Performance Test of Substrate Pasteurization using Evacuated Tube Collector Solar Water Heaters

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Abstract: Paddy straw is widely used for oyster mushroom cultivation in Nepal. It is generally pasteurized at 70°C in a metallic drum, cooled to room temperature and packed to small plastic bags before grain spawn is sprinkled. During pasteurization of straw in the drum it is steamed or heated by fuelwood. In this practiced system the heating of the substrate is uncontrollable; that is, non-uniform heating of the substrate leads to develop unwanted fungus in the substrate, which leads to production lost. Besides, the process is labour intensive which increases operating cost. In order to overcome this drawback of present practice it is suggested to use evacuated tube collector solar water heaters to pasteurize the straw with LPG back and raise the temperature to 70°C if needed.

Keywords: Oyster mushroom production, solar pasteurization of substrate, substrate pasteurization

1. Introduction

Mushroom cultivation is relatively new in Nepal. The research for mushroom cultivation began in 1974 under Nepal Agriculture Research Council (NARC). Cultivation of white button mushroom in 1977 was the first mushroom farming done by farmers. Plant pathology division in NARC began distribution of spawn. Oyster mushroom was introduced to farmers in 1984. In the beginning a handful of farmers started this farming in Bhaktapur and Kathmandu districts. After successful production of oyster mushroom, the number of farmers increased to 50. At present there are about 5000-6000 mushroom farmers in Kathmandu alone. The average production is about 8 - 10 tons per day. Pokhara and Chitwan are other major mushroom producing cities. Other districts also produce these two species but in very less amount, barely enough to meet local demand.

Mushroom is a highly nutritious food. Edible mushrooms contain high level of dietary fiber, substantial amount of protein, vitamins and minerals but are low in fat. They also have various properties for health benefits such as antioxidative, antitumour and hypercholesterolic effects (Wong and Cheung, 2001, http://un-csam.org/pub.asp).

According to Dr. Kesharlaxmi Manandhar (2004), Nepali farmers cultivate three different varieties of mushroom: oyster, white button and shiitake. Oyster mushroom cultivation has been very popular among the mushroom cultivator farmers in Nepal. Oyster mushroom cultivation is comparatively easy and less time consuming. The yield per unit of the substrate used is high.

Mushroom farming started in small scale among small farmers. There had been few big producers, such as Snow white mushroom, Himalayan mushroom. They had capacity to produce 5,000 kg per day. But these companies failed to make profit due to high cost of production and eventually closed down. At present, mushroom producers are mostly small farmers, producing 300-500 kg per day and meeting demand so far.

The cultivation methodology has practically not changed since its initial state. The traditional cultivation pattern is getting costlier every day for the cost of raw materials such as firewood/kerosene is increasing every day and the use of these commodities is creating environmental degradation.

The information provided by few oyster mushroom cultivators states that approximately 1 kilogram of firewood is used for the production of one kilogram of fresh mushroom. So, based upon above information to produce 8 – 10 tons of mushroom per day they are burning of 8 to 10 tons of firewood per day, and it is a huge amount of firewood consumption.

1.1 Objectives

The main objective of the research is to develop an alternative device and method of pasteurization of substrate for oyster mushroom cultivation.

The specific objectives are as follows:

a) To identify the existing problems related to substrate (straw) pasteurization technology.

b) To suggest the alternative technology/fuel for substrate (straw) pasteurization for mushroom cultivation.

c) To perform the efficiency of concentrated solar steam/water heater for pasteurizing substrate for mushroom cultivation.

d) To reduce carbon dioxide by replacing firewood based pasteurization process with solar thermal based pasteurization system.

2. Oyster Mushroom Production in Practice

2.1 Existing methodology of mushroom production

The cultivation method for oyster mushroom production using paddy straw in Nepal is as follows. Paddy straw is selected from the field by choosing fresh, not old, clean and straight pieces, of good quality. These straws are manually chopped into small pieces (2-3 inches long) using the locally hand-made chopper. Chopped straw is then soaked in water for 2-4 hours, or sometimes overnight, in a container or a small ditch specially made for this purpose.

The soaked straw is cleansed in water 1-2 times in a plastic bucket or some other container. The water from the straw is drained off in sieve. Most farmers drain the water off slowly by placing the cleansed straw on a sloped place, a procedure that takes 2-4 hours.

The drained straw is then steamed in a steamer. The local steamers are clay pots with a number of holes on the bottom. These steamers are put on top of a metallic vessel containing water. The water is boiled using firewood or kerosene stove. The mouth of the straw steamer is covered with thick plastic sheet and tied up by a string so as to make it tight. It takes about half an hour for the steam to reach the top of the steamer. Once the steam reaches to the top, steaming should be continued for about half an hour or more in order to sterilize the straw. The temperature in this process usually goes beyond 90°C.

Instead of the clay pot steamer, a metallic oil drum can be used. In such cases the metallic drum is filled with water to about 6 inches from the bottom and a tripod stand is used to support the grate. The drum is then filled with straw and covered with a plastic sheet. The steaming method is same as with the clay pot steamer. The steamed straw is cooled down in the same container or transferred into a plastic sack to prevent contamination from outside.

The plastic bags used for making packets are of different sizes: 12"×16" (small) and 18"×26" (large). These bags are punched to make holes at a distance of 4 inches apart. Cooled straw is packed in the bags in layers up to 4 inches deep and grain spawn is sprinkled in layer by layer. Once the bag is filled, mouth of the bag is closed with a rubber band. Incubation proceeds at room temperature for 20-21 days, until the mycelium spreads completely throughout inside the packets.

When the spawn run is completed, the bag is removed by cutting the plastic. The packets are arranged in a row on the floor using a brick or two underneath. Spacing between the packets is 6 inches, with 2 feet between the rows. Watering is done every morning and evening using a sprayer. In dry season, one more spraying of water should be done. Primordia appear after 4-5 days and develop into a full size mushroom within an additional 2-3 days. (http://www.alohamedicinals.com/book1/chapter-2.pdf, http://www.zanaravo.com/PDF/OysterMushroomCultivation-ViktorAndMickey.pdf)

Disadvantages of present practiced method of pasteurization (metallic drum steamer)

The metallic drum steamer (200 liter oil drum presently used to steam rice straw) uses firewood and it is inefficient and polluting. In this practiced system the heating of the substrate is uncontrollable; the uneven temperature distribution of substrate is another factor for production lost due to contamination of unwanted fungi. That is; non-uniform heating of the substrate leads to unwanted development of fungi in the substrate, meaning production lost. The process is labour intensive therefore increases operating cost.

2.2 Flow chart of oyster mushroom cultivation (existing)

The following Figure 1 summarizes the oyster mushroom cultivation. In this research only **substrate pasteurization** is focused and existing practice of pasteurization will be substituted by introducing environment friendly solar steam/water heater for the delivery of hot water.

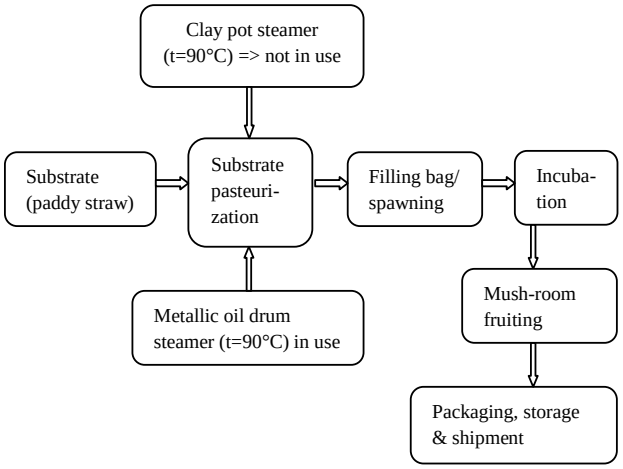

Figure 1: Flow chart of oyster mushroom cultivation

3. Proposed Methodology of Mushroom Production

The substrate materials are sawdust, paddy straw, wheat straw, cottonseed hull, etc. In this study paddy straw will be chosen as in the existing method. The straw has to be pasteurized and it is not necessary to steam the substrate. The ideal temperature for proper pasteurization of the paddy straw is about 65°C. Using hot water bath at 70°C for about forty five minutes will wet the substrate (paddy straw) properly and will destroy the harmful fungi as well. The use of concentrated solar steam/water heater with integrated biomass boiler (as back up) the consumption of firewood can be eliminated during sunny day and carbon dioxide emission is reduced which was produced by burning firewood in inefficient traditional stoves. The remaining process remains the same after pasteurization as in the traditional methodology.

3.1 Proposed substrate pasteurization method

Concentrated steam/solar water heater is used to heat water. The hot water will be used to pasteurize substrate on normal sunny days. In winter period and raining days the solar water heater may not be able to produce hot water of needed temperature above 70 degree Celsius, additional heating will be needed. The biomass boiler will be used to generate hot water of needed temperature which will be added in the pasteurization drum to maintain the temperature of water above 65°C for 30 to 45 minutes (Figure 2). Since the dry substrate will be pasteurized by submersing the substrate in hot water, the heating will be instant and will be homogeneous.

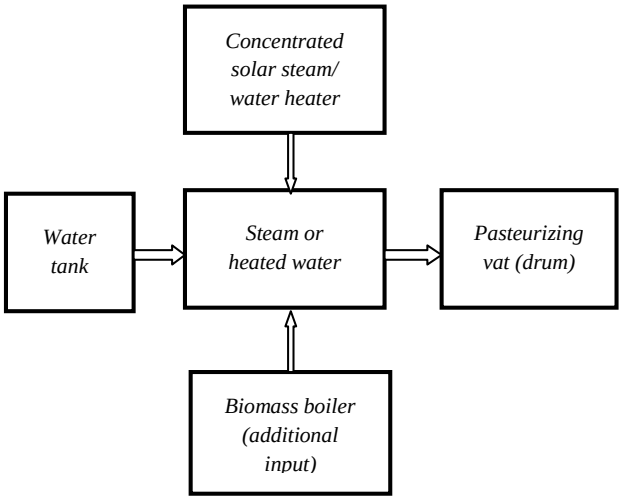

Figure 2: Flow chart of oyster mushroom cultivation

After the installation of set up as proposed in above Figure 2 pasteurization of paddy straw will be conducted and the mushroom fruiting will be waited as mentioned earlier. During the mushroom cultivation process mushroom production will be recorded for comparison. Economic analysis will be performed to determine the feasibility of introduction of concentrated solar steam/water heater for pasteurization of substrate. If it is economically viable the environmental benefit is no question.

4. Results and discussions

4.1 Drawbacks of existing pasteurization system using firewood

At present most of the oyster mushroom cultivators use traditional firewood based cook stove to boil water in the oil drum. The efficiency of these cook stove are not more than 9%, and the steaming drums are not insulated therefore heat lost is high. To maintain continuous constant steam pressure in the pasteurization drum the fire has to burn continuously.

Methodology and device

A 200 liter oil drum is used as steaming vessel. At the 10-15 cm height from the bottom of the oil drum a perforated steel disk is kept and water is filled touching the disk (nearly 10 cm height). Rice substrate is filled in the drum and compacted either in loose firm or packed in sacks and placed in the steaming drum. The drum is heated with firewood burning in the traditional fire stove. Once the steam fills the drum the straw filled drum is covered with jute sack and plastic sheets to make the steam remain inside. Firewood will be further lit for two hours so that steaming process does not stop and the whole straw is heated to steam temperature.

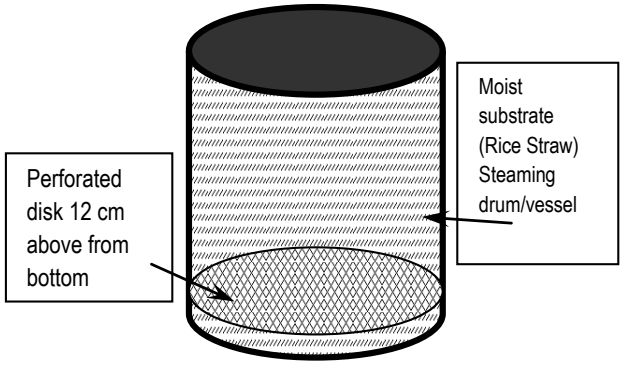

Figure 3: Existing method of pasteurization of rice straw using firewood cook stove

Test results

There is no standard size and shape set in construction of the fire stoves. Different cultivator has constructed the fire stove in their own way to suite their

requirement and the quality of fire woods are also vary from place to place and by the season. Authors' interview with mushroom producers revealed that the average consumption of the fire wood is about two kilograms of fire wood which is needed to pasteurize straw for one bulb of size 26" x 16" (Author's sample survey, 2014).

Quality of pasteurized substrate: uneven temperature is noticed and there exist contaminations etc.

Environmental issues: open fire burning smoke is the major environmental issue. Greater the firewood consumption greater will be the deforestation.

4.2 Substitution of firewood heating by solar thermal

The schematic diagram of equipment set up for pasteurizing substrate using solar water heater with LPG/biomass back up is shown in the following Figure 4. The water pump, cold water storage tank, solar water heaters (vacuum tube) and pasteurization vat (drum) are connected by pipes.

Mercury thermometers are used to measure the temperature of ambient temperature on test day. Hot water temperature T_1 is measured at the outlet tap of hot water tank to pasteurizing vat (vessel). T_2 is the collected water temperature at the vat and is measured by sampling the collected hot water in the vat. The diameter of the pasteurizing drum is 57 centimeter and water volume is measured as function of water level height in the vat (at the measurement height of 5 cm interval equivalent to 12.5 liters.

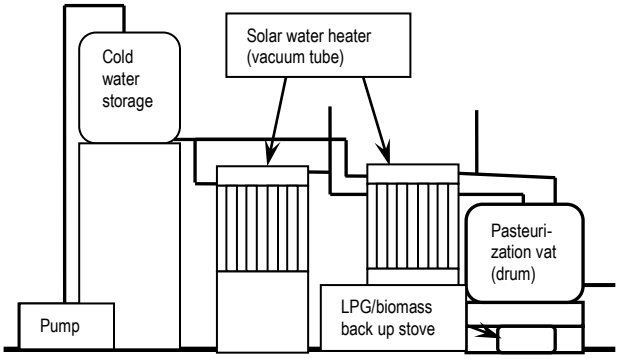

Figure 4: The schematic diagram of equipment set up for measuring water temperature

Test results

The solar water heater used in this program is procured locally available in the market. Two sets of solar water heater are installed to supply hot water for pasteurization. The system consist 1 unit of 140 liter hot water storage tank and 18 units of vacuumed glass tube connected to the storage tank. The storage tank functions as cold feed water tank too. That is, the storage tank is common for hot and cold water storage. Cold water is fed from down and hot water is extracted from top of the tank. The temperature of the hot water at the outlet decreases as the outlet volume increases (Figure 5). It is due to replacement of hot water by cold water in course of time interval. The outlet temperature of the water heater is measured after draining 12.75 liters of water each time and this water is poured into the pasteurization drum and the water temperature of the pasteurization drum is measured. The temperature of water at pasteurization drum varies from 52°C to 47°C when the water level in the drum is raised from 51 liter to 140 liters. The water temperature of drum was found to be 47°C when it was completely filled up. Similar result is obtained from the second solar water heater as shown in Figure 6. The variation in the water temperature in the pasteurization drum is about 6 degree Celsius in both cases.

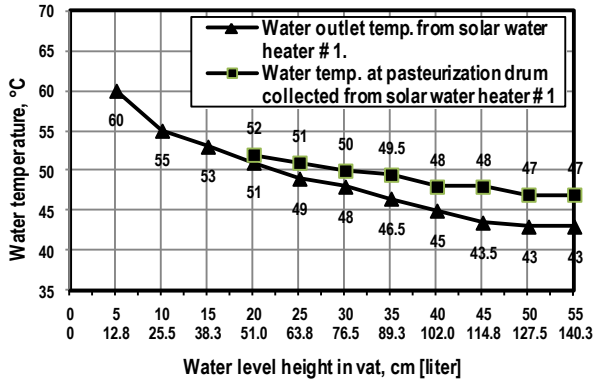

Figure 5: Water temperatures at different level of pasteurization drum from solar water heater 1

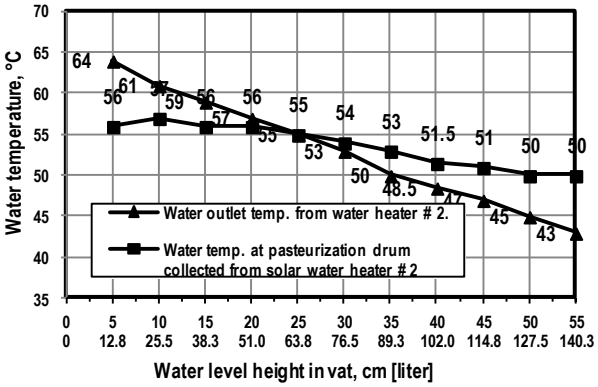

Figure 6: Water temperatures at different level of pasteurization drum from solar water heater 2

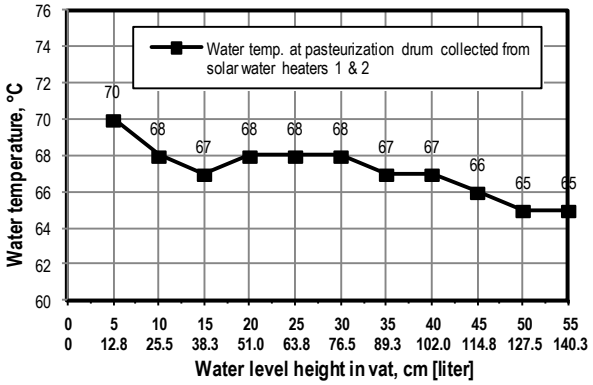

Figure 7: Water temperatures at different level of pasteurization drum from solar water heater 1 and 2 combined

Another test is conducted by collecting the hot water from both the solar water heaters at the same time to the pasteurization drum. The measured water temperature is shown in Figure 7. It is found that the temperature of water in the drum varied from 70°C to 65°C with the increase of volume of water in the drum.

The overall water temperature collected from both heaters at the same time is raised to 65°C when the drum is about to be filled up. The fall in temperature is 3°C in average.

The temperatures of water collected in the pasteurization drum collected from solar water heaters are compared in Figure 8. It has been noticed that the temperature fall in vat is significantly low when the hot water is collected from both solar water heaters in the ratio of 50:50. It is above 3°C. It is advisable to raise the temperature of hot water in the pasteurization drum to 70°C to ensure the proper pasteurization of straw.

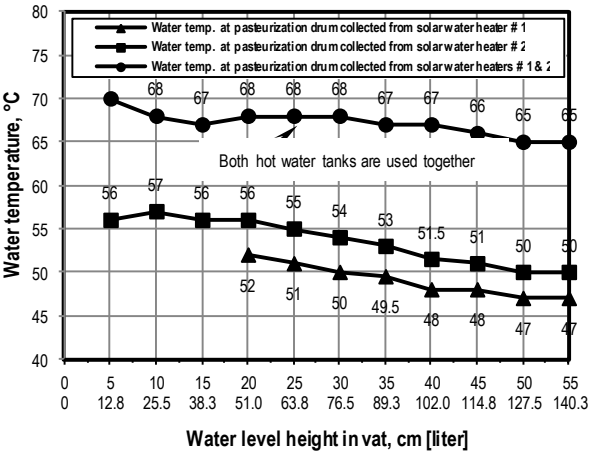

Figure 8: Water temperatures at different level of pasteurization drum from solar water heaters 1, 2 and combined

To meet this requirement LPG is used to raise the temperature of hot water to 70°C for a short duration. It is clear that in the insulated vat the heat lost is minimized by using the solar water heaters in parallel.

4.3 Reduction in production cost (introduction of efficient method of pasteurization).

At present most of the oyster mushroom cultivator practices traditional method of substrate pasteurization; that is steaming the substrate in the drum. Water is boiled by burning firewood. Since the type of firewood burn is not standard quality and the calorific value is difficult to fix. We just know the firewood consumption by weight and the average cost of the firewood.

To calculate the base line for the energy consumption in proposed method of pasteurization, we used locally available LPG gas burner to heat the required volume of water to 71^{o} C.

It can be seen that with the use of solar water heater there is saving of time as well as fuel. The heating time is reduced to one hour from two hours and fuel consumption is saved to 55% in each batch of pasteurization of substrate.

In average, from one batch of pasteurized substrate 7 bulbs of substrate are made and each one of them is put into the plastic bag of sized 16"x26". Each such bag produces in average two kilograms of mushroom and consumes about 2 kg of firewood. Thus, firewood needed to pasteurize substrate for 7 bulbs of each sized of 16"x26" plastic bags will be 14 kg. The average cost of pasteurization of substrate will be NRs 168 per batch at the rate of NRs 12/kg for firewood. The following Figure displays the comparative cost of fuel used for pasteurizing substrate for one batch.

Table 1: Use of LPG to heat the water in pasteurization vat

S. N.	Description	Measured/calculated values	
		With solar water heater	Without solar water heater
1	Ambient temperature, °C	29.32	30
2	Water volume in pasteurization vat (drum), L	139.23	140.28
3	Initial temperature of water in the vat, °C	45.94	21
4	Final temperature of water after heating, °C	68.71	71

5	Temperature of water raised in the vat, °C	22.77	50
6	Heat added to water to raise the final temperature, kJ	13,251.72	29,318.52
7	Time required to raise the final temperature of water, min	63	125
8	LPG used for heating water to final temperature, kg	0.69	1.53
9	Heat generated by burning LPH, kJ (HV_{LPG} = 46MJ/kg)	31.740	70,380
10	Cost of LPG (@1470/cylinder) per batch of pasteurization, NRs	70.46	156.23
11	Efficiency of LPG burner	41.8%	41.7%

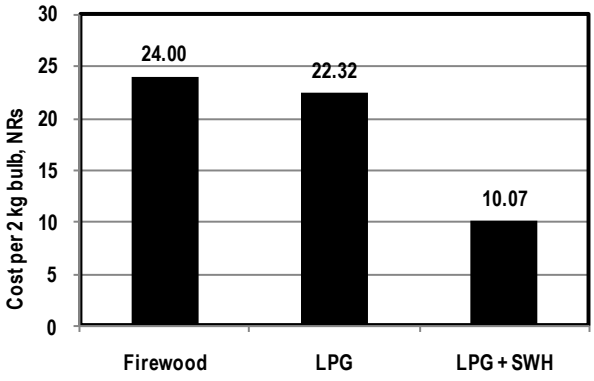

Figure 9: Comparative cost of pasteurization of substrate using different fuels

It can be seen from Figure 9 that the cost of pasteurization of substrate per 2 kg bulb is NRs 24, 22 and 10 for using firewood, LPG and LPG with solar water heater respectively. A significant amount of fuel can be saved if solar water heater is used together with LPG for pasteurization of substrate. This will reduce the cost by 2.2 to 2.4 times provided the day is sunny. The other benefits of using solar water heater are that the heating is uniform and reduces the pasteurization time. In case of using firewood stove someone has to look after it to maintain the constant heating whereas use of LPG stove with solar water heater reduces the constant human labour. Since the substrate is heated uniformly the mushroom production is of better quality with high demand in the market.

Reduction in GHG emissions by use of clean energy source

By substituting the firewood with LPG it can replace 14 kg of firewood in each batch of pasteurization of substrate. Use of LPG conserves firewood and reduces deforestation but it emits harmful emission and reduces national foreign reserves since it has to be imported. For pasteurizing one batch of substrate (14 kg) 1.53 kg of LPG is consumed. That is; it produces about 4.58 kg of CO_2e greenhouse gases in each batch of pasteurized substrate production. From the environmental point of view it is not desirable. So, introduction of solar water heater for pasteurizing substrate reduces the consumption of LPG by 55%. Only 0.69 kg of LPG is used as back up to heat the water to desired temperature. The consumption of LPG is reduced by 2.2 times reducing the GHG emission by 55%. It would have been much better if the required pasteurizing temperature of substrate is met by only using solar water heater. For this a parabolic trough type solar water heater can be used. It is not available in the market and has to be imported. The working temperature of water can be raised to 95°C with 300 liter tank which is enough for pasteurizing substrate of 4 batch equivalent to 28 bulbs per day.

5. Conclusions and recommendations

- Water temperature of the pasteurization drum has significantly increased to 65 to 70°C when the hot water is added from both the evacuated tube collector solar water heaters.
- Use of hot water from solar water heater has reduced the pasteurization time of straw from 2 hours to about 1 hour. It has not only saved the fuel and time but also the labour cost and improved the quality of substrate by minimizing the wastage.
- The cost of pasteurized substrate weighing 2 kg (one bulb) has reduced to NRs 10 when solar water heater with LPG back up is used instead of LPG or firewood alone for heating the substrate.
- The greenhouse gas emission has also reduced significantly since very little LPG is used.
- It is recommended to use parabolic trough type solar water heater instead of evacuated tube collector solar water heater in order to achieve higher working temperature to eliminate the use of LPG or fuelwood at all.

Acknowledgment

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