Development of portable indoor solar cooking device with energy storage facility

Dr. Dwaipayan Sen (PI)

Dr. Sulagna Chatterjee (Co-PI)

Mr. Subrata Mukherjee (Co-PI)

Department of Chemical Engineering

Heritage Institute of Technology, Kolkata

Industry Partner: Geetanjali Solar, P-14, Kasba Industrial Estate, Phase-1, E. M. By Pass, P.O. East Kolkata Township, Kolkata – 700107

Target Beneficiaries

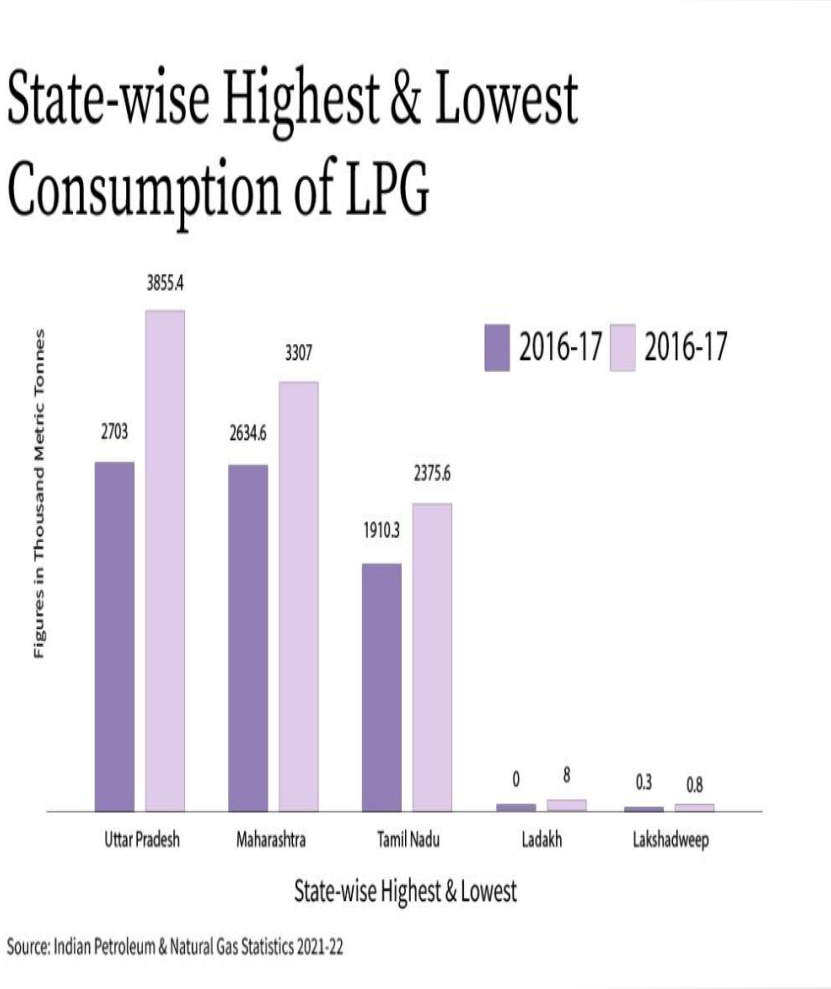
- Low income group consumers using smoky stoves (through burning coal, cowdung cake, wood) for cooking in rural and limited urban areas (such as slums, roadside food stall).
- The rural consumers for solar stoves are mainly served through the community-based facility, which has limited energy storage options and the cooking is limited during daytime at outdoor condition.

Identified Problems

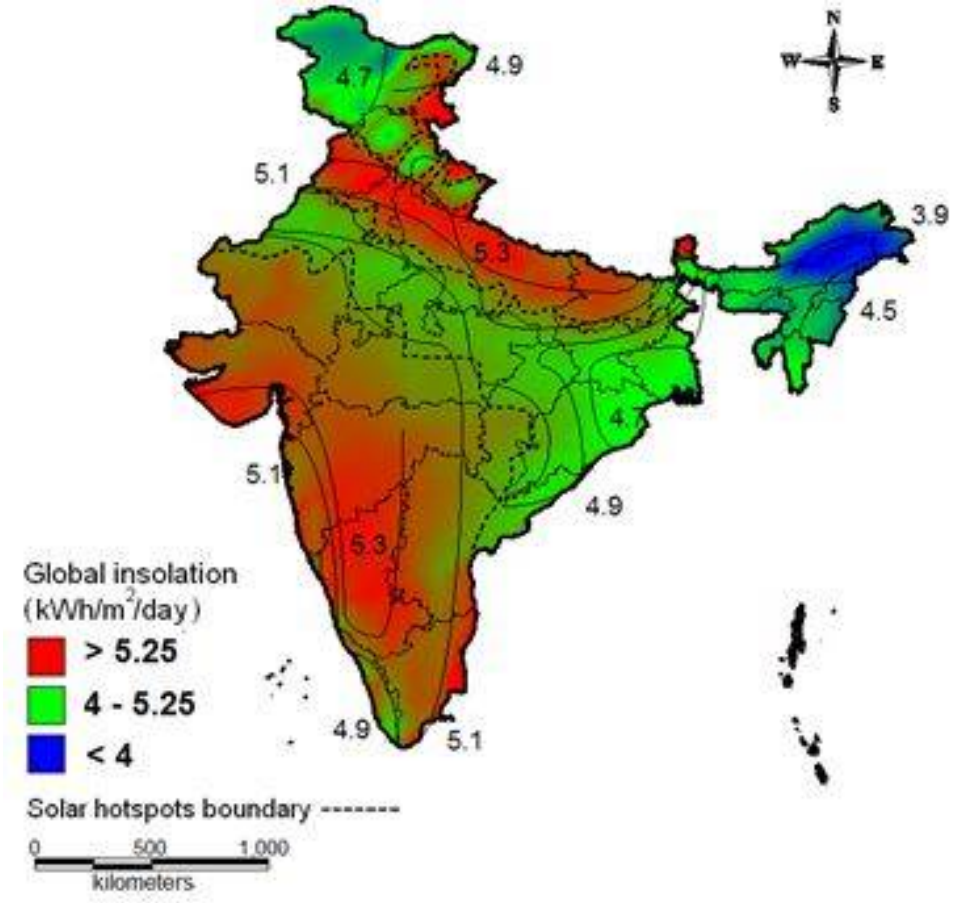
- Conventional solar stove (chullas) are only restricted to use during daytime.
- Present solar stoves are operated at outdoor condition, which might restrict the cooking procedure at adverse weather condition.
- PV based solar cooker requires large installation area.
- Use of dried biomass (wood) as energy sources with conventional solar stove (chullas) increases environmental carbon footprint reduction.

Issues with conventional cooking facility

- Price hike in LPG cylinder reduces LPG consumption. Below 45% in rural India (*Source: The Hindu, May 09, 2022*).
- Average rural casual labourers Rs. 368/day doesn't meet the expenditure (*Source: Business Standard, July, 17, 2023*)
- Solid fuel consumption in rural India 20% (India 15%) (*Source: Council of Energy, Environment and Water, Report, September, 2021*)

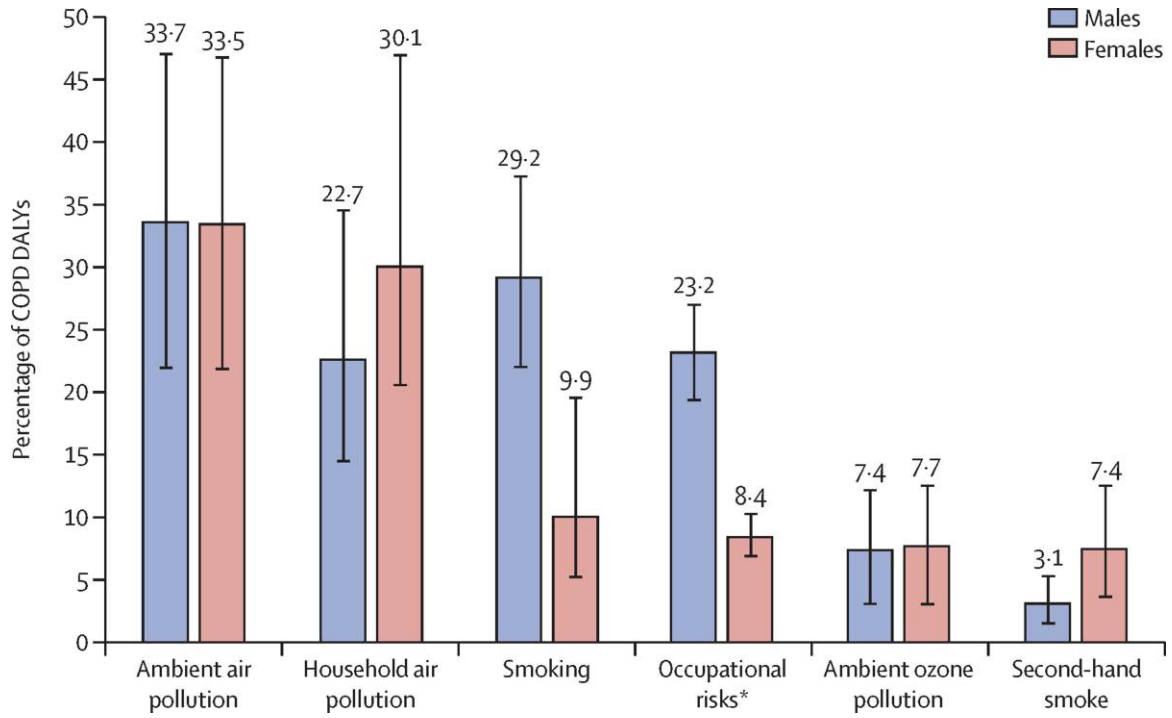


Issues with conventional cooking facility...contd.



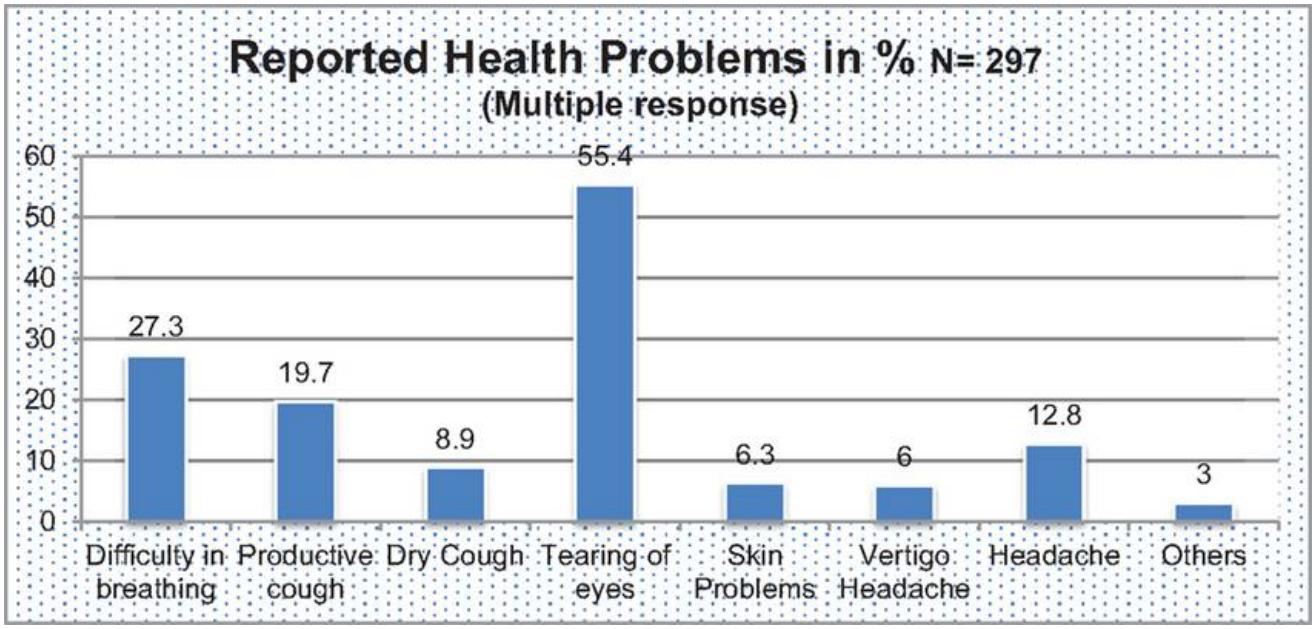
Annual average Global insolation map of India showing the isohels and solar hotspots *(Source: https://wgbis.ces.iisc.ac.in/energy/paper/hotspots_solar_potential/results.htm)*

Issues with conventional cooking facility...contd.



Percentage of COPD DALYs (Disability Adjusted Life Years) attributable to different risk factors in India by sex, 2016 (Source: Lancet Global Health, 6, 2018, e1363–1374)

Issues with conventional cooking facility...contd.



Reported health problems due to indoor air pollution *(Source: Frontiers in Public Health, 3, 2015, DOI:10.3389/fpubh.2015.00005)*

Problem statement

Development of portable solar cooker capable of solar energy storage and release of that energy during night time for cooking purpose.

Details of the existing Technologies in the proposed sector

- Newly launched “Surya Natun” solar stove from Indian Oil Corporation. Device is equipped with a PV installed which is solar irradiation, converting solar energy to electrical energy using thermal battery. (*The limitations might lie with its price and portability*)

Details of the existing Technologies in the proposed sector … contd.

- Smart Stoves from Greenway Infra Pvt Limited, Ergonomic front loading design, MOC: Steel and Aluminium with Bakelite Handles, Secondary Air Induction Mechanism, 65% Fuel saving and 70% smoke reduction. (*Limitations with the burning of wood leading to increase for carbon footprint*)
- Solar Parabolic Cooker 2.7 from Radha Solar Energy Cell, Capacity 15 people at time, Manual tracking. (*Limitations with the night time cooking*)

Phase change material design

- Mixing of 71.57% (w/w) sodium nitrate, 28.4% (w/w) potassium nitrate and 0.03% (w/w) graphite at room temperature.
- **Mixing wax (97%) (w/w) and graphite (3%) (w/w) at room temperature.**
- Aluminium silicate ceramic blanket insulation (k=0.06 W/mK; Specific heat: 1130 J/kgK; density: 96.1 kg/m^3)
- Properties of wax-graphite mixture:

❖ Thermal expansion coefficient: 0.0006/oC

❖ C_p (l) = 2100 J/kgK - C_p (s) = 2000 J/kgK

❖ k (l) = 0.25 W/mK – k(s) = 0.28 W/mK

❖ Density (l) = 790 kg/m^3 - Density (s) = 910 kg/m^3

❖ Viscosity = 0.0269 Pa.s

Material Standardization … contd.

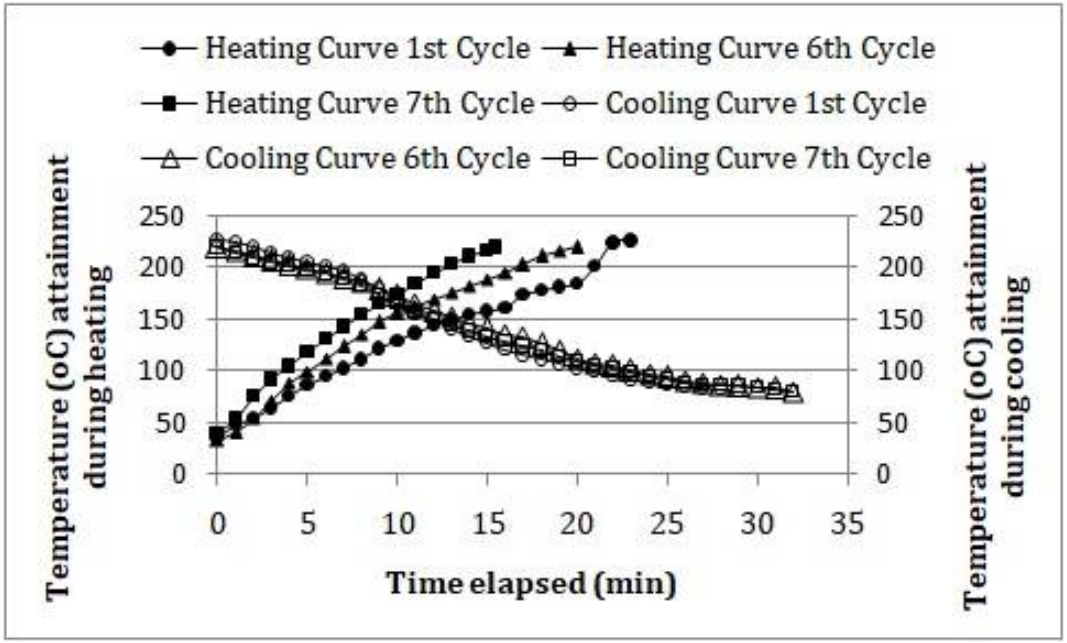


Fig. 3: Heating and Cooling Rate for wax and graphite mixture (71.57% (w/w) sodium nitrate, 28.4% (w/w) potassium nitrate and 0.03% (w/w) graphite) (Without insulation)
Heating was done with electrical heater

Material Standardization

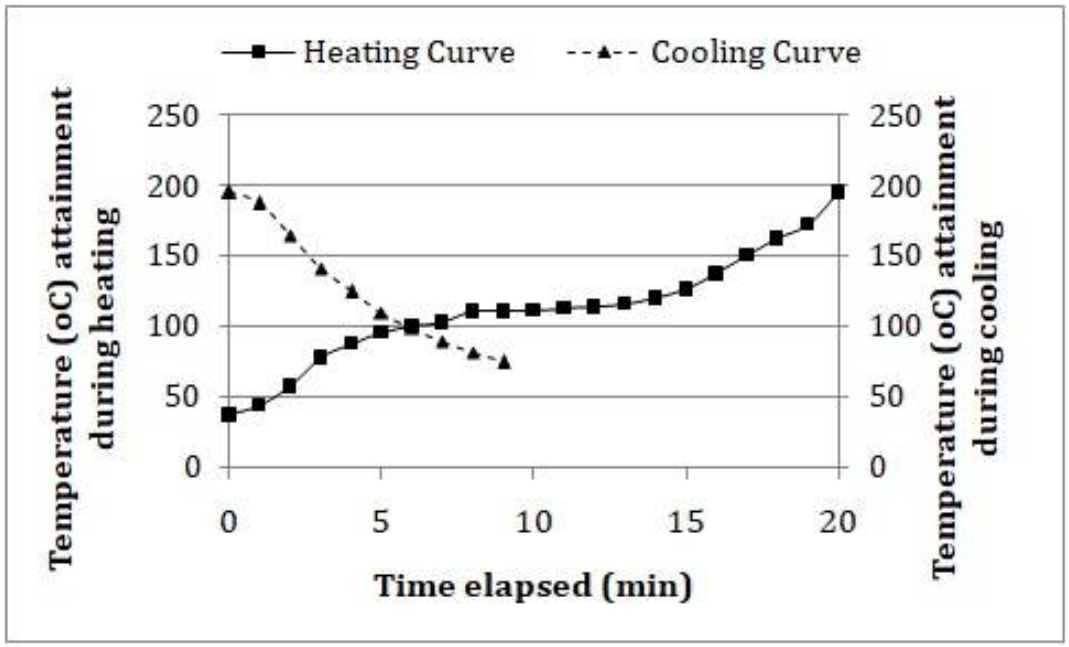


Fig. 1: Heating and Cooling Curve for wax and graphite mixture (97 wt% Wax and 3 wt% graphite) (Without insulation)
Heating was done with electrical heater

Material Standardization … contd.

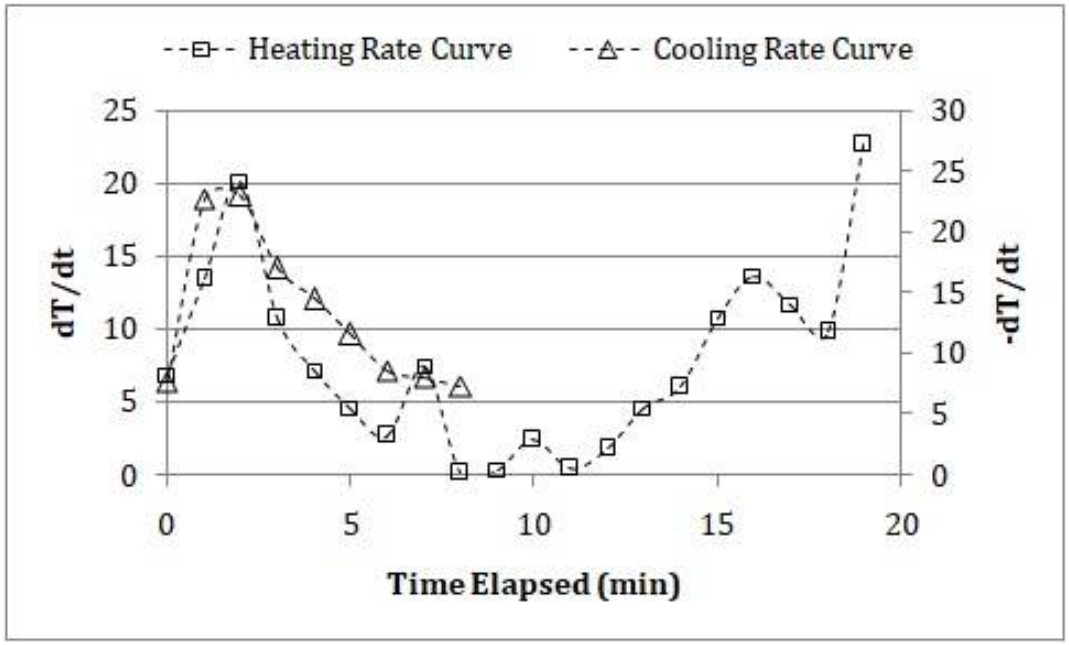


Fig. 2: Heating and Cooling Rate for wax and graphite mixture (97 wt% Wax and 3 wt% graphite) (Without insulation)
Heating was done with electrical heater

Bench-top study of the miniature solar cooker ... contd.

Fig. 4: Bench scale study of the solar salt curing technique

Bench-top study of the miniature solar cooker ... contd.

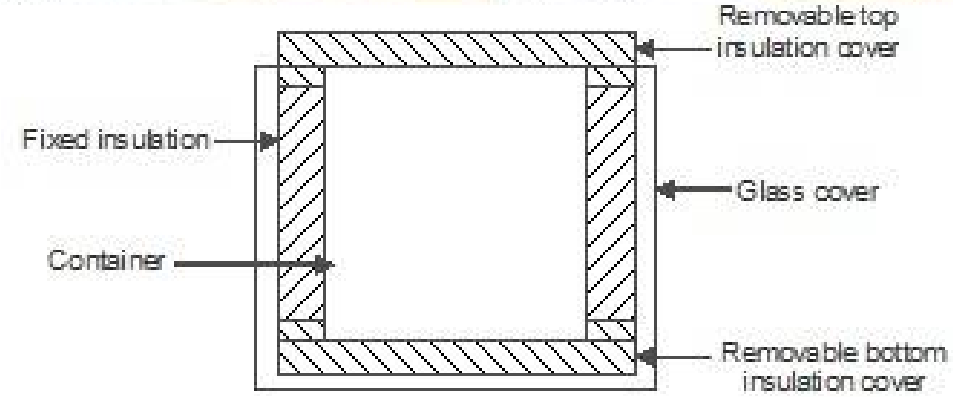


Fig. 5(a): Insulated bench scale apparatus (b) Schematic of the apparatus

Bench-top study of the miniature solar cooker ... contd.

Fig. 6: Heating of the bench-top cooker using parabolic solar concentrator at rooftop

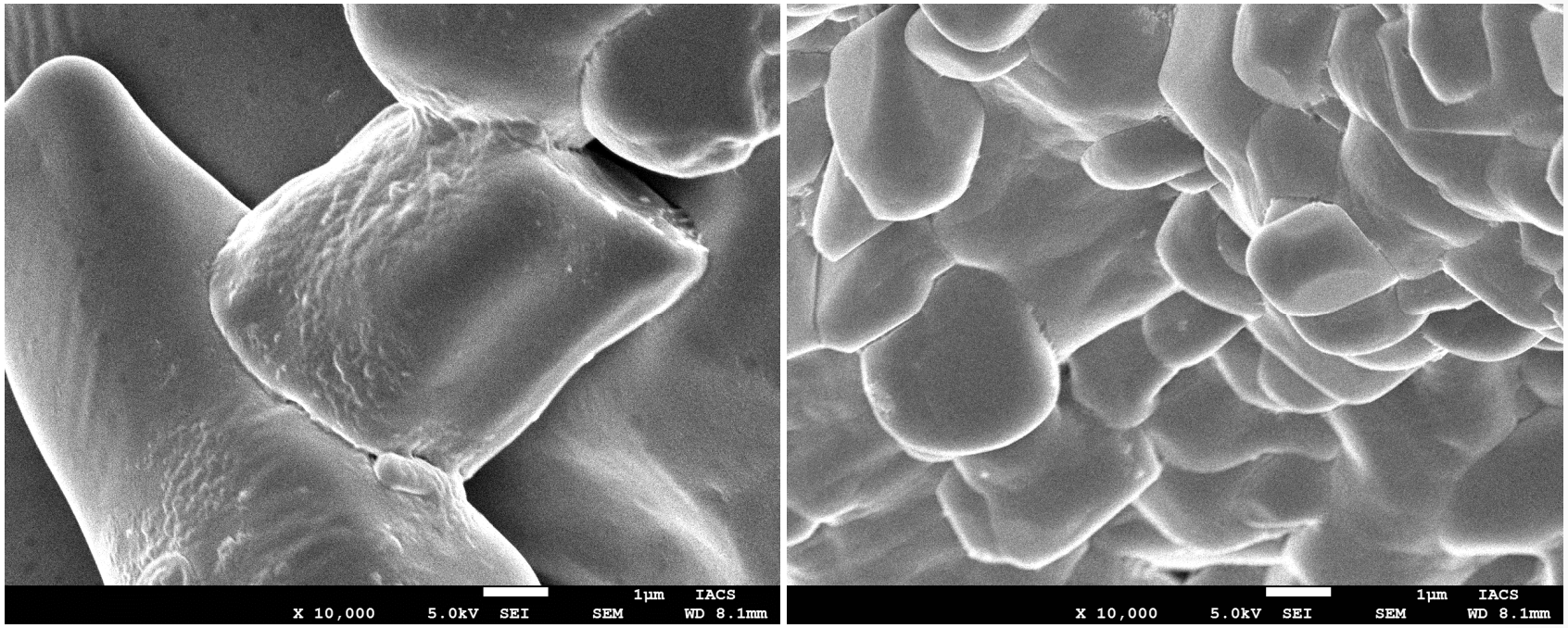
Bench-top study of the miniature solar cooker ... contd.

Aperture Area = 1.8144 m^2
Receiver area = 0.1257 m^2
Concentration ratio = 14.4
Average solar insolation in WB=5 $kWh/m^2/day$
Reflectance of material in solar collector = 0.92

Bench-top study of the miniature solar cooker ... contd.

Fig. 7: Onset of boiling over bench-top cooker after charging

Bench-top study of the miniature solar cooker ... contd.



0% graphite doped

0.03% graphite doped

Fig. 8: FESEM image of eutectic mixture with and without graphite

Bench-top study of the miniature solar cooker ... contd.

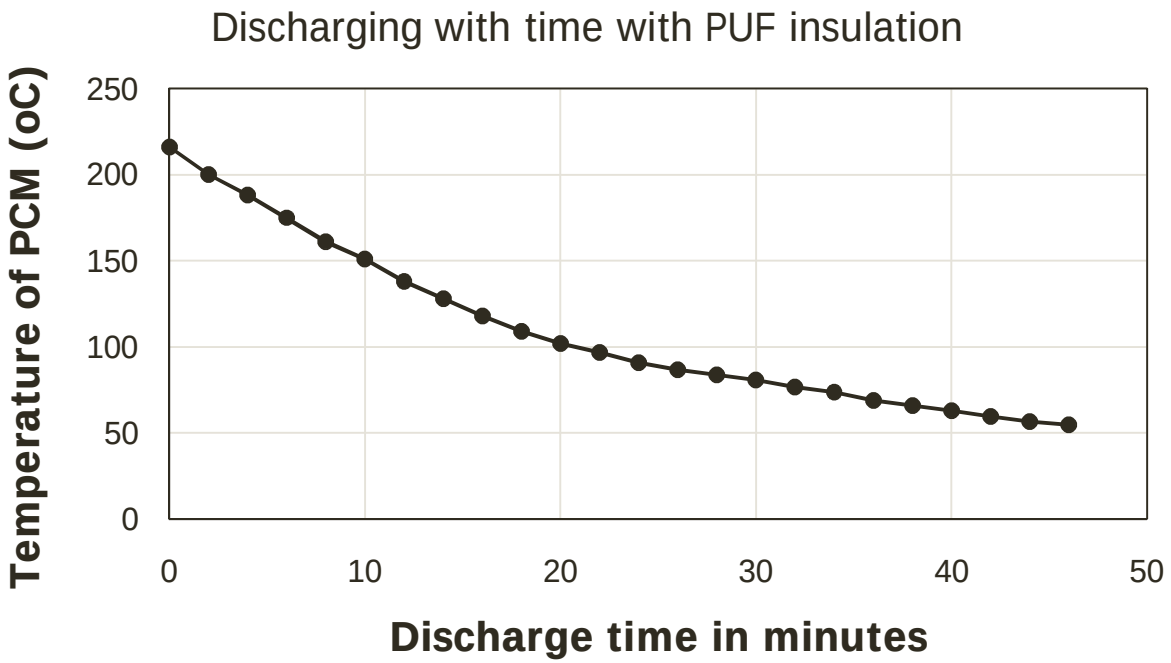


Fig. 9: Performance analysis of PUF insulation for eutectic mixture of salts with graphite

Bench-top study of the miniature solar cooker ... contd.

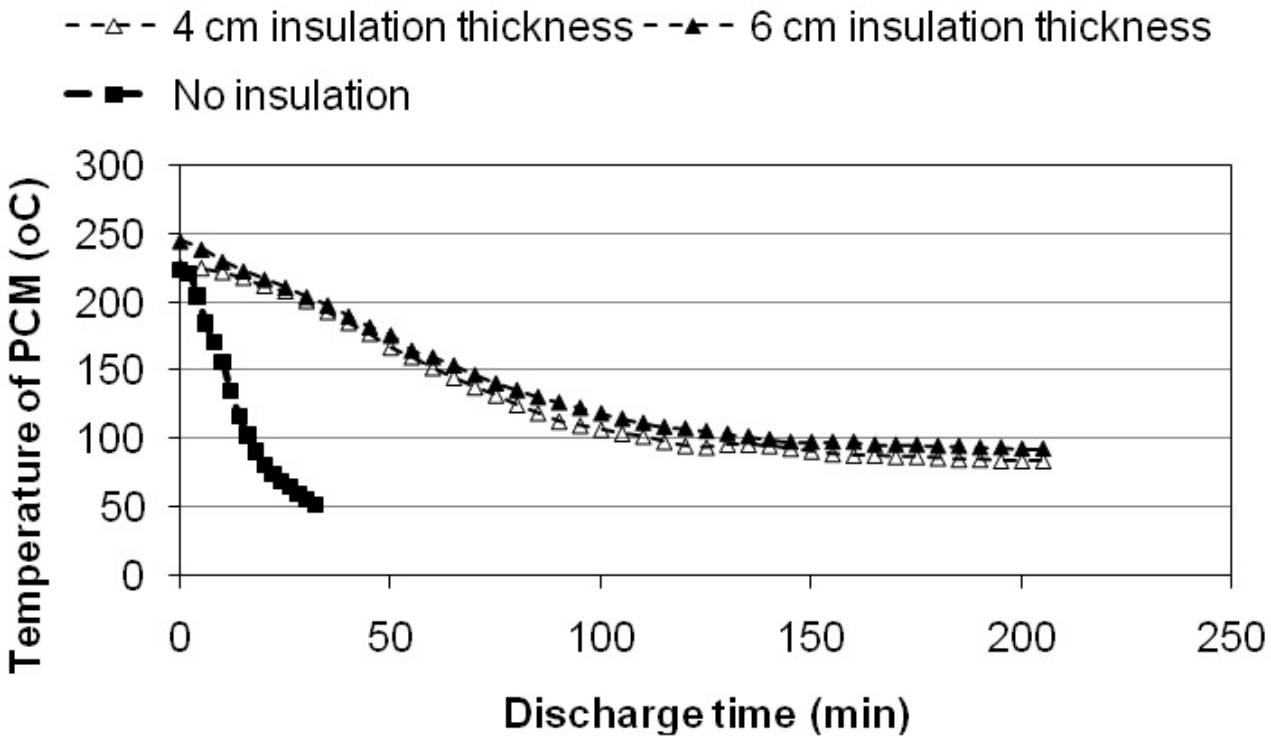


Fig. 10: Performance analysis with ceramic blanket insulation for eutectic mixture of salts with graphite

Bench-top study of the miniature solar cooker ... contd.

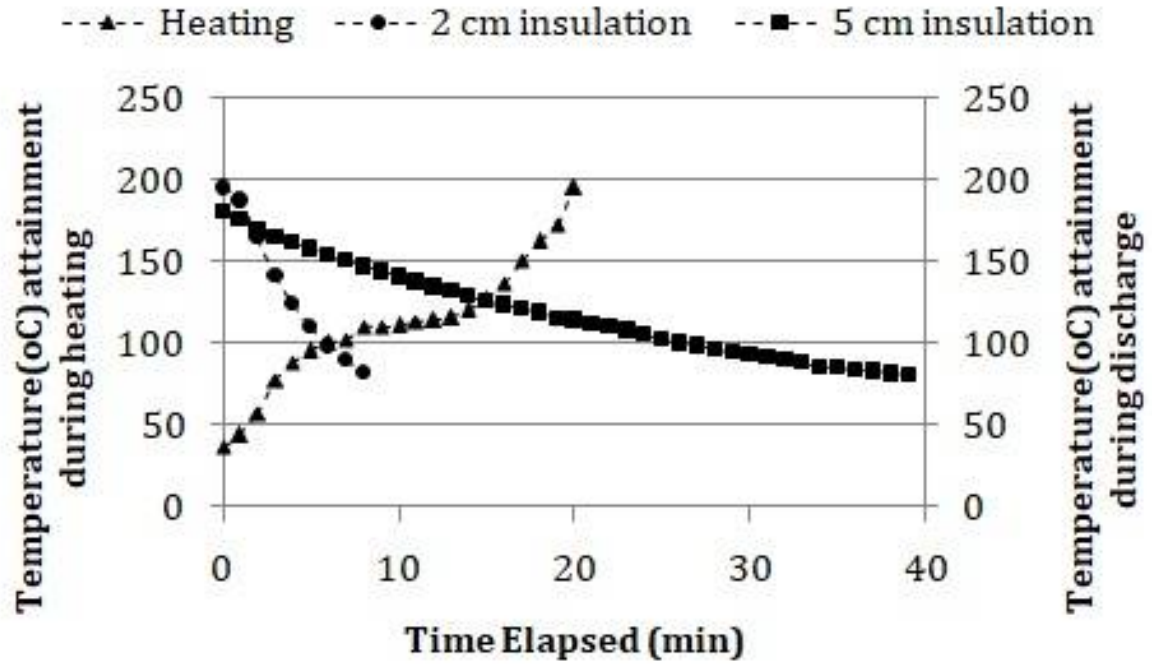


Fig. 11: Performance analysis with ceramic blanket insulation for wax with graphite

Bench-top study of the miniature solar cooker ... contd.

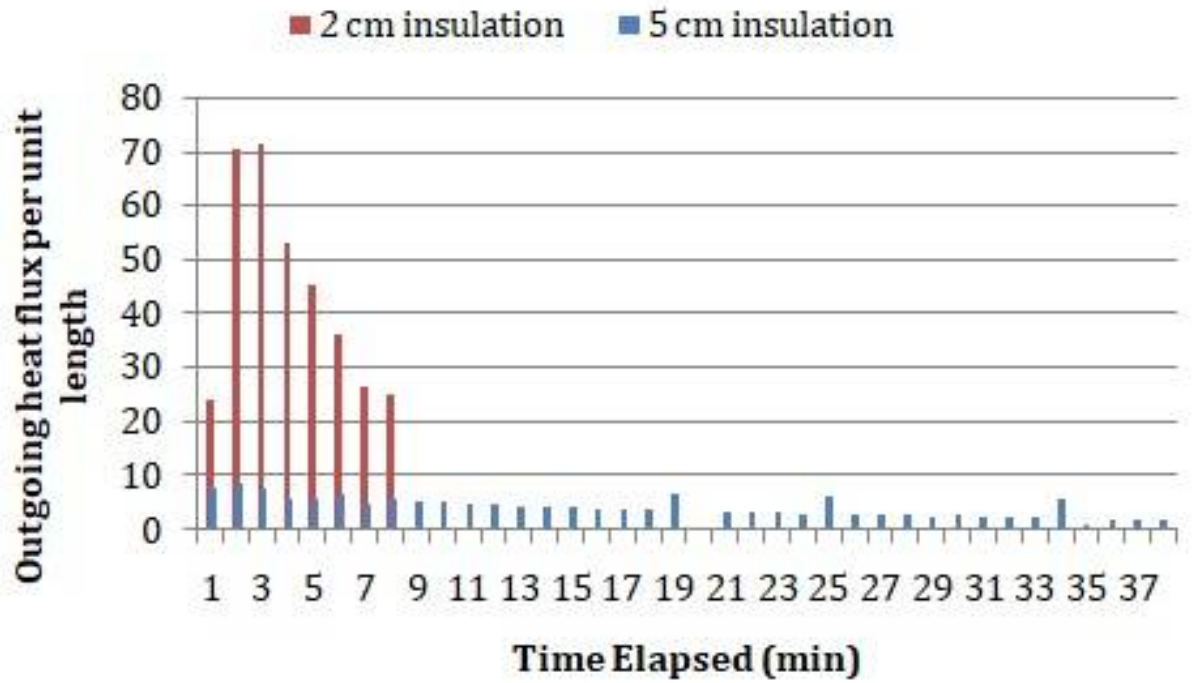
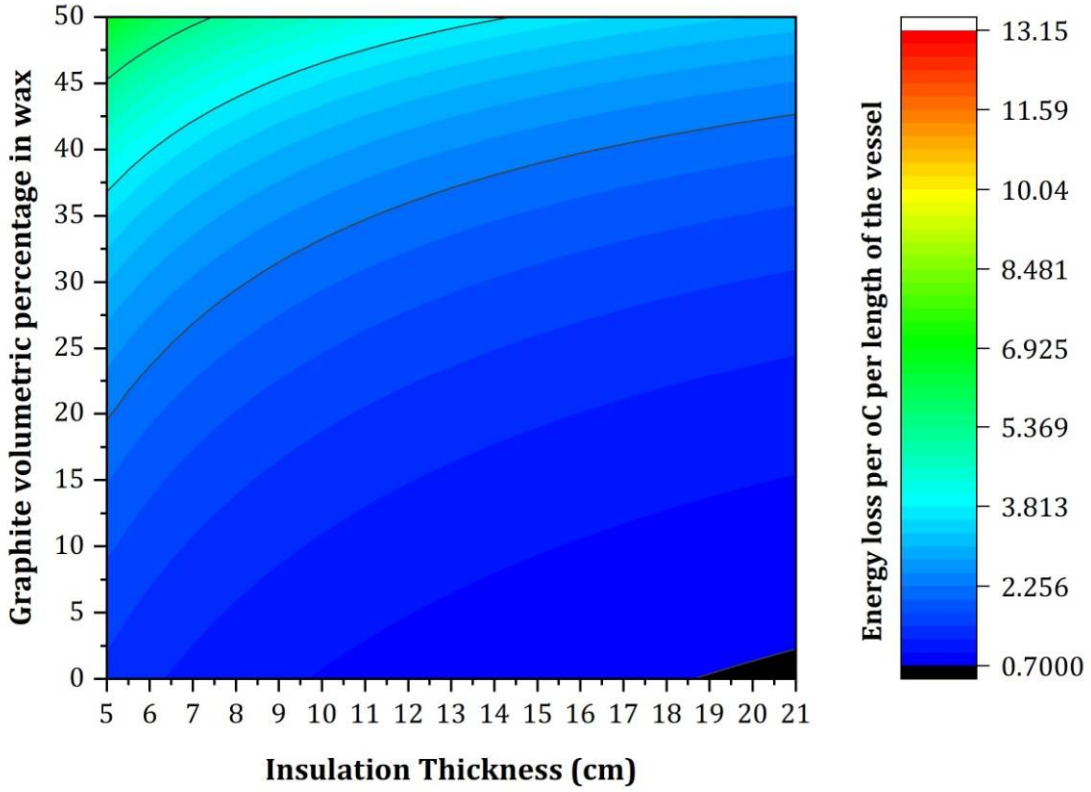


Fig. 12: Heat loss through ceramic blanket insulation for wax with graphite

Graphite percentage determination for optimum insulation



ax

Parametric consideration

- $D/\text{Thickness}_{\text{insulation}} = 1$
- Volumetric ratio of graphite = 2.5%
- $Gr_{bench} = 148032.6$
- $Pr_{bench} = 222.8$

$$Nu_{bench} = 0.133\left(Gr_{bench}.Pr_{bench}\right)^{0.326}\left(\frac{L}{r}\right)^{-0.0686} = 34.6$$

Ref: Journal of Mechanical Science and Technology 26 (3) (2012) 959-965

Proposed scale-up with insulation

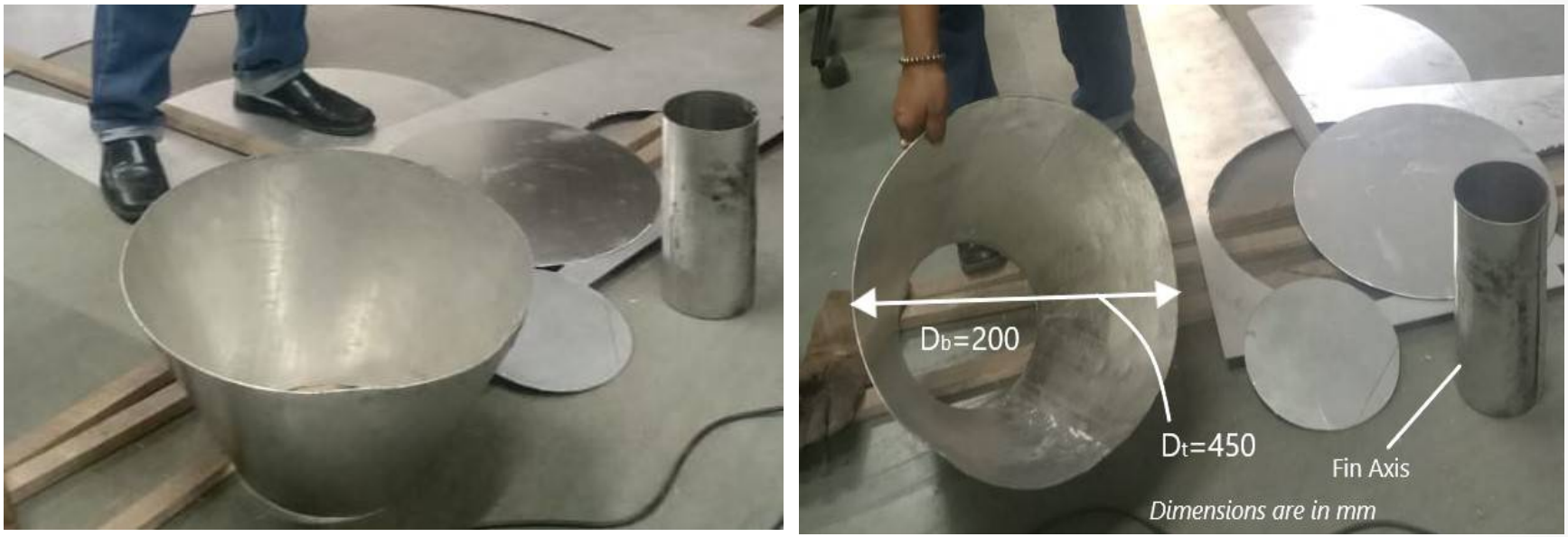


Fig. 14: Fabrication of solar oven in actual scale

Scale-up devise with insulation simulation result

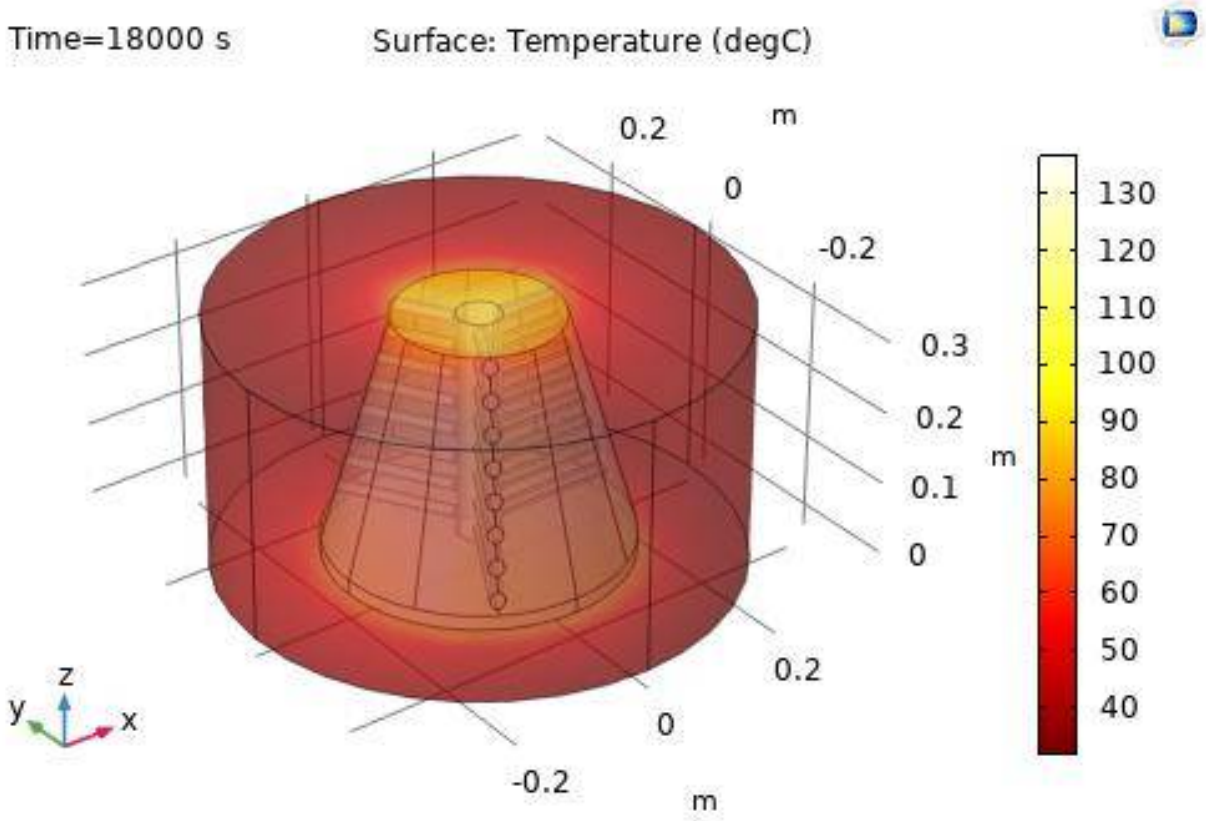


Fig. 15: Profile for energy transfer through insulation at 5 h

Scale-up devise with insulation simulation result … contd.

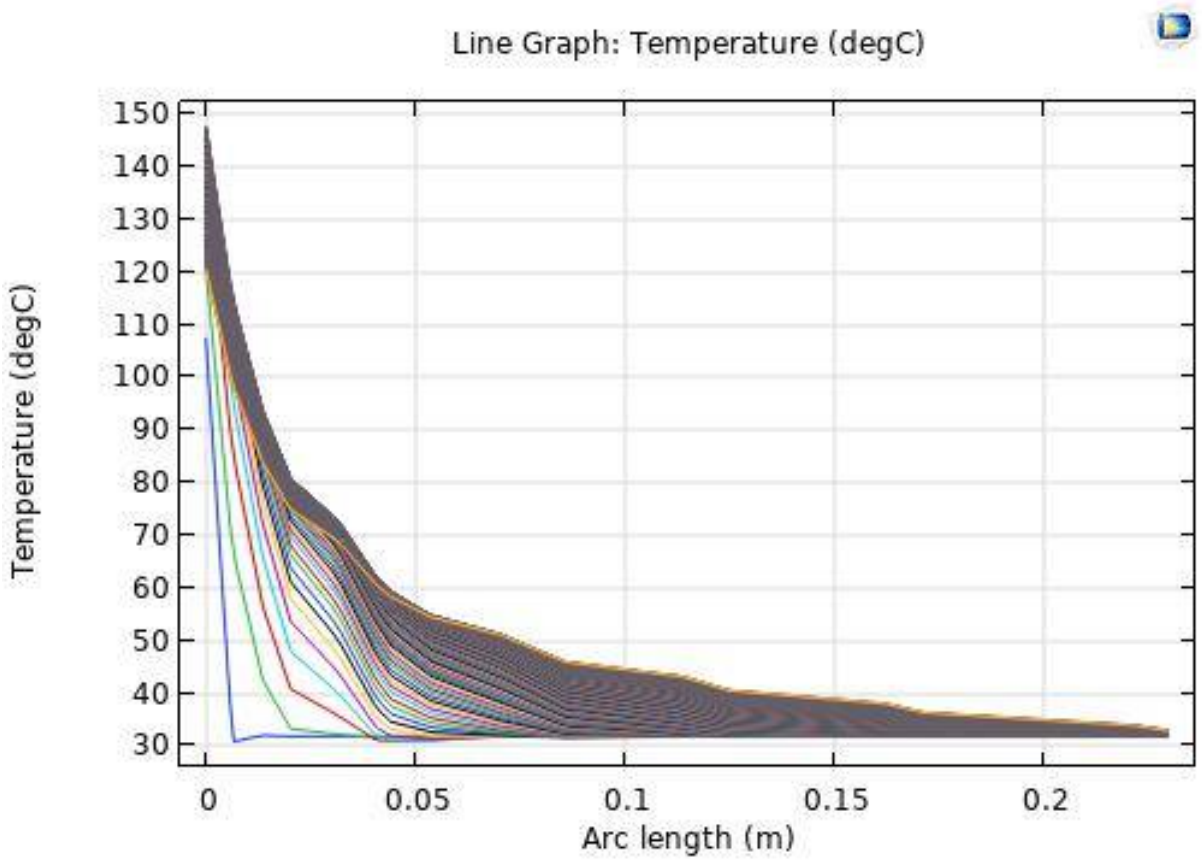


Fig. 16: Temperature profile through insulation from top surface of the cooking oven

Scale-up devise with insulation simulation result … contd.

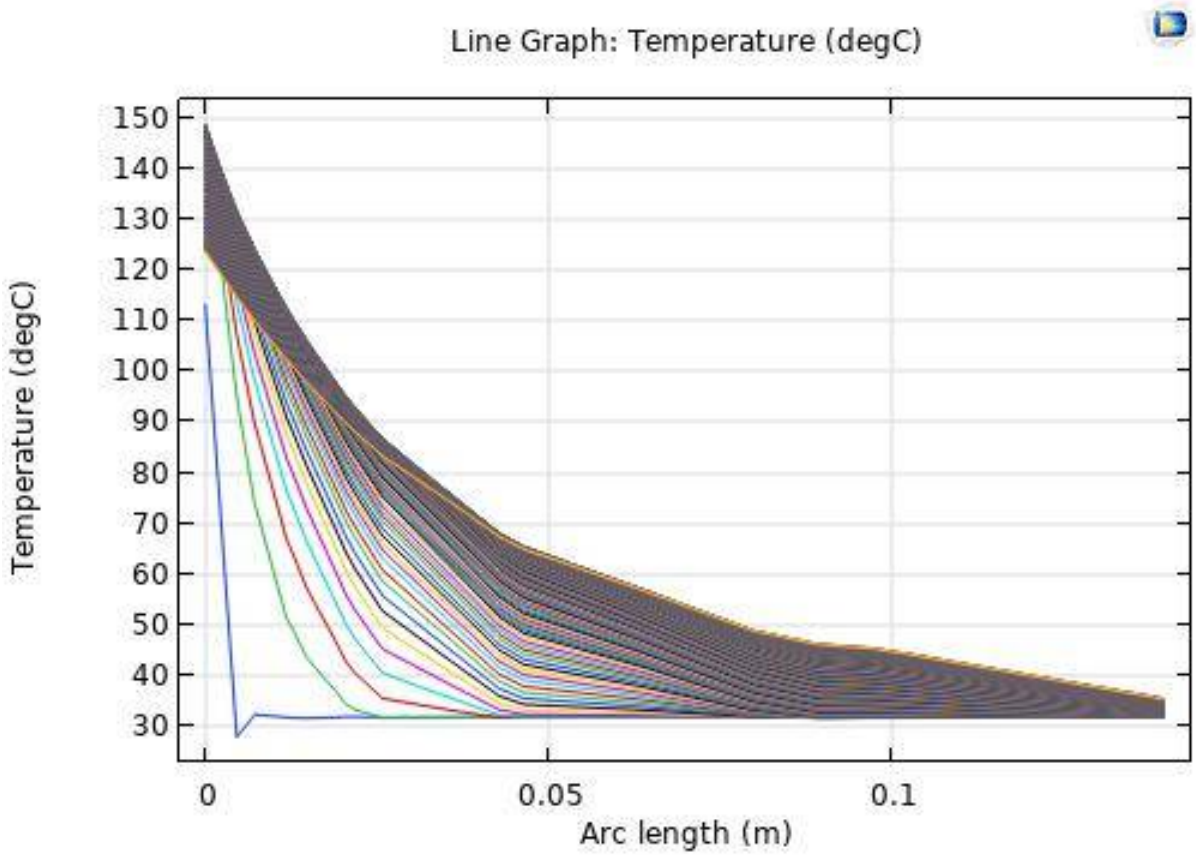


Fig. 17: Temperature profile through insulation from bottom surface of the cooking oven

Proposed cooking oven

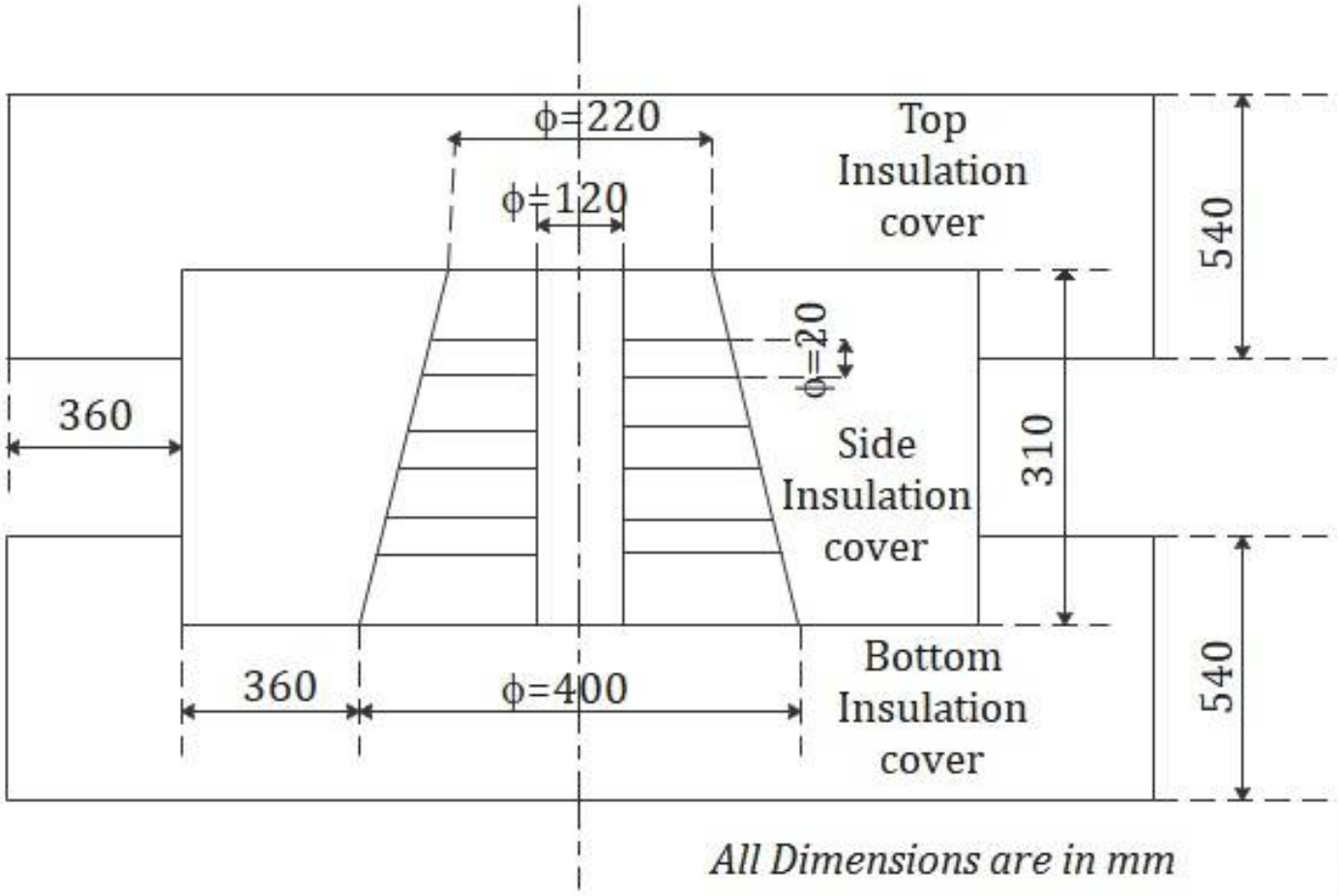


Fig. 18: Schematic of the proposed oven

Proposed cooking oven ... contd.

Fig. 19: Proposed oven

Outcome achieved, pending and deviations

- Selection of PCM and its standardization.
- Bench scale study of the insulated solar devise.
- Heating of water using bench scale set-up.
- Fabrication of scale-up version of cooking devise.
- **Insulation box design (Ongoing).**
- **Field testing towards cooking/boiling of water (Yet to accomplish)**
- **Deviation from the double solar reflector, which is replaced by parabolic solar concentrator.**

Expenditure statement

Non-Recurring	Expenditure (INR)	Expenditure (Euro) 1 Euro=88.48 INR	Total Budget allocated (Euro)
Solar concentrator	14,500	163.87	1937.50
Fabrication of solar devise	13,530	152.92	
Insulation box	Quotation yet to receive	-	
Toolbox			
Solar illuminator	10,030	113.36	
(A) Total Expenditure	**38,060**	**430.15**	

Expenditure statement … contd.

Recurring	Expenditure (INR)	Expenditure (Euro) 1 Euro=88.48 INR	Total Budget allocated (Euro)
Chemicals and consumables	5,758	65.08	3000.00
Analysis	6,770	76.51	
Travel	Yet to utilize	-	
Contingency	Yet to utilize	-	
Manpower cost	Yet to utilize	-	
(B) Total Expenditure	**12,528**	**141.59**	
Total Expenditure (A+B)	**50,588**	**571.74** ***(16.7% Fund received)***	**4937.50** ***(Fund received 3417.73 on 21.12.2022 1 euro = 87.9114)***

THANK YOU