Abstract— In general, surgical instruments and medications that enter an already aspetic part of the body (such as the blood stream, or penetrating the skin) must be sterilized to a high sterility assurance level. An autoclave is a device used to sterilize medical equipment. While there are many sterilization techniques available, the preferred method for this project is steam sterilization. In this process, water is raised to its boiling point (Steam) is generated at a temperature higher than 100°C. In fact, In order to fully eliminate all prions and bacteria associated with disease, saturated steam needs to be at least 121°C when in contact with the equipment being sterilized. Currently, many electrical autoclaves are being used. These autoclaves are usually electrically powered and use computers to monitor the internal temperatures and pressures. Unfortunately, many developing/under developed countries around the globe do not have the technology available to operate these types of autoclaves. As a result, nurses and doctors at remote health clinics in these rural areas are continually challenged with the decision to operate with unsanitary equipment, risking the spread of infection. A solar autoclave provides an alternative solution to this problem. Using only solar radiation, a solar autoclave can be an aid in remote health clinics as its inexpensive and efficient way to sterilize medical equipment. The main concept of this project is to utilize the available solar influx in Visakhapatnam and using a cylindrical parabolic concentrator to produce steam of required parameters for sterilization and the steam is utilized in the autoclave.

Keywords— cylindrical concentrator, concentrating collectors, steam sterilizer of medical instruments.

I. INTRODUCTION

Renewable sources of energy seem the obvious direction in which to devote efforts, since non-renewable energy can be very expensive and thus of particular concern for developing countries. Fossil fuels produce pollution which in turn has been linked to serious health problems. In contrast, solar energy produces no fumes, does not leave any kind of by product and is considerably cheaper than the fossil fuels. Since fossil fuels are non-renewable, there is a need to switch to renewable energy which is independent of the grid, particularly in the sterilization of medical equipment.

Using solar energy the investment costs are reduced and low power consumption. Burning of fossil fuels introduces many harmful pollutants into the atmosphere and contributes to environmental problems like global warming and acid rain, solar energy is completely non-polluting and the only land that must be destroyed for a solar energy plant is the land that it stands on. Indeed, if a solar energy systems were incorporated into every business and dwelling, no land would have to be destroyed in the name of energy. Solar energy can be used for power generation using solar panels. Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors, they can do so only when direct sunlight is available. The mirrored surface focuses sunlight collected over a large area onto a smaller absorber area to achieve high temperatures. Some designs concentrate solar energy onto a focal point, while others concentrate the sun's rays along a thin line called the focal line. The receiver is located at the focal point or along the focal line. These collectors reach much higher temperatures than flat-plate collectors. However, concentrators can only focus direct solar radiation, with the result being that their performance is poor on hazy or cloudy days. Concentrators are most practical in areas of high insolation (exposure to the sun's rays), such as those close to the equator and in the desert southwest United States.

Concentrators perform best when pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun. Single-axis trackers move east to west; dual-axis trackers move east and west and north and south (to follow the sun throughout the year). In addition to these mechanical trackers, there are passive trackers that use freon to supply the movement. While not widely used, they do provide a low-maintenance alternative to mechanical systems. Some residential solar energy systems use parabolic-trough concentrating systems. These installations can provide hot water, space heating and water purification.
Most residential systems use single-axis trackers, which are less expensive and simpler than dual-axis trackers. Although there are number of concentrating collectors available to collect solar radiation, for the solar autoclave a parabolic trough is considered as a clear choice for the following reasons.

1. The main advantage of concentrating collectors is that high temperatures can be attained due to concentration of radiation.
2. Efficiency of parabolic collectors is about 50-70%.
3. Parabolic collectors have concentration ratio up to 5-30 and temperature range of 150°C to 300°C. Because the temperature attainable with parabolic collector is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator system.
4. The absorber area of the concentrator system is smaller therefore the insolation intensity is greater.

II. DESCRIPTION OF THE PROBLEM

Concentrating collector for sterilization:

The main objective of the present work is to consider few design aspects of parabolic concentrator to sterilize the medical instruments. In order to kill the bacteria associated with it the required steam temperature is 121°C for complete sterilization. Already in many hospitals electrical autoclaves are used for sterilization of medical instruments but electrical autoclaves are expensive and power consumption is more. In order to save power, a renewable source of energy is used instead of electricity. The renewable source of energy is solar energy from sun. Plenty of solar radiation is available in India so this energy is utilized to generate steam for sterilization. The monthly average of solar radiation in Visakhapatnam is estimated and the total average of all the months during an year is estimated for further analysis to design parabolic concentrator.

The cylindrical parabolic collector also called parabolic concentrator is one of the best known commercially available solar concentrators and has been extensively both experimentally and theoretically. It consists of a parabolic reflector an absorber copper tube and a glass cover surrounding absorber. Water from the water source is allowed to flow into the absorber, a control valve is provided to control the flow of water. The cylindrical parabolic reflector focuses all the incident sunlight onto absorber tube placed along its length in the focal plane.

Fig 1 : Cylindrical Parabolic concentrator with autoclave for sterilization.
The water inside the absorber tube slowly gets heated up and converts into steam at the outlet and the steam produced is then passed through the pipe into an autoclave containing the medical equipment for complete sterilization in order to kill the bacteria associated with it. The steam, being less dense than the air within the chamber, slowly pushes the air out of the valve located at the bottom of the autoclave. Evacuating the air creates a better environment to sanitize the equipment. The valve should be closed once it begins discharging steam. After the valve is closed, the pressure begins to rise and therefore the temperature. The pressure and temperature will continue to rise in the absorber tube, and in turn the autoclave. This process will continue for at least 15-30 minutes until the equipment is safe for medical purposes. Reaching 121 °C is the goal for obtaining sterility, but this temperature must be maintained for a certain time span in order to guarantee every piece of equipment is clean and safe to use. Using insulation can help to retain heat and minimize heat loss. The thin walls of the autoclave and the pipe are two crucial places where heat will try to escape. The table below lists a variety of materials with low thermal conductivity. Materials with a low thermal conductivity will maximize the thermal resistance preventing heat loss.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Thermal conductivity of insulating materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSULATION MATERIAL</td>
<td>THERMAL CONDUCTIVITY, K VALUE W/mK</td>
</tr>
<tr>
<td>Thermablok Aerogel</td>
<td>0.014</td>
</tr>
<tr>
<td>Balsa Wood</td>
<td>0.048</td>
</tr>
<tr>
<td>Cork</td>
<td>0.07</td>
</tr>
<tr>
<td>Cork,regranulated</td>
<td>0.044</td>
</tr>
<tr>
<td>Fibreglass</td>
<td>0.04</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.04</td>
</tr>
<tr>
<td>Styrofoam</td>
<td>0.033</td>
</tr>
<tr>
<td>Corkboard</td>
<td>0.043</td>
</tr>
</tbody>
</table>

III. CALCULATING MONTHLY MEAN SOLAR GLOBAL RADIATION PER YEAR:

Estimation of average solar radiation:

The monthly average values of extraterrestrial radiation, \( H_0 \), can either be found by averaging the values of \( H_0 \) for the entire month where \( n \) is the day of the year. Values of \( n \) considered during a year = 1,32,61,92,122,153,183,214,244,275,305,335

\[
H_0 = \frac{24}{\pi} \ln \left(1 + 0.33 \cos \frac{360}{365} n \right) \left( \cos L \cos \delta \sin \omega + \omega \sin L \sin \delta \right) \tag{1}
\]

Hour angle: The hour angle \( \omega \) is the angle through which the earth must turn to bring the meridian of point directly in line with the sun’s rays.

The sunset hour angle in degrees is given as,

\[
\cos \omega = -\tan L \tan \delta \tag{2}
\]

The latitude and longitude angles for Visakhapatnam are,

**Latitude (\( \phi \)):** The latitude of a location is the angle made by the radial line joining the given location to the centre of the earth with its projection on the equatorial plane

Latitude – 17\(^\circ\).42\(^\circ\)N

**Longitude:** It is the angular distance of the location measured east or west from the prime meridian.

longitude – 83\(^\circ\).18\(^E\)

**Declination angle:** The angular displacement of the sun from the plane of the earth’s equator is termed as the declination of the sun, \( \delta \) is given by the equation below.

\[
\delta = 23.45 \sin \left[ \frac{360 \times (284 + n)}{365} \right] \tag{3}
\]

**Sun rise hour angle:** is at the time of sunrise or sunset, the zenith angle is equal to 90\(^\circ\) and the sunrise hour angle is given by the equation below. \( \cos \omega = -\tan L \tan \delta \tag{4} \)

CALCULATING \( H_o \) FOR ALL THE MONTHS IN AN YEAR,

\( H_o \) is the average monthly insolation at the top of the atmosphere and is calculated by the equation 1 and from the table below it is observed that the maximum heat gain is in the month of July it is 44,474.17kJ/m\(^2\)-day.
Table 2

<table>
<thead>
<tr>
<th>Month</th>
<th>Heat gain data (kJ/m²-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN</td>
<td>32177.074</td>
</tr>
<tr>
<td>FEB</td>
<td>33355.53</td>
</tr>
<tr>
<td>MAR</td>
<td>35518.71</td>
</tr>
<tr>
<td>APRIL</td>
<td>38548.308</td>
</tr>
<tr>
<td>MAY</td>
<td>41411.47</td>
</tr>
<tr>
<td>JUNE</td>
<td>43246.15</td>
</tr>
<tr>
<td>JULY</td>
<td>44474.17</td>
</tr>
<tr>
<td>AUG</td>
<td>41776.63</td>
</tr>
<tr>
<td>SEP</td>
<td>38988.524</td>
</tr>
<tr>
<td>OCT</td>
<td>35900.74</td>
</tr>
<tr>
<td>NOV</td>
<td>33504.69</td>
</tr>
<tr>
<td>DEC</td>
<td>32249.28</td>
</tr>
</tbody>
</table>

The monthly average solar horizontal solar radiation \( H_{avg} \) was given by angstrom, which is

\[
H_{avg} = \frac{H_x}{H_o} = \left( a + b \frac{S}{2} \right) \quad (5)
\]

Where a and b are arbitrary constants,

\[H_{avg} \approx 24,229.650 \text{ kJ/m}^2\text{day}\]

The useful energy is given as

\[Q_u = m C_f (T_{fi} - T_{ni}) \quad (6)\]

\[m = 0.22 \times 10^{-3} \frac{\text{kg}}{\text{sec}}, \quad C_f = 4.184 \frac{\text{kJ}}{\text{kg}^0\text{C}}\]

\[Q_u = 0.22 \times 10^{-3} \times 4.184 (125 - 30) \Rightarrow 0.08376 \text{ kJ}\]

\[Q_u = 83.76 \text{ J} \]

The calculated useful energy is 83.76 joules and \( H_{avg} \) is 281.2 J/m²-sec.

**Design Aspects Of Cylindrical Parabolic Concentrator:**

Design of a cylindrical parabolic concentrator considered using the calculated useful energy is 83.76 joules and the radiation absorbed by the receiver is calculated as 281.2 J/m²-sec for Visakhapatnam area with these values further analysis to design parabolic concentrator is performed.

The Hottel Hiller Bliss equation developed for performance evaluation of flatplate

\[Q_u = A_e f_g \left( \frac{H_a}{A_a} - \frac{A_r u_L (T_{ni} - T_a)}{A_a} \right) \quad (7)\]

Collector can also be used for concentrating collectors.

Where \( Q_u \) is the useful energy gain per unit aperture area.

\[A_a = \text{Aperture area}\]

\[T_{ni} = \text{Inlet fluid temperature}\]

\[T_a = \text{Ambient temperature}\]

\[H_a = \text{Radiation absorbed by the receiver}\]

\[T_{ambient} = 27, T_{ni} = 30, H_{avg} = 281.2 \frac{J}{\text{m}^2 \text{-sec}}\]

\[A_a = \text{Aperture area}\]

\[T_{ni} = \text{Inlet fluid temperature}\]

\[T_a = \text{Ambient temperature}\]

\[H_a = \text{Radiation absorbed by the receiver}\]

\[T_{ambient} = 27, T_{ni} = 30, H_{avg} = 281.2 \frac{J}{\text{m}^2 \text{-sec}}\]

The collector efficiency factor \( F^1 \) is given as

\[F^1 = \frac{1}{1 + \frac{D_{abs,o}}{D_{abs,i} + D_{abs,l}} + \frac{D_{abs,o} D_{abs,l}}{2k}} = 0.99 \quad (8)\]

Where \( k \) is the thermal conductivity of the absorber tube material.

For a tubular absorber with inside diameter \( D_{abs,i} \) and outside diameter \( D_{abs,o} \) having \( h_{ni} \) the convective heat transfer coefficient between the absorber and tube.

Overall heat loss coefficient \( U_L \) from the tube to fluid is given as,

\[U_L = \frac{Ar}{A_c (h_c + h_{r,c-a} + h_{r,c-a} + h_{r,c-a} + h_{r,c-a} + h_{r,c-a})} + \frac{1}{h_{r,c-a} + h_{r,c-a} + h_{r,c-a} + h_{r,c-a} + h_{r,c-a} + h_{r,c-a}} \]

\[h_{r,c-a} = \text{Radiation heat transfer coefficient between cover and ambient air}\]

\[\Rightarrow E_g c (T_{g} + T_{a}) + g^2 + T_{g}^2\]

\[= \frac{8.877W}{m^2 K} \quad (10)\]
h_{r-c} = \text{Radiation heat transfer coefficient between absorber tube and cover tube.}

\Rightarrow \sigma (T_{abs}^2 + T_g^2) / (1+\varepsilon_{abs}) + \frac{Ar}{Ac} [(1+\varepsilon_g) - 1] = 104.74 \text{ W/m}^2\text{k}

\text{(11)}

Glass thermal conductivity = 0.8 W/mK
Thermal conductivity of copper absorber tube = 401 W/mK

Procedure to estimate dimensions of solar panel:

Water inlet temperature to the solar collector is assumed to be 30°C as the average ambient temperature in Visakhapatnam is around 30°C and absorber surface temperature is assumed to be 125°C for the required steam parameters of 121°C.

The heat removal efficiency factor, \( F_g \) is defined as the ratio of actual gain to the gain if collector surfaces were at the inlet temperature.

The heat removal efficiency factor, \( F_g \) is given as

\[
F_g = \frac{m c_f}{A_{abs} U_L} \left[ 1 - e \left( \frac{-A_{abs} U_L F^1}{m c_f} \right) \right]
\]

\( = 0.988 \) \text{ (12)}

Where \( m \) is fluid mass flow rate and \( F^1 \) is the collector efficiency factor and

\( A_{abs} \) = absorber area

\( U_L \) = overall heat loss coefficient

Substituting all the calculated values in the equation below, Aperture area is calculated.

\[
Q_u = A_{a} F_g \left( H_a - \frac{A_r}{A_a} \times U_L (T_h - T_a) \right)
\]

\( A_{a} = 0.30 \text{m}^2 \)

Where \( A_a \) is the unshaded projected area of the reflector system which may be smaller than the total aperture area and \( r \) is the radius of the parabola.

\( D \) is the aperture diameter, \( D = 2 \times r = 382.16 \text{m}^2 \)

Formula of Sector is given as,

\[
r \times 0 = 0.30
\]

\( r = 191 \text{mm} \)

The focal length of the parabola \( f \), is related to rim angle \( \theta_r \), and aperture diameter \( D \) is given as,

\[
D = 4 f \tan (\theta_r/2) \Rightarrow 270.148 = 4 f \tan 22.5, \quad f = 163.02 \text{ mm}
\]

The above parameters are estimated to determine aperture area required to achieve a steam outlet temperature of 125°C.

IV. RESULTS AND DISCUSSION

The required temperature for complete sterilization of medical instruments is 121°C and for a given mass flow rate of 0.22 \( \times 10^{-3} \) kg/sec, the dimensions of the parabolic concentrator panel are estimated and found satisfactory for the given conditions.

Dimensions of the parabolic reflector are estimated as follows,

Area of the absorber tube, \( A_{abs} = 0.363 \text{m}^2 \)

Area of the glass cover, \( A_g = 0.383 \text{m}^2 \)

Inside and outside diameter of the absorber tube, \( D_{ai} = 0.038 \text{m} \) and \( D_{ai} = 0.034 \text{m} \)

Inside and outside diameter of the glass cover, \( D_{go} = 0.04 \text{m} \) and \( D_{go} = 0.038 \text{m} \)

Length of the tube, \( L = 3.048 \text{m} \)

Aperture area, \( A_{a} = 0.30 \text{m}^2 \)

Focal length, \( F_l = 1.63 \text{m} \)

Radius of the parabola, \( R = 191 \text{mm} \)

Aperture diameter, \( D = 270.01 \text{mm} \)

The graph plotted between average heat gain during any part of the year indicates that the maximum heat gain is in the months from April to September. So, for the major part of the year solar influx is available and this energy can be utilized to generate steam for sterilization.

![Fig. 2: Average heat gain data in kJ/m² per day in a year](image-url)
The graph plotted in between the declination angle in degrees during any part of the year, the declination angle is found to follow sinusoidal form reaching a peak value in June-July of the year.

Temperature profiles in absorber tube:

Temperature profiles in a absorber tube are analyzed using ANSYS package with inlet temperature of water 30°C and outlet temperature of steam 125°C. ANSYS is a general purpose software, used to simulate fluid dynamics and heat transfer aspects for engineers. So ANSYS, was used to simulate tests according to the working conditions, to test in virtual environment.

Fig 4 reveals the uniform surface temperature in the absorber tube with inlet temperature of 30°C and exit temperature of 125°C. Fig 5 describes the temperature variation along the length of the absorber tube in which the inlet temperature of the water is 30°C and along the length of the absorber tube the temperature is found to increase till the exit with an exit temperature of 125°C.
V. CONCLUSION

With the estimated data of average global solar radiation at Visakhapatnam, it is found analytically that with the available solar influx for major part of the year, it is possible to generate steam at required parameters for sterilization.

Temperature profiles are analyzed using ANSYS package at inlet and exit of the absorber tube. The temperature profiles are found to increase at the exit and the exit temperature is $125^\circ$C for a mass flow rate of $0.22 \times 10^{-3}$kg/s.

But as the mass flow rate is an important criteria, mass flow rate through the panels may be suitably increased with panels arranged in parallel.

REFERENCES