Solar Autoclave for Rural Areas

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Concept Generation

Document

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INTRODUCTION

Certain developing areas around the world have limited availability to sterilized medical equipment. In developing countries across the planet, people are unfortunately being treated with unsanitary tools, which cause greater harm than good. In most cases, the countries that cannot sterilize properly also cannot obtain electricity or natural gas for a traditional autoclave. A solar autoclave uses the renewable energy of the sun to sanitize medical equipment by building pressure to allow super heating of steam to kill bacteria. Clients could range from actual licensed practicing doctors, to qualified men and women in developing countries that work at a remote health clinic. The goal is to create a solar autoclave that can be easily used at these clinics in rural areas around the world.

CONCEPT GENERATION

The initial phase of the solar autoclave project included generating ideas for each of the major component of our design. Five components were identified, and include:

- Thermal Capture
- Heat Transfer into Fluid
- Maintaining High Pressure
- Insulation
- Thermal Storage

Thermal Capture

For solar thermal capture, there are three main designs that are used for efficiently harnessing the power of the sun. A parabolic trough, dish, and Fresnel lens all focus the radiation of sun to a single focal point. Focal points are different depending on the size and shape of the mirror or lens. Having a mirror or lens with a larger area than the pressure vessel and focusing the energy to a smaller point allows the system to reach and maintain the required temperature to superheat the steam at 121˚C.

Parabolic troughs, shown in Figure 1, focus heat onto a long cylinder of fluid which lies parallel to the trough at the focal point. These require a large area to operate. Parabolic dishes, shown in Figure 2, use a circular mirror to focus the heat onto a container held at the focal point. These are effective if used correctly and also require a large area. Both parabolic dishes and troughs can be made from a mosaic of smaller mirrors, allowing them to be made cheaper than a single mirror. Finally, a Fresnel lens uses concentric rings over a plastic lens. These rings are all manufactured to focus light to one location: the focal point. Since the amount of heat and radiation is intensified at this point, the rate of heat transfer is dramatically higher. This process takes a larger surface area of thermal collection than our pressure vessel, and focuses the heat onto that vessel, heating the system. Fresnel lenses can be found in rear projection televisions. Usually made from plastic, these lenses are lighter, cheaper, and more durable than mirrors. A downfall of lenses is that they act as a filter and can absorb some of the energy. For this application, this may or may not be a factor. A major problem with Fresnel lenses is their availability in remote countries. Locating one of these lenses or the flat panel televisions they are removed from may be difficult, if not impossible. A Fresnel lens is pictured in Figure 3. All three of these options offer feasible ways to capture the sun’s energy and are under consideration for our finial design.

Figure 1 - Parabolic Trough

Figure 2 - Parabolic Dish

Figure 3 - Fresnel lens

Heat Transfer into Fluid

Another important part of the solar autoclave is how the heat will transfer into the fluid. This is essential to the design because if heat cannot transfer into the fluid, steam cannot be created, and therefore the autoclave will not work.

In heat transfer, fins or fin arrays are used in order to heat or cool objects more effectively. Because of this, our team considered using an array of fins that would be directed internally, resting inside the container holding our fluid. If this container were placed at the focal point of a Fresnel lens or parabolic trough, all the light and heat would be directed toward it, and it would begin to heat up. Once the heat conducted to the fins, it would then convect into the liquid, heating it more rapidly. A fin array can be seen in Figure 4.

Figure 4 – Fin Array

Regardless if fins are present, having the container or boiler at the focal point is critical. Thus, it is undecided if additional effort will be needed outside of the absorption process to magnify the heat transfer rate.

Maintaining High Pressure

For an autoclave to work, a high pressure is required in addition to high temperature. The constraints are a temperature of at least 121^{o}C and a pressure of at least 2.05 bar for a minimum of 15 minutes. During the process, the medical equipment will sit in a pressure vessel and saturated steam will kill the bacteria, creating sanitary medical equipment. In order to achieve this high pressure, our team considered using a pressure vessel, seal the lid, and then clamp or screw down the lid. Pressure vessels can be copper pipes, in the case of troughs, cooking pots, for the case of dishes, or even an old pressure cooker, which can be seen in Figure 5 below. A combination of these different pressure vessels can be used with a boiler design as well. Maintaining high pressures and high temperatures are essential to the function of the device, thus this is one of the most important parts of the autoclave. Unfortunately high stresses develop on the inner surface of the pressure vessel and must be considered. The stress analysis for the pressure vessel will be detailed within the engineering analysis section of the report.

Figure 5 - Example of a pressure vessel **Figure 6** - Metal Clamp

An additional consideration for our design regarding pressure is the hose line from the fluid container to the pressure vessel. This hose can be composed of multiple types of materials depending upon what is available for the specific region. Several options for this hose line include:

- Copper pipe
- Garden Hose
- Radiator Hose

The disadvantages of using a copper pipe are that bends in the pipe would contribute to head loss. Also, a garden hose may not be able to withstand the interior pressure. Therefore, a radiator hose is most likely the best option.

Insulation

The purpose of insulation in the autoclave is to retain heat as efficiently as possible to temperatures greater than 121°C. The insulation must work well enough to maintain the sterilization temperature and pressure over an extended period of time while maintaining its shape by not deforming under high temperatures.

A great insulator for an autoclave would be NASA's Thermablok Aerogel, which can be seen in Figure 9. Thermablok Aerogel has a phenomenally low thermal conductivity of 0.014 $\frac{W}{mK}$. Unfortunately, obtaining this material is difficult. The cost is high, and it could possibly take months to acquire. Furthermore, because Thermablok Aerogel is so hard to obtain, it would be impossible for remote clinics to obtain any surplus, in case any needed to be replaced. Other options for insulation include typical household insulation and various other natural and manufactured insulations listed below:

- Clay-coated straw
- Mineral Wool
- Styrofoam
- Fiberglass
- Phenolic Foam
- Liquid Cement
- Cork

Figure 7 - Fiberglass

Figure 8 - Mineral Wool

Figure 9 - Thermablok

These materials are easy to obtain, especially in certain developing areas. Also, these are all much cheaper, which is another factor to consider when choosing insulation. A well-insulated system would work efficiently and reduce the amount of time it would take to reach the required temperature.

Thermal Storage

Solar thermal energy can be stored in an energy reservoir for later use. Thermal storage can save cost as well as deal with the intermittency of the sun. There are two forms of thermal storage: sensible heat storage and latent heat storage. For sensible heat storage, energy can be stored by raising the temperature of the storage medium. Likewise, latent heat storage works by altering the physical state of the storage medium. Latent heat storage is more effective and results in a high solar collection efficiency compared to sensible heat storage. Energy can be stored under isothermal conditions in relatively small volumes using phase change materials. Examples of this include molten salts, as seen in Figure 10, sand, and packed beds of metallic spheres. An insulated hot thermal storage tank can be used to hold the phase change material where the energy can be stored with minimal energy losses.

Figure 10: Molten Salts

CONCLUSION

After weighing the importance of the particular elements of the solar autoclave project, a few elements of the project stand out. The thermal capture and heat transfer into the fluid are the most important functions the solar autoclave must perform. Without these two functions, the autoclave will not reach the necessary temperature and will fail to sanitize the medical equipment inside. A close second is the autoclaves potential to maintain its high pressure. This pressure is essential to the sanitation process as it condenses the steam into a superheated vapor allowing the medical equipment to sanitize quickly. Insulation and thermal storage are other functions of the solar autoclave, but have been established as less important. Thus in designing our autoclave, our team must focus on the capture and transfer of heat as well as the pressure and attempt to include substantial insulation and a thermal storage device.

The next stage of our project is the engineering analysis of the autoclave. In this step we will focus on the properties of the materials and the thermal equations of the heat transfer and solar capture. It is our continuing goal to produce a working autoclave that meets and exceeds Team 6’s and our Sponsor Dr. Brent Nelson’s expectations.

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Sponsor:

Dr. Brent Nelson

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APPENDICES

APPENDIX A: Decision Matrices

Judgment of Importance	Numerical Rating
Best Option	1
	2
Worst Option	3

Figure 11: Numerical rating

Thermal Capture Design Options	Criteria	Column1	Column2
	Reliability	Cost	Flexibility
Parabolic Dish	2	2	3
Parabolic Trough	1	1	2
Fresnel Lens	3	1	3

Figure 12: Thermal capture decision matrix

Insulation Design Options	Criteria	Column1	Column2
	Weight	Cost	Thermal Conductivity
Aerogel	1	3	1
Mineral Wool	2	1	3
Fiberglass	2	1	2

Figure 13: Insulation decision matrix

Judgment of Importance	Numerical Rating
Extremely more important	**9**
	8
Strongly more important	**7**
	6
Moderately more important	**5**
	4
Slightly more important	**3**
	2
Equally important	**1**

Figure 14: Numerical rating

Column1	Thermal Capture	Heat Transfer into Fluid	High Pressure Maintenance	Insulation	Thermal Storage
Thermal Capture	1	1	.5	.2	0.11
Heat Transfer into Fluid	1	1	.5	0.25	0.11
High Pressure Maintenance	2	2	1	0.17	0.11
Insulation	5	4	9	1	.2
Thermal Storage	9	9	9	5	1
Total	18.00	17.00	19.00	6.42	1.33

Figure 15: Pairwise comparison matrix

Column1	Thermal Capture	Heat Transfer into Fluid	High Pressure Maintenance	Insulation	Thermal Storage	Overall Importance
Thermal Capture	0.06	0.06	0.03	0.03	0.08	0.26
Heat Transfer into Fluid	0.06	0.06	0.03	0.04	0.08	0.26
High Pressure Maintenance	0.11	0.12	0.05	0.03	0.08	0.39
Insulation	0.28	0.24	0.47	0.16	0.15	1.29
Thermal Storage	0.50	0.53	0.47	0.78	0.75	3.03

Figure 16: Overall importance matrix

APPENDIX B: Gantt Chart

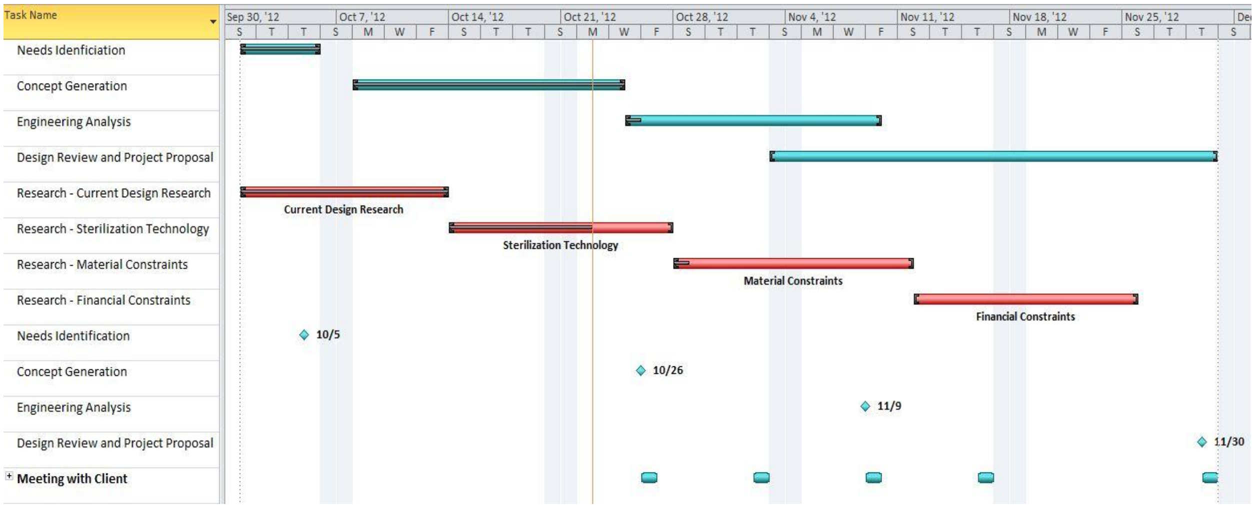

Figure 17: Gantt chart