Design and Simulation of Institutional Solar-Powered Cook Stove With Thermal Energy Storage System

Tihun Birhanu Beyene[1,2], Abdulkadir Aman Hassen[1*] and Kamil Dino Adem[1]

[1] School of Mechanical and Industrial Engineering, College of Technology and Built Environment, Addis Ababa University, Addis Ababa, Ethiopia

[2] Department of Mechanical Engineering, Haramaya University, Haramaya, Ethiopia

Abstract

The feasibility of a solar-powered institutional cook stove with heat storage using commercial SHELL THERMIA OIL B as heat transfer media and potassium nitrate salt (40% KNO_3+60% $NaNO_3$) as the Phase Change Material (PCM) for institutional cooking has been successfully demonstrated. A mixture of 41L Heat Transfer Fluid (HTF) (bulk temperatures up to 320ºC, and film temperature up to 340ºC) and 42 sealed copper tubes (Internal diameter 62.611 mm, 2 mm thickness 300 mm height) carrying a total of 60 kg of Phase Change Material (PCM) (melting point range of 210-220°C and the Latent heat of fusion 108.67 kJ/kg) is used to store heat. The HTF was filled in the storage compartment to cover the copper tubes and is assumed to fit within cylinder jackets that were wrapped around the tubes and also operate as a heat transfer medium. A heater with 4500 W and 220 V input power from the photovoltaic system is immersed inside the storage during the charging phase. The thermal storage's performance was assessed utilizing constant heat flux. The computer model was validated using existing experimental work. Based on the simulation results, a performance investigation was carried out, the thermal storage was able to store 53.5MJ of energy in 3.9 hours of charging time. The charging, and discharging efficiencies were 71.5%, and 85.6%, respectivelyThe results confirmed that the ANSYS Fluent CFD simulation for the stove was well validated and the model and simulation performance were good. Finally, the results indicate expanding the application of solar cooking at the institutional level is visible.

Keywords: Keywords: Solar-powered cookstove; Thermal Storage; Phase Change Material

1 Introduction

Humankind completely relies on carbon based fuels, accounting for more than 80% of world energy use (Lizaso, 2020). Cooking accounts for a substantial portion of family and institutional energy use, relying mostly on other polluting sources include coal, wood, and kerosene due to their minimum cost and ease of availability. Its volatile cost, as well as its future inadequacies, necessitate a global shift. Institutional cooking is a cooking done for beneficiaries in a centralized kitchen, and this kitchen requires a large volume of fuel to be combusted at a high intensity for mass cooking (Indora & Kandpal, 2018b) which is one of the key elements influencing the amount of global energy expenditure and greenhouse gas emissions. Since the energy used for cooking is so important, solar cooking is seen as one of the easiest, most practical, and most appealing choices for utilizing solar energy (Indora & Kandpal, 2019). Solar cookers can give a clean, alternative cooking option. However, the use of solar cooking at an institutional level takes into account issues such as solar resource availability, any mismatch in time between energy demand and solar resource availability, and the capabilities of the solar energy system to satisfy perceived demands. As a result, solar cookers must be combined with thermal energy storage technologies to overcome this issue. This function will help to bridge the gap between solar energy supply and cooking energy consumption. Furthermore, storage aids in the storage of extra solar energy during the day for later evening or early morning use (Tesfay et al., 2019).

10.18086/swc.2025.02.09 Available at http://proceedings.ises.org

Since the introduction of the first solar cooker in 1767, the world has seen a broad variety of solar cooker setups (Panwar et al., 2012). However, there is little research on institutional solar cookers, and much of the study has concentrated on family size solar cookers (Bhave & Kale, 2020; Bhave & Thakare, 2018; Kajumba et al., 2020; Kumaresan et al., 2018; Santhi Rekha & Sukchai, 2018; Senthil, 2021; Tesfay et al., 2014; Vigneswaran et al., 2017) whereas institutional solar cookers have been left out. However, Piroschka (2014) conducted research on warming up of solar cooking, several forms of motivating variables have a big influence on the adoption of this type of solar cooker. According to the study, economic, health, and environmental concerns were identified as motivating factors. On the other hand, (Indora & Kandpal, 2018a) investigated the economic attractiveness of the Scheffler dish for solar steam cooking at the institutional level in India. Considering Small (200 people), medium (500 people), and big (1000 people) institutional kitchens were evaluated. The study estimates that the discounted payback times for small, medium, and large institutional kitchens are 9, 7, and 6 years, respectively. This clearly proves the economic viability of large-scale solar steam cooking systems.

Also, Sekhon and Sethi (2019) Provided thermal modeling and analysis of a novel twin-chamber community solar cooker (TCCS) as an alternative for biomass-based cooking. Overall, the results show that the TCCS cooker can be easily modified for community-scale cooking and has a high potential to replace biomass/fossil fuel-based cooking in many nations in the future. Aggarwal (2020) investigated institution-based solar steam cooking systems in India. According to the study, a solar steam cooking system can be used to prepare food for 50 to 50,000 people, minimizing the need of conventional fuels. It may also be used to heat water. The Ministry of New and Renewable Energy (MNRE) is currently promoting three types of concentrator cookers in Indian institutions: manually tracked parabolic dish cookers (SK, PRINCE), fixed focus automatically tracked (East-West) Scheffler dishes, and fully tracked Fresnel dishes (Lizaso, 2020).

The objective of this study was to study and analyze the performance of an institutional solar powered cook stove with thermal energy storage system. This was conducted first by designing the thermal storage, selecting the proper materials, sizing the photovoltaic system and evaluating the performance of the thermal storage. The solar thermal storage system linked with the PV system for cooking was simulated using ANSYS fluent software. The numerical model simulates the unsteady temperature variation of PCM and HTF for charging and discharging situations by enthalpy porosity method. The reliability of the simulation results has been verified by comparing them to other experimental investigations.

2 Materials and methods Physical

2.1 Design of the model

A photovoltaic system is used as an electric power source to charge institutional cook stove coupled with thermal energy storage system. The institutional cook stove coupled with thermal storage consists of PCM, HTF and heater with integrated temperature controller in its storage tank. The heater receives power from the PV system and heats the HTF which is filled in a storage tank to completely immerse the copper tubes containing PCM and the heater itself (Figure 1).

Item No	Part Name
1	Insulation cover
2	PCM tube
3	Container Support
4	container
5	Inverter
6	Charge controller
7	Cable
8	PV

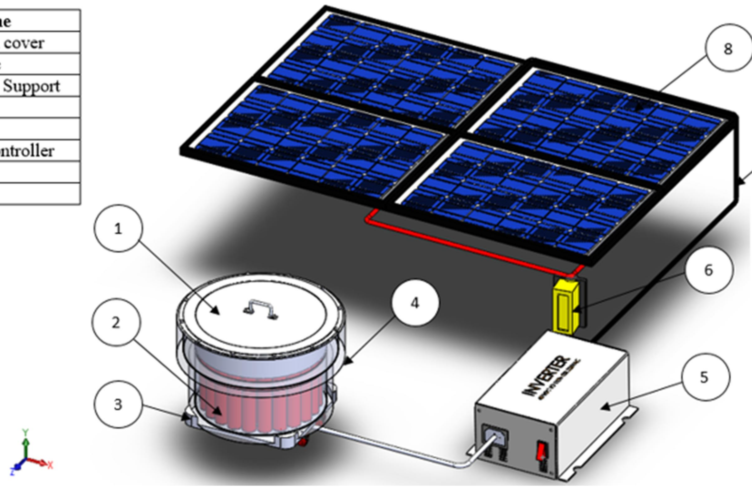


Figure 1: Schematic diagram of thermal storage integrated with photovoltaic system

The heat storage is achieved by a combination of 41L of commercial SHELL THERMIA OIL B (HTF) and sealed copper tubes containing a total of 60 kg of PCM (nitrate salt mixture of 40% KNO_3 and 60% $NaNO_3$). The PCM is contained in 42 cylindrical copper tubes 300mm long, 2 mm thickness and of 62.6 internal diameter. As depicted in Figure 2 capsules were threaded internally at both ends and caps with external threads made from copper plate used to seal both ends of the tube. In addition, the storage has 10% vacant space to avoid any pressure development and volume variation during phase transition of PCM.

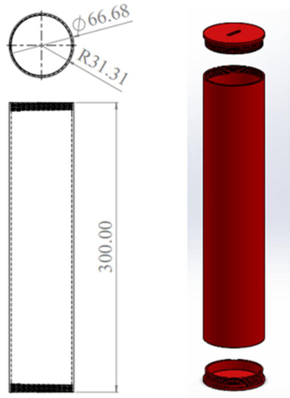


Figure 2: Encapsulation Copper Tube

The HTF (SHELL THERMIA OIL B) was filled in the storage space so as to immerse the copper tubes completely and also act as a heat transfer medium. A heater having 4500 W and 220 V is immersed inside storage as a power source during the charging phase. Table *1* shows detailed thermo-physical properties of Potassium nitrate salt mixture of 40% KNO_3 and 60% $NaNO_3$ and SHELL THERMIA OIL B

Table 1: Thermo-physical properties of nitrate salt and SHELL THERMIA OIL B

Thermo-physical properties of solar salt (NaNO3-KNO3) (Bhave & Kale, 2020)	
Property	Value
Thermal conductivity (W/m K)	0.8
Density (Kg/m^3)	1800(below 220°c)

	1700(above 220°c)
Enthalpy of fusion (KJ/Kg)	108.67
Melting point (^{O}C)	Solid liquid phase transition from 210-220°c
Phase transition enthalpy (KJ/Kg)	31.91

2.1.1 Storage design

The design of the institutional solar powered cook stove with thermal storage system includes quantifying the amount of PCM and HTF required, determining the size of the storage container and PV sizing. In this study the energy demand for boiling water in a cylindrical shaped cooking vessel shown in Figure 3 is considered for simplicity. Table 2 shows the design consideration of the thermal storage sizing.

Table 2: Design considerations

Parameters	value	Reference
Specific heat capacity of water 23°C (J/ kg K)	4185.5	(Nag, 2017)
The density of water (kg/m^3)	1000	(Nag, 2017)
Initial temperature of water (°C)	23	(kebede, 2020)
The latent heat of vaporization of water at 92°C (KJ/Kg)	2277.34.4	(Nag, 2017)
Boiling temperature of Water (°C) estimated by $\mathbf{T_b} = \left(\mathbf{100} - \frac{\mathbf{h}}{\mathbf{300}}\right)\mathbf{°C}$ Where h is $\mathbf{2349.69m}$ altitude.	92	Manual water boiling test
Water loss by evaporation during solar cooking process (%)	10	(Biadgelegn, 2018), (Bhave & Thakare, 2018)

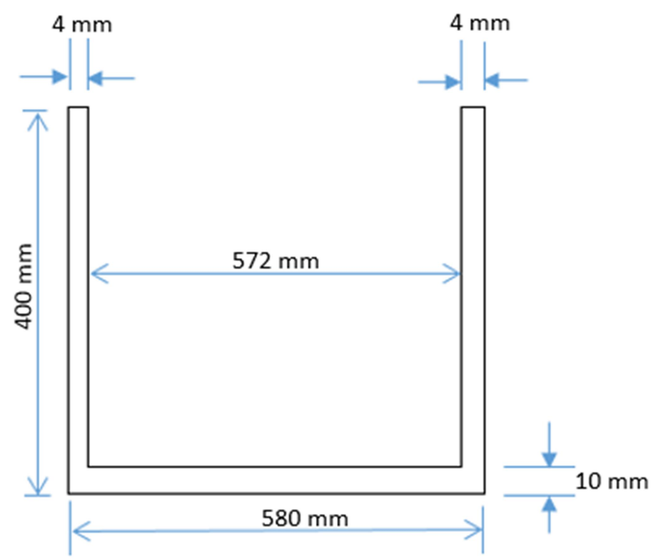


Figure 3: Representation of the cooking pot

Therefore, Volume of the cooking unit (V) can be calculated as;

$$V = \pi r^2 h \qquad \text{(eq. 1)}$$

According to Equation **Error! Reference source not found.** the cooking unit can hold approximately volume of 100lit, however, during boiling the pot is not filled to the maximum capacity, considering this 10% of the height of the pot is left void as a result the volume considered for the design of this study is 90 lit.
As a result, the energy required to boil 90 litters of water is calculated as;

$$E_{demand=} m c_p \Delta T + (m_i - m_f) h_{vaporization} \qquad \text{(eq. 2)}$$

To quantify the energy loss of the system assumptions considered are there is no heat loss from the device walls and top during solar energy collection stage or charging since the cooking device is fully insulated. However, during discharging 10% heat loss is considered.

$$\boldsymbol{Q_{PCM} = \int_{Ti}^{Tm} mC_p\, dT + ma_m \Delta h_m + \int_{Tm}^{Tf} m\, C_P dT} \qquad \text{(eq. 3)}$$

Where, m is mass of PCM, C_p specific heat capacity of PCM, Δh_m enthalpy of phase fusion and a_m is the fraction melted.

2.1.2 PV sizing

Considering solar data collected from the NASA for Addis Ababa the capital city of Ethiopia, which is situated at 9.0403° latitude and 38.7631° longitude. The system was sized on the basis of the lowest solar energy radiation month marked out. To design a stand-alone PV system for the considered institutional cook stove, the following steps are followed;

Taking the load demand required which is 46 MJ and considering 23% system loss (Bruce, 2021) the size of the PV array, used in this study, can be calculated by equation (4) (Gont, 2019):

$$\boldsymbol{PV_{area} = \frac{E_{demand}(KWh/day)}{H\left(\frac{\frac{KWh}{m^2}}{day}\right) * \eta_{PV} * PR}} \qquad \text{(eq. 4)}$$

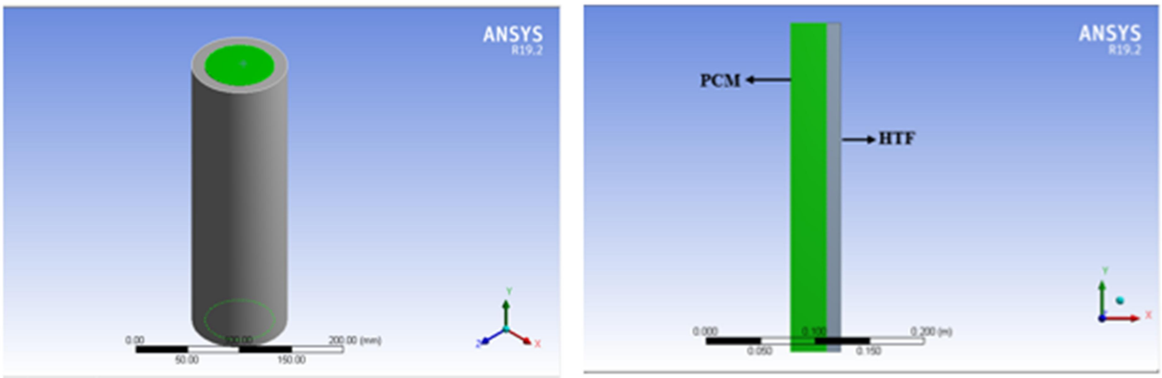
Where H is solar radiation on tilted plane (4.51 (kW-hr/m^2/day)), η_{PV} is PV efficiency (18.44%) and PR is performance ratio, coefficient for losses (default value = 0.75) (Skunpong & Plangklang, 2011).

2.2 Numerical approach

There are different commercial softwares for numerical analysis of the melting/solidification process. However, according to the review by Al-abidi et al. (2013) ANSYS Fluent is the most widely utilized software. Therefore, numerical study of the developed model was conducted using ANSYS Fluent 19.2. ANSYS Fluent uses the enthalpy-porosity approach in which the mushy zone is considered as a porous medium where the liquid fraction is its porosity.

2.2.1 Computational domain

The numerical simulations have been carried out by means of a finite volume numerical code using a 2D axisymmetric approximation according to the problem characteristics. Two separate zones are defined in order to apply the appropriate models to simulate the HTF and PCM. The HTF has been modelled by means of the well-known single phase Navier-Stokes equations (Iten et al., 2018). Whereas, the PCM behavior has been simulated by means of a solidification and melting model adding a correction term to the Navier-Stokes equations (Fornarelli et al., 2016)`. This is able to model the phase change of the mass within the closed shell where the PCM is confined. Moreover, the Boussinesq approximation is considered in order to take into account the buoyancy effect on the liquid phase of the PCM due to the fluid density (Joybari et al., 2017). For the model, we assume that the HTF surrounding the cylinders is situated in cylinder jackets all-round the tubes. Of course, the volume of all these cylinder jackets together is equal to the fluid volume in the real storage tank. Figure 4 Shows 2D axisymmetric domain considered for simulation.



(a) (b)

Figure 4: computational domain considered for simulation: a &b

2.2.2 Governing equations

In this sections the modelling procedure and its assumption as well as the considered initial and boundary conditions are presented

Assumption

According to the problem of concern and common considerations used in the literatures (Bellan et al., 2015; Joybari et al., 2017) the following assumptions are employed:

- Melting process is modeled using enthalpy-porosity technique.
- PCM capsules are uniform, homogenous, and isotropic bodies with thermos-physical properties constant with temperature.
- The flow of the liquid PCM was considered as laminar, incompressible Newtonian fluid flow,
- Molten PCM is considered Newtonian and Boussinesq fluid.
- Phase-wise constant thermophysical properties was assumed for the PCM except for the density, which was evaluated based on Boussinesq approximation to account for the buoyancy forces.
- Initially the temperature of the heat transfer fluid and PCM in the storage tank are considered uniform.
- Radiant heat transfer is ignored.
- Tank is perfectly insulated, and hence, there is no heat loss from the tank surface to the surrounding.
- Liquid fraction variation was assumed to be linear with temperature.
- The heat-transfer fluid is incompressible and it is considered as Newtonian fluid

2.2.3. Initial and boundary conditions

The entire system is initially at ambient temperature (Ta = 296 K) and the charging mode starts at t = 0 s by a constant power of 4500 W supplied to the heat transfer fluid. The system is considered to be adiabatic during charging process. Figure 5 shows the boundary conditions.

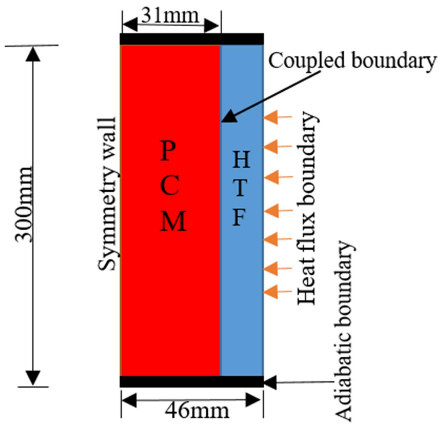


Figure 5: charging boundary condition

In the solidification case, it was considered that PCM is completely melted, this is made possible by patching the temperature of PCM based on the temperature reached during the melting case (300°C). In addition to that the heat transfer fluid is patched the same way as that of PCM.

However, in this case, heat is lost from the top part of the storage (which is the place where the stored heat is used for cooking) due to convection. The adiabatic boundary condition set during charging of the system remains the same, but the upper part is considered to have following boundary conditions: heat transfer coefficient of 244 (W/m^2K) with free stream temperature of 373K.

2.3 Analysis procedure

A step-by-step approach was taken in ANSYS Workbench to simulate the process. First, the 2D axisymmetric half of the simplified model was sketched using the Design Modeler environment. Then, ANSYS Meshing generated the mesh. Thereafter, the simulation was setup in ANSYS Fluent environment. To solve the equations, pressure-based solver was used since it is the only option in the software for solving melting/solidification processes. Semi-implicit pressure-linked equation (SIMPLE) method was used for pressure-velocity coupling. For spatial discretization of the pressure and momentum, PRESTO (pressure staggering option) and QUICK schemes were adopted, respectively.

2.3.1 Grid independency test

Grid independency analysis is conducted to determine the adequate grid size with the optimum solution and less computational effort. Three different grid sizes were investigated namely; Grid 1 (25200 elements), Grid 2 (55800 elements) and Grid 3 (99200 elements). The meshing of the model is done using multi zone methods. In all the three cases analyzed the initial HTF and PCM temperature, boundary conditions and time step sizes are fixed. Average of surface vertex value temperature for location inside PCM obtained from numerical model for the three different grids. Following the results obtained, the grid quality doesn't affect the result of simulation notably and hence grid with medium element (Grid 2) is selected.

2.3.2 Model validation

In this study the charging and discharging behavior of a PCM is investigated, however, in order to validate the model. The Charging process were compared with experimental data from earlier study (Bhave & Thakare, 2018) was used for validation of the melting process. Validation is done by simulating the charging process of thermal storage with magnesium chloride hexahydrate ($MgCl2·6H2O$) phase change material and Taurus Therm 500 heat transfer fluid. The thermal storage contained 21 tubes containing a total of 0.48 kg PCM (10 cm long and of 1.6 cm internal diameter) and 660 ml of heat transfer fluid. Figure 6 depicts a comparison of numerical and experimental average temperature values for the PCM and HTF, with the result indicating a percentage error of 8% for the HTF and 7% for the PCM. Hence, there is an acceptable agreement with experimental data the model can be used to numerically study the charging simulation of the institutional thermal storage based cook stove.

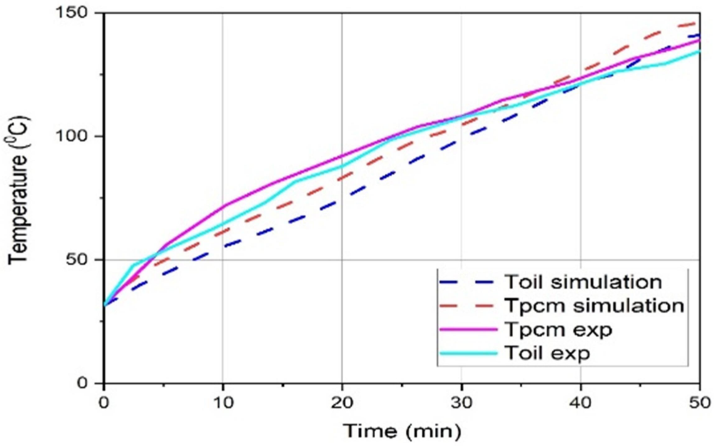


Figure 6: Comparison of the numerical and experimental results

3 Results and discussion

In this section first charging of the thermal storage with a constant PV output of 4500W was examined. The findings show storage temperature (PCM) rose to the point where the solid PCM began to melt and maintain constant temperature phase change. When the PCM completely melts, the temperature of the liquefied zone rises. Following charging for 3.9 hours, all PCM capsules in storage are liquefied. Figure 7 and Figure 8 shows the temperature distribution inside PCM, the phase transition or liquid fraction fluctuation of PCM total volume while charging, respectively.

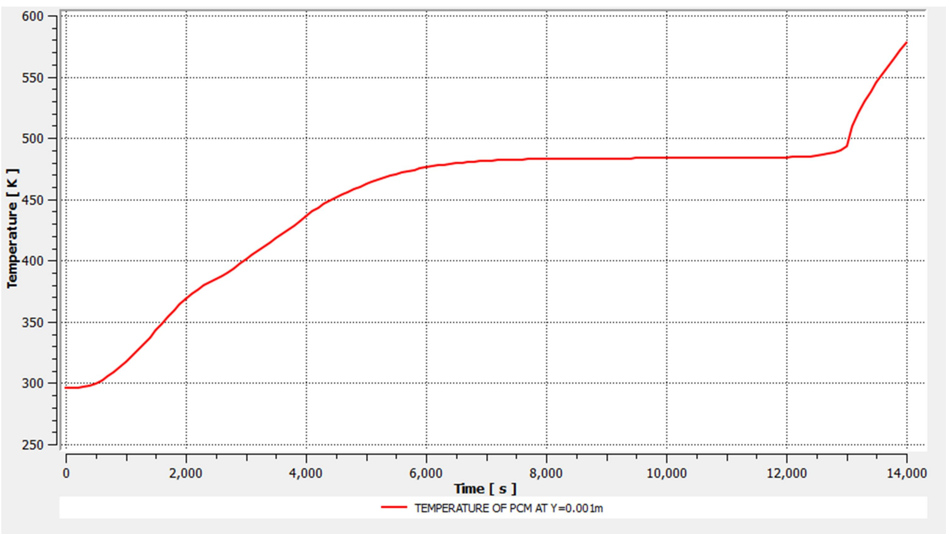


Figure 7: PCM temperature fluctuation while charging for 3.889 hours

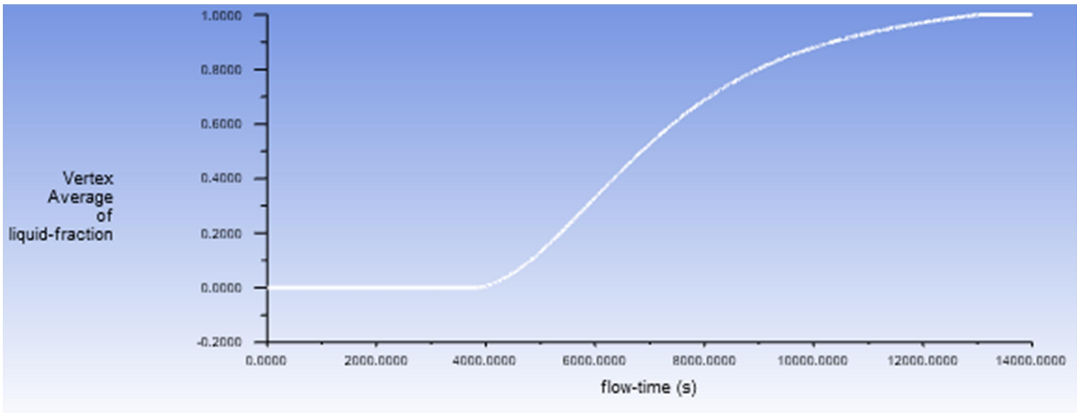


Figure 8: Melt fraction of volume of PCM versus time during charging

Next the heat stored in the PCM thermal storage can be discharged by natural convection placing the pot on the top of storage. The temperatures of the PCM has degraded after discharging for 5 hours using 244 (W/m^{2}K) convection heat transfer coefficient with free stream temperature of 373K. Figure 9 (a) shows temperature variation of the PCM thermal storage with respect to time during discharge. The solidification of total volume of PCM thermal storage is also described by melt fraction in Figure 9(b).

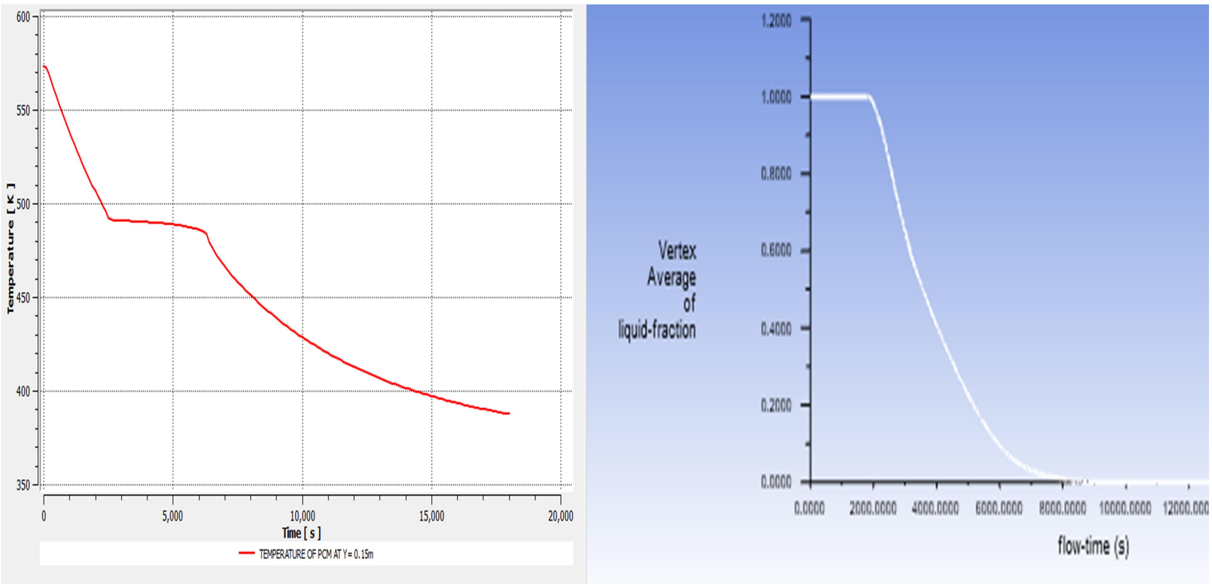


Figure 9 (a): Temperature variation at Y= 0.15m inside PCM during discharging and 9 (b) Melt fraction of volume of PCM versus time during discharging

On the other hand, the temperature fluctuation of HTF and PCM inside thermal storage tank and the liquid fraction at different points during charging inside PCM are depicted in Figures 10 and Figures 11 respectively.

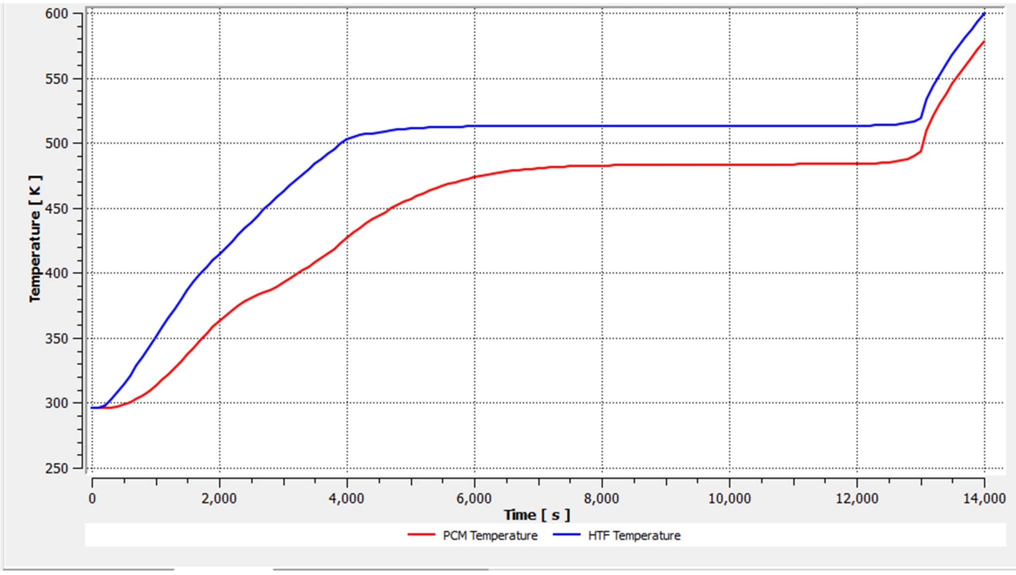


Figure 10: Temperature variation of HTF and PCM during charging for 3.889 hours

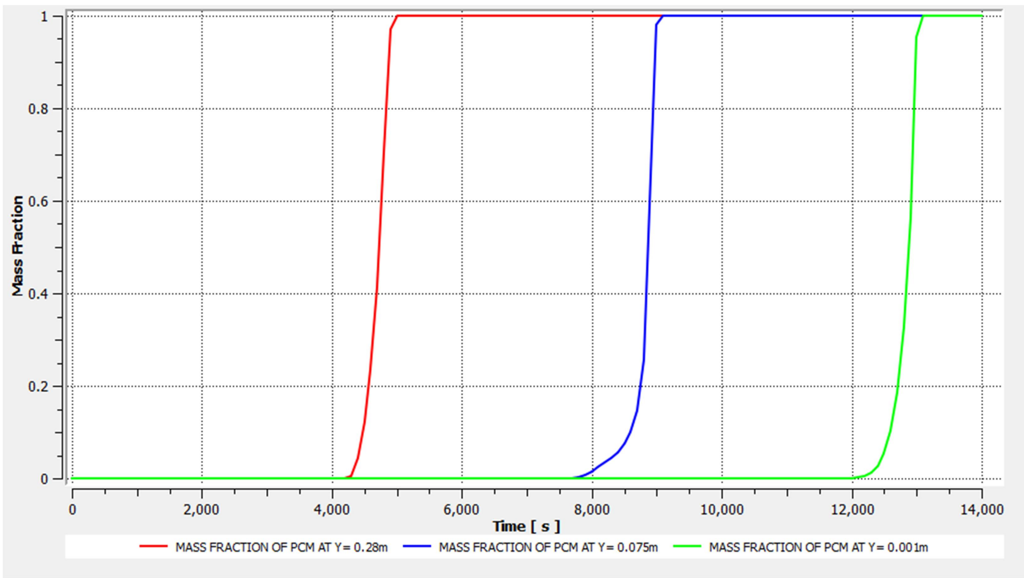


Figure 11: The liquid fraction at various point inside PCM during charging

Solar thermal energy storage is a great solution for limited energy supply and demand. In developing countries such as Ethiopia where 89% of all final energy supply was from biomass sources, which gives rise to the huge amounts of greenhouse gas emissions and deforestation. In this study the energy demand for one cycle boiling of water at institutional level is considered for simplicity which almost is the closer temperature required to cook most of Ethiopian meals according to (Alemu (2020); Yishak (2019)). However, the system enables constant temperature heat transfer to the food for frying, roasting and baking which occurs at a temperature of 150-190 °C (Bhave & Kale, 2020) in addition to the boiling type cooking which requires heat stored above 100 °C (Bhave & Thakare, 2018).

4 Conclusion

The feasibility of a solar-powered institutional cook stove with heat storage using shell thermia B as heat transfer media and solar salt as the PCM for institutional cooking has been successfully demonstrated. Thermal storage model describes the successful modeling of sensible and latent heat thermal storage integrated with photovoltaic systems and cook stove at the top of thermal storage. Constant heat flux were used to evaluate the performance of the thermal storage. The numerical model of PCM based thermal storage was validated for charging and the result was found to be consistent with an experimental work. From simulation results obtained performance analysis was performed. The thermal storage has a capacity of storing 53531kJ of energy, and the thermal storage charging and discharging efficiency were 71.5% and 85.6% respectively. The results confirmed that the performance of the proposed model were good and expanding the application of solar cooking at the institutional level is visible. Finally, we advocate conducting a cost analysis of the system with its payback period to provide institutions with a more accurate feasibility of the system is much more attractive.

Reference

Agarwal, N., Kumar, A., & Varun. (2013). Optimization of grid independent hybrid PV–diesel–battery system for power generation in remote villages of Uttar Pradesh, India. *Energy for Sustainable Development, 17*(3), 210-219. doi: 10.1016/j.esd.2013.02.002

Aggarwal, R. (2020). Institution based solar steam cooking systems in India. *Current World Environment, 15*(2), 204.

Al-abidi, A. A., Bin Mat, S., Sopian, K., Sulaiman, M. Y., & Mohammed, A. T. (2013). CFD applications for latent heat thermal energy storage: a review. *Renewable and Sustainable Energy Reviews, 20*, 353-363. doi: 10.1016/j.rser.2012.11.079

Alemu, M. (2020). *Design and cfd analysis of thermal energy storage using pcm for cooking application.* (Degree of Master of Science in Mechanical Engineering (Thermal Engineering Stream)), Addis Ababa University.

Bellan, S., Alam, T. E., González-Aguilar, J., Romero, M., Rahman, M. M., Goswami, D. Y., & Stefanakos, E. K. (2015). Numerical and experimental studies on heat transfer characteristics of thermal energy storage system packed with molten salt PCM capsules. *Applied Thermal Engineering, 90*, 970-979. doi: 10.1016/j.applthermaleng.2015.07.056

Bhave, A. G., & Kale, C. K. (2020). Development of a thermal storage type solar cooker for high temperature cooking using solar salt. *Solar Energy Materials and Solar Cells, 208*, 110394. doi: 10.1016/j.solmat.2020.110394

Bhave, A. G., & Thakare, K. A. (2018). Development of a solar thermal storage cum cooking device using salt hydrate. *Solar Energy, 171*, 784-789. doi: 10.1016/j.solener.2018.07.018

Biadgelegn, M. (2018). *DESIGN AND EXPERIMENTAL INVESTIGATION OF SOLAR COOKER WITH THERMAL ENERGY STORAGE.* (Mastres degree), Addis Ababa.

Bruce, J. (2021). Solar Panel Sizing – How To Calculate Home Solar System Size. *Solar Energy Website - DIY Solar Projects*.

El Shenawy, E., Hegazy, A., & Abdellatef, M. (2017). Design and optimization of stand-alone PV system for Egyptian rural communities. *International Journal of Applied Engineering Research, 12*(20), 10433-10446.

Fornarelli, F., Camporeale, S. M., Fortunato, B., Torresi, M., Oresta, P., Magliocchetti, L., Miliozzi, A., & Santo, G. (2016). CFD analysis of melting process in a shell-and-tube latent heat storage for concentrated solar power plants. *Applied Energy, 164*, 711-722.

Getenet, G. (2011). *HEAT TRANSFER ANALYSIS DURING THE PROCESS OF INJERA BAKING BY FINITE ELEMENT METHOD.* (masters), Addis Ababa Univeristy

Gont, S. D. (2019). Design of a standalone photovoltaic system for a typical household around Dessie City-Ethiopia. *American Journal of Electrical and Electronic Engineering, 7*(1), 1-7.

Indora, S., & Kandpal, T. C. (2018a). Financial Appraisal of Using Scheffler Dish for Steam Based Institutional Solar Cooking in India. *Renewable Energy*. doi: 10.1016/j

Indora, S., & Kandpal, T. C. (2018b). Institutional and community solar cooking in India using SK-23 and Scheffler solar cookers: A financial appraisal. *Renewable Energy, 120*, 501-511. doi: 10.1016/j.renene.2018.01.004

Indora, S., & Kandpal, T. C. (2019). A framework for analyzing impact of potential financial/fiscal incentives for promoting institutional solar cooking in India. *Renewable Energy, 143*, 1531-1543. doi: 10.1016/j.renene.2019.05.097

Iten, M., Liu, S., & Shukla, A. (2018). Experimental validation of an air-PCM storage unit comparing the effective heat capacity and enthalpy methods through CFD simulations. *Energy, 155*, 495-503. doi: 10.1016/j.energy.2018.04.128

Joybari, M. M., Haghighat, F., & Seddegh, S. (2017). Numerical investigation of a triplex tube heat exchanger with phase change material: Simultaneous charging and discharging. *Energy and buildings, 139*, 426-438.

Kajumba, P. K., Okello, D., Nyeinga, K., & Nydal, O. J. (2020). Experimental investigation of a cooking unit integrated with thermal energy storage system. *Journal of Energy Storage, 32*(October).

kebede, D. (2020). *Computational Modeling and Performance Analysis of Solar Thermal Storage Integrated with Parabolic Solar Concentrator for Cooking Application.* (PhD), Addis Ababa.

Kumaresan, G., Santosh, R., Raju, G., & Velraj, R. (2018). Experimental and numerical investigation of solar flat plate cooking unit for domestic applications. *Energy, 157*, 436-447. doi: 10.1016/j.energy.2018.05.168

Lizaso, M. (2020). A review of cooking technology around the world and the potential of solar cooking.

Nag, P. (2017). *Engineering Thermodynamics*.

Pal, A. M., Das, S., & N.B.Raju. (2015). Designing of a Standalone Photovoltaic System for a Residential Building in Gurgaon, India. *Sustainable Energy, 3*. doi: 10.12691/rse-3-1-3

Panwar, N. L., Kaushik, S. C., & Kothari, S. (2012). State of the art of solar cooking: An overview. *Renewable and Sustainable Energy Reviews, 16*(6), 3776-3785. doi: 10.1016/j.rser.2012.03.026

PEIMAR. (2022). Peimar Full Black 300 Watt, 20V 60-Cell Monocrystalline Solar Panel (SG300M-FB).

Piroschka, O. P. (2014). Warming Up to Solar Cooking – A Comparative Study on Motivations and the Adoption of Institutional Solar Cookers in Developing Countries. *Energy Procedia, 57*, 1632-1641. doi: 10.1016/j.egypro.2014.10.154

Santhi Rekha, S. M., & Sukchai, S. (2018). Design of Phase Change Material Based Domestic Solar Cooking System for Both Indoor and Outdoor Cooking Applications. *Journal of Solar Energy Engineering, 140*(4). doi: 10.1115/1.4039605

Sekhon, M., & Sethi, V. (2019). Thermal modeling and analysis of novel twin-chamber community solar cooker as a replacement of biomass-based cooking. *International Journal of Green Energy, 16*(2), 167-184.

Senthil, R. (2021). Enhancement of productivity of parabolic dish solar cooker using integrated phase change material. *Materials Today: Proceedings, 34*, 386-388. doi: 10.1016/j.matpr.2020.02.197

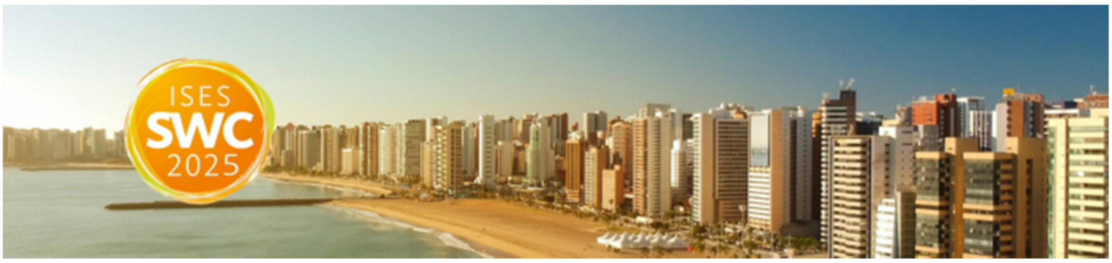
Skunpong, R., & Plangklang, B. (2011). A Practical Method for Quickly PV Sizing. *Procedia Engineering, 8*, 120-127. doi: 10.1016/j.proeng.2011.03.022

Tesfay, H, A., Kahsay, M. B., & Nydal, O. J. (2019). Numerical and experimental Analysis of Solar Injera Baking with a PCM Heat Storage. *Momona Ethiopian Journal of Science, 11*(1), 1. doi: 10.4314/mejs.v11i1.1

Tesfay, A. H., Kahsay, M. B., & Nydal, O. J. (2014). Solar Powered Heat Storage for Injera Baking in Ethiopia. *Energy Procedia, 57*, 1603-1612. doi: 10.1016/j.egypro.2014.10.152

Vigneswaran, V. S., Kumaresan, G., Sudhakar, P., & Santosh, R. (2017). Performance evaluation of solar box cooker assisted with latent heat energy storage system for cooking application. *IOP Conference Series: Earth and Environmental Science, 67*, 012017. doi: 10.1088/1755-1315/67/1/012017

Yishak, N. D. (2019). *Experimental Investigation, Selection and Thermal Performance Evaluation of Eutectic Mixture Using PCM for Cooking Application.* (Degree of Master of Science in Thermal Engineering experimetal), Adama Science and Technology University.



Paper Title: Design and Simulation of Institutional Solar-Powered Cook Stove With Thermal Energy Storage System

Author (s): Tihun Birhanu Beyene, Abdulkadir Aman Hassen and Kamil Dino Adem

Company/Institute: Addis Ababa University

Upload date: October 29, 2025

Please complete and sign this agreement when submitting your paper.

This document certifies that I,

……Abdulkadir Aman Hassen ....
(lead author name), with the consent of all co-authors,

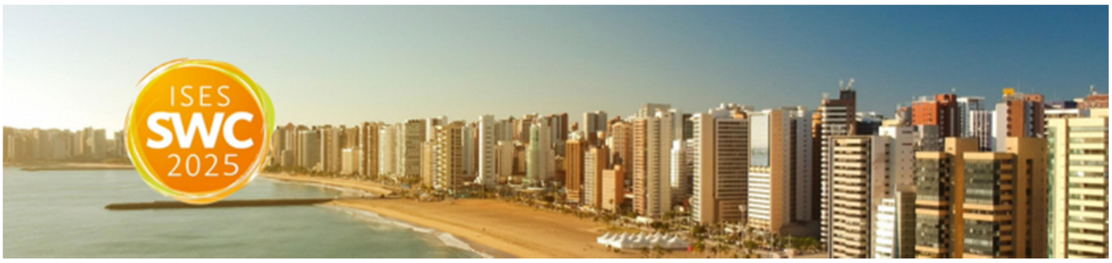
hereby assign the copyright of the paper identified above to the **International Solar Energy Society (ISES),** and that ISES owns the right to print, publish and reproduce, in whole or in part the paper, in all forms of media, including the Internet, in written, electronic or any other form as part of the Book of Abstracts as well as the Congress Proceedings, and in an online database of ISES Conference Proceedings, throughout the world for the full term of the copyright, effective when and if the paper is accepted for publication.

Notwithstanding the author's rights for use stipulated below, ISES shall be entitled to transfer the assigned copyright partly or completely to third parties.

No compensation shall be claimed for such publication. I understand that I retain or am hereby granted (without the need to obtain further permission) rights to use certain versions of the Paper for certain scholarly purposes, as described and defined below and that no patents, trademarks or other intellectual property rights are transferred to ISES.

- The right to make copies (print or electronic) of the paper for own personal use, including for classroom teaching.
- The right to make and distribute copies (electronic and paper) of the article to research colleagues for personal use but not for commercial purposes[1].
- The right to post the paper on the author's personal or institutional website or server, incorporating the complete citation and with a link to the Digital Object Identifier of the paper.
- The right to present the paper at a meeting of conference and to distribute copies of the paper to the delegates or meeting
- For the author's employer, if the paper is made within the scope of the author's employment, the right to use all or part of the information in the paper for intra-

[1] Commercial purposes: The use of the accepted paper for commercial purposes is prohibited or requires ISES' prior written permission. Examples of commercial use include but are not limited to the use or posting of the paper for commercial gain, including for use by customers; for commercial exploitation such as directly advertising with such postings; the charging of fees for the document access, or the use of the paper by a for-profit, commercial organisation for promotional purposes, whether free or for a fee.



company or intra-institution use, such as training, including posting the paper on a secure, company/institution internal intranets.

- The right to include the paper, in full or in part, in a thesis or dissertation
- The right to use the article or any part in a compilation of works of the author, such as collected writings or lecture materials, and
- The right to prepare other derivative works, to extend the article into book-length form, or to otherwise re-use portions or excerpts in other works, with the full acknowledgement of its original publication in ISES conference proceedings.

I affirm that the paper, including all images, graphics, illustrations, supplement tables and other information submitted, is an original work of the author(s) and has not been published elsewhere. The paper is not currently being considered for publication by any other journal or for any other conference, and will not be submitted for such review while under review for the "Solar World Congress 2025". The paper will not in any way violate or infringe any rights of third parties and contains no material of an obscene, defamatory, unlawful or libelous nature, and does not contain any statements or information that is intentionally misleading or inaccurate. If excerpts from other works held in copyright are reproduced, the author(s) has (have) obtained the necessary permission from the appropriate copyright holders.

I confirm I have reviewed and compiled the paper with the relevant Author Instructions provided in the abstract and full paper templates.

If the paper was prepared jointly with other authors, the undersigning author has informed the coauthors of the terms of this agreement and is signing on their behalf representing that he/she is authorized to do so.

This Assignment shall be subject to the laws of Germany. Place of jurisdiction shall be Freiburg im Breisgau, Germany.

Any amendments to this agreement shall not be valid unless made in writing and signed by both parties.

Date: October 29,2025 Authorised Signature ____________

Please upload the signed form when you submit your manuscript**.**

International Solar Energy Society e.V.
International Headquarters
Wiesentalstr. 50
79115 Freiburg
Germany