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Experimental and economic analysis of concrete absorber collector solar water heater with use of dimpled tube

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ABSTRACT

To increase the usage of solar water heaters in India, a low-cost solar collector made of concrete is experimentally investigated in Pune. The concrete slab consisting metal fibers is placed in a wooden box, with immersed serpentine copper tube and provided with glazing on top. With an objective of improving the efficiency of the collector, a heat transfer augmentation technique (dimple) is fabricated on water carrying serpentine tube. Testing is carried out in rainy, winter and summer seasons for different water flow rates to understand the working of collector throughout the year. Testing results show that average water temperature collected per day is 59 °C–69 °C. Further, to find the exact effect of dimples on outlet water temperature, two completely identical concrete plate collectors–one with a dimpled tube and other with a smooth tube, are designed, fabricated and tested simultaneously. The effect of dimples is observed up to 2.5 °C. Also, a detailed economic analysis and environmental benefits of concrete collector solar water heater for India are investigated in this paper.

1. Introduction

India comprising over one-sixth of a total population of the world is the third biggest primary energy consumer [1], fifth largest power market in electricity generation [2], having one of the largest growing economy and fastest growing energy markets [2]. To meet her growing energy demands, large amount of fossil fuels need to be imported (as of 2014–15)–25% coal (212.10 million tons), 85% crude oil (189.43 million tons), 57% petroleum products (20.42 million tons) and 30% natural gas (15.47 billion cubic meters) of total consumed fuels were imported [3]. Also, the consumption of LPG (liquefied petroleum gas) has escalated by 8.2% [4] and India's reliance on this imported fossil fuel was 89% for the year 2012–13 [5]. This has led to increased environmental concern due to air pollution caused by coal-based power generation (64.26% [3]) and has made India, the fourth largest CO_2 emitter in the world with 2000 million tons of emissions [2]. Of all sectors, domestic sector is one of the major consumers of energy and researchers accept that buildings are responsible for over a third of the world's energy demand [6,7] and will sooner or later contribute nearly the same amount to greenhouse gas emissions [7]. In India, electricity consumption in 2014–15 by domestic sector was 22.93% [3] (water heating and space cooling being major contributors) and this will further increase due to use of water heating and space heating/cooling applications at increasing rate owing to increased electrification, rising incomes, improved technology and lifestyle, increased global warming and rapid climate change. Thus, the growing global concern with climate change, air pollution and energy crisis caused by the use of conventional methods for water heating (i.e. electric geyser, LPG, burning of wood, coal, kerosene, etc.) along with a growth of economic development have motivated the use of solar energy for water heating in India.

Solar energy is an abundant, inexhaustible, clean and free source of energy and India is endowed with vast solar energy of about 5000 trillion kWh per annum, incident over India's land area (3.287 million km^2) with annual average GHI (Global horizontal irradiance) of 4.5–6.0 $kWh/m^2/day$ for most parts of the country [8]. This overall solar energy distribution is even better than China which is leading in installed solar collectors by a huge margin [9,10]. Hence solar thermal technology can be effectively harnessed, providing huge scalability for solar water heaters (SWHs) in India.

The proposal here is to design an efficient and cost-effective concrete absorber plate SWH and later integrate that design into the roof of a building, as the roof has maximum exposure to sunlight throughout the day. This large amount of unused roof area

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could be used for water heating purposes for domestic, commercial and industrial applications such as bathing, washing, cooking, space heating/cooling or as preheating systems. This design consists of dimpled copper serpentine tube partially embedded in reinforced concrete slab, kept in a wooden box with glazing on top and inclined at the latitude of the place. As compared to conventional SWHs (evacuated tube collector, ETC and flat plate collectors, FPC), fabrication of concrete SWH does not need many technical skills, special workshops and can be installed by any amateur during construction of buildings itself, making it economically very feasible. This concept will eliminate dead loads on buildings making them energy efficient and environment-friendly.

2. Literature review and theory

2.1. Concrete collector

A number of studies consisting of experimental, analytical and computational research work have been done on concrete collector SWH either as a separate entity or as integrated within the roof. Nayak et al. [11] carried out experimental studies on concrete solar collectors with polyvinyl chloride (PVC) tubes embedded in it and established optimal pitch and later Bopshetty et al. [12] carried out an analysis to study the effect of various governing parameters on the collector performance. Whereas Jubran et al. [13] and Hassan and Beliveau [14] evaluated solar heating systems using F-chart technique and finite element models respectively. Chaurasia, on the other hand, did an experimental study with aluminum tubes embedded in the surface of solar concrete collectors [15] and revealed that the temperature rise of water was enhanced by 2 °C–4 °C by simply blackening the absorbing surface [16]. Recently Krishnavel et al. [17] conducted experiments simultaneously on three reinforced concrete collectors and proved that use of aluminum pipes over PVC pipes and the addition of iron scrap in concrete, improves the efficiency of the collector. Whereas O'Hegarty et al. [18] examined 6 influential parameters of concrete solar collectors by numerical simulation and concluded that the pipe spacing, concrete conductivity, and the pipe embedment depth have the greatest effect on the collector's performance. Unglazed solar roofs for heating and cooling, as discussed in Sarachitti et al. [19], examined thermal performances of two rooms, with and without roof integrated solar concrete collector of area 5.75 m^2 and observed that the roof provides hot water along with a reduction of heat transfer to the room by 2.3°C. Also, Hazami et al. [20] conducted an experimental analysis on integrated solar storage collector of an area of 2 m^2 with serpentine copper pipe embedded in concrete whereas, Blecich and Orlić [21] studied the performance of a similar system with a surface area of 50 m^2. In addition to residential buildings, work of Tanzera and Schweiglera [22] shows how facades of industrial buildings can be used as a heat source for a heat pump heating system. Apart from building purpose, an experimental investigation was also conducted on solar concrete collector for agricultural greenhouses, to maintain greenhouse temperature [23] and asphalt pavements and airport runways, for heating and cooling of adjacent buildings, as well keep the pavements ice-free [24].

The concrete will be exposed to a temperature around 100 °C (maximum possibility), as heat will be trapped due to a glass plate at the top; thus the effect of elevated temperature on concrete is studied. Up to 100 °C, flexural strength, splitting tensile strength and modulus of elasticity of concrete remain same or reduces marginally, whereas the compressive strength of concrete remains constant or even increases slightly; no micro-cracks are observed till 100 °C [25,26]. Also, the effect of steel fibers in concrete is reviewed as it affects concrete's performance. Steel fiber reinforced concrete improves energy absorbing capacity, tensile strength and fatigue strength; it inhibits cracking and improves resistance to material deterioration as a result of fatigue, impact, and shrinkage or thermal stresses; also steel fibers reduce the permeability and water migration in concrete, ensuring protection of concrete owing to the ill effects of moisture [27–30].

2.2. Serpentine tube

In our experiment, serpentine tubes are embedded in concrete slab which carries water in laminar range. Only Ciofalo and Di Liberto [31] investigated heat transfer in serpentine pipes for fully developed laminar flow by numerical simulation. This alternate U-bends connected between straight segments creates a recirculation (secondary flow) pattern which may enhance mixing and heat or mass transfer with respect to the straight pipe, at the cost of an increase in pressure drop [31]. Thus, serpentine tube leads to turbulence in curved and straight sections [31].

2.3. Dimple

Several methods are used to increase the thermal performance of surfaces by increasing the heat transfer rate, by use of protrusions, dimples, fins, wire coils, etc. Thus, to improve heat transfer augmentation from serpentine tube to water flowing through it, dimples are created on outside surface of tubes (i.e. internal pipe surfaces have protrusions on them), as they are easy to fabricate without any increased material and cost. García et al. [32] have recommended the use of different heat augmentation techniques based on Reynolds number (R_e) range and use of dimpled tubes are recommended for R_e above 2000 which satisfies this experiment case. The dimpled tubes provide higher heat transfer rates with an increase in pressure drop compared to smooth tubes under similar conditions has been proved by many experiments conducted. For different conditions and parameters investigated, Turnow et al. [33] found that heat transfer rate could be enhanced compared to smooth surface by 201%; Vicente et al. [34] had results with heat transfer increase from 20%–110% with increase of friction factor coefficient by 150%–350%; whereas Chen et al. [35] concluded that heat transfer enhancement ranged from 25%–137% with friction factor increase by 8%–135% for dimpled tube compared to smooth tube. Dimpled surfaces can create following conditions that are responsible for an increase in heat transfer coefficient with a consequential increase in the friction factor–an increase of the degree of turbulence due to interruption of the development of the boundary layer, an increase in effective heat transfer area and rotating and/or secondary flows generation [35]. It was found that the dimple parameters further affect the heat transfer rate and the best-dimpled tube had the largest dimple depth-to-tube inside diameter ratio, dimple depth to- pitch ratio, dimple depth-to-dimple diameter ratio, and a number of dimple columns [35]. García et al. have recommended a range of dimple depth based on R_e and inner tube diameter for best thermal hydraulic performance [32], whereas dimple diameter is found using dimple depth as per work of Turnow et al. [33]. Flow visualization and flow characteristics of fluid over dimples in tubes are investigated by Tay et al. [36] and Xie et al. [37] in their work and how dimples affect fluid flow could be observed. It was also found that dimples lead to no increase in fouling [35] and reduction in discharge coefficient [38].

3. Design and fabrication

Concrete collector absorbs the incident solar radiations falling on it and transfers this heat to the water flowing in the tube in order to heat it, which is finally stored in an insulated tank of 150 l by once through or meander principle. Design of this collector is explained in detail in Table 1.

Table 1.
Design parameters of concrete collector SWH.

	Parameters	References/ Formulae/Explanation	Dimension/ Specifications
1	Reinforced concrete slab		
	Top surface area of absorber plate (A_p)	–	2 m × 1 m
	Thickness of absorber plate (T_p)	Calculated as per Indian Standard code 456 of civil engineering as suggested by Chaurasia [15]. Effective thickness of slab = Effective span of a slab/35, where effective span is shorter of the two spans [39]	3.5 cm
	Amount of metal (mild steel) fibers in concrete slab	Calculated by X × (Weight of concrete). And X is calculated from $K = X \times K_m + (1-X) \times K_c$, where X-unit mass of mild steel fibers K (conductivity of absorber plate) = 4 W/mK [18], K_c (conductivity of concrete) = 2 W/mK [40], K_m (conductivity of mild steel) = 54 W/mK [41],	7 kg
2	Inclination of collector	Maximum annual insolation is received at inclination of latitude of place [42] Pune lies in northern hemisphere at latitude of 18.5°	19° due South
3	Serpentine copper tube		
	Tube outer diameter (D_o)	Have negligible effect on performance [18]; smaller diameter allows more consistent temperature distribution within the cross-section of the fluid and is more cost effective [14]	10 mm
	Tube inner diameter (D_i)	Kept minimum thickness of 1 mm for better heat transfer	8 mm
	Spacing between tube (W)	Suggested by Nayak et al. [11]	8 cm
4	Water flow rate through collector ($\dot{m}$)	To fill 150 l of insulated storage tank in 5 h of operation	30 lph (liters per hour)
5	Dimple dimensions		
	Reynolds Number (R_e)	$R_e = (\rho \times V \times D_H)/\mu$ [43], where Values of ρ (density of water), μ (dynamic viscosity of water) are taken from [44], D_H (hydraulic diameter of pipe) = D_i = 8 mm V (velocity of water) = flow rate of water/ area of flow	2016.15 (It is laminar flow [43])
	Dimple depth (h)	$0.083 < h/D_i < 0.119$ [32]	1 mm
	Dimple diameter (d)	h/d = 0.26 [33]	3 mm
	Dimple spacing (p)		5 cm
	Number of dimple columns		4

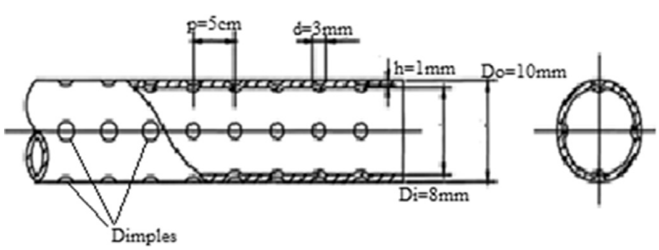

Fig. 1. Dimpled tube.

The collector box is prepared from wooden plywood with inner dimensions of 2 m × 1 m × 0.1 m covered with an aluminum foil of 0.3 mm thick on inner sides of the box to reflect solar radiations on concrete absorber plate. Then the dimpled serpentine Copper tube of given dimensions (as shown in Fig. 1) tied to mild steel wire mesh is placed in concrete mix such that 50% of tube is directly exposed to sunlight and 50% remains inside concrete mix (as shown in Figs. 2 and 3), to give enough strength to the pipes so that they remain fixed within the R.C.C. (Reinforced cement concrete) slab [15]. The top surface of absorber plate is then painted black and provided with glazing on top and inclined at 19° (Fig. 4).

The reinforced concrete slab of 3.5 cm thickness is fabricated using approximately 25 kg cement, 50 kg sand, 100 kg aggregate and 7 kg of mild steel fiber (around diameter 1.5 mm and length 30 mm). The wire mesh in slab provides reinforcement to the concrete slab, improves the efficiency of the collector by increasing thermal conductivity of slab [11,15], and also acts as a fixture for the serpentine tube. Copper is used as tube material because of its high thermal conductivity. Spherical shaped dimples are created on the tube using hammer and tool. The absorptivity of concrete is increased from 0.65 to 0.95 by applying black paint to the top surface of concrete [21]. As thermal conductivity of concrete is very low, that is about 2 W/m-K [40], so mild steel fibers are added to the concrete mixture to increase the conductivity of the absorber plate which improves the performance of collector [17]. Thus concrete mixture with higher thermal conductivity improves collector performance [18]. Steel fibers are added up to a limit because performance returns are diminished beyond 4 W/mK [12].

4. Testing results and discussions

4.1. Dimpled pipe concrete collector

Testing of the collector is done in months of September (rainy season), January (winter season) and April (summer season) for 5 different water flow rates–20 lph, 25 lph, 30 lph, 35 lph and 40 lph (lph–liter per hour); where water is flowing through collector continuously for 5h from 11.00 a.m. to 4.00 p.m. for particular flow rate per day. The water flow rate ($\dot{m}$) is adjusted using measuring jar and stopwatch. Atmospheric temperature (T_a), Inlet water temperature (T_i) and outlet water temperature (T_o) are measured using thermocouples and thermometer. Solar insolation (I_p) is obtained by using Pyranometer. Due to the large thermal mass of concrete collectors, the concept of instantaneous efficiency does not carry any significant meaning, in characterizing the thermal performance of the collector, so the performance is judged on the basis of outlet water temperature (T_o) and useful heat gained by the collector (Q_u). Q_u is calculated by $Q_u = \dot{m} \times C_p \times (T_o\text{-}T_i)$ and Q_u/A_p is useful heat gain per square meter

As this concrete collector SWH is designed for a flow rate of 30 lph, readings for assumed flow rate are shown below. Following observations are noted from Fig. 5a–c.

1. Inlet temperature (T_i) is higher than ambient temperature (T_a) due to heat absorbed by pipes connected to inlet of the collector from tap.
2. Heat inside collector is unutilized till water flows through it, so at start (11:00 a.m.), water temperature is highest followed by speedy decrease with utilization of heat and then again increases gradually up to 1:00 p.m. (time of maximum solar

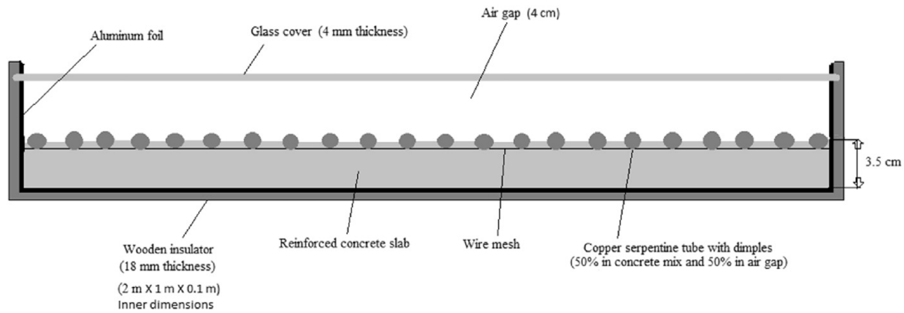

Fig. 2. Cross-section of concrete plate collector.

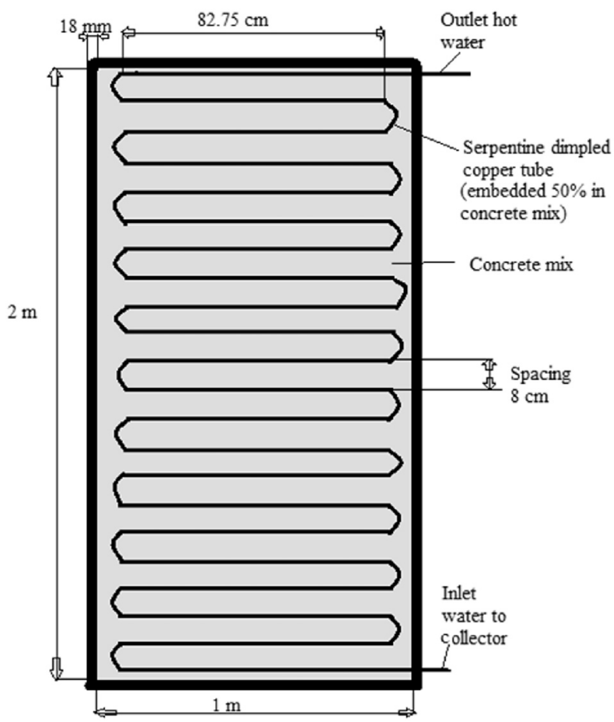

Fig. 3. Top view of concrete collector.

Fig. 4. Photo of solar concrete collector with insulated storage tank.

insolation), and then finally goes on decreasing with reduction in solar insolation.

3. Due to concrete's property of heat storage capacity, the collector continues to deliver hot water for some time even at low solar radiation and also effect on T_o is minimum, compared to severe solar radiation fluctuations during the day.
4. As inlet water temperature goes on increasing, efficiency of collector decreases due to a reduction in Q_u. Thus, the efficiency of a concrete collector in summer is lesser compared to rainy and winter seasons.
5. T_o range obtained in rainy season is 52°C–65 °C (Fig. 5a), in winter season is 49°C–64 °C (Fig. 5b) and in summer season is 62°C–76 °C (Fig. 5c), for time of day from 11:00 a.m. to 4:00 p.m. at water flow rate of 30 lph.

Fig. 6 conveys following interpretations for 2 m^2 concrete SWH for all seasons:

1. For all seasons and for all $\dot{m}$ (except for winter season for $\dot{m} = 40$ lph), obtained average temperature of water in storage tank was more than 50 °C which is the required temperature of water for bathing purpose.
2. The amount of hot water collected increases by 25 l with an increase of $\dot{m}$ by 5 lph but with a reduction in average T_o by 3.5 °C.
3. This collector can be operated for higher $\dot{m}$ (more than 30 lph), for more storage capacity with 5 h operation or for a lesser time of operation with higher $\dot{m}$, for same storage capacity. Thus its working can be varied as per climate and domestic requirements.

4.2. Comparison of smooth tube and dimpled pipe concrete collectors

In order to find the exact effect of dimples on T_o, two identical cement concrete solar collectors are fabricated and tested simultaneously (as shown in Fig. 7) in April (summer season), for 4 different water flow rates–20 lph, 25 lph, 30 lph and 35 lph; where water is flowing through collector continuously for 5 h from 11.00 a.m. to 4.00 p.m., for particular flow rate per day and data was recorded every 15 min.

Following observations are made from readings recorded in Figs. 8 and 9:

1. Dimple effect on T_o is observed in the range of–1 °C–2.5 °C for all $\dot{m}$, with most readings showing an increase in T_o, few readings exhibiting a reduction in T_o and only some readings displaying having no effect on T_o.
2. Commonly more positive effect of dimples is observed for higher $\dot{m}$, because the turbulence due to dimples reduces the discharge coefficient slightly, with an increase in the rate of mixing of water, leading to enhanced heat transfer rate.
3. A variation is observed in the dimple effect. The observed variation appears to be due to the fact that accurate quantity measurement procedures have not been followed during the fabrication of concrete absorber plate. The variation may also be due to the possibility that there is a little difference in the quantity of the aggregates used-dimpled tube collector comprising slightly lesser aggregates than smooth tube collector. As aggregates have different heat storage and thermal conductivity than

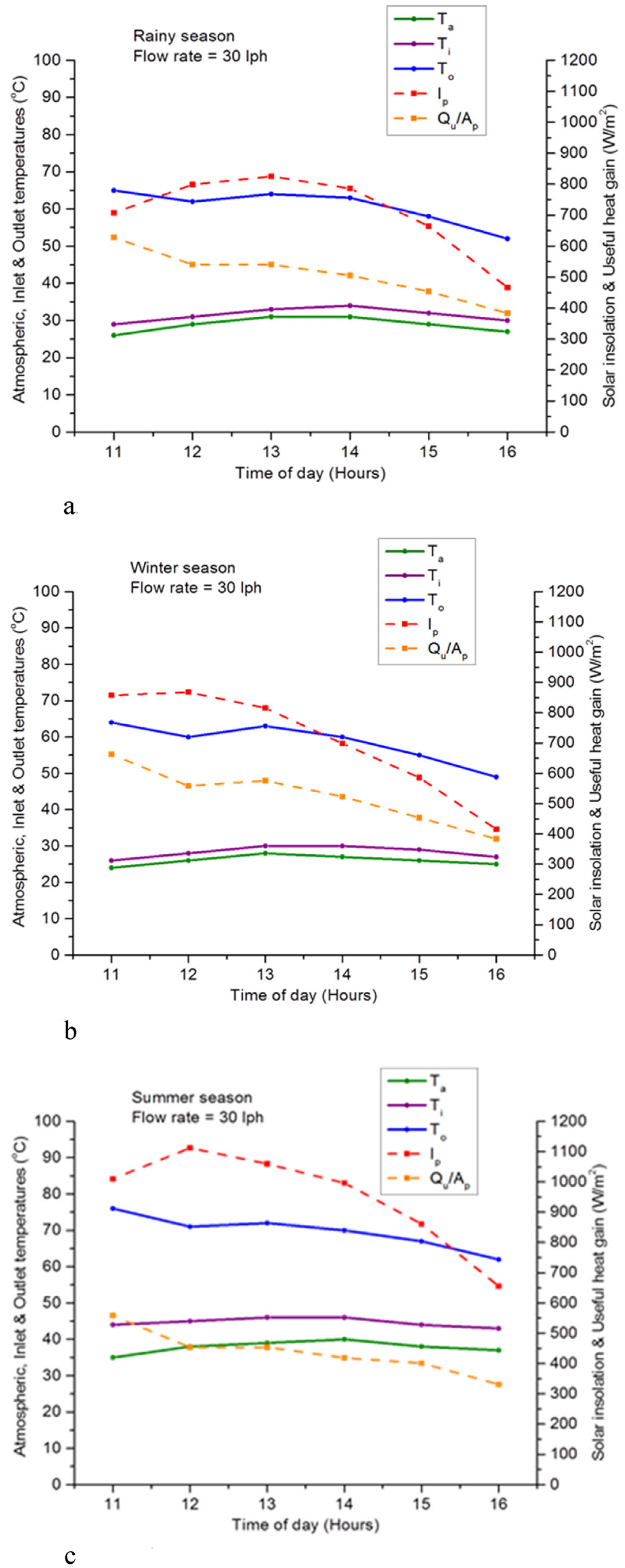

Fig. 5. a. Readings on a clear day during rainy season. b. Readings during winter season. c. Readings during summer season.

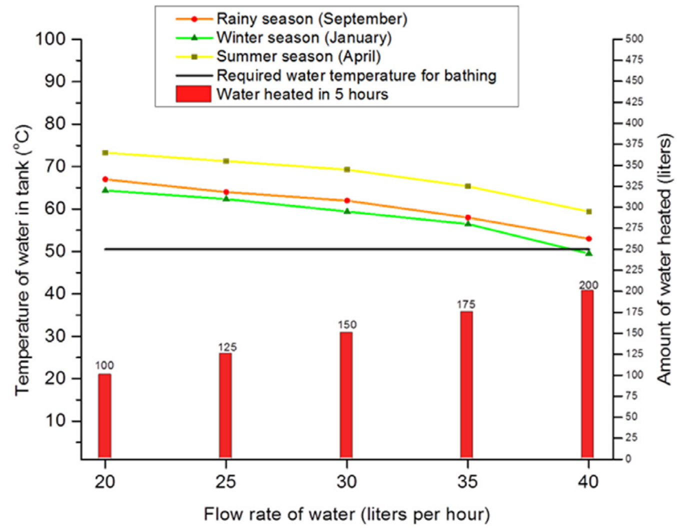

Fig. 6. Water temperature and water quantity obtained during all seasons for different water flow rates.

Fig. 7. Photo of simultaneous testing of dimpled tube and smooth tube concrete collectors.

other concrete constituents, so there is a hope of seeing a further increase in T_o.

5. Economic analysis and environmental benefits

Cost analysis: The cost of complete collector without wooden box and stand (as they will be eliminated while integrating into the roof) is Rs. 6500 ($97.6; as $1 = 66.6 Rs). The connection of 150 l tank and insulated piping will take total cost to Rs. 19,000, which is noticeably lesser compared to both ETC SWH (minimum Rs. 20,000) and FPC SWH (minimum Rs. 26,000), for same water storage capacity. Collector cost may further reduce considerably, if mass procurement of materials and fabrication of collector during construction of roof slab is done.

Previous studies performed on SWH economic and environmental benefits are based on energy absorbed by SWH, quantity of water collected in an insulated storage tank, usage of hot water even in summer, considering a room temperature as initial temperature throughout the year and not taking into account SWH as preheater in rainy or foggy days. Those methods thus slightly overestimate and don't give actual SWH benefits. Therefore, this study proposes the concept of yearly benefits based on - actual usage of hot water by persons, exclusion of usage of hot water for 45 days of summer, consideration of different initial temperatures for different months as per climate of Pune [45] and then calculating average temperature as 21 °C; also considered 50 rainy, 4 foggy and 6 squally days in a year [45], where water is heated up to 35 °C only

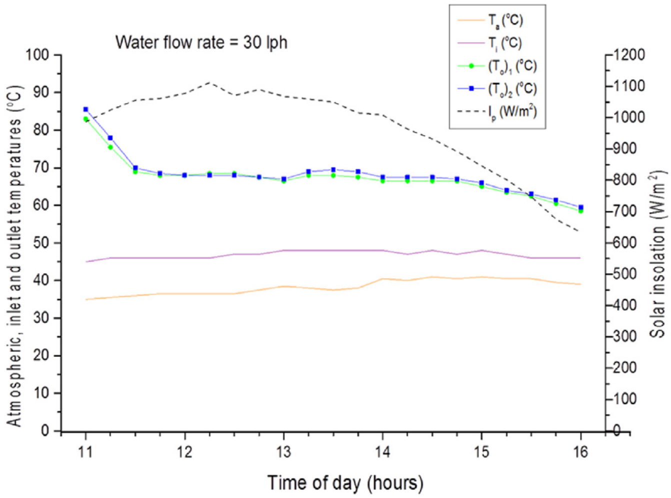

Fig. 8. Comparison of smooth tube (1) and dimpled tube (2) collector's outlet water temperatures for $\dot{m} = 30$ lph.

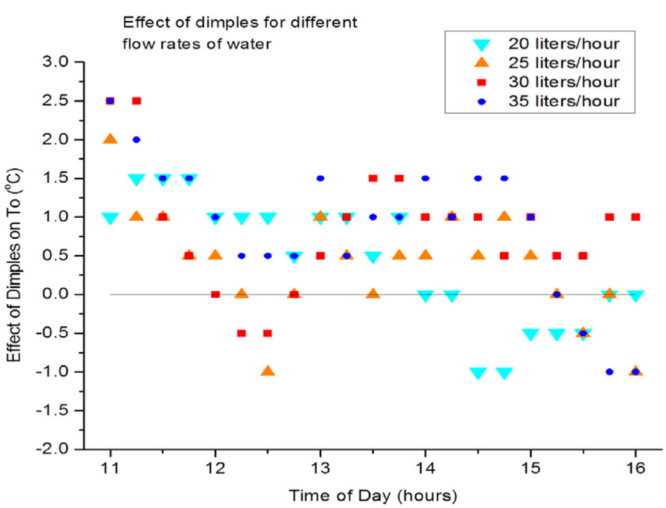

Fig. 9. Effect of dimples on outlet water temperature (T_o) for different water flow rates.

and acts as a preheater for another water heating equipment during these 60 days. The study is being made on energy savings, cost savings, payback period and greenhouse gasses and air pollutants reduction, for replacement of electricity, LPG and firewood (which are principal water heating methods in India), by concrete SWH, as shown in Table 2. In India, as of 2011, firewood was used by 67.3% of rural and 14.0% urban households, followed by LPG, which was used by 15.0% rural and 68.4% of the urban households for cooking [46]; making them an important source of heating water. Though most houses are electrified, electricity supply to many households is intermittent, unreliable or completely absent, especially in rural areas. Thus, usage seen in India is - electricity for most urban and few rural houses; LPG for few urban houses; and firewood for poor urban and most rural houses, for water heating for bathing purpose.

$$\text{Energy saved/year, E} = \frac{\text{m} \times \text{Cp} \times (\text{Tr} - \text{Tia}) \times (\text{no. of days SWH used})}{\eta} \text{ [47]} \quad (1)$$

$$\text{Payback period (year)} = \frac{\log\left[\frac{(E-M)}{(a-b)}\right] - \log\left[\frac{(E-M)}{(a-b)} - C\right]}{\log\left[\frac{(1+a)}{(1+b)}\right]} \text{ [47]} \quad (2)$$

Eqs. (1) and (2) [47] are used for calculating economic analysis as shown in Table 2. Where, m (quantity of water heated) = 150 l (for cases–10 persons using 15 l hot water/day, 8 persons using 18 l hot water/day, 6 persons using 25 l hot water/ day for bathing purpose [48]), C_p (specific heat of water) = 4.187 KJ/Kg.K, T_r(required water temperature for bathing is 50–60 °C [48]) = 50°C, T_{ia} (average water temperature to inlet of heating equipment) = 21 °C, η (efficiency of heating equipment replaced by SWH), E (replaced energy saving by SWH per year), M (maintenance cost of SWH per year) = 2% of total SWH cost, C (total SWH cost) = Rs. 19,000, a (compound interest rate per year) = 10%, b (inflation rate in energy per year).

It is observed from Table 2 that

1. Energy savings for water heating are most in winter followed by rainy and then in summer season, as cold water is preferred during hot climate. Electrical savings are more for households consuming higher electrical units and also for hostels, hotels, hospitals and other commercial applications as they are charged at a higher rate per unit usage.
2. Here utilization of total 150 l of hot water for bathing is considered, however, if hot water remains, then it could be utilized to wash utensils and clothes. In addition to this, water flowing through tubes integrated into roof carries away the heat, and thus, heat transfer to the room is reduced in the night by 1–2 °C [19] during summer, thus reducing electrical usage of an air conditioner (6.14% for 1 °C [55]). Also, during the winter season, extra hot water could be sent to the heat pump to heat rooms, hence making use of concrete SWH as a preheater to heat pump, saving more energy.
3. This technology has huge potential in rural areas to replace the shortage of electricity and LPG; whereas this system will help in mitigating the urban heat island effect in urban areas [21].

6. Conclusion

Following concluding observations are obtained after conducting the investigation on 2 m^2 concrete absorber plate solar water heater (SWH):

1. Fabrication of concrete collector is very simple, which can be produced locally with locally available materials, without any requirement of a skilled or specialized workforce or special workshop. Also, its cost is lesser compared to the evacuated tube and the flat plate collectors, and it will reduce further if mass procurement of materials and fabrication of collector during construction of roof slab is done.
2. Average water temperature of 150 l of water collected per day in September (rainy season), January (winter season) and April (summer season) is 62 °C, 59 °C and 69 °C respectively, for water flow rate of 30 lph. Thus, this SWH satisfies the domestic need of hot water for bathing, totally, for all normal weather days and partially, for cloudy or foggy days in a year.
3. Along with water heating for domestic, commercial or industrial applications, this technology could be used for space heating, by acting as a preheater for a heat pump; and for cooling purpose, by taking away the heat transferred from roof to rooms, thus leading to further conservation of energy. Also, increase in an area of the concrete solar collector will cover more loads of the buildings.
4. More hot water quantity or higher outlet water temperature can be obtained as per requirements, just by changing the wa-

Table 2.
Economic and environmental benefits of concrete SWH.

Energy source replaced by concrete SWH for heating 150 l water at 50 °C	Colorific value of energy source	Efficiency of energy source (%)	Energy cost per unit (Rs.)	Energy source saved per year	Cost saved per year (Rs.)	Inflation rate in energy source (%)	Pay-back period (years)	CO_2 emissions prevented per year (kg)	Other benefits with reduction in
Electric geyser (Residential usage units)	3.6 MJ/kWh [49]	90[49]		1624.1 kWh		2 [5]		1331.7 [50]	Import of coal & natural gas [3]; air pollutants NO (7 kg) & SO_2 (11.4 kg) [51]
(100)			3.76 /kWh		6106.5		4.1		
(200)			5.485 /kWh		8909.3		2.6		
(300)			6.06 /kWh		9838.3		2.3		
LPG	45.48 MJ/kg [5]	57 [5]	33.26 /kg	203.1 kg	6754.5	4 [5]	3.5	1155.6 [5]	Imports [5]
Firewood	15 MJ/kg [52,53]	17.3 [49]	–	2028.1 kg	–		–	3334.3 [53]	Deforestation, ill effects on health, fire-accidents [49,54]; air pollutants[54] CO (149 kg), CH_4 (6 kg), NO_x (4.56 kg) [53]

(Currency conversion 1 $ = 66.6 Rs, 1 € = 70.9 Rs).

ter flow rate, thus, enabling manual change in the working of the collector.

5. Dimple tube concrete collector provides higher outlet water temperature than smooth tube concrete collector. The effect of dimples is observed in the range of–1 °C–2.5 °C, with most readings showing a slight increase in water temperature, thus improving the efficiency of the collector without any extra expenses or modifications.
6. Economic analysis shows that payback period is low. Further due to the reduction in the use of conventional energy sources leading to decrease in India's dependence on foreign fuels, this water heating system gives protection from future fuel shortages and price hikes along with environmental benefits of reduction in air pollutants and greenhouse gasses. Thus roof integrated concrete collector water heating technology can contribute to economic, environmental, energy and thus national security of India.

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