



# Design of Solar Water Pasteurization System with Slow Sand Filtration

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## **Abstract:**

Solar water pasteurization system with slow sand filtration works by integration of filtration unit and pasteurization unit. The system can be utilized in rural as well as the urban areas of the country to produce reliable drinking water source. The filtration unit has layers of gravels and sand, and the pasteurization unit works by use of solar collector utilizing solar energy. The final output water is drinkable by treatment of water pathogens through the integrated units. The use of two systems: Pasteurization unit and Filtration unit independently checks and corrects the flaw of the other to produce clean and pure drinking water. The output water from the integrated system is tested and found to have reduced TDS from 159 mg/l to 137 mg/l, E. coli count from 6 CFU/100ml to 0 CFU/100ml and Total coliform count from 52 CFU/100ml to 0 CFU/100ml. This hybrid system uses solar energy for water pasteurization so it can be utilized effectively for drinking water purposes.

**Keywords:** Water Pasteurization, Filtration, Solar Pasteurization, Slow Sand Filtration

## 1 INTRODUCTION

Globally, in 2012, 89% of people had access to water suitable for drinking. Nearly 4 billion had access to tap water while another 2.3 billion had access to wells or public taps. 1.8 billion people still use an unsafe drinking water source which may be contaminated [1].

Typically in developing countries, tap water meets drinking water quality standards, even though only a small proportion is actually consumed or used in food preparation. Water may also be unacceptable due to levels of toxins or suspended solids. Reduction of waterborne diseases and development of safe water resources is a major public health goal in developing countries[2]. With the various problem of drinking water supply, the perennial solar radiation can be used for the purification. Earth receives  $1.7 \times 10^{17}$  W of total solar power [3]. This solar power can be utilized to produce heating effect. The heating effect is further utilized for water purification. The solar water purification system has huge potential of reducing carbon emissions by avoiding boiling water with firewood or charcoal. The use of solar radiation can be a better option for the purification of drinking water, since the perennial solar radiation contains huge amount of energy, the energy is free, there are no emissions, the running cost is almost null, regular maintenance is very simple and the initial cost can be reduced with the use of locally available materials in comparison to other filters available in the market.

## 2 DESCRIPTION

**Slow Sand Filtration:** Slow sand filtration is a type of centralized or semi-centralized water purification system. A well-designed and properly maintained slow sand filter effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step. Only under the prevalence of a significantly high degree of turbidity or algae-contamination, pre-treatment measures (e.g. sedimentation) become necessary. Slow sand filtration systems are characterized by a high reliability and rather low lifecycle costs. Moreover, neither construction nor operation and maintenance require more than basic skills. Hence, slow sand filtration is a promising filtration method for small to medium-sized, rural communities with a fairly good quality of the initial surface water source. As stated by the WHO, slow sand filtration provides a simple but highly effective and considerably cheap tool that can contribute to a sustainable water management system [4]. In slow sand filtration, water is filtered through about one meter of fine sand. A biological film grows on the top of the sand. This film helps slow sand filtration produce a 2-log reduction in bacteria, viruses, and protozoa. The filtration rate is much slower than that of roughing filters [5].

Straining is the process whereby particles can be removed from water flowing through a sand bed; that is, particles that are too large to fit through the pores between sand grains become lodged and are therefore removed from the

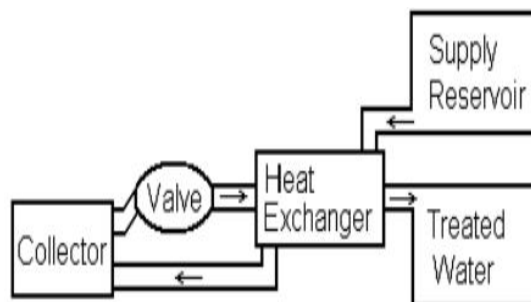
water. Because of the slow flow rates many of the larger solid particles will settle out in the head of water above the sand bed. The water flows so that particles move close enough to a sand grain to become attached. Gravitational forces move particles downwards onto the top surfaces of grains. Particles in a velocity gradient often develop a rotation which provides lateral forces that move particles out of the water stream and into contact with sand grains [6]. Slow sand filters have small flow rates hence most solid particles are removed in the top 0.5 to 2cm of sand. This top layer of sand develops into a biologically active area known as the Schmutzdecke (which translates roughly from German as ‘dirty layer’). While most of the biological activity occurs in this region some activity continues down to a depth of about 0.5m. The biological layer becomes less effective at lower temperatures. When the air temperature drops to below 2°C for any prolonged period the filter should be covered to prevent heat loss or chlorination should be used on the filtered water as a safeguard [6].

**Solar Water Pasteurization:** Pasteurization is the process of heat processing a liquid or a food to kill pathogenic bacteria to make the food safe to eat. The use of pasteurization to kill pathogenic bacteria has helped reduce the transmission of diseases, such as typhoid fever, tuberculosis, scarlet fever, polio, and dysentery [7]. Solar water pasteurization works by pasteurizing water using solar energy that comes in form of irradiance. The pasteurization process is based on the use of one of following time and temperature relationships. *High-Temperature-Short-Time Treatment (HTST)* -- this process uses higher heat for less time to kill pathogenic bacteria. *Low-Temperature-Long-Time Treatment (LTLT)* -- this process uses lower heat for a longer time to kill pathogenic bacteria. Today, many foods, such as eggs, milk, juices, spices and ice cream, are pasteurized. Sometimes higher temperatures are applied for a shorter period of time [7]. The temperatures and times are determined by what is necessary to destroy pathogenic bacteria and other more heat-resistant disease-causing microorganisms [8]. Water from a contaminated supply is heated through a solar collector to the desired pasteurization temperature. Often a flow control valve is used to make sure the water leaving the collector is at the desired temperature. Simple density difference system can also be built to ensure the output flow has reached the desired temperature. Upon leaving the collector the water enters a holding tube. The holding tube is sized to make sure the water stays at an elevated temperature for the desired time. Once the water has been pasteurized it gets collected to the receiver [10]. Solar water pasteurization

in flow through system can be done with solar collector as flat plate collector, vacuum tube collector, etc.

**Flat plate solar collector for pasteurization:** Flat plate collectors are the solar collectors that consist of a flat plate absorber, a transparent cover (glazing) that avoids the heat loss, and air in between the space for heat transport and insulated backing to prevent the heat loss. Flat plate collectors have been used in our world as they are cost efficient and cheaper models when they have to be used in the household purposes where their potential to produce low temperature energy at a minimum cost is regarded as must [10].

**Overview of the System:** Untreated water enters the system from an elevated reservoir. The untreated water is then pre-heated in the heat exchanger by hot treated water. The water then enters the circulation loop where it is heated by flat plate solar collector. Once properly heated, water is flowed over the spill-over and into the holding tube. After flowing through the holding tube, the water re-enters the heat exchanger where it was cooled before entering the treated water reservoir. To reach the treated water reservoir the water has to pass over a secondary spill-over point. Without the secondary spill-over point there would have been no way to keep water in the heat exchanger or the holding tube.



**Figure 1: Basic overview of Pasteurization system**

**Sun Angle:** Depending on the design of the collector, the output may change as the angle between the collector and the sun changes. This is referred to as Incidence Angle Modifier (IAM). Flat plate collectors generally all have the same curves, but evacuated tube collectors and those with reflectors can have very different curves throughout the day. For this reason, it is important to understand and consider the Sun Angle Factor for collectors when doing a comparison [11].

The two types of IAMs are as follows:

- Transversal IAM measures the change in performance as the angle of the sun in relation to the collector changes through the DAY.

- Longitudinal IAM measures the change in performance as the angle of the sun in relation to the collector changes through the YEAR [11].

**Thermosiphon:** Thermosiphon is a method of passive heat exchange, based on natural convection, which circulates a fluid without the necessity of a mechanical pump. Thermosiphon process is used for circulation of liquids and volatile gases in heating and cooling applications such as heat pumps, water heaters, boilers and furnaces [11]. Natural convection of the liquid starts when heat transfer to the liquid gives rise to a temperature difference from one side of the loop to the other. The phenomenon of thermal expansion means that a temperature difference will have a corresponding difference in density across the loop. The warmer fluid on one side of the loop is less dense and thus more buoyant than the cooler fluid on the other side. The warmer fluid will "float" above the cooler fluid, and the cooler fluid will "sink" below the warmer fluid. This phenomenon of natural convection is known by the saying: "heat rises". Convection moves the heated liquid upwards in the system as it is simultaneously replaced by cooler liquid returning by gravity. A good thermosiphon has very little hydraulic resistance so that liquid can flow easily under the relatively low pressure produced by natural convection [10].

### 3 DESIGN OF THE SYSTEM

Table 1: Slow Sand Filtration Unit

SN	Component Description
1	Lid: It is made of the same material as casing and the main purpose is to cover the filter.
2	Level Valve: It maintains the water level not only of the filter but also of the whole system.
3	Water Inlet: Water from the source enters through the inlet to the filtration chamber.
4	Diffuser Box: Box with small holes. It holds the iron nails pieces (Arsenic Removal). Its main purpose is not to disturb the sand layer while pouring the water.
5	Backwashing Gate Valve: The valve is used for backwashing the filter and also when filling up the filter for the first time.
6	Sand: Sand layer of about 40-50 cm is kept, through which the water is purified physically and biologically.
7	Supporting Gravel: Supporting gravel supports the sand so that the sand doesn't flow away with the water.

1. Water Supply Unit: Water supply unit for our water purification system can consist of general water reservoirs used in households made of polyethylene,

concrete, stone, etc. and these water supplies can directly be connected to our purification system.

2. Size and dimensions of filter casing: PVC material is selected for the casing of the filter. Since PVC can't be easily molded to the required size, market available PVC bucket is selected for casing.

Height of the bucket;  $h = 70$  cm,

Circumference of the bucket = 127 cm

Diameter of the bucket;  $d = 40.40$  cm

Cross section area of the bucket;  $A = 1281 \text{ cm}^2 = 0.1281 \text{ m}^2$

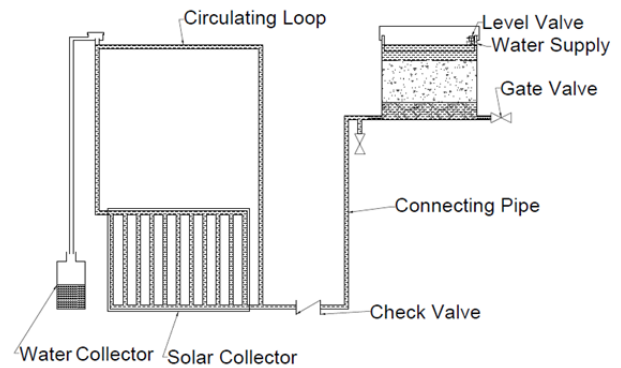


Figure 2: Schematics of water purification system

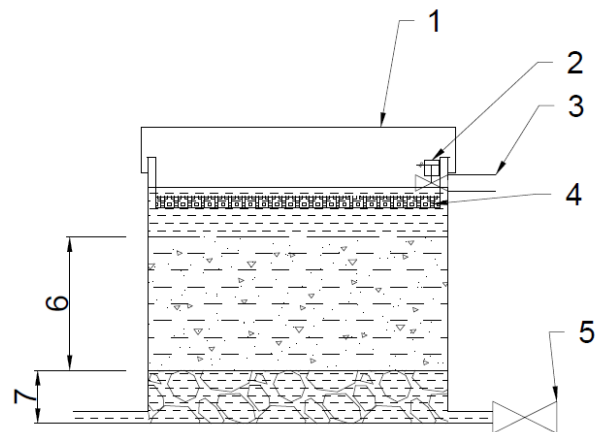
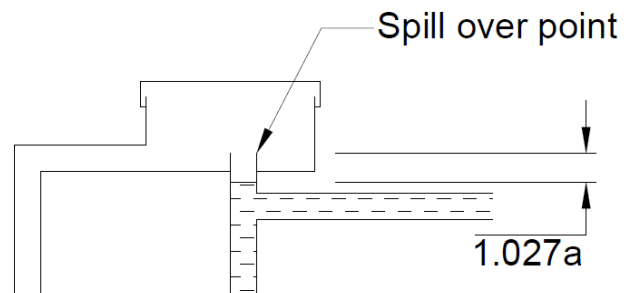


Figure 3: Slow Sand Filtration Unit



Where,  
 $a$  is the total height of the water level from the ground.  
 The spill over height is of 1.027 times the total height 'a' as determined from Thermosiphon Principle.

Figure 4: Schematics of Spill over system

Since, the literature flow rate of the slow sand filter is 100-200 ltr/m<sup>2</sup>/hr [9]. The calculated flow rate of the filter is 12.8 ltr/hr. – 25.62 ltr/hr.

3. Determination of spill over height: Density difference control system is the simple way of controlling the water flow after the desired temperature is reached. For instance, the supply reservoir height is of 100cm, the input water supply is at 20°C with density of 998.2 kg/m<sup>3</sup> and the output is of 80°C with density of 971.8 kg/m<sup>3</sup>. For the given condition the spill over height will be 1.027 (998.2 / 971.8) times the supply reservoir height. That is the spill over height will be of 102.7 cm.

The supply of water can be colder than 20°C, but even if the supply had the average density of 5°C water (1000 kg/m<sup>3</sup>) the treated water will not spill over until it has average density of 78°C (973 kg/m<sup>3</sup>).

4. Calculation of flow rate of the collector: The collector used has useful heat transfer of ( $Q_u$ )= 1145.4375 W [2].

The maximum flow rate of the collector is =  $(3600 \times Q_u) / (S \times (T_2 - T_1)) = 16.357 \text{ Kg/hr}$

Where, S = Specific Heat Capacity

Assumed that, Minimum inlet temp. ( $T_1$ ) = 10°C, Maximum outlet temp. ( $T_2$ ) = 70 °C. The flow rate of the collector is fully dependent upon the solar insolation and doesn't exceed the maximum flow rate calculated.

5. Water collector: The supply to water collector is purified water treated with slow sand filtration and pasteurization process. Water collector has to be uncontaminated from any source so that purified water maintains its purity. Any material that does not contaminate purified water can be used as water collector.

6. Connecting pipes: The connecting pipes must have following properties:

- i. Should not change chemical properties when heated water is passed through it
- ii. Should not contaminate water due to growth of algae
- iii. Must allow uninterrupted flow of water through it

## 4 RESULT AND CONCLUSION

The filter's output was tested with the following results.

SN	Days of Installation	Flow Rate (kg/hr.)
1	1	18.947
2	4	18.54
3	7	19.012
4	11	18.872
5	15	18.725
6	20	18.921
7	25	18.874
8	30	18.549
9	36	18.954
10	43	18.978
11	50	19.1
12	60	18.543
	Average flow rate	18.834

- i. The flow rate of filter was obtained in the calculation range.
- ii. The day 1 of the observation is approximately the 31<sup>st</sup> day of filter installation. There was no drastic change in the flow rate of the filter within the 90 days interval.
- iii. Since, the maximum flow of the collector is always less than the flow of the filter, the flow rate of collector is unaltered by the flow of the filter.

**Table 2: Test results of water samples**

Parameter Tested		pH	Total Dissolved Solids (mg/L)	E. Coli (CFU/ 100ml)	Total Coliform Count (CFU/ 100ml)
Water Sample	1	7.25	159	6	52
	2	-	165	0	42
Filtrate Sample	1	7.25	3	0	124
	2	-	188	10	30
Pasteurized Sample	1	7.25	137	0	0
	2	-	-	-	-

### Test results of Water Samples

Sample 1 (2017/07/31)	Spring Water, Dhulikhel
Sample 2 (2017/08/07)	Tap Water, Kathmandu

- i) The test result for filter is not good enough to conclude that the fabricated filter can be implemented in practice immediately. Thus, the filter can only be implemented with certain correction like introduction of SODIS, cleaner sand and use of rust-free components.
- ii) The result of the imperfection of the filter is corrected by the pasteurization unit, which has eliminated all the Coliform and *E. coli* in the tested samples.
- iii) The Total Dissolved Solids is in the consumable range and the unit fabricated has no role in decreasing/eliminating the Dissolved Solids.
- iv) The pH for all the samples was in the consumable range at the time of testing.

Remarking the result, the fabricated prototype is not applicable immediately and needs certain changes in the system for proper application. Referring the results and the literature, clean drinking water is possible with the Solar Pasteurization System and Slow Sand Filter independently, also if used together the flaw of any of the system can be corrected by the other to have clean and pure drinking water.

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