Design and Development of Solar Autoclave

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Abstract

Objective: To design and develop cost effective solar panel and autoclave for steam sterilization of medical equipment and disposal of hospital waste using solar energy. Methods/Analysis: An attempt has been made to design and develop an autoclave to sterilize the medical instruments by generating the steam in a vessel using the environment friendly solar energy. For this purpose, the solar parabolic trough for generating steam and a vessel which can be used as an autoclave for steam sterilization by subjecting the equipment and tools and medical waste to steam at 121°C for 15 minutes have been designed using low cost material. Findings: The vessel reached the maximum temperature of 132°C and pressure 15 PSI for more than 15 minutes. The desired outcome of temperature and pressure required for sterilization was achieved with 3 litre aluminium pressure vessel after making modifications in its safety valve. The combined cost of all the materials used in fabrication of parabolic trough and its trolley and modification of the vessel for conducting all the experiments is Rs.30,000/- approximately. The design can be further improved by identifying the optimum size of the vessel and modifying the safety valve. Novelty/Improvement: An ordinary pressure cooker has been converted into an autoclave and the solar parabolic trough developed is also of low cost. The whole set up designed is of very low cost and can be effectively used in remote areas.

Keywords: Autoclave, Evacuated Tube, Heat Pipe, Manifold, Parabolic Trough, Sterilization

1. Introduction

In developing countries, public health care is an important and critical issue. One of the important requirements of health care is sterilization of medical equipment and treatment of hospital waste. The most common sterilization is with the help of steam generated in a device called autoclave powered with electricity. The use of equipment which is not properly sterilized increases the risk of spread of infection, rather than controlling it.

With the global warming and scarcity of fossil fuels, the use of renewable sources of energy is becoming very important as they are environment friendly. As a result, researches are being conducted all over the world towards development of renewable and non-conventional sources of energy and related technologies. A solar autoclave is one such technology that uses only solar radiation. It can also provide remote health clinics with an inexpensive and efficient way to sterilize medical equipment. It can be easily used in regions across the globe in need of sterile medical equipment, with ample amounts of sunlight to power the solar autoclave. Apart from this, the excess heat generated can also be used in heating the water used in clinics/hospitals.

The efficacy of solar-thermal powered autoclave for wet sterilization of medical instruments in off-grid settings has been tested where electric power is not readily available and it was found that 100% efficiency was achieved for steam sterilization when the temperature was more than 121°C for 30 minutes. The compact solar-steam autoclaves in two different set ups have also been tested; one for sterilizing medical and dental equipment and another for sanitizing human waste and it was found that the heat and pressure generated by the steam killed...
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Even the most heat-resistant living microbes, spores and viruses.\(^2\)

Another design of solar autoclave was tested in Central Africa and sterilizing the medical equipment to temperatures greater than 121\(^\circ\)C for at least 15 minutes was proven successfully. It took on an average 40 minutes to reach steady-state temperature and pressure when the autoclave is effectively sterilizing the medical equipment contained inside the pressure vessel.\(^3\) An attempt was also made to design a portable solar collector so as doctors can easily transport solar autoclaves with them to rural areas where there is no electricity. However, the desired power output could not be achieved and the design, currently, depends on non-solar power sources also to properly operate the autoclave.\(^4\)

Another attempt has been made to generate steam from solar influx, using a cylindrical parabolic concentrator, at required parameters for sterilization purposes in the autoclave. The exit temperature of 125\(^\circ\)C for a mass flow rate of 0.22 x 10\(^{-3}\) kg/s was obtained and it was concluded that the mass flow rate through the panels can be suitably increased with panels arranged in parallel.\(^5\) Another manual method is to produce a closed parabolic trough solar energy collector box based on the elasticity of the material to make high efficiency solar collectors against very low cost, particularly suited for teaching, research or demonstration purposes.\(^6\)

A sunflower configuration for solar autoclave suitable for use at any altitude has also been designed. The unit designed is lightweight, portable and less costly. The size of the reflectors might be increased for quicker heating or for large size autoclaves. It can process three runs on a sunny day. However, in gusting wind, a single reflector blew away occasionally.\(^2\)

Thus, various researchers all over the world have tried to find ways to use solar energy for sterilization purpose. For this, many designs of solar autoclave have been developed but so far, there is no commercially viable design. An attempt has been made in this study to design and develop cost effective solar autoclave as well as solar panel.

### 2. Objective

The objective of the present study is to sterilize the medical instruments and medical waste by generating the steam in a container using environment friendly solar energy.

For this purpose, the following items were designed to achieve the above mentioned objective:

1. Cost effective solar panel to use the solar energy for generating steam.
2. Low cost vessel which can be used as an autoclave for steam sterilization by subjecting the equipment and tools to steam at 121\(^\circ\)C for 15 minutes.

The steam so generated can be used for many purposes. One important use of the steam is to sterilize medical waste and medical instruments. The apparatus so designed can be used for this purpose in a cost effective, environment friendly and least hazardous manner at any location where sunlight is abundant.

### 3. Methodology

Parabolic Trough was designed and fabricated using Evacuated Glass Tube Collector with heat pipe in it. The Parabolic Trough was fabricated using wooden parabolic frames made of plywood of 10 mm thickness. These wooden parabolic frames were joined together with aluminium angles and screws. The anodized aluminium sheet of 0.4 mm thickness was used as a reflector sheet. The ETC Tube of 58 mm diameter and 1800 mm length with copper heat tube was used as a collector. This heat pipe is positioned in evacuated tube with the help of aluminium fin inside the evacuated tube. The concentration ratio of Parabolic Trough is about 17. The area of Parabolic Trough is 1 m x 1.6 m = 1.6 m\(^2\). The focal length of focus balanced Parabolic Trough is 183 mm. The cross section of Wooden Parabolic Reinforcement is 10 mm x 100 mm. Seven such Wooden Parabolic Reinforcements were used to make the Parabolic Trough. This trough is mounted on a trolley for shifting and easy manual orientation.

The performance of a parabolic trough solar collector is dependent on its concentration ratio and its optical efficiency. This parabolic trough solar collector uses a reflective sheet to reflect and concentrate sun radiations towards a receiver tube located at the focus line. The receiver absorbs the radiations and transforms them into thermal energy. It is then transported by a fluid medium circulating within the heat pipe of the receiver tube. This method of concentrated solar collection has the advantage of high efficiency and low cost.

After developing the trough for solar energy, the experiments were conducted to generate the steam. The
experiments were conducted in four different setups. The setups have been explained below:

3.1 Setup 1
The first setup consists of 10 Litre aluminium autoclave with copper manifold and solar parabolic trough with evacuated glass tube collector. A small size manifold as shown in Figure 1, of 60 ml was used in order to increase the response time for generating the steam. The water from the reservoir enters the manifold through inlet pipe. The steam is generated in the manifold by the heat pipe of evacuated glass tube. The steam then goes to 10 litre aluminium pressure container through the outlet pipe.

Figure 1. Copper Manifold fitted on the heat pipe of evacuated tube with inlet and outlet pipe.

The lid of the pressure vessel is fitted with pressure gauge, safety valve and thermocouple for measuring the temperature inside the vessel. Before starting the experiment, the vessel is filled with 1.5 Litres of water. The temperature in this vessel did not reach beyond 79°C because the steam generated in the manifold started flowing back towards the inlet reservoir resulting in loss of heat and steam. The PVC inlet and outlet tubes of the manifold also got melted due to the heated manifold.

3.2 Setup 2
The second setup consists of 10 Litre aluminium autoclave (without manifold) and solar parabolic trough with evacuated glass tube collector. In this experiment, manifold is eliminated. Instead, the Aluminium Pressure Vessel is modified and fitted with a copper tube of 14 mm inside diameter closed at one end. There is 10 mm clearance between the tube and base of the vessel. This tube fitted in the vessel as shown in Figure 2 is submerged in the water.

Figure 2. Closed end copper tube fitted in the vessel.

The Heat Pipe condenser is directly fitted in this vessel tube, as shown in Figure 3a and 3b, to transfer heat which in turn heats the water in the vessel for generating the steam.

Figure 3a. The pressure vessel directly mounted on the heat pipe of the evacuated tube and the evacuated tube mounted on the focal line of parabola.

Figure 3b. The pressure vessel directly fitted with the heat pipe of the evacuated tube and the evacuated tube mounted on the focal line of parabola.
Before starting the experiment, the vessel is filled with 1.50 litre of water.

The lid of the pressure vessel is fitted with pressure gauge, safety valve and thermocouple for measuring the temperature inside the vessel. The temperature in this vessel could not reach beyond 90°C because the small amount of steam was continuously leaking from the safety valve and the heat loss occurred in the environment from the vessel surface.

3.3 Setup 3

The third setup consists of 3 Litre aluminium autoclave (without manifold) and solar parabolic trough with evacuated glass tube collector. Since the desired temperature could not be achieved in 10 litre vessel, therefore, a smaller aluminium vessel of 3 litres was considered for carrying out the experiment.

![Figure 4. Safety valve covered with polyethylene tape and tied with a thread; the lid fitted with thermocouple and 3M Steam Indicator Tape also pasted on the inner surface of the lid.](image)

The ’Prestige’ pressure cooker with outer lid of 3 litre capacity was selected and modified. It was fitted with a copper tube closed at one end. This tube fitted in the vessel is submerged in the water. The Heat Pipe condenser is directly fitted in this vessel tube to transfer the heat which in turn heats the water in the vessel for generating the steam. Before starting the experiment, the vessel is filled with 750 ml of water. The lid of the pressure vessel is fitted with pressure gauge, safety valve and thermocouple for measuring the temperature inside the vessel. In this case, the temperature in the vessel could not reach beyond 119°C and stabilized at that level due to continuous leakage of steam from the safety valve.

3.4 Setup 4

The experiment done in setup 3 was carried out again with modifications that the safety valve which is fitted on the lid of the vessel as shown in Figure 4, is covered with polyethylene and adhesive tape on it. Further, it was tied with the thread so that the release of steam from the safety valve is restricted. In this case, the temperature in the vessel reached to 124°C and 128°C within a span of 70 minutes on different days.

When the vessel was covered with woollen cloth, the temperature reached to 132°C and pressure to 15 PSI in 80 minutes. The temperature above 121°C was achieved for more than 15 minutes as shown in Figure 5.

4. Results and Discussion

1. All the experiments were conducted using the same parabolic trough. The desired temperature and pressure was achieved after modifications in the design of pressure vessel. This indicates that the parabolic trough designed is effective for generating steam for sterilization.
2. Better results were achieved with elimination of manifold from the design.

![Figure 5. Temperature and Pressure inside 3 Litre Autoclave.](image)
3. However, the expected results could not be achieved with 10 litre aluminium pressure vessel even after elimination of manifold due to leakage of steam from the safety valve.

4. The desired outcome of temperature more than 121°C and pressure 15 PSI for sterilization was achieved for more than 15 minutes with 3 litre aluminium pressure vessel after making modifications in its safety valve.

5. The combined cost of all the materials used in fabrication of parabolic trough and its trolley and modification of the vessel for conducting all the experiments is Rs.30,000/- approximately.

6. Scope for Further Research

The pressure vessel of capacity 8.5 litre is being designed and is in advance stage of fabrication. In this design, the closed end copper tube which is fitted in the vessel in Setup Number 2, 3 and 4, is eliminated and the heat pipe is directly fitted with the vessel. This will improve the efficiency of heat transfer.

Also, the vessel with spring loaded safety valve is being fitted in place of the present dead weight safety valve so that the steam does not leak in the environment before the desired pressure and temperature is achieved in the vessel.

7. Conclusion

The temperature of autoclave reached to 132°C and pressure above 15 PSI in 80 minutes and was above the desired temperature of 121°C and pressure 15 PSI for more than 15 minutes, required for sterilization. The restricting of release of steam from the safety valve has played a crucial role in increasing the temperature and pressure to the desired level.

Thus, with simple modifications in the aluminium pressure cooker, the cost effective and environment friendly autoclave can be commercially designed for use in areas where sunlight is abundant and where initial and operating cost of an autoclave is a major factor.

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9. References

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