Water heating system using concrete slab solar collector with phase change material: - a review

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Abstract: Keeping present scenario of energy crisis in mind we need to move towards renewable sources of energy in which solar energy is one form of available renewable energy on earth and it is environment friendly and free in nature. Hence we have to move towards the efficient utilization of solar energy. It has a main drawback as it is only available in day time or limited period of time, hence using phase change materials in different solar energy storage setup is a way to store solar energy and utilize that in day time as well as night also. In concrete slab solar collector, solar energy is absorbed and transferred into the medium, space and fluid for domestic as well as industrial heating applications. In this paper we would be doing a critical review of the water heating system using concrete slab solar collector with phase change material (PCM). Further various performance parameters and setbacks would be discussed pertaining to solar heating systems.

Keywords: concrete slab solar collector, PCM, latent heat and glazing.

1. Introduction

The permanent rise in emission of greenhouse gases into atmosphere and the continuous hike in fossil fuel prices are the cause behind efforts to efficiently use of various sources of renewable energy [1]. A renowned professor Richard E. Smalley talked about humanity's top problems for next fifty year. According to him depletion of non-renewable energy is the biggest problem for humanity. In many countries, direct solar energy is taken as future source of energy. Efficient accumulation of renewable energy reduces the consumption of non-renewable sources and meet the requirements. It also increase the performance and dependability of renewable energy systems. In solar collectors, it is needed for an effective storage of energy in which the most part of the heat collected during periods when sun is over headed, and later released for utilization during the night [2]. Solar energy utilization is categorized in two form active and passive solar heating. Active solar heating have higher efficiency compare to passive. Active heating is used in industrial purpose where high load and demand is needed [3].One of the efficient techniques for storing thermal energy in concrete slab solar collector with the use of phase change materials (PCM). An efficient thermal storage system is required for solar energy collector. Thus, the successful function of solar energy depends, to a point, on the method of energy storage used. So using phase change material is best for enhancement of passive heating system. The latent heat of PCM energy that needs to be absorbed or released when a material changes phase from solid state to liquid state or vice versa. Following is the list of energy storage method:

1.1 Energy storage methods:

The energy is stored in different manner like thermal, electrical and mechanical etc.

1.1.1 *Mechanical energy storage:* Flywheel is a mechanical energy storage device which store intermediate energy and releases for smoothing the power output of an energy source.

1.1.2 *Electrical energy storage*: Battery is an example of electrical energy storage. It is connected to direct current uses direct electricity but when disconnected it uses stored chemical energy and change into electrical. The familiar type of batteries is the lead acid and Ni–Cd.

1.1.3 Thermal energy storage: The thermal heat storage is mainly of two types (i) Sensible or specific heat type and (ii) latent heat type, in former type of thermal storage heat is absorbed or released in direct contact as hot water absorbs heat when come in contact with rocks. In latent heat type, storage uses the material which can change phase when absorbed or releases heat as their heat of fusion.

1.1.3.1 Sensible heat storage: In sensible heat storage, storing of energy is cause of temperature rise. Sensible heat storage system uses the heat capacity for the rise and fall in temperature of the substance during the process of absorbing and releasing. Sensible heating is two type (a) direct contact (b) indirect contact in direct contact storage system both substance in contact and come under thermal equilibrium in indirect contact a thin wall separate the absorbing and releasing medium.

1.1.3.2 Latent heat storage; It is depend on storing of energy when material goes under phase change from liquid to solid or solid to liquid. The change of phase of liquid to the vapor at constant temperature and pressure is latent heat and storage of energy in heat fusion is latent heat storage. In latent heat transition of solid-solid, heat is absorbed as the material is changed from one crystalline to another [4].

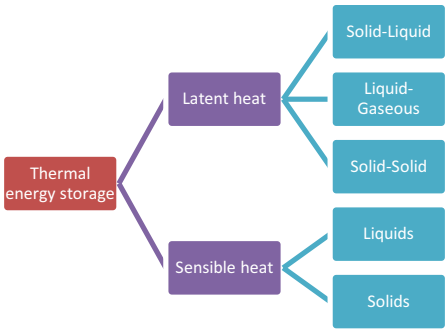

Figure 1: Type of thermal energy storage

2. Types of solar collector

A solar collector is a type of heat exchanger that absorbed heat from solar energy. A conventional type heat exchanger differs in many manner from solar collector. Solar collector is different type it is concentrating and non-concentrating type solar collector in non-concentrating type solar collector absorber and collector are is same but in non-concentrating type solar collector storage is bigger than the absorber. Different type of solar collectors have been discussed as following:

2.1 Flat plate collector

Flat plate collector is discovered by Hottel and Whillier in 1950. It has several components in the set-up, there is a material surface known as absorber and further solar insolation falls on it. For reducing heat loss by the absorber a transparent cover is used which trap the most of the insolation between the absorber and

transparent surfaces and also prevent absorber plate from dust [5]. For better absorption of radiation absorber have selective coatings. After serpentine design of pipe, Rittidech and Wannapakne [6] proposed new design in 2006. A flat plate solar collector operating in association with a closed-end fluctuating heat pipe was discovered. This system consisting closed end pipe have reasonable cost effective alternative method compared to other solar collector that utilizes heat pipe. This closed-end system could attain 62% efficiency.

2.2 Evacuated tube collector

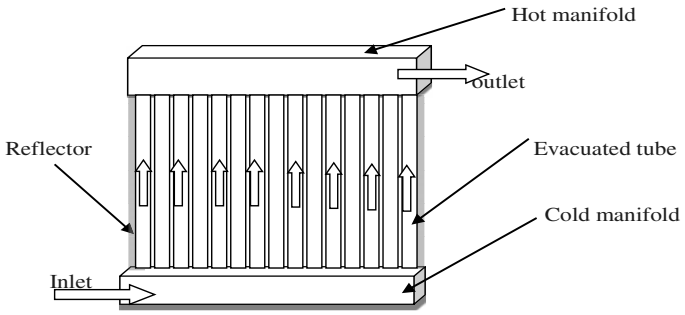

Figure 2: Evacuated tube collector

After combining multiple glass tube evacuated heat pipe tubes is composed, each tube having an absorber plate attached to a heat pipe. Heat is transferred to the circulating water or any antifreeze mix for water heating in a heat exchanger called a manifold. Manifold is covered with insulating material for reducing heat loss [7]. It is works better in colder condition compare to flat plate collector. Evacuated tube has disadvantage in cold environment as snow and frost may affect the performance and getting stuck in between pipes gaps. Presently the main component in solar thermal utilization is glass tube collector because of they have high heat absorbing efficiencies and comparatively less heat loss to flat plate collector.

2.3. Compound parabolic concentrator

Evacuated tube collector and flat plate collectors are broadly used in solar thermal storage system mainly to provide temperature in low to mid-range like 20 °C to 120 °C. For maximizing the thermal storage type of solar collector is used which have parabolic concentrator are non-imaging type and having the ability to reflect most of the incident insolation to the absorber [5]. The sunlight which is collected using a tracking receiver is concentrated at the focal line of a spherical reflector. Receiver is containing pipes which carry fluid for thermal changes. Compound parabolic concentrator is also termed as solar bowl.

In past years, there was many type of non-imaging concentrator. Kaiyan et al. [8] have introduced different types of parabolic concentrator which contain many type of dimpled surface that could deliver forward reflective and imaging light beam. Figure-2 shows system which consist a parabolic and a flat contour.

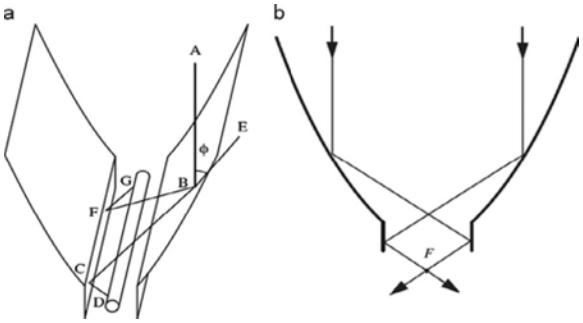

Figure 3: Figure of the different curved surface concentrating collector (a) Light transmission pattern; (b) concentric model and the passed light *[8]*

2.4. Latent heat storage materials

Phase change materials (PCM) are used as latent energy saving materials because of latent heat absorption, it can largely increase the thermal behavior of buildings compared to conventional building materials [9]. The thermal energy transfer occurs in latent heat storage material when a material changes phase from solid to liquid, or vice-versa [10]. It is unlike conventional storage material phase change material absorbs and release heat at nearly constant temperature. They absorb more heat per unit volume than sensible heat storage material like water or rock. Latent heat storage is most accepted because of high releasing and storing capacity of PCM at a constant temperature and equalizes energy imbalance between production and demand [11]. Here is many type of phase change material like inorganic compounds, organic compounds, salt that absorb and release heat at a range of temperature [12]. Phase change material is used in solar thermal storage, energy efficient buildings etc.

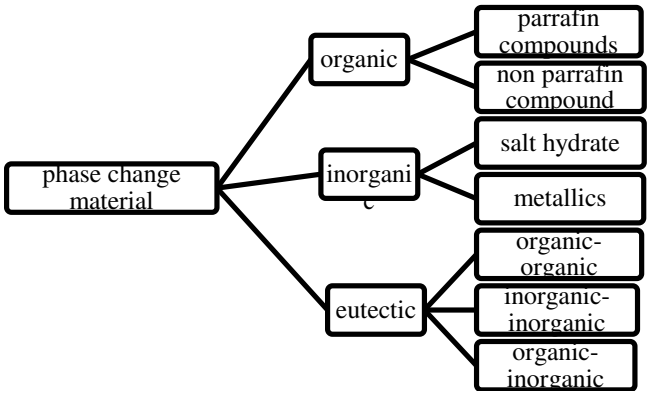

Figure 4: Classification of PCM conventionally applied for latent heat storage [9]

3. Water heating system

Water heating system is basically tow type

(i) Sensible or active heating
(ii) Latent or passive heating

In the sensible heat storage the temperature of the fluid changes at charging or discharging of storage but in the latent heat storage type the temperature of fluid is changes when it goes to change in phase or state. Latent heat storage system have an advantages of less heat loss and high storage capacity as compared to sensible heat storage.

P.B.L Chaurasiya [1] In day time during winter hot water can be obtained at medium temperature range 35 °C to 55 °C by using concrete slab of $2m^2$ area as heat storage. Slight change in the structure of roof or modifying the roof and embedding the network of aluminum pipe which gives a low cost solar storage in terms of water heating. This water heating technique is very easy to construct in buildings. This is the sensible heating process in which solar energy directly used as water heating system.

Atul Sharma et al. [12] Reviewed the availability of solar energy with phase change material with multiple application which is very useful for human being and for energy conservation. The reviewer presents the current research in thermal energy storage with focus on thermodynamic properties of phase change

material. The thermal storage used as a part of solar air heating, water heating, cooking and space heating for buildings in night or when solar energy is not available.
Shukla [13] discussed latent heating with PCM at two different type of solar water heater both have different design one has tank type storage and other has joined type of storage using a reflector. They were found to be 45% and 60% efficiency respectively. Both the collector uses paraffin wax as latent energy storage.
Suat et al. [14] Introduced a traditional passive solar water heating system using phase change material sodium thiosulfate penta hydrate ($H_{10}Na_2O_8S_2$) were experimentally examined in November and enhancement of solar water heating system performance with same heating system without phase change material was investigated. It is observed experimentally that total heat absorbed by the thermal energy storage system using phase change material is approximately 2.6 to 3.5 times of traditional sensible heat storage system in this also found that in hydrated salt disodium hydrogen phosphate have higher thermal energy storage.
Cabeza et al. [15] Constructed a plant to observe the behavior of PCM in real life conditions. Several test is done with two, four, six phase change material component were carried out in real setup. 90% volume of sodium acetate tri-hydrate and 10% volume of graphite was picked as the PCM. Author finished that the use of PCM in water tank for heating of water is very worthy technology. Different shape and dimension of concrete slab and pipe embedding ratio is used and efficiency is measured.

4. Problems of solar water heating systems

The use of solar energy for water heating is discovered in late 1800 when open water tank is left in open for warming of water [16]. The key use of solar energy is come under consideration in 20th century. The prospective of solar water heating system is mainly depend on accessibility and availability of solar insolation and cost that is affordable for households [17]. After studying it is seen that common water heating system is not able to generate temperature above 100 °C and this setup is mostly used as preheating of water for the devices where water temperature is above 100 °C.

4.1 Problem

In previous decade solar water heating system gained most popularity due to high energy cost and to avoid harmful environment and developed environment friendly energy sources. Even though people is aware about clean energy its usage and acceptance are still inadequate. The main problem for less acceptability is economic and technical it is different in every region.

4.2 Economic problem

Several economic problem obstructed uses of solar storage system this is cause of awareness issue, lack of energy policy, high initial cost, low level of affordability this problem occur in developing countries.in developed countries poor promotion and most of customer did not know the difference between PV cell system and solar storage system. For solving this economic problem government must take a step and make policies for better regulation, promotion and provide subsidy. To increase awareness about renewable sources benefits promotional event should organized.

4.3 Technical problem

Technical problem which occur in solar water heating system is higher energy loss during night by energy conversion system and the different shape of surfaces is necessary for better absorptivity of solar insolation to avoid this technical problem there must be a reflector or transparent surface which reduce the

heat loss during night [18]. Presently solar water heating system have very low efficiency to increase this many research work is needed.

5. Conclusion

This paper has been carried out a critical review of thermal energy storage systems and various design of concrete slab solar collector with uses of latent heat mechanism. These systems are very much beneficial for society and environment also. In this paper advancement of solar collector and phase change materials has been classified for enhancement of efficiency of heating systems. Further technical and economic problems and their outcomes have also been discussed pertaining to solar energy storage systems. The application of such systems are in domestic as well as industrial heating. Still the implementation of concrete slab solar collector has not commercialized due to less awareness. Finally this review recommend the installation of concrete slab solar collector because of its less cost and better efficiency.

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