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Performance of PCM and Cooking Vessel in Solar Cooking System

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Abstract: *In this system the thermal performance of solar cooker is improved by using various heat enhancement techniques. The heat enhancement techniques for cooking vessel have been proposed for both late evening hours and sun shine hours. The heat enhancement technique during the sunshine hours was, introducing the annular cavity under the cooking vessel. During late evening hours PCM having the properties of thermal storage have been used as the source of heat for the cooking unit .The annular fins have been proposed for the maximum heat absorption to the PCM present in the system. In this system new PCM substance called Benzoic acid is used because its melting point is around 122.7^{O}C.The charging and discharging process of the system for both steady state and transient system have been analyzed and the melting of the PCM with respect to change in distance and time have been analyzed.*

Key points*: Solar Cooking, PCM, Annular cavity, Fins, Melting point*

I. Introduction

Solar energy is used in various applications like distillation process, drying process, heating process, power generation process and cooking process, out of which the most economical application is cooking process. In the cooking process for the late evening cooking PCM is used. For the usage of PCM, concentrating type solar cooker should be used so that the PCM can attain its maximum melting temperature. The PCM can be used for both heating and cooling process [1].For the heat enhancement in the solar cooking vessel the annular cavity is used.

Various fins such as Y-Shaped, Cross-fins, T-shaped fins and were proposed [2] to have the maximum heat to get stored to the PCM annular fins were proposed. The cooking system uses the PCM as benzoic acid.

The PCM used in this cooking system charges during the sunshine hours and it releases its heat to the cooking vessel during the late evening times.The various PCMs were analysed in the system[3][4],out of which reason why we are using benzoic acid is due its melting point and economical availability.The main properties of benzoic acid are, it has the density of around 1.27g/cm^3, conductivity is about 0.00139W/cmK and it has the specific heat of about 1.196J/gK, latent heat of fusion is about 142.8KJ/Kg. Its melting point is about 121.7^{o}C.[5] The performance gets increased by using the central annular cavity where as the efficiency of the system increases to about 2.4% more than the existing system.

In this system various performance analysis is to be made using theoretical and simulation analysis. The position of liquid solid interface can be found for certain temperature and the temperature of the PCM .the designing of the solar cooker and the cooking vessel can also be founded out

II. Design of system

The efficient system designing is required for the efficient operation of the system. Various units such as cooking vessels, PCM storage unit are theoretically designed using the given procedures.

2.1 Design of solar cooking vessel

The position of solid liquid interface at certain time and temperature is calculated as proceeded in [6].Using this formula the position of the liquid solid interface at certain time can be found out.

$$X(t) = \left[2\left[\frac{\lambda_l}{\rho h_{sl}}\right]\int_0^t [T_0(t) - T_m]\right]^{\frac{1}{2}} \qquad (1)$$

By finding the position of the liquid solid interface from the above formula the temperature of the position and the position below the interface can be founded using the formula given below.

Temperature of PCM region in melting process [6]

$$\mathrm{T_1(x,t) = T_0(t) - [T_0(t) - T_f]\frac{x}{X(t)}} \qquad (2)$$

The design of the solar cooking vessel can be designed by knowing the Energy required to cook the substance. The mass of PCM required can be calculated by using the formula

$$Mass\ of\ PCM\ required = \frac{E_{Stored}}{L.H.F} \quad (3)$$

In the above formula the energy required for the cooking process and latent heat of fusion of the PCM is substituted in the above formula and the Amount of PCM required can be calculated.

The energy stored by the PCM can be calculated by using the specific heat (C_{pcm}), melting temperature(T_m)and the maximum temperature (T_{pcmmax}) of the PCM .The energy stored by the PCM can be calculated so that the required amount of PCM for dish can founded out as in [6].

$$Q_{stored} = M_{pcm}[C_{pcm}(T_m - T_a) + L + C_{pcm}(T_{pcmmax} - T_m) \quad (4)$$

The heat released from the PCM and food can be calculated by using[6], the (M_f) mass of food, specific heat of water(C_w), temperature of food , (T_m)melting temperature of the system.

$$Q_{released} = M_f C_w(T_f - T_m) + M_{pcm}C_{pcm}(T_{pcm} - T_m) + M_{pcm}L \quad (5)$$

The energy loss of the system is the amount of energy that get wasted due to the losses in the system.
Using the equation as[7]

$$U_L = \frac{Q_{released}}{A(T_f - T_a)} \quad (6)$$

The energy loss from the cooking vessel can be found out by using the food temperature (T_f)and ambient temperature (T_a) and the heat released from the system.

The fins are provided for the heat enhancement in the cooking system the fins are attached to the inner walls of the PCM vessel such that the cooking unit after finishing its process provides heat to PCM via fins[8].

$$L = R_0 - r_1 \quad (7)$$

$$L_C = L + \frac{t}{2} \quad (8)$$

Where the fins can be designed by using the outer and inner radius of the fins and cooking vessel R_0, r_1 where the thickness of the system be t and the length of the system be L, Where L_C is the corrected length of the fins where the length of the system fins can be calculated by using this relation.

2.2 Design of parabolic solar cooker

The cooking vessel placed over the parabolic solar cooker, for the efficient heat transfer parabolic solar cooker designing is made such that it reflects the maximum heat to the cooking vessel present in the focal point. The main criteria for designing the efficient parabolic system is assigning the best focal point that is required for the parabolic area

The surface area can be calculated by using the various parameters such as focal point and depth of the system. The surface area can be calculated by using the [9] given formulas.

$$A_S = \frac{8\pi f^2}{3}\left\{\left\{\left(\frac{d}{4f}\right)+1\right\}^{\frac{3}{2}}-1\right\} \text{ m}^2 \quad (9)$$

The depth of the parabola can be given by the equation as

$$d = \frac{\left(\frac{L}{2}\right)^2}{4f} \quad (10)$$

The focal length of the system can be given by the equation as

$$f = \frac{h^2}{4R} \quad (11)$$

The surface area of the parabolic solar cooker can be calculated by using the focal length of the system. The focal length can be calculated by using the height and radius of the system

The arc length of the parabola can be calculated by using the depth and height of the parabola using [10].

$$S = \frac{d}{2}\sqrt{\left(\frac{4h}{d}\right)^2 + 1 + 2fln\left[\left(\frac{4h}{d}\right) + \sqrt{\left(\frac{4h}{d}\right)^2 + 1}\right]} \quad (12)$$

The thermal efficiency of the parabola can be calculate by using [11],the mass and specific heat of water and pot,final and initial temperature of the water

$$\eta = \frac{(M_w C_w + M_{pot} C_{pot})(T_{wf} - T_{wi})}{A_{parabola} \int_0^t I_b dt} \quad (13)$$

The rim angles were required for the parabolic system for the efficient focusing. There are number of rims that were connected to form a parabola so that angle of the rim in the parabola can be given by the given as

$$tan\emptyset\ rim = \frac{1}{\left(\frac{dh}{8}\right) - \left(\frac{2h}{d}\right)} \quad (14)$$

The power of the parabolic cooker can be given by the equation as[12].

$$P_s = \frac{(M_w C_w)(T_{wf} - T_{wi})}{600} * \frac{700}{I_b} \quad (15)$$

The capacity of the system can be given by keeping the standard solar radiation as 700w/m^2. The time can also be given as 600 sec and is represented in the formula.

2.3 Specifications

Focal length of parabolic cooker =1.5m
Area of parabolic cooker=0.79m^2
Diameter of the cooker =1m
Base rod length =1m
Cooker placing stand=25x25cm
Volume of the PCM stored vessel=1141cm^3
Volume of the cooking unit=998cm^3
Radius of annular cavity=3cm
Mass of PCM =1.45Kg

III. Simulation

In this system 2d modeling of solar cooker is made with annular cavity as in [13], for the steady state operation. The thermal performance analysis is made for charging and discharging process of the system. During the charging process the thermal storage unit absorbs the heat and during the discharge processes the stored heat from the PCM moves to the cooking vessel.

3.1 Steady state analysis

The steady state process shows the variation of the system for the time being constant and analyzed the overall temperature of the system.

3.1.1. Charging process

During charging process solar radiation passes through the system so that the solar radiation passes gets transferred to cooking vessel and some solar radiation directly passes into the PCM unit .The cooking unit also transfer its heat to the PCM during charging process of the system, so that the fins are used, so that the heat conduction area of the PCM increases and the heat storage capacity of the PCM can be increased.

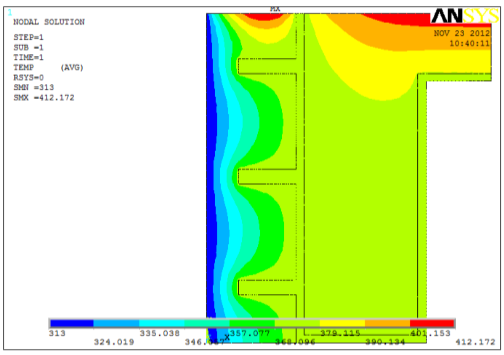

Fig 1.Steady state analysis temperature variation for charging process of PCM

In the above figure.1during the charging process the heat at the most passes to the cooking vessel and the heat gets stored into the PCM. When the heat is absorbed by PCM, the PCM stores the maximum heat that is capable of. During charging process of the system the PCM near the outside layer of vessel is of lower temperature where as near the fins the temperature is high because of the heat flow from the cooking vessel to the PCM.

3.1.2. Discharging Process

During the discharge process of the system from fig.2there will not be any solar radiation present in the surroundings so that the heat necessary for the cooking will not be available so that the heat stored during the charging process can be utilized efficiently for the late evening cooking in the system so that the heat stored in the PCM moves to the cooking unit for cooking the food.

Where as in the discharging process, the PCM is of lower temperature where the most of the heat gets passed to the cooking material. The food material is at higher temperature due to the heat that gets passed from the PCM storage material .The PCM material is at lower temperature due to the heat that gets passed into the cooking unit.

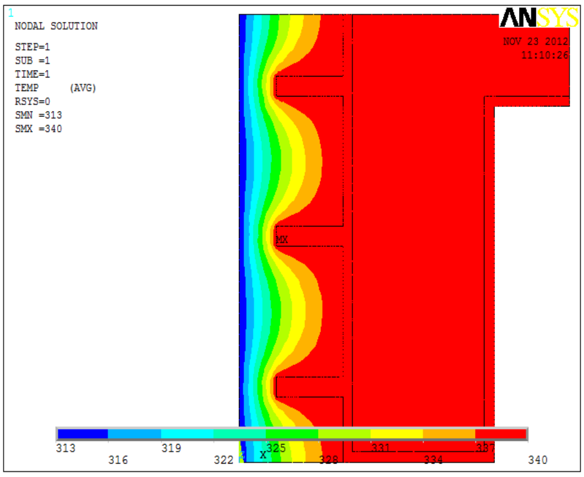

Fig 2.Steady state analysis temperature variation for discharging process of PCM

3.2 Transient analysis

In this system the transient analysis is made for 600seconds for both the charging and discharging process of the system.

3.2.1. Charging Process

During the charging process shown in fig 3, the solar radiation passes, the PCM changes its form by melting and then stores the energy for the process; it is able to store the maximum storage heat capacity of the PCM present. The temperature distribution can be achieved for 600 sec such that during charging process. The PCM side gets more heat so its temperature profile is high.

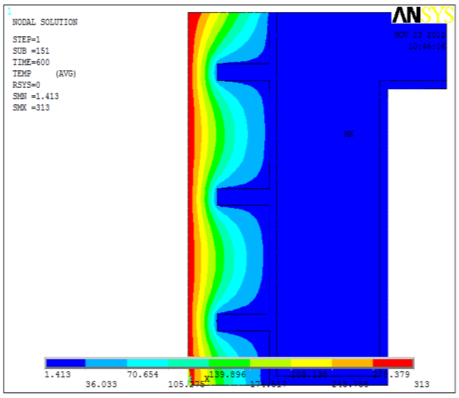

Fig 3: Transient analysis temperature variations for charging process

The cooking unit do not get that much heat from the solar radiation during the 600sec.The PCM gets its maximum heat and used as the thermal storage system.

3.2.2.Discharging Process

During the discharging process of the system for the 600sec some amount of heat get passes to the cooking unit. The evening cooking is possible due to the discharge of heat from the PCM unit. Efficient cooking operation can be obtained using PCM, in the late evening.

In the discharging process from fig.5 the PCM has more amount of heat and is transferred to the cooking materials so temperature of water increases and the temperature discharge shows the various change in temperature of the system.

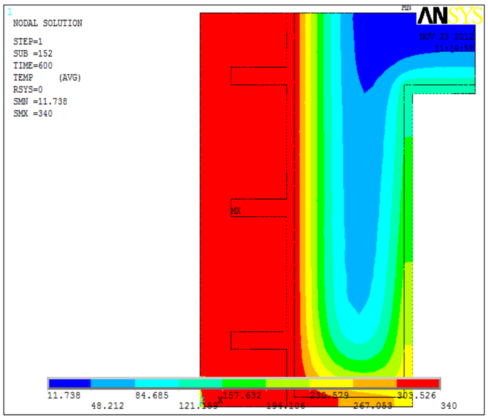

Fig 4: Transient analysis temperature variations for discharging process.

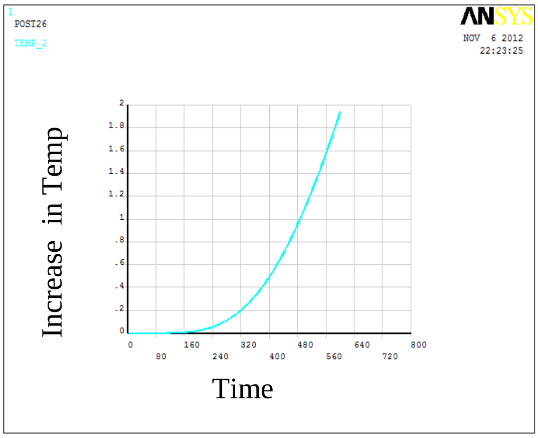

Fig 5: Temperature variation at node with respect to time.

The graphical representation shown in figure 5.The temperature variation with respect to distance is plotted for 600 sec in a single node the increase in temperature with respect to time for 600sec has been plotted.

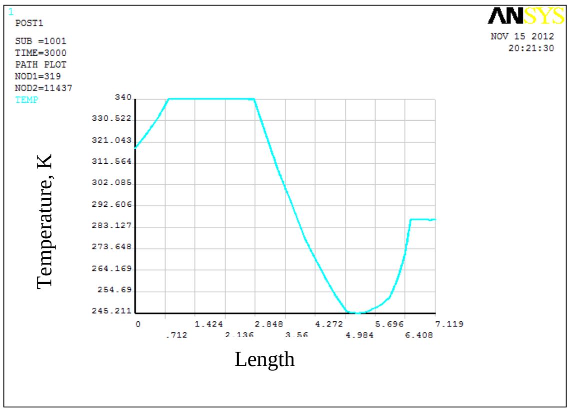

Fig 6.Temperature variation during discharging process for 600sec

During the discharging process in fig.6 the PCM storage unit there will be maximum heat which is stores in the PCM. when the solar Radiation is minimum the stored heat in the PCM discharges so that the when the distance increases up to the PCM storage unit the temperature will be maximum and due to discharge of the stored heat the temperature goes on decreasing for 600sec,when the time increases the discharge also increases.

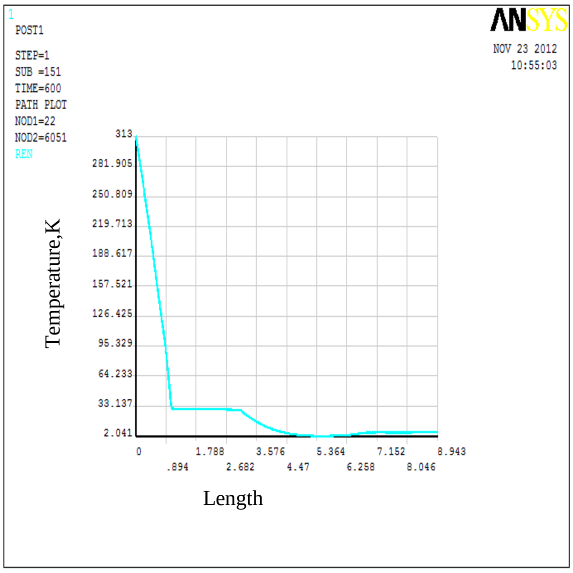

Fig 7.Temperature variation during charging process for 600sec

In charging process due to solar radiation in fig. 7 the PCM temperature is high when the distance increases from the cooking vessel wall the temperature decreases. Due to the presence of annular cavity in the cooking vessel the temperature of the system increases and is plotted in the graph.

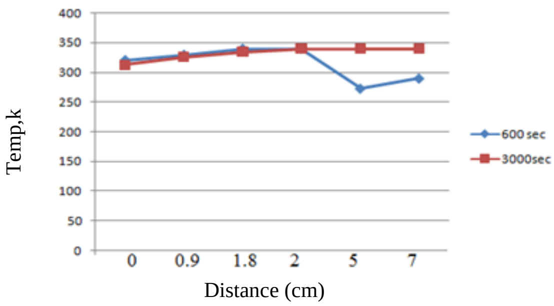

Fig 8: Variation of temperature with respect to distance at various timing

In this graph fig.8 the temp variation at various distances with respect to time is plotted for 3000sec and 600sec.In 600sec the temperature goes on decreasing and then it increases due to the presence of annular cavity .In its 3000 sec the temperature at the most attain at its maximum.

IV. Conclusion

From the above results obtained, by using the simple analysis it is known that the heat gets transferred efficiently through the annular cavity and the heat also gets transferred to the PCM through the fins so that the maximum heat gets transferred to the PCM.

Benzoic acid can be used as the thermal storage unit so that late evening cooking is also possible for the system so thermal storage unit using benzoic acid is analyzed and is found to get efficiently operated.

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