PERFORMANCE EVALUATION OF DIFFERENT CONFIGURATION OF SENSIBLE STORAGE USING TRNSYS

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ABSTRACT

Evacuated tube (ET) solar collectors are utilized in all climatic condition for harnessing solar energy. This work aims to investigate thermal performance of ET with compound parabolic concentrator, integrated with different configuration of Sensible thermal energy storage (STES) . A Higher temperature driving potential is attained in Sensible Heat Storage With Water as a Storage Medium.It is found that the energy storage was augumented by 41% and 35% compared to packed bed storage and cascaded Sensible Heat Storage . Higher stratification number in Sensible Heat Storage reveals the significant of Sensible Storage in improving the charging efficiency of TES system. This configuration of TES system facilitates the augmenting the energy charging supply the HTF at lower temperature in comparison with other two configurations. The instantaneous thermal efficiency of collector with the Sensible Heat Storage configuration has been as high as 58 %, storing 27 MJ/day. Use of ET CPC and TES system has find a potential application in water heating system.

1.INTRODUCTION

Effective utilization of abundantly available solar energy with intermittent nature depends on the selection of appropriate energy storage methods to reduce the mismatch between energy demand and supply. Thermal energy storage (TES) system is the most promising one, as the stored energy can be directly consumed in the form of hot or cold energy, minimizing the energy losses during conversion in different applications.[1,2] Energy can be stored either in the form of sensible or latent heat, retrieving energy in a nearby isothermal condition.. However, their inherent low thermal transport properties, particularly thermal conductivity inhibit the heat transfer during the TES. A Higher temperature driving potential is attained in Sensible Heat Storage With Water as a Storage Medium.It is found that the energy storage was augumented by 41% and 35% compared to packed bed storage and cascaded Sensible Heat Storage . Higher stratification number in Sensible Heat Storage reveals the significant of Sensible Storage in improving the charging efficiency of TES system.

1.1 INTRODUCTION TO TRNSYS

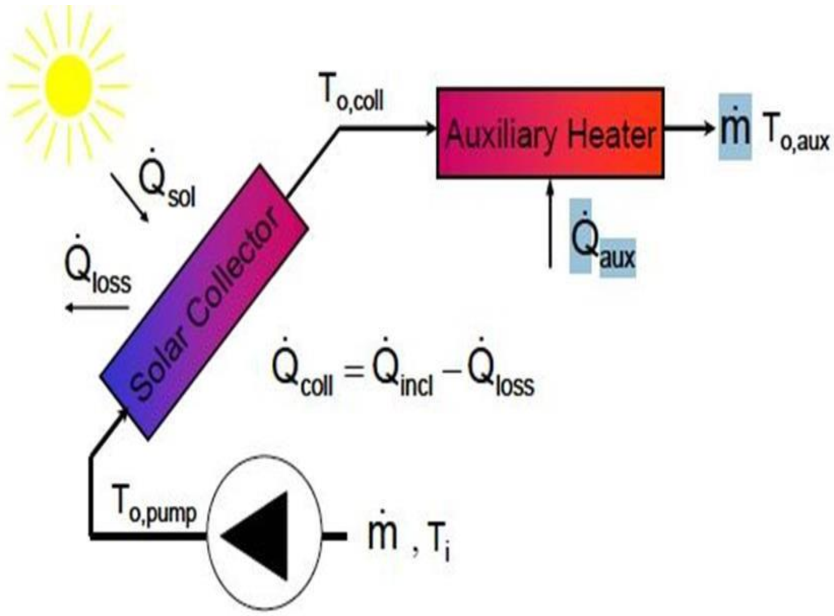
TRNSYS is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. The TRNSYS software package consists of the Simulation Studio, the graphical front-end for TRNSYS, TRN Build, the interface for the TRNSYS building model, Type Studio, the dedicated Fortran environment for developing new TRNSYS content, TRN Edit, and TRNSYS3D.The TRNSYS is basically the simulation software used mainly to simulate the behavior of transient systems. It is mostly used to simulate solar -based heating and cooling systems in building cooling. The TRNSYS gives prediction for the output in dynamic processes modeling such as traffic control and biological analysis.TRNSYS is a simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design. One of its original applications was to perform dynamic simulation of the behaviour of a solar hot water system for a typical meteorological year so that the long-term cost savings of such a system could be ascertained.

It has been used in a plethora of scientific and technical publications for system simulations of various renewable and conventional energy sources. TRNSYS (pronounced 'tran- sis') is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. While the vast majority of simulations are focused on assessing the performance of thermal and electrical energy systems, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes.TRNSYS is an excellent simulation program for analyzing solar domestic hot water (SDHW) systems are components both in the standard library of TRNSYS components and the TESS Libraries that are very useful for TRNSYS SDHW simulations. Components for water draw profiles, storage tanks, controllers, valves, pipes, pumps, and collectors may be implemented in the Simulation Studio graphical interface just as the mechanical diagrams of the actual system. Product design and optimization is a process of interpolation through iteration.

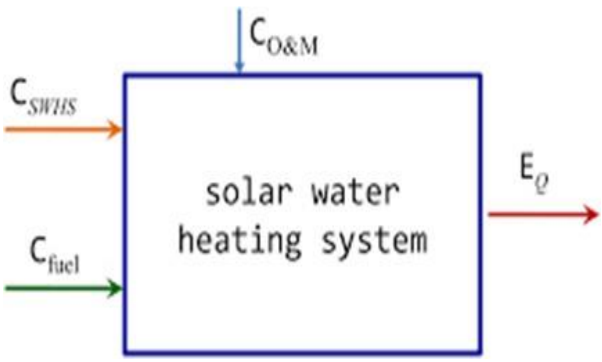
Rating and certification process involves thorough testing of the product in standard test conditions. But real world experiments are full of variations and uncertainties. Moreover it is not feasible to create extreme testing environments in laboratory experiments.

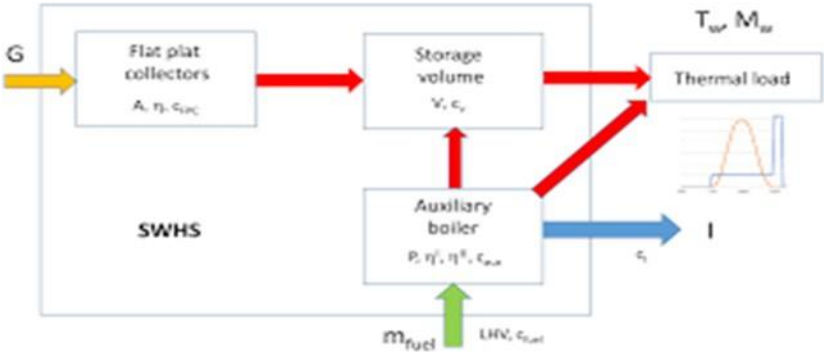
1.2 TRNSYS Connecting components System description

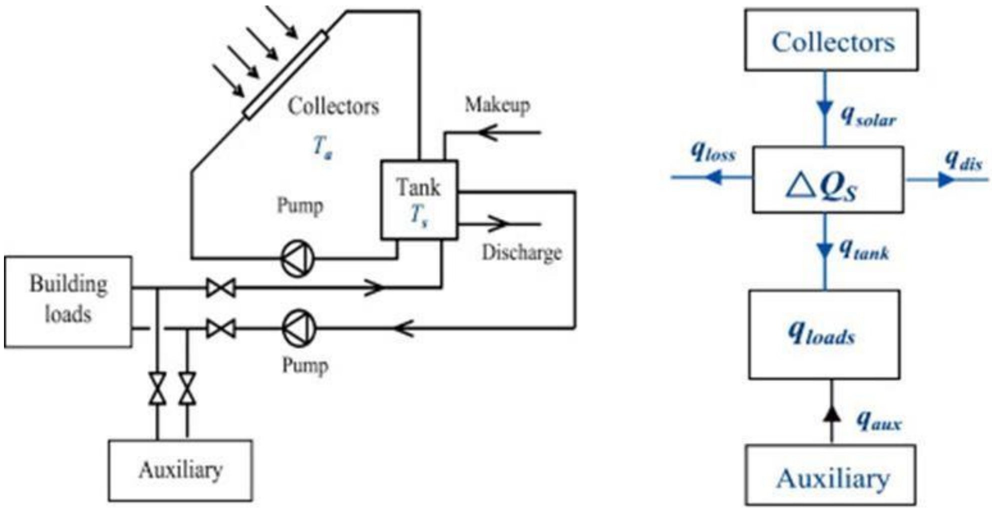
The simulated system is represented in the below Figure. It is a simple solar thermal application where solar collectors are used to preheat water in an industrial process. Components are connected using the Link tool, which is activated by pressing the link button. When you move the mouse over a component icon, the 8 available connection points become visible. Click one of them to select the starting point, then go to the component you want to link and select a connection point again. Click to create the link. The newly created link is empty, i.e. it does not connect any (output; input) couple yet. This is shown by a different link color (blue by default, while links with connections are black).



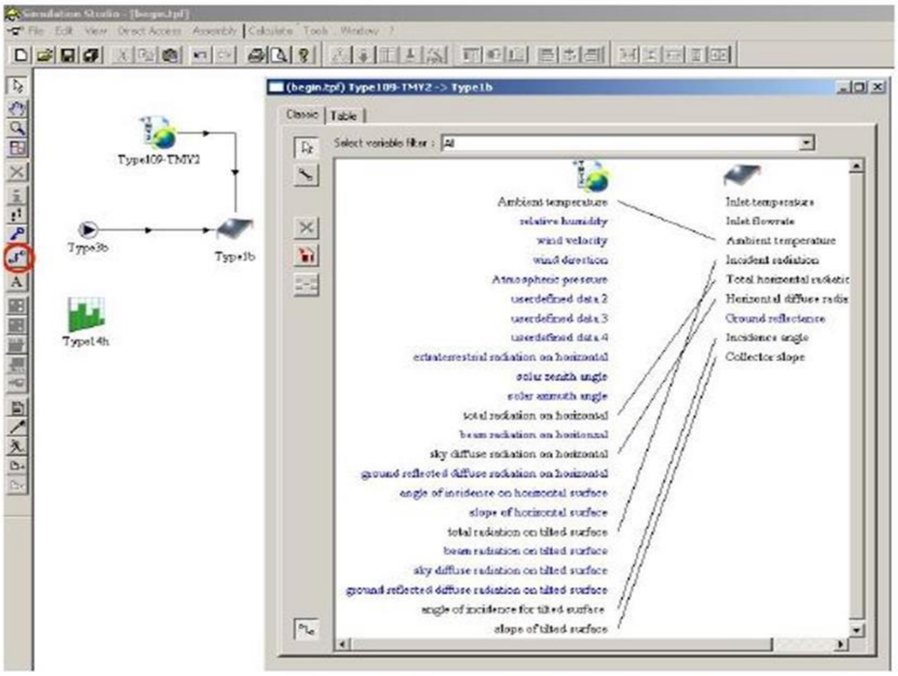
A simple solar pre-heating application







(a) Configuration of a solar water heating system (b) Heat flows of main components



Connecting two components with the link tool

FIGURE 1: TRNSYS Connecting components System

To connect outputs to inputs inside a link, you must go back to the selection tool by clicking on the white arrow icon or by pressing the ESC key. You can then double-click on the link and edit the connections as shown in Figure .You can use the filter and align tools and the alternative "table view" to make connections easier, as discussed.The connections to be made in our case are listed here below:

1.3 System Connections

Type109 (Weather data) to Type1 (Solar collector)

1.3.1.1 Ambient temperature → Ambient temperature
1.3.1.2 Total radiation on horizontal → Total horizontal radiation
1.3.1.3 Sky diffuse radiation on horizontal → Horizontal diffuse radiation
1.3.1.4 Total radiation on tilted surface → Incident radiation
1.3.1.5 Angle of incidence for tilted surface → Incidence angle
1.3.1.6 Slope of tilted surface → Collector slope Type 14 (Forcing Function) to Type 3 (Pump)
1.3.1.7 Average value of function → Control signal Type 3 (Pump) to Type 1 (Solar collector)
1.3.1.8 Outlet fluid temperature → Inlet temperature
1.3.1.9 Outlet flow rate → Inlet flow rate Type 1 (Solar Collector) to Type 6 (Auxiliary heater)
1.3.1.10 Outlet temperature → Inlet fluid temperature
1.3.1.11 Outlet flow rate → Inlet flow rate

1.3.2 Connections to Output Devices

Connections to Type 24 (Integrator)

1.3.2.1 Type 1 (Solar collector), Useful energy gain → Input to be integrated-1
1.3.2.2 Type 6 (Auxiliary heater), Required heating rate → Input to be integrated-2 Connections to Type 65 (Online plotter)
1.3.2.3 Type 3 (Pump), Outlet fluid temperature → Left axis variable-1

1.3.2.4 Type 1 (Solar collector), Outlet temperature → Left axis variable-2
1.3.2.5 Type 1 (Solar collector), Useful energy gain → Right axis variable-1
1.3.2.6 Type 6 (Auxiliary heater), Outlet fluid temperature → Left axis variable-3
1.3.2.7 Type 6 (Auxiliary heater), Required heating rate → Right axis variable-2 Connections to Type 25 (Printer)
1.3.2.8 Type 24 (Integrator), Result of integration-1 → Input to be printed-1
1.3.2.9 Type 24 (Integrator), Result of integration-2 → Input to be printed-2

2. The TRNSYS Simulation Engine

The simulation engine is programmed in Fortran and the source is distributed (see the \SourceCode directory). The engine is compiled into a Windows Dynamic Link Library (DLL),TRNDll. The TRNSYS kernel reads all the information on the simulation (which components are used and how they are connected) in the TRNSYS input file, known as the deck file (*.dck). It also opens additional input files (e.g. weather data) and creates output files. The simulation engine is called by an executable program, TRNExe.exe, which also implements the online plotter, a very useful tool that allows you to view dozens of output variables during a simulation.

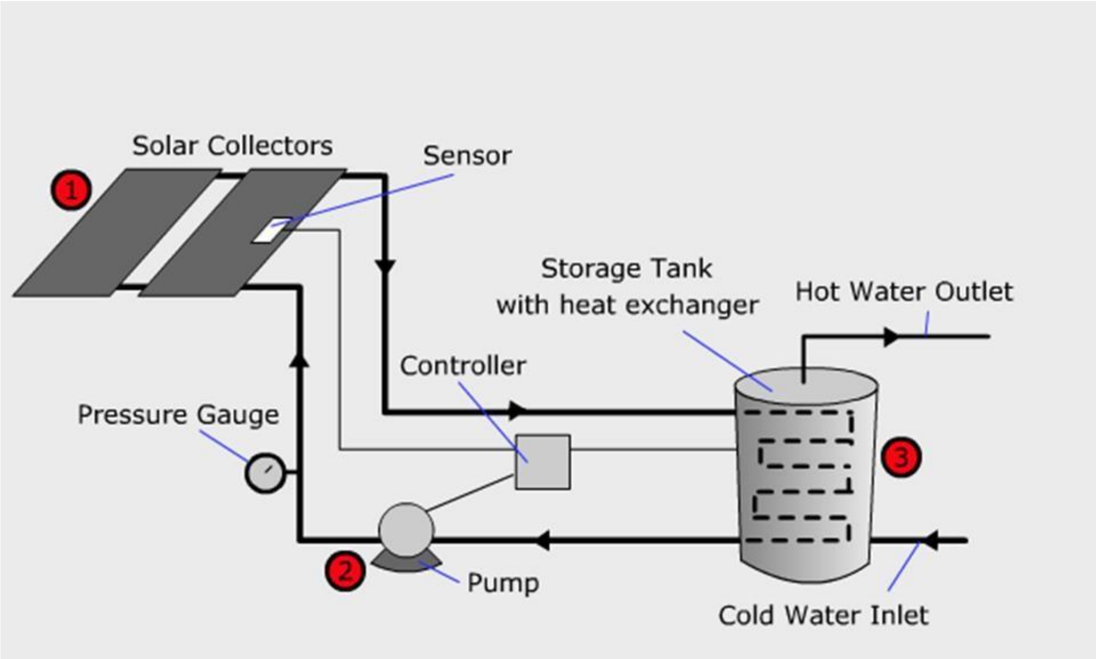


FIGURE 2 GENERAL REPRESENTATION OF SOLAR WATER HEATING

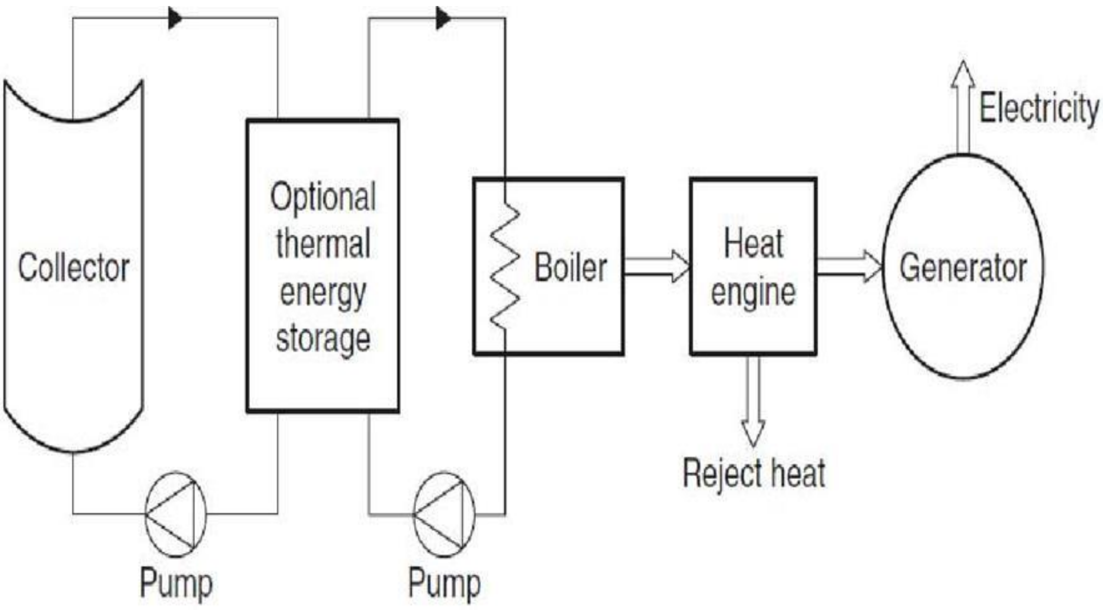


FIGURE 3 SCHEMATIC REPRESENTATION OF SOLAR HEAT GENERATION

3. METHODOLOGY

3.1 DEPICTION OF THE COMPONENTS USED FOR SOLAR WATER HEATING SYSTEM

3.1.1 XCPC SOLAR COLLECTOR

To optimize the system, characteristic factors of XCPC solar collector with $TINO_X$ on the absorber plate are considered with $_0$=0.77, a_0=0.55 W/m^2 K, a_1=0.003 W/m^2 K[24]. To optimize the collector, a theoretical XCPC solar collector is modeled; and collector annual and monthly characteristics factors are studies over a period of time.

3.1.2 STRATIFIED STORAGE TANK

The performance of the thermal storage tank is analyzed through varying tank L/D ratio.

3.1.3 FORCING UNIT

This component is used to apply hourly load profile on sequential form based on energy demand

3.1.4 AUXILIARY ELECTRIC HEATER

Auxiliary heater is coupled after storage tank to elevate the required temperature; desired HTF is set to 90 °C.

3.1.5 PUMP

Pump is used to circulate water between the XCPC solar collector to storage tank and storage tank to series of applications.

Solar water heating system consists of several key components that work together to harness solar energy and heat water. Here's a depiction of the main components:

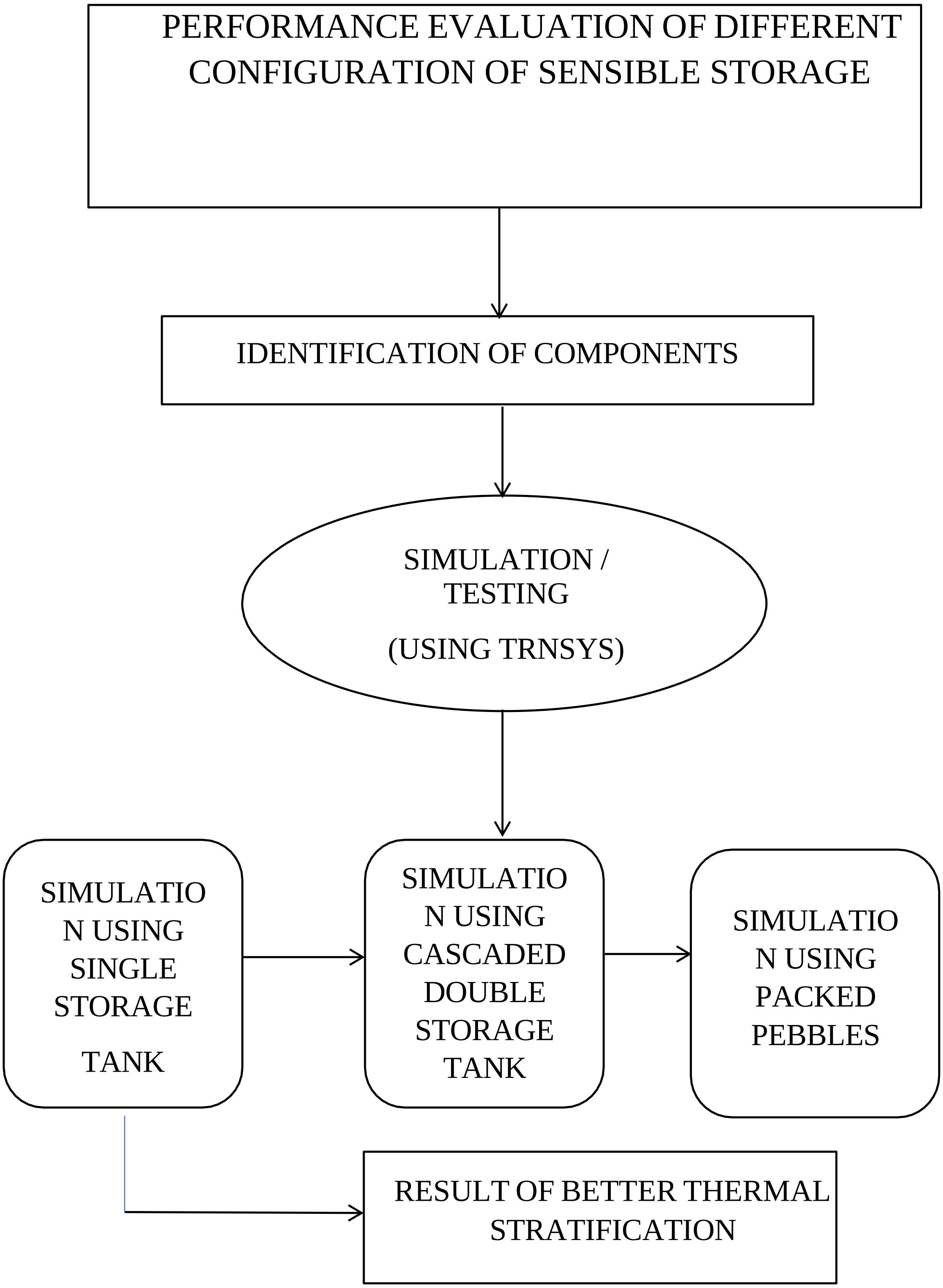
Solar Collectors – Absorb sunlight and convert it into heat. Common types include:

- Flat Plate Collectors
- Evacuated Tube Collectors

Storage Tank – Insulated tank to store heated water for later use.
Heat Exchanger – Transfers heat from the collector to the water without direct contact.
Circulation System – Moves water or heat-transfer fluid between the collectors and the storage tank. It can be:

- Active (using pumps)
- Passive (using natural convection)

Controller & Sensors – Regulate the system, ensuring efficient operation by detecting temperature differences.
Pump (for Active Systems) – Circulates water or heat-transfer fluid through the system.
Expansion Tank – Accommodates pressure changes in closed-loop systems.
Piping & Insulation – Distributes hot water while minimizing heat loss.
Backup Heater – Provides additional heating when solar energy is insufficient.


PERFORMANCE EVALUATION OF DIFFERENT CONFIGURATION OF SENSIBLE STORAGE
IDENTIFICATION OF COMPONENTS
SIMULATION / TESTING
(USING TRNSYS)
SIMULATION USING SINGLE STORAGE TANK
SIMULATION USING CASCADED DOUBLE STORAGE TANK
SIMULATION USING PACKED PEBBLES
RESULT OF BETTER THERMAL STRATIFICATION

4. RESULTS AND DISCUSSION

4.1.Instantaneous energy stored

Experiments have been carried out in the test facility under sensible heat storage, respectively. The corresponding measured global radiation and ambient temperature during the experiments are given in Figure 5. The intensity of solar radiation and ambient temperature range between 303 – 995 W m^{-2} and 32 – 35 °C respectively.

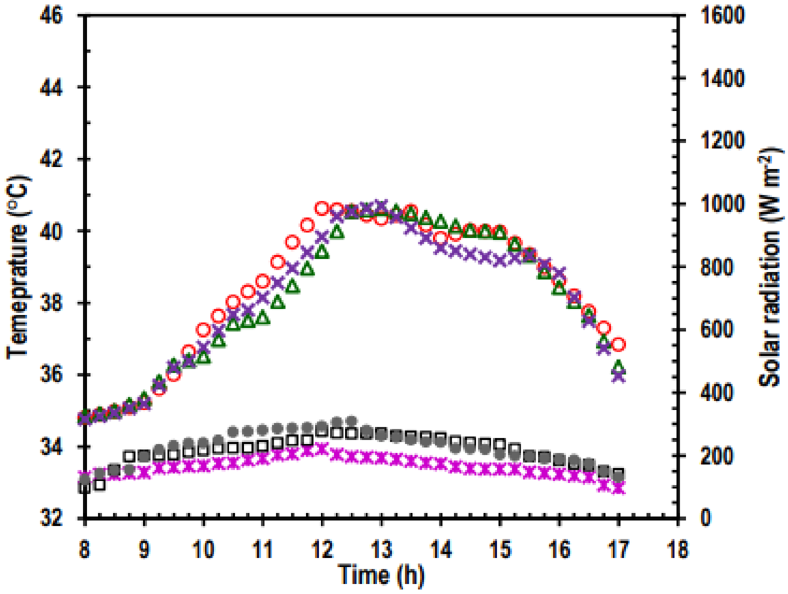


FIGURE 5 Measured solar radiation intensity and ambient temperature

To explore the effects, the instantaneous energy stored is evaluated for sensible heat storage, 'Case 1' and 'Case 2' configurations using Equation (1) and the results are compared in Figure 6. The amount of energy stored at any 13

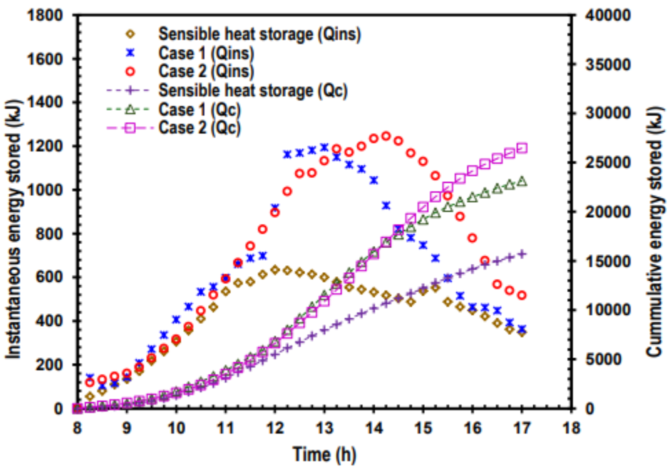


FIGURE 6 Energy stored in different configurations of TES system

and the cumulative energy storage of 4.5 MJ, 5.5 MJ and 5.3 MJ is stored between the locations x/L = 0.05 - 0.35, 0.35 - 0.65 and 0.65 - 0.95, respectively. A major portion of SHS heats during 12.00 h - 16.30 h at all the locations for 'Case 1', sustaining the higher temperature driving potential of 11 °C, 24 °C and 28 °C at x/L = 0.05, 0.35 and 0.65, respectively. The increasing trend of the HTF temperature during this period is much higher for ‘Case 1’ and ‘Case 2’ than the sensible heat storage configuration, mainly due to the melting of PCMs in a nearby isothermal manner. On the other hand, the energy stored drops at a faster rate during 14.50 h - 17.00 h, primarily due to two reasons; the sensible heating in the liquid region causing a reduction in the temperature driving potential and a greatly reduced available solar radiation. In conclusion, thermal performance of the TES system is improved passively by storing a higher amount of energy through SHS arrangement with narrow melting temperatures.

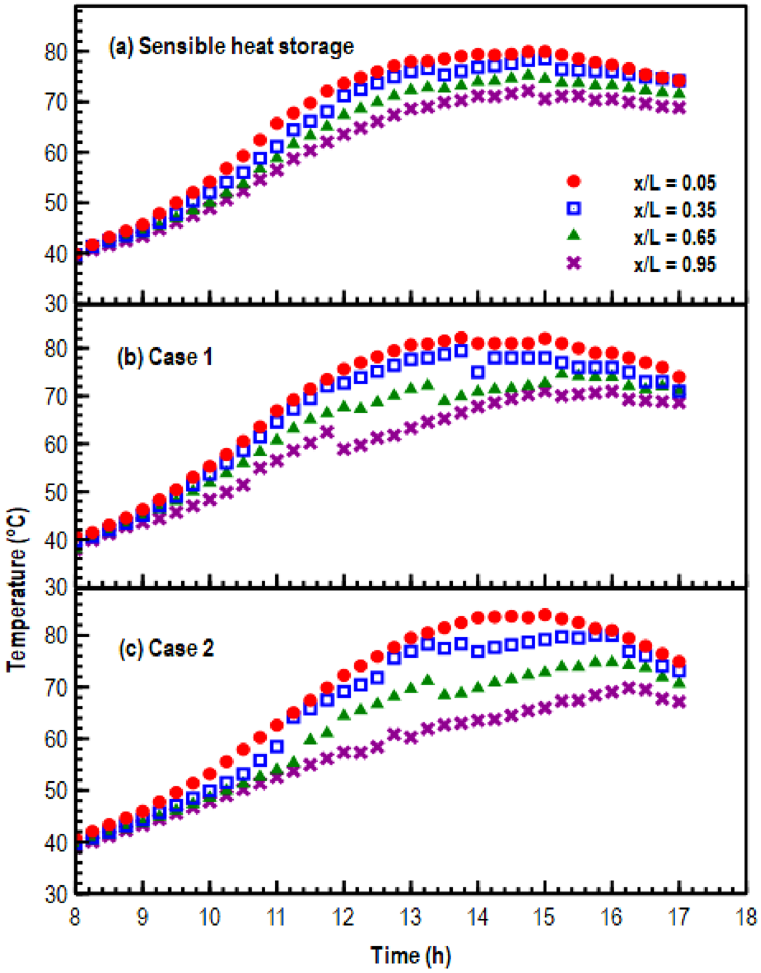


FIGURE 7 T – t history of HTF at different locations in the TES system

4.2.Stratification number

This dimensionless number characterizes the ratio of instantaneous temperature gradient to temperature gradient at the beginning of charging process. Figure 8 presents the variation of stratification number with respect to non-dimensional time, reaching the maximum and a subsequent decline as the charging proceeds for all the configurations. During the initial periods, the existence of a high thermal gradient increases the stratification number, attaining the maximum of 14, 26.8 and 27 for sensible heat storage, 'Case 1' and 'Case 2' configurations, respectively. The increase in stratification number results from the existence of a high thermal gradient in 'Case 1' and 'Case 2'and the corresponding values are found to be 17.7 °C m^{-1} and 19.8 °C m^{-1} on comparing with the baseline case of 10.2 °C m^{-1} for the sensible heat storage. This improvement in thermal stratification can be explained by the specific placement with a narrow melting temperature range and also the presence of aluminum capsules.

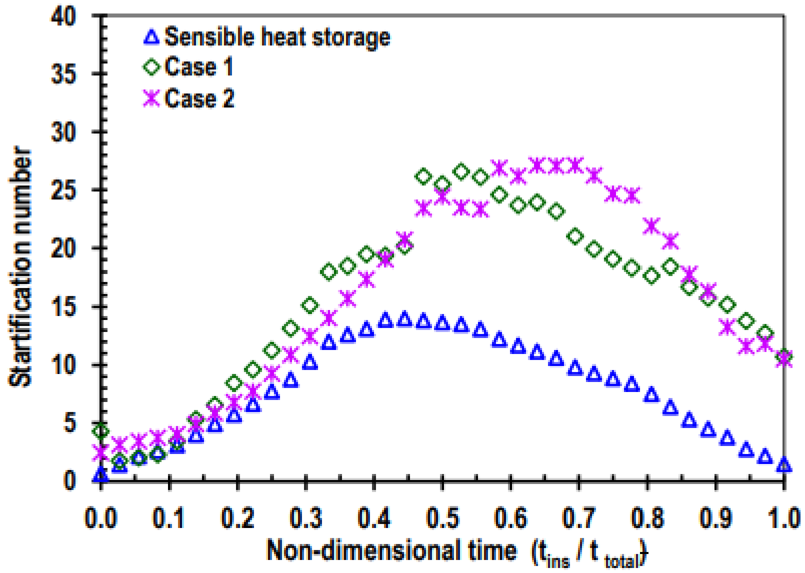


FIGURE 8 Variation of stratification number

A diminishing trend of stratification number is noticed as charging advances, but with the higher values in 'Case 1' and 'Case 2' than the sensible heat storage configuration. This trend can be attributed to the predominant effects of mixing forces due to the continuous circulation of HTF over a period of time and reduced solar intensity. From the above analysis, it is established that the integration of SHS improves the charging efficiency of the TES system though the higher thermal stratification.Instantaneous thermal efficiency

Figure 9 show the temperature variation of HTF inlet of solar collector for different configuration of TES system. Here, it should be pointed out that the HTF temperature at the collector inlet drops sharply around 12.00 h in 'Case 1', resulting from the heating in the TES system. Due to the supply of HTF at the relatively low temperatures to the solar collector as noticed in Figure 8 (b), the convection heat losses from the collector decrease significantly, attaining a peak thermal efficiency of 49 % and 58 % in 'Case 1' and 'Case 2', respectively. The higher collector efficiency for 'Case 2' is solely due to the augmented energy gain in the collector, resulting from the supply of HTF relatively at low temperatures with the cascaded arrangement. As time proceeds, the thermal efficiency decreases gradually for all cases, but the solar collector paired with 'Case 2' shows the higher thermal efficiency, in spite of reduced solar radiation, particularly between 15.00 h – 17.00 h.

Thermal efficiencies of the ET-CPC solar collector calculated from Equation (5) for three configurations are compared in Figure 10. As can be seen, the ET-CPC solar collector performs better when integrated with the TES system in ‘Case 1’ and ‘Case 2’ than sensible heat storage, showing an increasing trend of thermal efficiencies from the start of the experimentation.

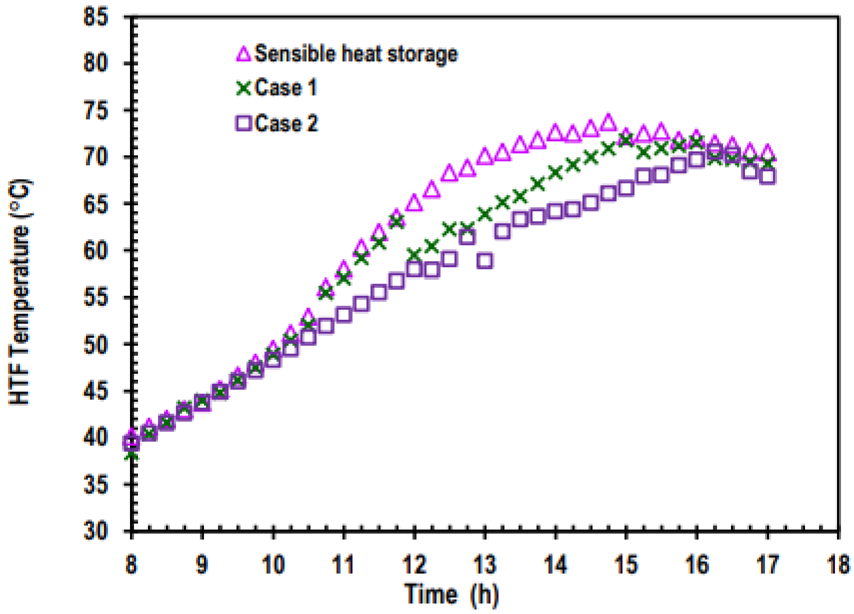


FIGURE 9 HTF temperature at collector inlet with local time.

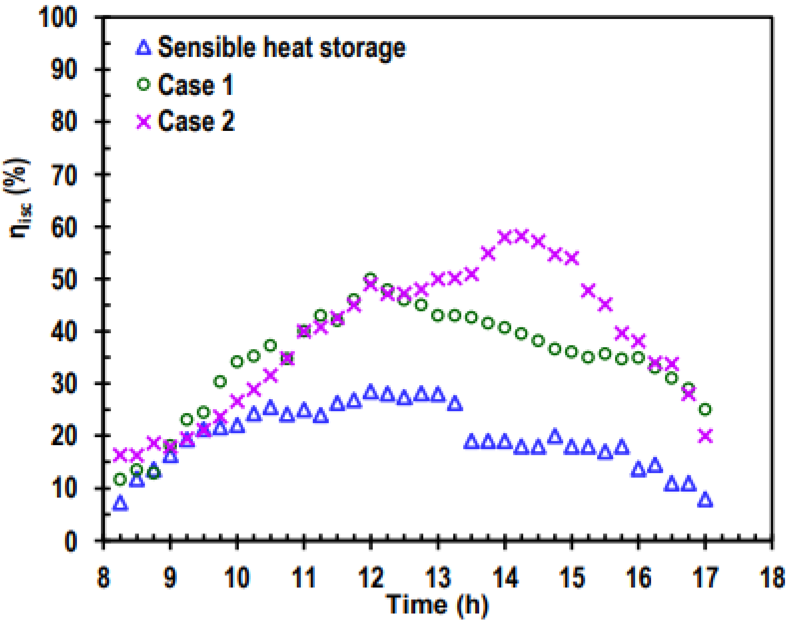


FIGURE 10 Instantaneous thermal efficiency of the collector

slope of the curve representing ‘F_RU_L/C_R’ is found to be the lowest in ‘Case 2’, indicating the minimal overall heat losses compared to other configurations. The heat transfer rate inside the absorber tubes is augmented with lower ‘F_RU_L/C_R’ thereby increasing the thermal efficiency of the solar collector. As noticed, thermal efficiency drops with an increase in heat loss parameter, emerging from the decrease in thermal resistance between the outer surface and the evacuated tubes. The intercept with the vertical axis denoting ‘$F_R\eta_o$’ of the collector is 0.52, 0.69 and 0.7 paired with sensible heat storage, ‘Case 1’ and ‘Case 2’, respectively.

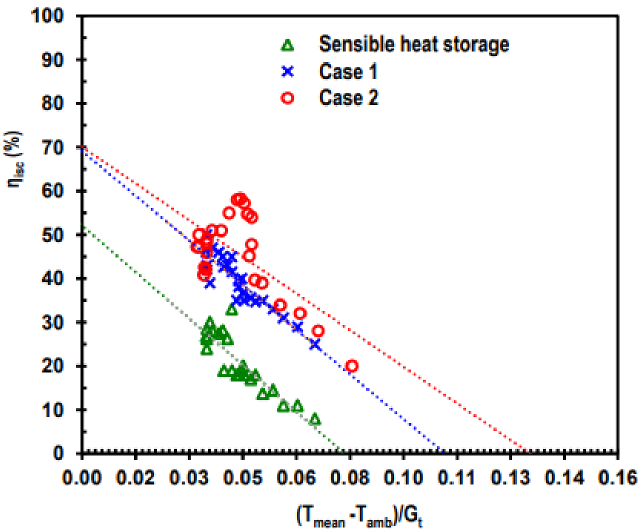


FIGURE 11 Thermal efficiency as the function of loss coefficient

For establishing the advantages of employing CPC and the thermal energy storage system, the present results are compared with the obtained results from a similar configuration of solar collector under Indian climatic conditions.[28] For a given collector area, the thermal efficiency of the solar collector in the present study is higher, demonstrating the predominant role of the SH based TES system. Furthermore, the results of Zambolin et al[29] using an evacuated tube collector of aperture area of 3.5 m^2 exhibited the lower thermal efficiency than the present study, signifying the functional enhancement by the CPC. The distinctive advantage of the CPC solar collector is the minimum thermal losses, which are inversely proportional to its concentration ratio and the lower values of ‘F_RU_L/C_R’ in ‘Case 2’ ultimately improve the thermal efficiency of the ET-CPC solar collector. Considering the improved thermal efficiency of the ET-CPC collector for ‘Case 2’, the overall efficiency of the system is enhanced by 8 % and 23 % than ‘Case 1’ and sensible heat storage configurations, respectively.

5.CONCLUSION

This study reports the thermal performance of the ET-CPC solar collector through the integration of the TES system configured with Sensible Heat Storage System. Results of charging experiments reveal that the STES configurations introduce a desired temperature driving potential for effective charging, fetching a higher temperature difference of HTF across the TES system. Consequently, an enhancement in energy storage of 41 % is accomplished respectively. Stratification number is higher than the other two configurations, establishing a better thermal stratification. It is concluded that the combined effects of the CPC and Sensible Heat Storage based TES system facilitates the development of an efficient solar based water heating systems for various domestic and industrial applications. Sensible heat storage means shifting the temperature of a storage medium without phase change. It is the most common simple, low-cost, and longstanding method. This storage system exchanges the solar energy into sensible heat in a storage medium (usually solid or liquid) and releases it when necessary. Water remains the most widely used material in sensible heat storage systems with best compromise between cost, heat storage capacity, density and environmental impact. It is concluded from the experimental results that the sensible storage concepts reduces the size of the storage tank appreciably compared to conventional storage system.

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