© AUG 2019 | IRE Journals | Volume 3 Issue 2 | ISSN: 2456-8880

Design of Thermosyphon Solar Water Heating System at Banmaw in Myanmar

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Abstract- This paperfocus on calculating the design ofthermosyphon solar water heating system. One of thepromising options is to make more expensive use of the renewable energy from the sun. The solar energy is transmitted from the sun through space to the earth by electromagnetic radiation. It can be used both directly and indirectly. Myanmar is situated between north latitude 10° and 29°, therefore the solar energy is available through the years. In this paper, Design of Solar Water Heating System has been chosen and designed to use for water heating in domestic. General theory of solar radiation and characteristic of passive solar water heating system are studied in this thesis. The main components of the systems are collector, water tank, and back insulator. The design location is in Banmaw(Latitude 24 15' N, East longitude is 97 36' E) and the elevation above the sea level is 115 m (379 ft). In this thesis, heat load calculation for the designed hot water capacity 40 liters/day and the collector area is 0.64 m2. The outlet temperature for eight from the collector is and the efficiency of the collector is 77% at 1:00 PM. In this paper, calculations are done by using the details of Department of Meteorology and Hydrology (Banmaw).

Indexed Terms- hydraulic power, efficiency, blades number, inner diameter, blade pitch, Distance of jet from center of shaft, Distance of jet from inner periphery of wheel

I. INTRODUCTION OF SOLAR WATER HEATING

Solar water heating (SWH) is the conversion of sunlight into heat for water heating using a solar thermal collector. A variety of configurations are available at varying cost to provide solutions in different climates and latitudes. SWHs are widely used for residential and some industrial applications. A sun-facing collector heats a working fluid that passes into a storage system for later use. SWH are active (pumped) and passive (convection-driven). They use water only, or both water and a working fluid. They are heated directly or via light-concentrating mirrors. They operate independently or as hybrids with electric or gas heaters. In large-scale installations, mirrors may concentrate sunlight onto a smaller collector.

There are four systems in solar water heating system. They are;

1) Active Open Loop Solar Water Heating System
2) Active Close Loop Solar Water Heating System
3) Passive Thermosyphon System
4) Passive Integral Collector Storage (ICS) System

Passive solar water heating systems are popular because of their inherent simplicity and reliability, no pumps or controllers or wiring. Passive systems can be divided into two types: Thermosyphon and Integral Collectors Storage (ICS). Thermosyphon is a method of passive heat exchange, based on natural convection, which circulates a fluid without the necessity of a mechanical pump. Thermosiphoning is used for circulation of liquids and volatile gases in heating and cooling applications such as heat pumps, water heaters, boilers and furnaces. Thermosiphoning also occurs across air temperature gradients such as those utilized in a wood fire chimney or solar chimney.

This circulation can either be open-loop, as when the substance in a holding tank is passed in one direction via a heated transfer tube mounted at the bottom of the tank to a distribution point-even one mounted above the originating tank-or it can be a vertical closed-loop circuit with return to the original container. Its purpose is to simplify the transfer of liquid or gas while avoiding the cost and complexity of a conventional pump.

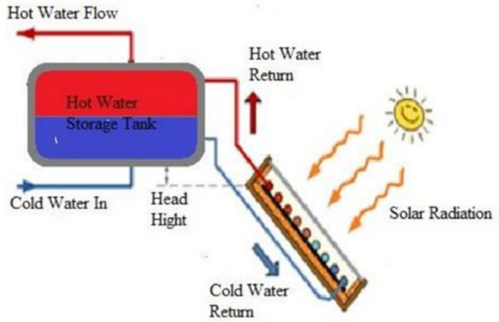


Figure 1. Description of a Thermosyphon Solar Water Heater

II. COMPONENTS OF THERMOSYPHON SOLAR WATER HEATING SYSTEM (PASSIVE SYSTEM)

The components of thermosyphon solar water heating system are;

1) Flat Plate Solar collector
2) Hot Water Storage Tank
3) Insulated Pipe

2.1 Flat Plate Solar Collectors

The FPC-A32 flat plate solar thermal collector is suitable for residential or commercial solar water heating projects. The flat plate collector features a low profile design (80mm / 3.15" profile), which combined with ultra-lightweight melamine foam insulation, makes it one of the lightest flat plate panels per m2 on the market. The TINOX Energy Aluminium absorber sheet absorbs up to 95% of available sunlight converting into usable heat for hot water production. While the basic flat plate design has been around for a long time, and is the most widely used type of solar thermal panel for domestic hot water supply, not all collectors are designed and made alike.

Choice of material and design aspects can greatly affect not only the solar thermal performance but also the reliability when operating in many varied environmental conditions. Apricus has chosen onlythe highest quality materials to ensure reliable, efficient operation and collector longevity. The diagram below shows the basic construction of the collector.

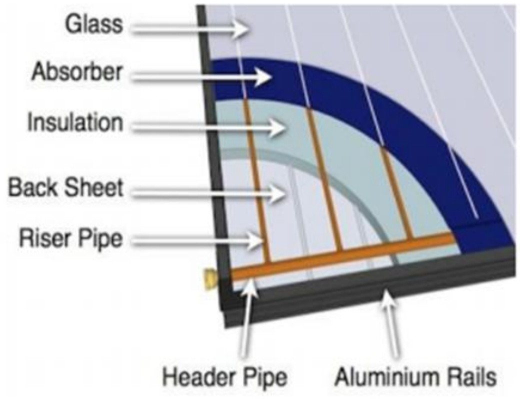


Figure 2. Basic Construction of the Collector

2.2 Hot Water Storage Tank (Stainless Steel Tank)

Solar hot water system normally incorporates a solar hot water tank that stores the solar heated water. Depending on the system design a single tank may incorporate both solar and auxiliary heating (gas, electric etc) or a dedicated solar tank may supply pre-heated water to a second tank that is heated by traditional energy sources.

Tank designs vary somewhat between countries and markets depending on climate, local regulations and system design norms. Apricus is able to supply a range of hot water tanks to suit most domestic application either Apricus branded or using quality local brands where appropriate.

2.3 Insulated Pipe

Insulated pipes are connected between solar collector and hot water storage tank to flow down cold water and to rise hot water. Insulated pipes (called also pre-insulated pipes or bonded pipe) are widely used for district heating and hot water supply. They consist of a steel pipe, an insulating layer, and an outer casing. The main purpose of such pipes is to maintain the temperature of the fluid in the pipes. A common application is the hot water from district heating plants. Most commonly used are single insulated pipes. By using insulated pipe supports, direct heat transfer between pipes and their supports are prevented.

The insulating material usually used is polyurethane foam or similar, with a coefficient of thermal conductivity k=0.033-0.024 W/m-K (thermal conductivity). Outer casing is usually high-density polyethylene (HDPE). Production of pre-insulated pipes for district heating is regulated by the standard EN253. According to EN253:2003, pipes must be produced to work at constant temperature of 130 °C (266 °F) for 30 years, keeping thermal conductivity less than or equal to 0.033 W/m-K. There are three insulation thickness levels.

Insulated pipelines are usually assembled from pipes of 6 meters (20 ft), 12 meters (39 ft), or 16 meters (52 ft) in length, laid underground in depth 0.4–1.0 meter (1 ft 4 in–3 ft 3 in). Efficient working life of district heating pipelines networks is estimated at 25–30 years, after which they need to be replaced with new pipes.

III. DESIGN CONSIDERATION

3.1 Estimation of Clear Sky Radiation

Solar radiation information is needed in several different forms, depending on the kinds of calculations. The effects of the atmosphere in scattering and absorbing radiation are variable with time as atmosphere conditions and air mass change. It is useful to define a standard clear sky and calculate the hourly and daily radiation which would be received on a horizontal surface under those standard conditions.

Hottel (1976) has presented a method for estimating the beam radiation transmitted through clear atmosphere which takes into account zenith angle and altitude for a standard atmosphere and four climate types. The atmospheric transmittance for beam radiation τb is Gbn/ Gon and is given in the form

$\tau_b = a_0 + a_1 \exp(-k/\cos\theta_z)$ (1)

The constants a0, a1 and k for the standard atmosphere with 23 km visibility are found from a0*, a1* and k*, which are given for attitude less than 2.5 km by

$a_0^* = 0.4237 - 0.00821\,(6 - A^2)$ (2)

$a_1^* = 0.5055 - 0.00595\,(6.5 - A^2)$ (3)

$k^* = 0.02711 + 0.01858\,(2.5 - A^2)$ (4)

Where; A is the attitude of the absorber in kilometer. Correction factors are applied to a_0^*, a_1^* and k* to allow for change in climate types. The correction factors $r_0 = a_0/a_0^*$, $r_1 = a_1/a_1^*$ and $r_k = k/k^*$ are given in (Table). The transmittance of this standard atmosphere for beam radiation can be determined for any zenith angle and any altitude up to 2.5 km.

Table 1. Correction Factors for Climate Types

Climate Type	r_0	r_1	r_k
Tropical	0.95	0.98	1.02
Mid-latitude Summer	0.97	0.99	1.02
Subarctic Summer	0.99	0.99	1.01
Mid-latitude Summer	1.03	1.01	1.00
Humid Subtropical	1.08	1.05	1.04

where;

$$G_{on} = G_{sc}\left\{1 + 0.033\cos\left(\frac{360 \times n}{365}\right)\right\}$$

The clear sky horizontal beam radiation is

$G_{cb} = G_{on}\tau_b\cos\theta_z$ (5)

For period of any hour, the clear sky horizontal beam radiation is

$I_{cb} = I_{on}\tau_b\cos\theta_z$ (6)

It is also necessary to estimate the clear sky diffuse radiation on a horizontal surface to get the total radiation. Liu and Jordan (1960) developed on empirical relationship between the transmissions coefficients for beam and diffuse radiation for clear days;

$\tau_d = 0.271 - 0.294\,\tau_b$ (7)

$I_{cd} = I_{on}\tau_d\cos\theta_z$ (8)

$I_c = I_{cb} + I_{cd}$ (9)

$I = I_c \times K_T$ (10)

Temperate;

$K_{Tmax} = 0.6313 + 0.267\overline{K}_T - 11.9\left(\overline{K}_T - 0.75\right)^8$ (11)

Monsoon;

$K_{Tmax} = 0.362 + 0.597\,\overline{K}_T$ (12)

where;

τ_b = transmittance for beam radiation

I_{on} = hourly extraterrestrial radiation

I_{cb} = hourly clear sky horizontal beam radiation

I_{cd} = hourly clear sky horizontal diffuse radiation

I_c = hourly clear sky horizontal total radiation
G_{cb} = clear sky beam normal radiation
τ_d = transmittance for diffuse radiation
K_{Tmax} = maximum clean index
$\overline{K}_T$ = monthly average clean index

3.2 Wind Heat Transfer Coefficient (h_w)

$$Re_L = \frac{VL}{\upsilon} \qquad (13)$$

$$Nu = \frac{hL}{K} = 0.332 \text{ x } Re^{1/2} \text{ x } Pr^{1/3} \qquad (14)$$

$$h_w = \frac{Nu.K}{L} \qquad (15)$$

3.3 Radiation Heat Transfer Coefficient

$$h_{r,c\text{-}a} = \varepsilon_g\, \sigma\, (T_c + T_a)\, (T_c^2 + T_a^2) \qquad (16)$$

3.4 Top Loss Coefficient

The energy loss through the top is the result of convection and radiation between parallel plates.

For one cover system,

$$U_L = \frac{1}{R_1 + R_2} \qquad (17)$$

The resistance to the surroundings R_1 is then given by,

$$R_1 = \frac{1}{h_w + h_{r,c\text{-}a}} \qquad (18)$$

The resistance R_2 can then be expressed as,

$$R_2 = \frac{1}{h_{c,p\text{-}c}} + \frac{L}{K} \qquad (19)$$

A similar expression can be written for R_3, the resistance between the covers. Top loss coefficient (U_t) is,

$$U_t = \left[\frac{1}{h_w + h_{r,c-a}} + \frac{1}{h_{c,p-c}} + \frac{L}{K}\right]^{-1} \qquad (20)$$

3.5 Conduction Heat Transfer Coefficient

Thermal conduction is simply the focus of heat through on object or material. Heat energy can only flow when one point in the material is at a higher temperature than other point. The energy loss through the bottom of the collector is represented by two series resistors, R_3 and R_4, where R_3 represents the resistance to heat flow through the insulation and R_4 represents the convection and radiation resistance to the environment. The magnitude of R_3 and R_4 are such that it is usually possible to assume R_4 is zero and all resistance to heat flow is due to the insulation.

$$U_b = \frac{1}{R_3} = \frac{K}{L} \qquad (21)$$

Where;
K = the insulation thermal conductivity
L = the insulation thickness

3.6 The Useful Energy Gain per Unit Length of Tube

The quantity F_R is equivalent to the effectiveness of conventional heat exchanger, which is defined as the ratio of the actual heat transfer to the maximum possible heat transfer. The maximum possible useful energy gain (heat transfer) in solar collector occurs when the whole collector is at the inlet fluid temperature; heat loss to the surrounding are then at a minimum. The collector heat removal factor times this maximum possible useful energy gain is equal to the actual useful energy gain Q_u. ΔT is the inlet and ambient temperature different.

$$Q_u = L\, [F_R(W - D) + D]\, [S - U_L\Delta T] \qquad (22)$$

$$q_u = \frac{Q_u}{L} = [\, F_R\,(W - D) + D]\, [S - U_L\Delta T] \qquad (23)$$

Where F_R is a collector parameter that accounts for the heat transfer from the absorber surface to the fluid. F_R is called collector efficiency factor or heat transfer factor and is also known by the symbol F'. It depends on the construction of the collector but is practically independent of operating conditions. Typical values for F_R are in the range of 0.8 ~ 0.9 for non-evacuated air collectors, 0.9 ~ 0.95 for non-evacuated liquid collectors, and 0.95 ~ 1 for evacuated air collectors.

Daily efficiency may also be based on the period while the collector is operating. The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the amount of solar radiation striking the collector surface during any period of time. Thus, [09 Joh]

$$\text{Collector Efficiency} = \frac{\text{Solar Energy Colllected}}{\text{Total Solar Striking CollectorSurface}}$$

$$\eta = \frac{q_u}{I_T} = \frac{q_u \times L}{I_T \times A_c} \qquad (24)$$

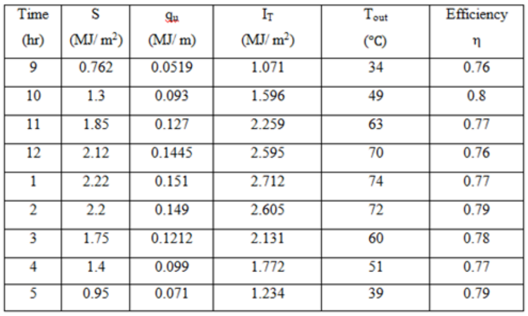
IV. DESIGN RESULTS

Design location = Banmaw, Myanmar
Latitude of location,Φ= 24° 15' N = 24.27°
Longitude of location, L_{loc}= 97° 36' E = 97.2°
Elevation above sea level, A = 115 m
Date of design = 15th January, 2017
Design time= 9:00 AM to 5:00 PM
The local standard time of meridian, L_{st}= 99° 6' E = 99.1°
The solar constant, I_0= 1373 W/m^2
Tilt angle β = 45°
Number of day n=15 (for 15th January)
Wind velocity (Banmaw) v= 1.43 m/s

Table 2. Incident Solar Radiation on 15th January

Time	I	I_d	I_b	R_b	I_T
9	0.542	0.079	0.463	2.1	1.071
10	0.778	0.114	0.664	2.188	1.596
11	1.531	0.225	1.306	1.514	2.259
12	1.828	0.268	1.56	1.448	2.295
1	1.935	0.284	1.651	1.427	2.712
2	1.837	0.27	1.567	1.447	2.605
3	1.256	0.185	1.071	1.774	2.131
4	1.111	0.163	0.948	1.654	1.772
5	0.642	0.094	0.548	2.037	0.981

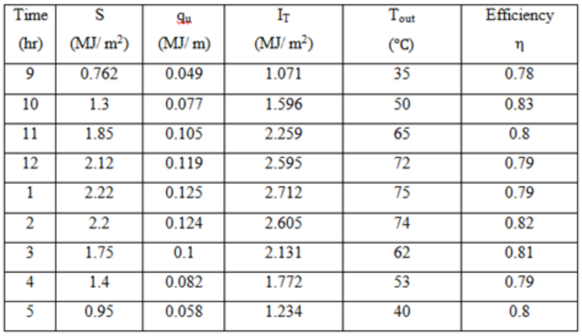
Table 3. The Useful Energy Gain per Unit Length, Outlet Temperature and Efficiency (For 8 pipes)



Time (hr)	S (MJ/ m^2)	q_u (MJ/ m)	I_T (MJ/ m^2)	T_{out} (°C)	Efficiency η
9	0.762	0.0519	1.071	34	0.76
10	1.3	0.093	1.596	49	0.8
11	1.85	0.127	2.259	63	0.77
12	2.12	0.1445	2.595	70	0.76
1	2.22	0.151	2.712	74	0.77
2	2.2	0.149	2.605	72	0.79
3	1.75	0.1212	2.131	60	0.78
4	1.4	0.099	1.772	51	0.77
5	0.95	0.071	1.234	39	0.79

Average temperature outlet, T_0 = 64°C

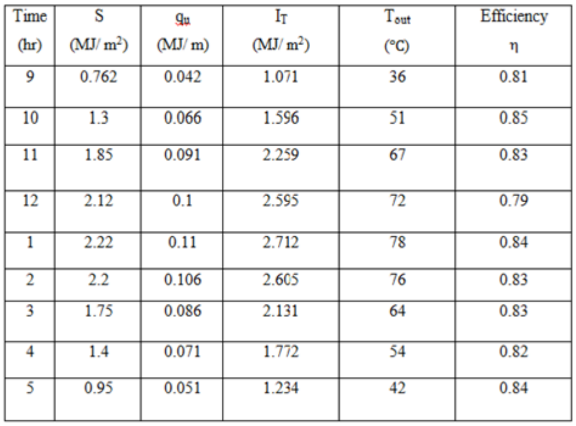
Table 4. The Useful Energy Gain per Unit Length, Outlet Temperature and Efficiency (For 10 pipes)



Time (hr)	S (MJ/ m^2)	q_u (MJ/ m)	I_T (MJ/ m^2)	T_{out} (°C)	Efficiency η
9	0.762	0.049	1.071	35	0.78
10	1.3	0.077	1.596	50	0.83
11	1.85	0.105	2.259	65	0.8
12	2.12	0.119	2.595	72	0.79
1	2.22	0.125	2.712	75	0.79
2	2.2	0.124	2.605	74	0.82
3	1.75	0.1	2.131	62	0.81
4	1.4	0.082	1.772	53	0.79
5	0.95	0.058	1.234	40	0.8

Average temperature outlet, T_0 = 66°C

Table 5. The Useful Energy Gain per Unit Length, Outlet Temperature and Efficiency (For 12 pipes)



Time (hr)	S (MJ/ m^2)	q_u (MJ/ m)	I_T (MJ/ m^2)	T_{out} (°C)	Efficiency η
9	0.762	0.042	1.071	36	0.81
10	1.3	0.066	1.596	51	0.85
11	1.85	0.091	2.259	67	0.83
12	2.12	0.1	2.595	72	0.79
1	2.22	0.11	2.712	78	0.84
2	2.2	0.106	2.605	76	0.83
3	1.75	0.086	2.131	64	0.83
4	1.4	0.071	1.772	54	0.82
5	0.95	0.051	1.234	42	0.84

Average temperature outlet, T_0 = 68°C

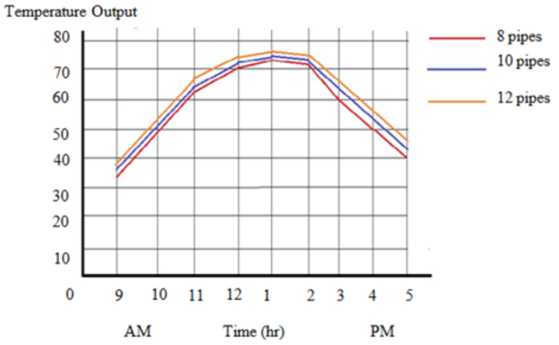


Figure 3. System Temperature Variation for 15th January

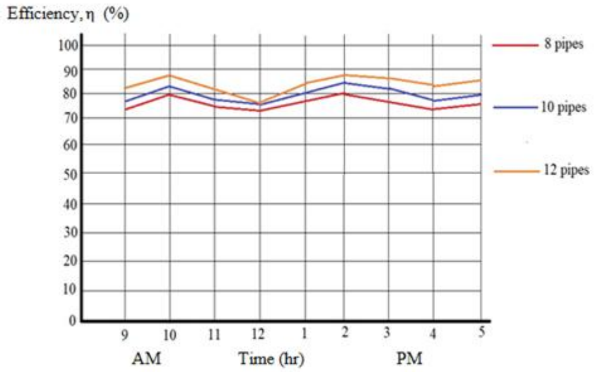


Figure 4. System Efficiency Variation for 15th January

V. CONCLUSION

A solar-powered water heater is a long-term investment that can help us save money and energy for many years. Like other renewable energy systems, solar-powered water heaters minimize the environmental effects of enjoying a comfortable, modern lifestyle at reduced costs because they do not have the hazards introduced by fossil fuels but are environmentally friendly and almost completely running cost free. The system designed in this work requires little or no maintenance because of the thermosyphon principle involved. It was made basically from locally available raw materials. It has no moving parts and almost the entire system works automatically, but there are some procedures to carry out to ensure proper functioning of the solar water heater and thus increase electricity savings:

1) The glass should be cleaned regularly to remove dust and dirt that may have settled on the glass cover which will block the sun rays and will reduce the output of the system.
2) Prevent any shade on the collector. Trim the branches of trees around the collector to allow as much sunlight to reach it.
3) Ensure that there is always cold water supply to the tank and flush out the entire system to remove any floating and settled dirt at least once in a year.
4) The glass seal should be checked from time to time. The following recommendations are suggested to improve on the system:

- A pump can be introduced in the system with the storage tank being at any point below the collector. If this is adopted, the heat removal efficiency will be high. Solar energy can be used instead of electrical energy to power the pump. (2) An automatic gate valve can beincorporated for effective performance, in order to regulate the flow.
- A heat exchanger can be introduced for preheating of inlet water.
- An auxiliary heating system can be incorporated to use when there is virtually no sunshine. These additional features will however increase the overall cost of the system which seeks to minimize.

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