce the heating and cooling load of the building. This passive solar technology of concrete collector will aim at maximizing this approach. In this paper the heat absorbing capacity of roof slab is also taken into consideration while designing the concrete collector.

2. Literature Review

Kern and Harris (1975) calculated that the value of annual optimum tilt for solar insolation falling on the collector, and said it is approximately equal to the latitude of the location and these findings were similar to Morse and Czarnecki (1958) [1].

Bopshetty, Nayak and Sukatme (1992) developed mathematical model to estimate performance of PVC tubes embedded inside concrete collectors and found that lower inlet fluid temperature, lesser pitch and higher flow rate gives more efficiency and also stated that change in absorptivity affects the efficiency of the collector [2].

Chaurasia (2000) [3] carried out study on solar concrete collectors providing domestic hot water with aluminum pipes embedded over concrete slab without glazing on the top or insulation at the back with absorbing surface area of about 1.06 m^2. The aluminum pipes with diameters of 12 mm, 19 mm and 25 mm were tested and better results were obtained with 19 mm. Testing also concluded that the temperature of output hot water obtained from the concrete collector was increased by 2°C to 5°C when painted with a single coating of the blackboard paint. And most important, the hot water at moderate temperature (36°C to 58 °C) was obtained in buildings during the daytime in winter.

NamrataSengar, PrabhaDashora and VikasMarwal (2011) [4] did a study of building material housing solar water heater (BMHSWH) of trapezoidal shape collector with 2 layer insulation and found that this system is capable of delivering about 65 liters of hot water at temperature 40˚C above ambient temperature per day with the collector area of just 1.14 m^2 in winter conditions. They stated that payback period of BMHSWH for various fuels was reasonably small and the itsaverage efficiency with polymeric double glaze came out to be 62% whereas with single glass glaze it was 57%.

V. Krishnavel, A. Karthick, K. Kalidasa Murugavel (2014) [5] conducted simultaneous experiments on three different types of concrete collector design, first collector fabricated with concrete embedded with aluminum pipes, in second design, thermal conductive material was added with concrete and in third design, PVC pipes were used. Results showed that the slab 1 with aluminum pipes and metal scrap is most efficient, also it is inferred that, the building integrated solar water heater system with cheaper PVC pipe is capable of delivering moderate temperature hot water suitable for different domestic applications.

Rangsit Sarachittia ,Chaicharn Chotetanormb, CharoenpornLertsatitthanakornb, Montana Rungsiyopasc (2011) [6] examined thermal performance of 2 rooms; 1 room with reinforced cement concrete slab and 2nd room with roof-integrated solar concrete collector with PVC pipes embedded in it, without glazing on top and without insulation. The experimental results showed that the room with concrete solar collector slab produces up to 40 liters of hot water per day at temperature from 40 to 50˚C, also reduces heat gain to house and economic analysis indicated that the payback period is fast.

3. Design Studies

Concrete collector is a type of heat exchanger which absorbs the incident solar radiations falling on it and transfers this heat to the water flowing in tube in order to heat it, which is finally stored in an insulated tank by once through or meander principle.

Metal absorber plate of conventional solar collector is replaced by concrete plate for following reasons: Concrete is a common building material, costs very low and its technology is well established. Thermal storage capacity of concrete is extremely high. The absorptivity of concrete can be increased to 0.96 from 0.65, simply by painting the top absorbing surface with black paint [7]. Also no considerable effects are found on mechanical properties of concrete upto 100° C which could be maximum possible operating temperature of concrete plate [8].

As thermal conductivity of concrete is very low,that is about 2 W/m-K [9] (Basalt type of aggregate is used in concrete), so metal scrap is added to concrete mixture to increase conductivity of the absorber plate.Addition of metal (mild steel) scraps will increase efficiency of collector [5] and improve the residual mechanical properties of concrete at high temperature [8].Further, in order to make design calculations applicable for all types of metal fibers and assuming random distribution of scrap or fiber, a minimum value of 4.0 W/m-K is chosen as thermal conductivity for concrete plate [7].

Further instead of parallel riser type arrangement of tubes (thermo symphonic type) used in metal absorber plate, we use serpentine tube made of copper to allow continuous and uniform flow of water. This is easier to construct, less prone to leaks and less expensive than parallel riser type arrangement. The purpose of using copper for tubes is its high thermal conductivity of 384 W/m-K [10]and its ductile nature.

Steel wire mesh in slab not only provides reinforcement to concrete slab, but also provides support and acts as fixture for serpentine tube.

The glass plate is fixed at the topreducesheat losses from the collector.

A liquid flat plate collector is fixed at one position, such that maximum annual insolation is received at that particular tilted angle. This collector is tilted facing south at 19° [1], as Pune lies in northern hemisphere at latitude of 18.5° [11].

Following parameters in design of concrete collector are considered:

a) Top surface area of absorber plate (A_p): In order to compare concrete collector with commercially available conventional metallic collectors, absorbing area of 2 m × 1 m is considered. Thus$A_p=2\ m^2$.

b) Thickness of absorber plate (T_p):The optimum thickness of a reinforcement cement concrete (R.C.C.) simply supported slab spanning in two directions,was calculated as per Indian Standard code 456 of civil engineering (IS code 456) [3]. This design is especially applicable for roof integrated concrete collector. The shorter of the two spans should be used for calculating effective thickness of slab [12].
Effective thickness of slab= Effective span of a slab/35 [12] (1)

Effective span of slab is taken as center to center distance between supports[12].Support by angle iron stand is provided on all four outer sides of slab of width35 mm on each side. The metal wire mesh of 2 m^2 embedded in concrete slab increases its strength. Also the copper tube embedded in R.C.C slab which flows in direction parallel to 1m side, further increases the strength of slab. So the concrete slab will be sufficiently strong to avoid flexure, if we consider span of slab as 1m.
Effective span of slab =1 – (0.07/2) = 0.965 m.
Effective thickness of slab= 0.965/35 = 0.027 m or 2.7 cm

So, minimum thickness of slab should be more than 2.7 cm to avoid flexure failure.Thus take T_p = 3.5 cm

c) Mass flow rate (ṁ)= 25 lit/hr

d) Outer diameter (D_o) =12 mm, as suggested by A. A. Keste and S. R. Patil in their fabrication [7].

e) Inner diameter (D_i) =10 mm

f) Spacing (W)=8 cm, as suggested by A. A. Keste and S. R. Patil in their design [7].

g) Amount of metal fiber in concrete slab: Here we use mild steel scrap in powdered form, whose thermal conductivity is 54 W/m-K [10]. To find conductivity of concrete plate, following relation is used:

$K= X\times Km + (1-X) \times Kc$ (2)
$4=X\times54 + (1-X) \times2$ as K=4 W/m-K [7].
X= 0.0384

For 175 kg weight of concrete, minimum 7 kg of mild steel scrap will be required.

Theoretical analysis of concrete collector:In order to see effects of change due to design parameters like T_p, K, ṁ, W, D_o and D_i on performance of collector, theoretically, we need to calculate plate effectiveness, collector efficiency factor and collector heat removal factor. Though the heat flow inconcrete absorber plate would be different from conventional liquid flat plate collector,following design calculations are made based on an approximate method following the analysis of ordinary liquid flat plate collector under steady state condition due to absence of rigorous analysis of concrete absorber plate.

h) Heat transfer coefficient on inside surface of tube (h_f):To find h_f, we need to find whether water flow through tube is laminar or turbulent, which is found by calculating Reynolds number

$R_e= (\rho\times V\times D_H)/\mu$ [13]. (3)
ρ at 40°C = 992.2 kg/m^3 [14]
V =flow rate of water/ area of flow (4)
Area of flow $=\pi\times D_i^2/4 =7.8539\times10^{\wedge-5} m^2$ (5)
$V= 6.944\times10^{\wedge-6} / 7.8539\times10^{\wedge-5} = 0.0884$ m/s
μ at 40°C $=0.6527\times10^{\wedge-3}$ Pa-sec [14]
For circular pipe, the hydraulic diameter is exactly equal to inside pipe diameter. $D_H=D_i$= 0.006m
$R_e= (\rho\times V\times D_H)/\mu = (992.2\times0.0884\times0.01)/\ 0.6527\times10^{\wedge-3}$ = 1344.019

Thus it is laminar flow as R_e is less than 2300 [13].Since the flow of water through the tube is laminar, the heat transfer coefficient from the tube wall to water is calculated from the following co-relation
$(R_e\times P_r\times D_i)/\ l_f$ (6)
$P_r = \mu\times C_p/K_f$ (7)
C_p = 4187 J/kg-K
K_f at 40°C =0.6305 W/m-K
$P_r = \mu\times C_p/K_f=0.6527\times10^{\wedge-3}\times4187/0.6305 = 4.3344$

l_f=23.7 m
$(R_e \times P_r \times D_i)/ l_f = (1344.019 \times 4.3344 \times 0.01)/23.7 = 2.458$
For $(R_e \times P_r \times D_i)/ l_f \leq 10$,
$N_u = h_f \times D_i/K_f = 3.656$ [2] (8)
So, h_f = 230.511 (W/m^2-K)

i) Overall loss coefficient (U_L):It is heat loss from the collector from top, bottom and sides. Its value ranges from 2 to 10 W/m^2-K [1]. We consider maximum heat loss. Thus U_L= 10 W/m^2-K.

j) $$F = \tanh\left[\frac{m(W-D_o)}{2}\right] / \left[\frac{m(W-D_o)}{2}\right] \text{ [1]} \quad (9)$$

Where $m = (U_L / K \times T_P)^{\wedge 0.5}$ (10)

k) $$F' = \frac{1}{W.U_L\left[\frac{1}{U_L[(W-D_o)F+D_o]}+\frac{T_P}{K.D_o}+\frac{1}{\pi.D_i.h_f}\right]} \text{ [1]} \quad (11)$$

l) $$F_R = \frac{\dot{m}.C_p}{U_L.A_P}\left[1-\exp\left\{-\frac{F'.U_L.A_P}{\dot{m}.C_P}\right\}\right] \text{[1]} \quad (12)$$

Table 1. Thermal conductivity of slab

K (W/m-K)	F	F'	F_R
2	0.9484	0.8648	0.6518
4	0.9733	0.8821	0.6613
6	0.982	0.8881	0.6646
8	0.9865	0.8912	0.6662
10	0.9891	0.893	0.6672
12	0.9909	0.8943	0.6679
14	0.9921	0.8951	0.6684
16	0.9932	0.8958	0.6687
18	0.9939	0.8963	0.669
20	0.9945	0.8967	0.6692

The performance parameters increase with increase in conductivity of absorber plate initially and then remain constant. After 4 W/m-k, the increase rate of performance parameters is less, thus minimum value of K is chosen.

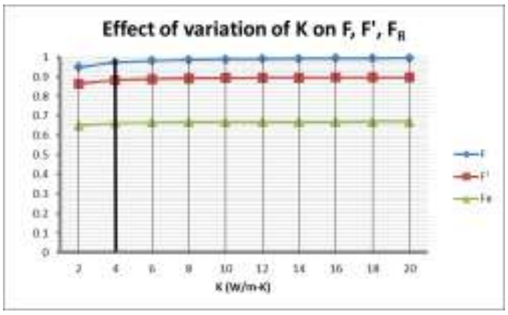

Fig. 1. Effect of variation of K on F, F', F_R

Table 2. Thickness of concrete absorber plate

T_P (cm)	F	F'	F_R
1	0.9136	0.8406	0.6383
2	0.9545	0.869	0.6541
3	0.9671	0.8792	0.6597
4	0.9766	0.8844	0.6625
5	0.9812	0.8875	0.6643
6	0.9842	0.8897	0.6654
7	0.9865	0.8912	0.6677
8	0.9881	0.8923	0.6677
9	0.9894	0.8932	0.6677
10	0.9905	0.8939	0.6677

The performance parameters increase with increase in thickness of absorber plate initially and then remain constant. After 3.5 cm, the increase in thickness will not increase performance parameters much but will increase cost and weight of system, so selected3.5 cm.

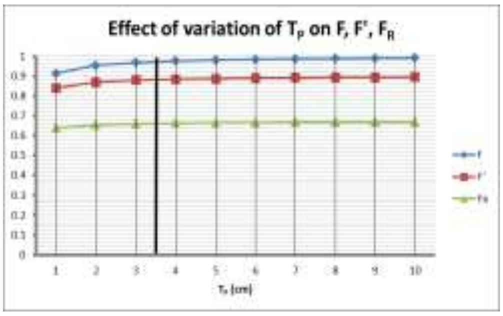

Fig. 2. Effect of variation of T_P on F, F', F_R

Table 3. Outer diameter of serpentine tube

D_o (mm)	F	F'	F_R
4	0.9669	0.875	0.6574
6	0.9686	0.8769	0.6584
8	0.9702	0.8787	0.6595
10	0.9718	0.8805	0.6604
12	0.9733	0.8821	0.6613
14	0.9748	0.8836	0.6621
16	0.9763	0.8851	0.6629
18	0.9777	0.8865	0.6637
20	0.9791	0.8878	0.6644

There is no much change on performance parameters due to tube diameter size. Therefore to increase contact area of water with copper tube the assumed size of D_O =12 cm and D_I =10 cm is kept as it is easily available in market.

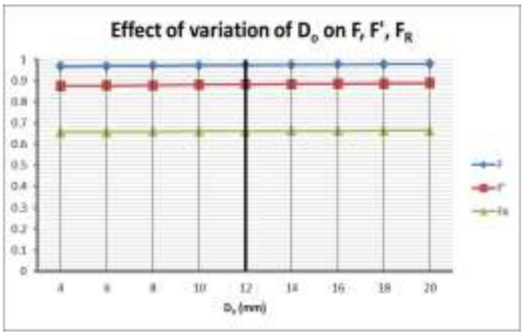

Fig.3. Effect of variation of D_O on F, F', F_R

Table 4. Spacing between serpentine tube

W(cm)	F	F'	F_R
2	0.9996	0.9729	0.7093
4	0.9953	0.9447	0.6947
6	0.9865	0.9143	0.6786

8	0.9733	0.8821	0.6613
10	0.9563	0.8488	0.6429
12	0.9359	0.8151	0.6239
14	0.9127	0.7812	0.6043
16	0.8872	0.7477	0.5845
18	0.8601	0.7149	0.5647
20	0.8319	0.6813	0.5451

The performance parameters decrease with increase in spacing between tubes. After 8 cm the performance parameters decrease rapidly.And lower the spacing more will be the length of tube thus more will be the cost. Thus 8 cm spacing is selected.

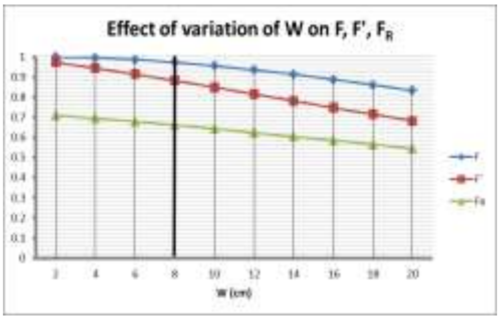

Fig.4. Effect of variation of W on F, F', F_R

4. Fabrication

The collector box was prepared from commercially available water proof wooden plywood of thickness 18 mm with inner dimensions of 2 m × 1 m × 0.1 m. With reference to height of serpentine tube fixed from bottom, two holes are drilled at the side flank to have access to inlet and outlet pipe. The wooden enclosure was applied varnish and wood preservative and the inner surface of box was covered with aluminum foil of 0.3 mm thickness to provide reflecting surface on the sides of the box.

Then the concrete slab is fabricated from cement, sand, coarse aggregate of maximum 10 mm diameter and steel wire mesh embedded in it. To this mixture of concrete, 7 kg of mild steel scrap was added in powdered form of diameter less than 3mm so that it won't create any voids in the slab. M15 grade concrete mix was used where the ratio of concrete mix was 1:2:4 (1-cement: 2-sand: 4-coarse aggregate). Approximately 25 kg cement, 50 kg sand, 100 kg aggregate with 7 kg mild steel scrap was used to construct the slab. This mixture is poured into the wooden box at a height of 3.5 cm from the bottom. Wire mesh was embedded at a height of 2.9 cm from bottom such that 50 % of serpentine tube fixed on this mesh is directly exposed to sunlight and 50% remains inside concrete slab as suggested by Chaurasia [3]. This wire mesh provides reinforcement to the slab and also causes a slight increase in overall thermal conductivity of slab. Cross section of collector is shown in Fig. 6. After curing blackboard paint is applied on slab.

The copper tubes were made into serpentine flow arrangement using a pipe bending machine and brazing torch. And then these tubes were tied to a wire mesh using metal wires to maintain the spacing.The grid is shown in Fig.5.The total length of Cu tubing used was 23.7 m with straight lengths 82.75 cm and bend radius of 4.6 cm. There are 22 rows and 21 turns. The tube spacing was kept 8 cm.

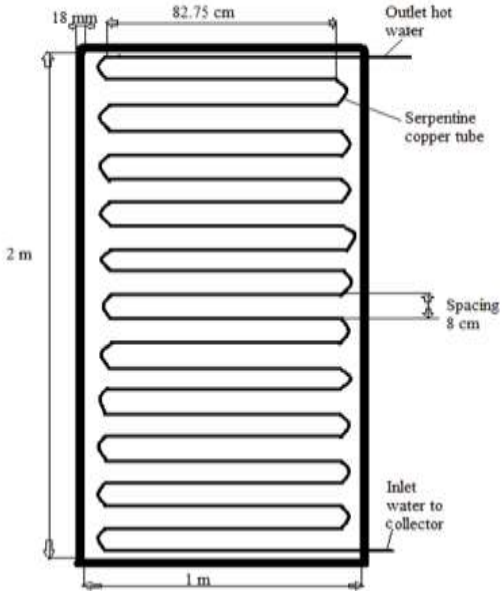

Fig.5. Top view of collector with serpentine tube

A 4 mm thick toughened glass was placed on the top of the wooden cabinet by keeping air gap of 4 cm from slab.

Mild steel stand of thickness 3 mm is made such that when the collector is mounted on it, it is inclined at an angle of 19° due south. The collector is mounted on this inclined stand. A 150 liters capacity insulated storage tank is connected to the collector by means of hose pipe as shown in Fig. 7.

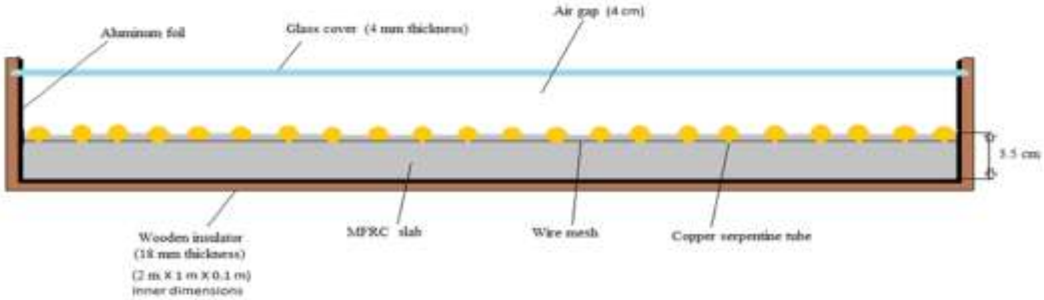

Fig. 6. Cross section of concrete collector

Fig.7. Experimental setup

5. Performance Testing

Pyranometer instrument was used to measure incident solar insolation on the collector plate. 2 K-type thermocouples connected to temperature indicator were used to obtain inlet and outlet temperatures of water of collector.The required flow rate is measured with the help of the measuring flask.

Heat absorbed by water is given by,

$$Q = \dot{m} \times C_P \times (T_O - T_I) \quad (13)$$

Table 5. September month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	27	53	727.3	604.79
	12	29	55	820.8	604.79
	13	30	57	880.3	628.05
	14	30	55	759.6	581.52
	15	29	53	667.4	558.26
25	11	29	52	782.2	668.75
	12	30	54	825.1	697.82
	13	30	55	832.7	726.90
	14	31	52	682.6	610.59
	15	30	50	641.3	581.52
30	11	29	51	741.6	767.62
	12	31	52	814.3	732.73
	13	30	52	751.9	767.62
	14	29	49	601.8	697.84
	15	29	47	472.2	628.06

Table 6. October month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	28	53	761.2	581.52
	12	30	55	836.8	581.52
	13	31	57	863.7	604.78
	14	31	55	805.6	558.26
	15	29	52	710.8	535.00
	14	31	55	805.6	558.26
	15	29	52	710.8	535.00
25	11	29	53	773.6	697.82
	12	30	54	841.7	697.82
	13	31	56	909.5	726.90
	14	31	53	801.3	639.67
	15	30	49	663.6	552.44
30	11	29	52	791.7	802.52
	12	31	54	833.2	802.52
	13	31	53	825.3	767.62
	14	30	51	811.5	732.73
	15	30	48	662.5	628.06

Table 7. November month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	27	54	764.6	628.05
	12	28	56	836.8	651.31
	13	30	57	875.3	628.05
	14	30	55	785.9	581.52
	15	28	52	611.2	558.26
25	11	27	52	757.5	726.90
	12	28	53	843.2	726.90
	13	29	55	899.6	755.98
	14	29	53	758.3	697.82
	15	28	49	523.7	610.59
30	11	26	50	713.2	837.41
	12	29	54	869.4	872.30
	13	30	54	850.5	837.41
	14	29	52	826.6	802.52
	15	29	50	661.7	732.73

Table 8. December month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	27	53	727.5	604.79
	12	29	55	825.8	604.79
	13	30	57	855.6	628.05
	14	29	54	783.3	581.52
	15	28	52	597.1	558.26
25	11	27	50	700.2	668.75
	12	29	53	813.7	697.82
	13	29	54	889.2	726.90
	14	28	52	811.9	697.82
	15	28	51	607.1	668.75
30	11	27	50	725.8	802.52
	12	29	53	831.5	837.41
	13	30	54	870.1	837.41
	14	29	51	822.5	767.62
	15	28	48	555.3	697.84

Table 9. January month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	28	56	717.2	651.31
	12	29	58	809.8	674.57
	13	31	59	911.6	651.31
	14	29	57	790.3	651.31
	15	29	56	601.5	628.05
25	11	28	54	723.3	755.98
	12	30	56	821.7	755.98
	13	31	56	905.8	726.90
	14	30	55	803.6	726.90
	15	29	53	581.4	697.82
30	11	28	53	691.9	872.30
	12	30	55	812.1	872.30
	13	31	56	891.3	872.30
	14	30	54	726.1	837.41
	15	29	52	529.2	802.52

Table 10. February month testing

ṁ (lph)	Day Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	32	60	802.6	651.31
	12	33	61	906.8	651.31
	13	34	63	929.1	674.57
	14	34	60	768.5	604.78
	15	33	58	595.4	581.52
25	11	33	58	781.2	726.90
	12	35	60	896.7	726.90
	13	36	62	911.9	755.98
	14	35	60	798.3	726.90
	15	34	57	621.8	668.75
30	11	33	57	760.1	897.41
	12	34	59	933.7	872.30
	13	35	59	925.3	837.41
	14	34	58	824.5	837.41
	15	34	56	681.6	767.62

Table 11. March month testing

ṁ (lph)	Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	38	67	872.5	674.57
	12	41	70	956.2	674.57
	13	42	72	971.3	697.83
	14	43	69	868.7	604.79
	15	42	65	732.9	535.00
25	11	39	64	869.8	726.90
	12	42	67	963.6	726.90
	13	43	66	968.5	668.75
	14	42	64	846.5	639.67
	15	41	63	691.2	639.67
30	11	39	62	858.3	802.52
	12	43	64	949.4	732.73
	13	44	66	986.8	767.62
	14	43	65	894.6	767.62
	15	42	63	711.2	732.73

Table 12. April month testing

ṁ (lph)	Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	44	75	915.2	721.09
	12	46	78	1040.6	744.35
	13	47	80	1081.7	767.61
	14	47	75	948.1	651.31
	15	46	73	753.2	628.05
25	11	42	70	992.7	814.13
	12	45	72	1125.1	785.05
	13	45	74	1112.3	843.20
	14	46	69	1027.4	668.75
	15	45	67	911.5	639.67
30	11	43	67	940.2	837.41
	12	45	70	1062.8	872.30
	13	47	71	1054.9	837.41
	14	46	69	1002.1	802.52
	15	46	68	851.3	767.62

Table 13. May month testing

ṁ (lph)	Time	T_I (˚C)	T_O (˚C)	I_P (W/m^2)	Q (W)
20	11	43	73	907.2	697.83
	12	45	76	1072.3	721.09
	13	46	79	1108.8	767.61
	14	46	76	993.9	697.83
	15	46	72	883.1	604.79
25	11	42	67	924.5	726.90
	12	45	70	994.2	726.90
	13	46	72	1030.7	755.97
	14	46	70	919.1	697.82
	15	46	66	852.5	581.52
30	11	42	65	931.4	802.52
	12	44	69	988.9	872.30
	13	47	70	1063.2	802.52
	14	47	69	898.1	767.62
	15	46	66	861.3	697.84

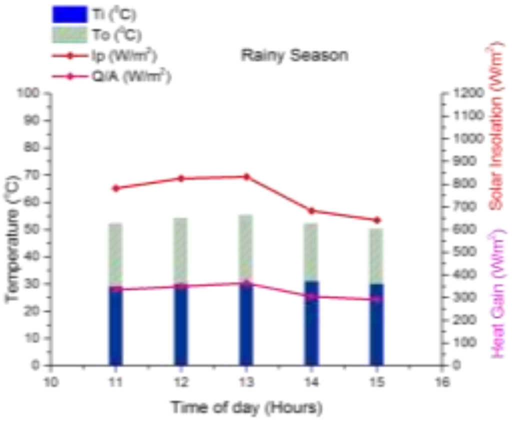

Fig. 9. Rainy season testing results at ṁ=25 lph

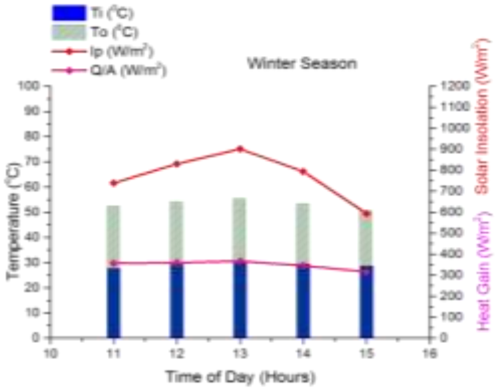

Fig. 10. Average winter season testing results at ṁ=25 lph

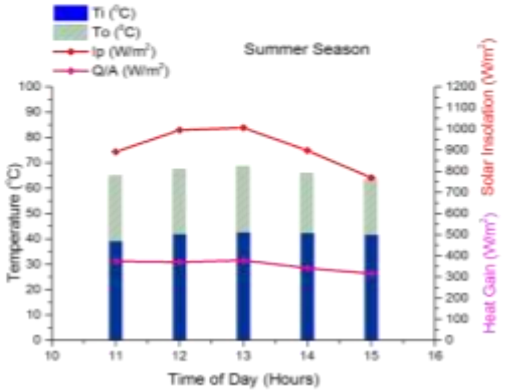

Fig. 11. Average summer season testing results at ṁ=25lph

6. Results

Tests were conducted from September to May with three different mass flow rates: 20, 25 and 30 liters per hour and it were observed that:

a. Concrete collector provides outlet water temperature in the range of 47˚C to 80˚C.

b. Performance of concrete collector is comparable with conventional metal collector, though efficiency of metal collector is higher.

c. There is a phase lag between maximum heat absorbed by water and maximum incident solar insolation mostly in morning phase.

7. Economic Analysis

Overall maximum cost of concrete collector (2m^2) 100 lit/day capacity including insulated tank, plumbing and labour = Rs 21,000
Savings in the electrical energy/year = Rs 4700
Therefore capital is recoverable in a period of 4.5 years.

8. Conclusion

Following conclusions were obtained after conducting experiment on concrete absorber plate SWH

a. Fabrication of concrete collector is simple which can be done by any unskilled worker without any requirement of special workshop. But installation has to be done at the site of use as it is not convenient to transport because of its weight.

b. The materials used are easily available and mass production of concrete collector will reduce its cost.

c. About 50 ˚C of water is required for bathing which is provided by concrete collector for most of days, thus can be used for domestic applications.

d. The cement concrete collector can be integrated within the inclined roof facing south or even flat roof of buildings which will further decrease cost of setup to provide hot water. Also this setup would reduce heat gain to building providing space cooling.

e. This low cost concrete collector will be more suitable in rural areas havingload shedding or in remote areas where there is no supply of electricity.

f. Also concrete solar collector can be used as pre-heater to any water heating system and also for commercial purposes where water up to 70˚C is required.

9. Future Scope

a. For predicting accurate behavior of concrete collector trials should be conducted for varying slope, tube spacing, amount of metal scrap and insulation on inner sides and bottom of wooden box.

b. The performance of concrete collector can be improved by using heat transfer augmentation techniques inside the copper tubes such as Dimple surface, protrusions, fins, ribs, etc.

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