Deutsche Gesellschaft
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On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Building and Nuclear Safety

of the Federal Republic of Germany

GOVERNMENT OF INDIA
MINISTRY OF NEW
AND RENEWABLE ENERGY

Measuring Solar Heat Generation

Monitoring Results of a Solar Water Heating System for Process Heat
Case I - Synthokem Labs, Pharmaceutical Company in Hyderabad

SoPro India
Solar Water Heating for
Industrial Processes in India

Under SoPro India (ComSolar) Project

Disclaimer

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Abbreviations

BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
ComSolar	Commercialisation of Solar energy in Urban and Industrial areas
ETC	Evacuated Tube Collectors
FPC	Flat Plate Collectors
Fraunhofer ISE	Fraunhofer Institute for Solar Energy Systems ISE
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GSM	Global System for Mobile Communications
HC	Heat Counter
IGEN	Indo German Energy Programme
kWh	Kilowatt Hour
MNRE	Ministry of New and Renewable Energy, Government of India
RO	Reverse Osmosis
R&D	Research and development
SHIP	Solar Heat for Industrial Processes
SoPro India	Solar water heating for industrial processes in India
SWHS	Solar Water Heating Systems

Introduction

The lack of reliable data of the energy output of Solar Water Heating Systems (SWHS) is one barrier for their deployment. Monitoring of SWHS shall on one hand show, how much fossil fuels and money can be saved by solar thermal energy and shall allow on the other hand allow to analyse the performance and identify possible improvements of the technical concept of the monitored systems.

Within Solar water heating for industrial processes in India (SoPro) India – project under ComSolar, highly sophisticated monitoring systems, which are typically used by Fraunhofer ISE to do monitoring on a scientific level, are implemented to two SWHS to provide reliable data as a reference for further discussions. Based on these experiences, recommendations for a simple and cheap monitoring concept were derived, which can guide for designing monitoring systems for the Indian SWHS market.

Two SWHS were monitored within the SoPro India project, the SWHS utilising flat plate collectors at Himachal Dairy in Tehsil-Rampur Bushar, Himachal Pradesh, and the SWHS utilising evacuated tube collectors at Synthokem Labs in Hyderabad, Telangana. The result overview of the SWHS installed at Synthokem labs - a pharmaceutical company in Southern India - is presented and analysed in the following pages.

Monitoring System Design

Monitoring system for the solar water heating system at Synthokem Labs, Sanath Nagar, Hyderabad, Telangana

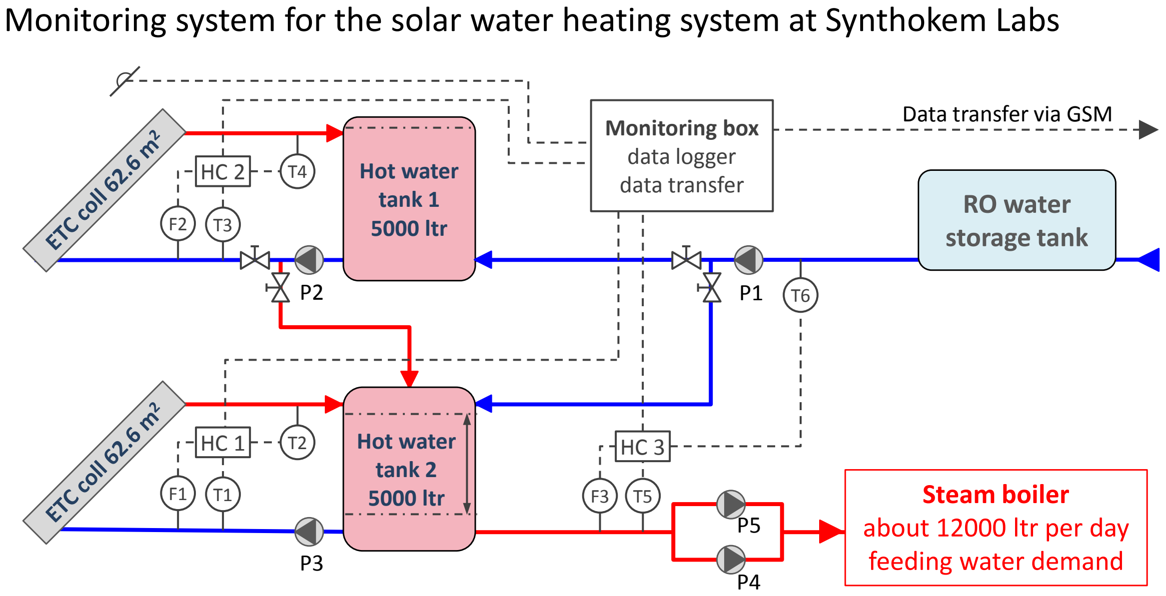

Figure 1 Scientific monitoring system to measure the yield of the solar water heating system and subsystems

Operation

Each heat circuit has an own heat counter, which uses a flow meter F and the temperature difference between two temperature sensors T to calculate the thermal energy generated. Heat counter 1 and 2 measure the solar yield of the two solar collector fields, heat counter 3 measures the total thermal energy delivered to the boiler which should be about the sum of heat counter 1 and 2 minus the heat losses of the storage tanks. Principally the two temperature sensors of a heat counter must be positioned at places where the fluid is flowing at the same time. This is not possible in the case of heat counter 3, however this is not a problem in this case since the RO water temperature T6 is constant. The pyranometer is positioned in the same angle than the collectors and measures the intensity of the solar irradiation.

Overview on the Monitored Performance of the SWHS

The Synthokem SWHS is a non-pressurised, open system, composed of two Evacuated Tube Collector (ETC) fields with 62.6 m2 each, 125.2 m^2 total collector area and two water storage tanks with 5000 litre volume each. The system was installed in 2009 on the roof-top of the company building and is used for pre-heating the feeding water of a steam boiler.

The system was monitored for one year from October 2014 until September 2015, the monitored data per day can be found under the tab "weekly results" on the project website www.soproindia.in. Due to different reasons such as broken sensors, failures in data storage or data transfer, monitored parameters are not available for several days or weeks. However, since the heat meters sum up their values continuously, the energy generated could be calculated for each month.

The key monitoring results of the Synthokem SWHS for the period of October 2014 until September 2015 (one year) are shown in Table 1 and Table 2.

Table 1: System performance values of the solar system (for the entire system with 125.2 m^2 collector area)

Lines, formulas	Description of parameter	Annual values of the whole system	Average daily values of the whole system
(1)	Solar irradiation on collector area	224 MWh/a	614 kWh/d
(2)	Solar yield collector loop "Day demand"	25.5 MWh/a	70 kWh/d
(3)	Solar yield collector loop "Night demand"	30.1 MWh/a	83 kWh/d
(4)=(2)+(3)	Solar yield of both collector loops	55.6 MWh/a	153 kWh/d
(5)=(4)/(1)	Solar collector efficiency	25%	
(6)	Solar energy delivered to process	44.2 MWh/a	121 kWh/d
(7)=(6)/(1)	Solar system efficiency	20%	
(8)	Water volume delivered to process	4,138 m3/a	11.3 m^3/d
(9)=(6)/((8)*1.14)	Average temperature increase of water delivered to the process	9.4 °C	
(10)	Energy demand to pre-heat water from 27°C (average ambient temp Hyderabad) to 110°C	417 MWh/a	
(11)=(6)/(10)	Solar fraction on pre-heating of water	11%	
(12)	Total energy demand for steam production (pre-heating plus evaporation heat)	2,906 MWh/a	
(13)=(6)/(12)	Solar fraction on total energy demand	1.5%	
(14)	Boiler efficiency assumed	70%	
(15)=(6)/(14)	Fuel saved (energy content)	63 MWh/a	173 kWh/d
(16)=(15)*0.11	Fuel saved (heating oil)	6,900 L/a	19 L/d
(17)	Fuel cost saving (50 ₹ per litre fuel)	345,000 ₹/a	950 ₹/d
(18)	Investment (total system costs)	₹ 865,000	
(19)=(18)/(17)	Simple pay-back time	2.5 years	
(20)	Carbon emissions saved (2.68 $kgCO_2e/L$)	18.5 tCO_2e/a	51 $kgCO_2e/day$

To ease the comparison of different solar systems with different collector areas, the values per square meter collector area are shown in Table 2.

Table 2: System performance values of the solar system (per square meter of collector area)

Lines, formulas	Description of parameters	Annual values per square meter collector area	Average daily values per m^2 collector area
(1)	Solar irradiation on collector area	1,789 $kWh/(m^2a)$	5.9 $kWh/(m^2d)$
(2)	Solar yield collector loop "Day demand"	408 $kWh/(m^2a)$	1.3 $kWh/(m^2d)$
(3)	Solar yield collector loop "Night demand"	481 $kWh/(m^2a)$	1.6 $kWh/(m^2d)$
(4)=((2)+(3))/2	Solar yield of both collector loops	445 $kWh/(m^2a)$	1.5 $kWh/(m^2d)$
(5)=(4)/(1)	Solar collector efficiency	25%	
(6)	Solar energy delivered to process	353 $kWh/(m^2a)$	1.2 $kWh/(m^2d)$
(7)=(6)/(1)	Solar system efficiency	20%	
(8)	Water volume delivered to process	33.0 $m3/(m^2a)$	90.5 $L/(m^2d)$
(9)=(6)/((8)*1.14)	Average temperature increase of water delivered to the process	9.4 °C	
(14)	Boiler efficiency assumed	70%	
(15)=(6)/(14)	Fuel saved (energy content)	500 $kWh/(m^2a)$	1.4 $kWh/(m^2d)$
(16)=(15)*0,11	Fuel saved (heating oil)	55 $L/(m^2a)$	0.15 $L/(m^2d)$
(17)	Fuel cost saving (50 ₹/L fuel)	2,750 ₹/(m^2a)	7.5 ₹/(m^2d)
(18)	Carbon emissions saved (2.68 $kgCO_2e/L$)	147 $kgCO_2e/a$	0.4 $kgCO_2e/day$

Description of Parameters

The solar irradiation (1) on the collector surface is about 1,800 kWh/m^2 per year, which is in the expected range. This corresponds to an average daily irradiation of 5.9 kWh/m^2 collector area during this year.

The SWHS splits in two collector loops called "Day demand" and "Night demand". The solar heated water in the tank of the "Day demand" loop is directly used if the steam boiler demands feeding water. Therefore, the water level of the storage tank of the "Day demand" loop is declining continuously until the tank is refilled. The storage tank of the "Night demand" loop is filled in the morning, heated up during the day and the heated water is pumped into the other tank in the evening.

Solar yield collector loop "Day demand" (2) and "Night demand" (3) is the heat generated by the solar collector fields, which is delivered to the storage tank of the collector loop. Though both collector fields have the same collector area of 62.6 m^2, the solar yield of the "Night demand" collector field is 18% higher than the "Day demand" collector field. The primary reason is that the "Day demand" collector field is partly shadowed in the afternoon.

If the solar yield is divided by the solar irradiation, the solar collector efficiency (5) results, which is 23% for the "Day demand" collector loop and 27% for the "Night demand" collector loop and 25% in the average. At some days, e.g. in week 31 (July) in 2015, the solar yield of the collector loops reaches up to 38%.

The most relevant value of the SWHS is the solar energy delivered to the process (6) and the related solar system efficiency (7), this is calculated by dividing the energy delivered to the process by the solar irradiation. The Synthokem system delivers 44,000 kWh solar energy to the process which results in a solar system efficiency of 20%. With this amount of energy, the temperature of the water volume delivered to the process (8) was increased by 9.4°C in the average (9).

Only a part of the energy content of the fuel is converted into heat due to the efficiency of the boiler (14), which is assumed as 70%. Therefore, the solar energy delivered to the process (6) must be divided by the boiler efficiency (14) to derive the energy content of the fuel saved (15). The volume of the fuel saved is given in (16) and the saved fuel costs in (17). The simple pay-back time is calculated with 2.5 years in (19) considering the investment costs given in (18).

Summary of the System Performance

Each SWHS has losses, which depends on the quality and efficiency of the components used, the design of the system, the water temperature needed by the process, the ambient temperature, the solar fraction on the overall heat demand, the maintenance of the system, and the operation of the SWHS. Therefore, the expected solar system efficiency varies a lot. For a system like the Synthokem SWHS a system efficiency of about 20% to 40% could be expected. This means, that the performance measured is acceptable, but there is room for improvements of the performance.

Discussion of the Monitored Performance

In the following, the monitoring results and possible reasons for the values are described. Figure 2 illustrates the measured efficiencies of the Synthokem SWHS.

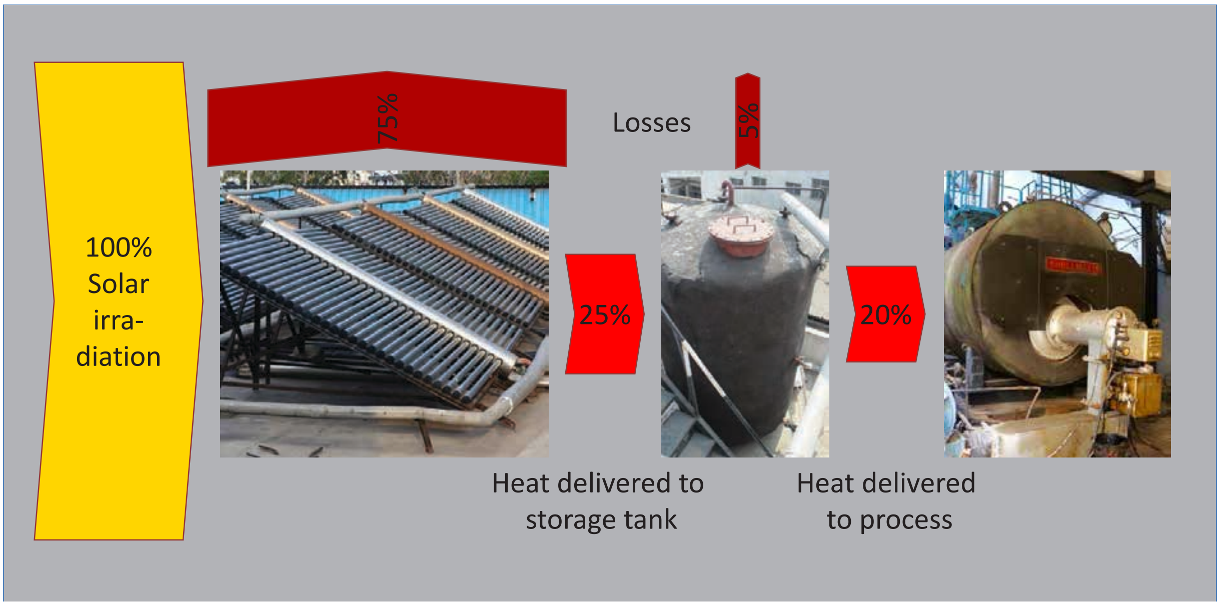

Figure 2 Measured energy flow and losses of the Synthokem SWHS

Efficiency of the collector field and circuit

The typical maximum efficiency of ETC collectors is about 60%. With increasing temperature difference between the absorber and the ambient the thermal losses are increasing and the efficiency is decreasing. However, due to the vacuum, the losses are relatively low and since the output temperature of the collector field is usually only at about 60°C and the ambient temperature is not low, the temperature difference is low and the thermal losses of the collector should be small.

Following causes could be responsible for the 75% of energy losses from the solar radiation to the heat delivered to the storage tank:

1) Typically 60% of the solar irradiation is converted into heat, this means, about 40% losses are caused by reflections and non-optimal transmission of the glass and non-optimal absorption of the absorber. The area between the glass tubes is counted as aperture area as well, since there is a reflector installed behind the glass tubes. Therefore, the non-optimal reflection of this reflector is contributing to the losses as well.

2) The hot absorber is losing heat through the ETC tubes to the ambient (or through the box in case of flat plate collectors) but these losses should be rather low in this case.

3) Losses happen, if the collector field is not equally flown through by water, e.g. if air is included in the pipes, the water flow of parts of the collector field could be obstructed.

4) Heat losses occur on the way from the collector to the tank, by improper insulated pipes and fittings.

5) The solar yield is also reduced if the collector circuit is not operated (collector circuit pump is not switched on) though the sun is shining. Since the pumps are operated manually, operation failures can happen. In the monitored results presented at the website the pump operation time for both collector circuits are shown and can be compared.

6) If the heat generated is not used, this means the solar heated water is not pumped from the "Night demand" storage tank to the other tank in the evening, the collector input temperature is higher, as well as the collector outlet temperature and therefore the thermal losses are higher.

Solar system efficiency

Additional losses of 5% (in relation to the solar irradiation) between the collector circuit and the heat demanding process are caused by:

1) Heat losses through the surface of the storage tanks (losses are reduced by insulation).

2) Heat losses of the pipes and fittings, which are not well insulated.

3) Solar heated water not transported to the process, e.g. solar heated water from the Night demand storage tank is pumped to the Day demand storage tank in the evening, since the pipe is not connected at the lowest point of the storage tank, about 10% of the water remains in the storage tank and cannot be used by the process. This not used volume can be even higher if the Day demand storage tank is not empty in the evening and only a part of the Night demand storage tank water volume can be filled in.

It is not possible to identify exactly, which cause is responsible for which share of the losses. Some of the losses cannot be avoided, e.g. the reflection on the glass tubes or the heat losses of the pipes and the storage tank, but they can be reduced by a good quality of the products used. However, the energy and cost savings by reduced losses should be higher or at least comparable to the additional costs for high quality components.

Other losses can be avoided by a good operation and maintenance of the SWHS. E.g. if the collector circuit pumps are operated manually, it must be assured, that collector circuits are always operating, if the sun is shining. If the heat demand and the solar irradiation is very constant over the year and the solar fraction on the energy demand is relatively low, a manually operated system could have the same performance like an automatically operated system. However, if demand and irradiation varies a lot an automatically operated pump is more reliable.

Further it is important to prevent that air is included in the collector circuits. This can be assured by the installation of vent valves at the highest points of the collector circuits. Especially, in non-pressurised, open systems they are important, since air comes continuously into the hydraulic system, when the collector circuit pump is not running. Such vent valves are installed at the Synthokem SWHS (see Figure 3). Vent valves should be checked regularly, to assure that they function properly.

Figure 3 Vent valve to remove air from the collector circuit

Losses can also occur due to a suboptimal design. Figure 4 shows the storage tanks of both collector circuits at four time instances. The "Night demand" storage tank is filled with cold water in the morning and heated during the day by the collector field. In the evening, the hot water is pumped into the other storage tank. Since the socket, where the pipe is connected with the tank is not at the lowest point of the tank, a part of the hot water is remaining in the tank and cannot be used (as already described above).

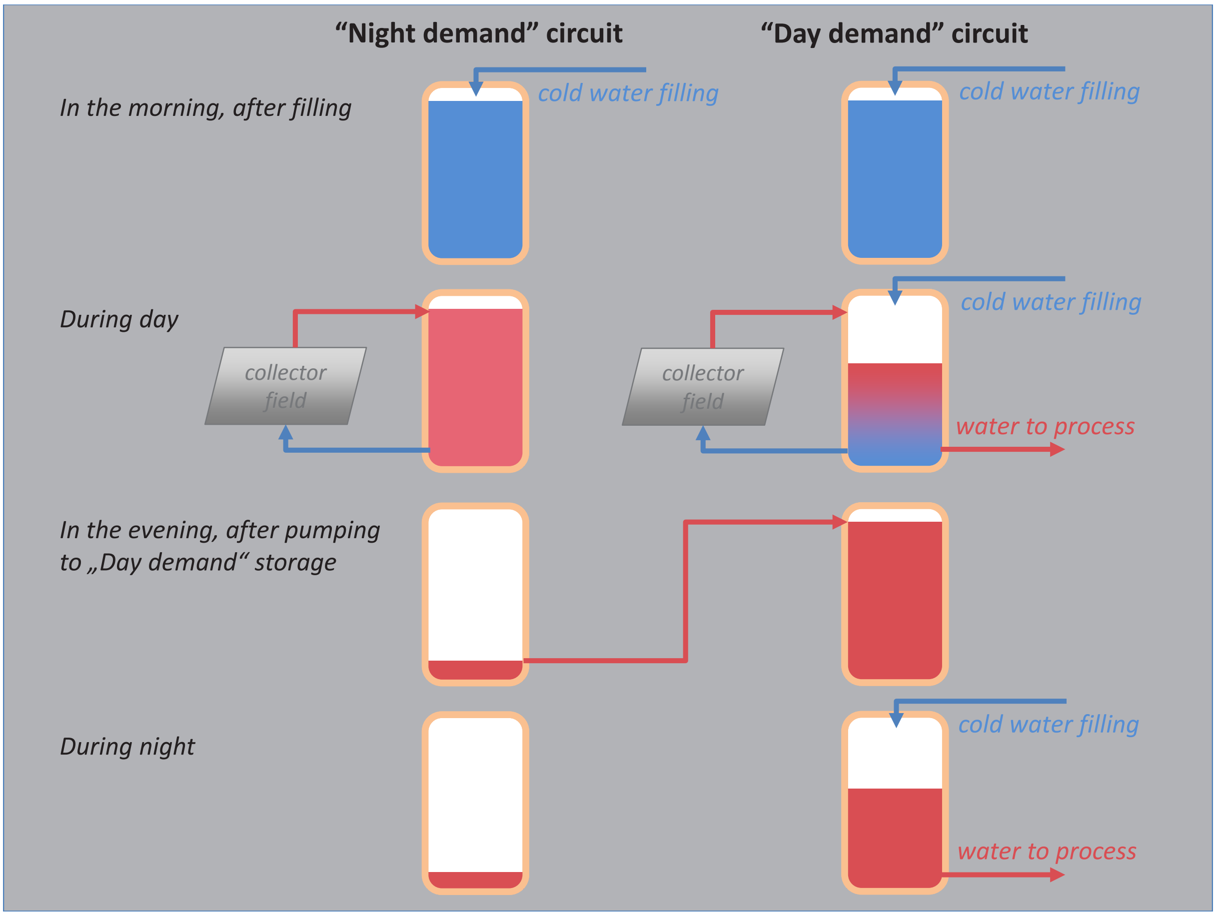

Figure 4 Operation of the storage tank of the "Night demand" collector circuit (left) and the "Day demand" collector circuit (right) at four different points of time: in the morning, after filling the tanks, during day while the collector circuits are operating, in the evening, after the hot water is filled from the "Night demand" storage tank to the "Day demand" storage tank and during night.

Both storage tanks are filled in the morning, but the water of the "Day demand" storage tank is continuously used for feeding the steam boiler, therefore the water level is declining during the day and the tank is refilled, if below a specific level. The measurements show, that the system design is not optimal: in the morning cold water is removed from the bottom and pumped to the boiler, while hot water from the collector field is already at the top of the storage tank, since it is filled in from the top of the tank. Due to the stratification of the different temperature levels of the water, the hot water remains at the top. Only if the entire storage water is circulated through the collector field and mixed, the solar heat is used as feeding water for the boiler.

This example shows, that storage stratification is only worthwhile, if the water is removed at the top of the storage. If it is removed at the bottom of the storage tank, which is necessary in an open system with a varying water level, the hot water inlet socket should be placed at the bottom of the storage tank as well to assure a mixture of the hot and cold water.

Recommendations

Recommendations for the existing solar system

Since the solar system is economically running with a system efficiency of 20% and a simple payback time of 2.5 years, there is no need for changes in the system design. The general recommendation is to assure that the pumps are switched on during sunshine and the refilling of the storage tanks is done properly to get the maximum yield from the solar system.

However, for new solar water heating systems it is recommended to use a different design to achieve a higher system efficiency. This improved system design is described below.

Design optimisation recommendations for new solar systems

As long as the energy demand for hot water heating is much higher than the energy delivered by the solar system (in this case the solar fraction is 11%, see line 11 at Table 1), the separation of the solar system into two collector fields with two storage tanks providing the solar heated water during day from the first and during night from the second collector field is not required and not beneficial. The average increase of the water delivered to the process of the Synthokem SWHS is 9.4°C (line 9 at Table 1), while the process water has to be heated from 27°C (annual average temperature in Hyderabad) to 110°C. If the entire collector field would only pre-heat the water during the day, the water temperature would be increased from 27°C to 46°C (instead of from 27°C to 36°C under the assumption, that the process water demand is the same during day and during night). This temperature level can be provided by the solar system without any problem.

Therefore, the system design could be improved by connecting both collector fields to one water storage tank, which is storing the feeding water for the steam boiler. This would avoid the heat losses of the second water storage tank and the losses caused by hot water remaining in the "Night demand" storage tank if the water is pumped to the other storage tank.

Another design aspect to be improved is the point of connection (height of inlet socket) of the solar circuit to the water storage tank. Since the feeding water for the process is removed at the bottom of the storage tank continuously, a temperature stratification of the water (hot water at the top, cold water at the bottom) is undesired. Therefore, the hot water from the collector circuit should be fed into the tank also from the bottom to mix the water continuously. In addition, an automated refilling device of the storage tank is recommended to assure a sufficient water level in the storage tank.

“Solar water heating system saves fossil fuels. It has twin benefits – reducing operational costs thus increasing profits and improving company’s environment footprint. By SWHS we achieve a temperature rise of 25-30°C in the feed water to boiler. In addition, it is easy to operate and maintain the system. From our experience of using all solar technologies, we strongly recommend to use SWHS for process heat requirements.”

Mr K Laxma Reddy
Vice President (Corporate Operations)
Synthokem Labs, Hyderabad

Citation

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