MODIFIED SOLAR COLLECTOR ANNEXED WITH RESIDENTIAL SOLAR COOKER

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ABSTRACT

In this modernized world, energy is the major prerequisite for the ballgame of equipments without which man cannot survive. Solar energy is very abundant and everlasting comparable to all other energies. Scientists and researchers are still being inquired to harness the full potential of the solar radiation. By focusing sunrays to a point or line, lavish amount of heat energy is generated which is used for the cooking purpose. The predicament of solar cooker is that cooking has to be taken place under direct sunlight and absence of night time cooking. Recent developments are in progress to make possibility of residential solar cooker. This paper eliminates the predicaments of residential solar cooking in night time and also increases the efficiency of cooking by introducing vacuum tubes for better heat absorption and insulation. Phase change materials (PCM) are used for better heat storage medium as a backup for night time cooking. Factors like energy requirement, processing time, design for heat ex-changers, volume of PCM required, mass flow rate of water etc., are considered to design the system for a domestic house. Finally, this solar cooker can be the substitute for all other cooking systems and mainly reduces pollution because of LPG, kerosene, wood etc., which is used as a cooking fuel.

Keywords: Solar energy, Vacuum tubes, Phase change materials, Reduces pollution, Night time cooking, Designing the system.

I. INTRODUCTION

Energy is strewn all over the world whose ubiety is very immense. Man has perpetually yearned to capture it and utilize it for humans. The necessity of energy escalates from day to day but legion of the fossil fuels and conventional fuels fire up to extinct. Most of the relic fuels are consumed for the cooking purpose. Cooking using solar energy is the peerless surrogate for tackling LPG demand if its efficiency is aggrandized and it also has zero pollution. Its hefty advantage is that the rays of sun are very intensive and it has the adequacy to do any work but it relies upon the way
and effectiveness by which energy is extracted. At beginning box type, panel types, paraboloidal type of solar cookers are used, but these cookers are not successful. This is because of the predicaments to cook under direct sunlight and also the absence of solar energy at night time which made us to rely on other conventional cooking systems. There is also variety of appliances which inputs heat energy but the major detriment is that it has only low efficiency and sluggish processing. This paper primarily focuses on residential solar cooker with night time backup by means of vacuum tube crammed with phase change materials. The intention for choosing black layered vacuum tube is that it absorbs heat energy by incident solar irradiation, that travels through the vacuum jacketed glass tube and it traps the infrared radiation in solar rays. These trapped radiations are converted to heat energy. This heat energy does not travel through vacuum expect radiation losses. But this radiation loss is negligible due to small temperature difference. Hence in vacuum tubes the absorbed heat energy will not be transmitted to the atmosphere. The entire heat cannot be utilized at once and so heat storage medium is obligatory.

Phase change material is the most admirable heat storage medium compared to other resources because it delivers the stored latent heat energy at a particular (constant) melting point temperature. The efficiency of the solar cooker is significantly amplified by means of the design and placement of vacuum tube along with phase change material. This design not only heats the cooker efficiently but also stores the heat for the future usage. The cooker is enclosed by jacket where hot water or steam is circulated for cooking the food. The small tank is sited next to the cooker for the condensation of wet mixture of water vapour because no pump will handle both liquid and vapour phases. The circulation of water procures higher temperature for the food to cook and phase change materials stores the heat for the time in the absence of solar irradiation.

II. DESCRIPTION
Cooking is vital and it has to be done in all places. Energy required for this operation is only from either LPG or electricity. Troubles will be faced in the production of both LPG and electricity. The effective cooking is also done by the alternative resources like solar energy which is explained below. The intact unit consists of vacuum tubes, phase change materials, cooker surrounded by the jacket, small tank, insulated tubes and parabolic collector. The system is designed with the assumptions of 5 persons in a domestic house. The vacuum tubes of size 124 mm diameter are filled with phase change material within that copper tube arrangements are made. The two vacuum tubes are positioned in either side with a centre cube of phase change materials. The intent for choosing PCM is that it has superior latent heat storage. The volume of phase change material is calculated. According to the pondered volume, phase change materials are crammed in two vacuum tubes and excess PCM is placed inside the insulated cubical box at the centre. The cubical box is chosen as it has lower value of surface area to volume (SA/V) ratio compared to other standard shapes. Hence heat loss will be minimum at the night time. The copper tubes are placed inside the vacuum tube which is bent for greater surface contact and to enhance the better heat transfer and water is promulgated inside the copper tube. This entire setup is positioned in the line focus of the parabolic collector. The area of parabolic collector is calculated by considering available solar irradiation per unit area and the energy required. Seven coils of copper tube are to be found for better surface area contact in the cube of phase change material located in the centre. The small tank is sited next to the cooker for condensation of the wet mixture. A pump is also built-in for the circulation of water and it completes one cycle. The temperature of water increases aggressively and it cooks the food in the cooker. If this system is erected in the universe, we can easily face the LPG and electrical power demand. By eliminating the usage of LPG, we can control the carbon emissions in large quantity.

III. WORKING

The entire arrangement works by utilizing heat from the solar irradiation and the efficiency relies upon the effective ways which harness the full potential of the sun. The parabolic collector is selected for the rationale of obtaining line focus in it. The parabolic collector reflects sun rays and converge it into a line where the vacuum tube packed with phase change material is positioned. Copper tubes are mounted inside the phase change material. The water as a working substance is circulated inside the copper tube which absorbs the heat extracted by the vacuum tube. In between the vacuum tube, cube of PCM is located which is well insulated from the surroundings which also
plays an effective role in heat transfer. Hot water is transferred to the cooker by insulated pipes to eliminate transmission heat loss. Due to the solar irradiation, water gets heated up in step by step process. This hot water is made circulated through the jacket in the cooker. The small tank is sited next to the cooker for the condensation of the wet mixture of water vapour. A pump is used to drive the system of fluids. A valve is fitted for the adjusting of mass flow rate of water. This mass flow rate will controls the cooking temperature. If the mass flow rate is higher, it obtains lower cooking temperature and vice versa. This system surely meets the demand of LPG and power consumption and it also reduces pollution.

IV. CALCULATION

Assumptions
1) It is assumed that 7L cooker is suited for 5 people in a house
2) The cooking food is considered to be water
3) The location for cooking is chosen to be Madurai, Tamilnadu, India
4) It is assumed that maximum final temperature of the food is 130-150°C
5) Parabolic collector to be designed for PCM to attain maximum temperature of 160°C
6) Optimum melting point of PCM is 120°C
7) Time required to cook food during night time is assumed to be 1½ hours

1. Energy required to cook food
   Volume of the Cooker V = 0.007 m³
   For water,
   Density = 1000 kg/m³
   Mass m = 7 kg
   Specific heat (at constant pressure) \( C_p = 4.187 \text{kJ/kg K} \)
   Initial temperature of food \( T_A = 30°C \) (room temperature)
   Maximum final temperature of food \( T_B = 130°C \)
   Temperature difference \( dT = 100°C \)
   Required heat energy \( Q = m * C_p * dT \)
   \[ Q = 7 * 4.187 * 100 \]
   \[ Q = 2930.9 \text{kJ} \]

2. Time for backup
   Due to absence of sunlight during night time cooking,
   let maximum time required to cook during night time = 1½ h

3. Temperatures
   Maximum Cooking temperature \( T_1 = 150°C \)
   Maximum temperature of PCM \( T_2 = 160°C \)

4. PCM selection
   Required melting point of PCM = 120°C
   Name = S117
   Melting point = 117°C
   Density \( \Box = 1450 \text{kg/m³} \)
   Latent heat \( L = 160 \text{kJ/kg} \)
   Specific heat capacity \( C_p = 2.61 \text{kJ/kgK} \)
   Thermal conductivity \( k = 0.7 \text{W/mK} \)
5. **Mass of PCM**
   Heat energy required to boil 1L $q = 291.14$kJ
   By experiment,
   Time taken to reach boiling point of water = 20 min
   For 20 min energy supplied = 291.14 kJ
   Let us assume backup time $t = 1 \frac{1}{2}$ h
   For $1 \frac{1}{2}$ h energy required $Q = 1310.13$ kJ/L
   For 7 L,
   Total energy required $Q = 9170.91$ kJ
   $Q = m \times L$
   $m = Q/L$
   $m = 57$ kg

6. **Design Calculation**
   Available vacuum tubes diameter
   
<table>
<thead>
<tr>
<th>S.No</th>
<th>Diameter (mm)</th>
<th>Volume occupied by PCM (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>124</td>
<td>25</td>
</tr>
</tbody>
</table>

   Mass of PCM occupied in single vacuum tube (124mm dia) $m_1 = 25$ kg
   Mass occupied by copper pipe in single vacuum tube $m_2 = 5$ kg
   Difference in the mass $dm = 20$ kg
   Mass of PCM that can be filled in a single vacuum tube = 20 kg
   By placing 2 vacuum tubes i.e., No. of vacuum tubes $n = 2$
   Total mass of PCM that can be filled in vacuum tubes = 40 kg
   Total mass of to be filled to get $1 \frac{1}{2}$ h backup = 57 kg
   Remaining volume of PCM = 17 kg
   17 kg of PCM can be filled in a cube of side 23 cm
   Copper pipe is coiled in that cube of PCM

7. **Design of coil**
   **Assumptions**
   ✓ Copper pipe diameter $d = 12$ mm
   ✓ Coil diameter $D = 150$ mm
   ✓ Free gap $G = 10$ mm
   ✓ No. of turns $n = 7$
   ✓ Secondary Length of the coil $l = 100$ mm
   • Total length of the coil,
     $$L = n \times ((2 \times \pi \times r) + G) + (2 \times l)$$
     $$L = 53$$ cm
8. Mass of CO$_2$ emission by LPG

LPG contains 70% propane and 30% butane.
The chemical reactions are

Propane:
\[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

Butane:
\[ 2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O} \]

By atomic weight calculation,

It is found that 1 ton of LPG emits 3.04 ton (approx) of CO$_2$

RESULTS AND DISCUSSION

The above graphs shows the temperature readings in Madurai with average day time temperature as maximum temperature and minimum temperature to be a night time temperature. This graph shows that there will be enough solar irradiation in the tropical regions especially in India to implement the steam cooking which is more suitable for houses and also hotels.
The calculation is performed for above all assumptions and the total system is designed for the domestic house. From the graph, it is found that the average day temperature of Madurai is 35°C hence it meet the cooking requirements by adopting the above design. The drawbacks in this system will be little more investment than other systems. But the payback period will be few years after which total cost of cooking will be only the maintenance cost of the system. By improving the design of vacuum tubes, PCM selection, tracking mechanism collector shapes etc., will have a great scope in the market. In future this would be a new backup storage collector which stores heat energy for the multi purposes.

V. CONCLUSION

As our demand for LPG and electrical energy are escalating day by day, the amount of fossil fuel will become scarce on one day. By implementing this system, it eradicates power consumption for cooking. The key behind this efficacious solution is the phase change material. In previous papers, the overall system will work only during the daytime and if PCM is kept inside the house then it will not be compact and there will be many predicaments. By adopting this residential solar cooker in each and every house will replace LPG and electric stove. Installation of this system in India reduces more than millions of tons of CO₂ emissions. The rise in the rate of global warming temperature can be greatly reduced in the future. Thus this system could bring extravagant changes to this hectic world. The effects of thermo physical properties of PCM, installation methodology, location of PCM are the scope for future work.

REFERENCES


