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

Ajinkya Sable*

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

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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

* Correspondence to. M-102, Wondercity society, Katraj, Pune 411046, Maharashtra, India.
*E-mail address:* sableajinkya@gmail.com

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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.