Presented at the COMSOL Conference 2010 Paris

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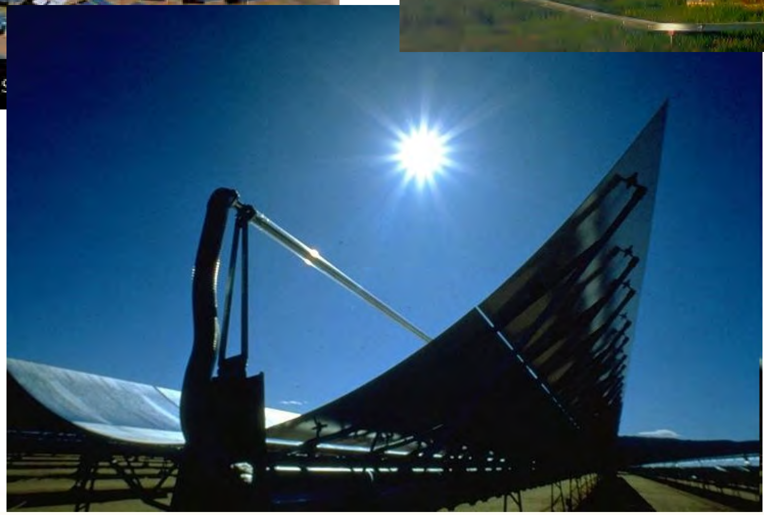
Numerical Study of a High Temperature Latent Heat Storage (200-300 ^{0}C) Using $NaNO_3$-KNO_3 Binary Mixture

Foong Chee Woh, 17-11-2010

Background



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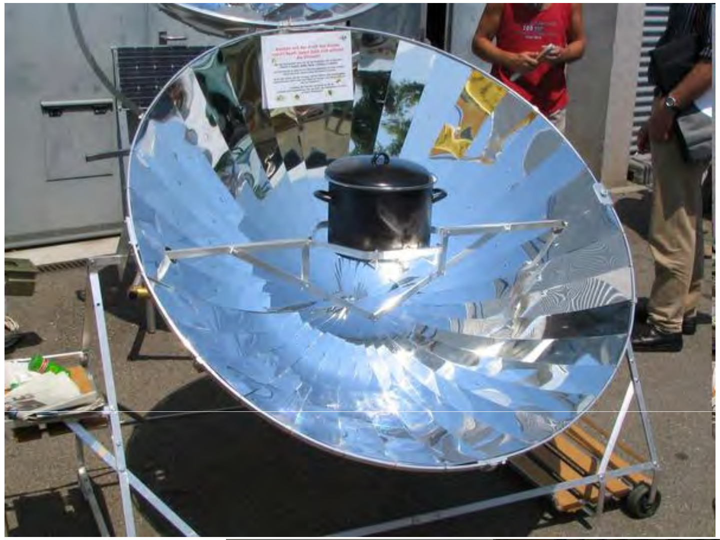

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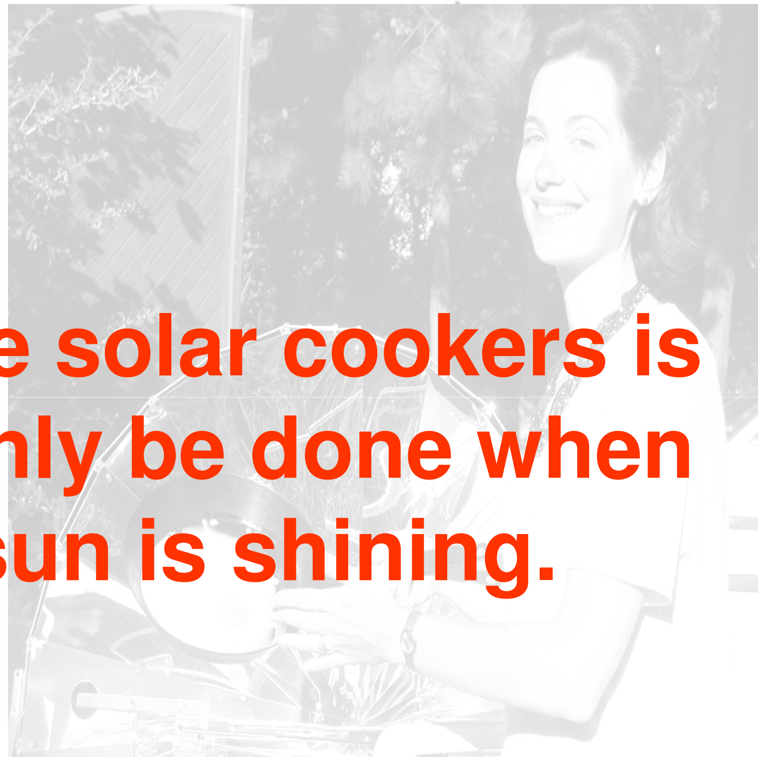

A limitation of these solar cookers is that cooking can only be done when and where the sun is shining.

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Background

In our research team, a small scale concentrating solar system with heat storage is currently under development using different principles and heat storage methods.

Parabolic dish and trough system are being tested using air/oil/steam as heat transfer fluid (HTF).

Thermal heat storage can be sensible or latent heat. Rock bed and phase change materials are used in the study.

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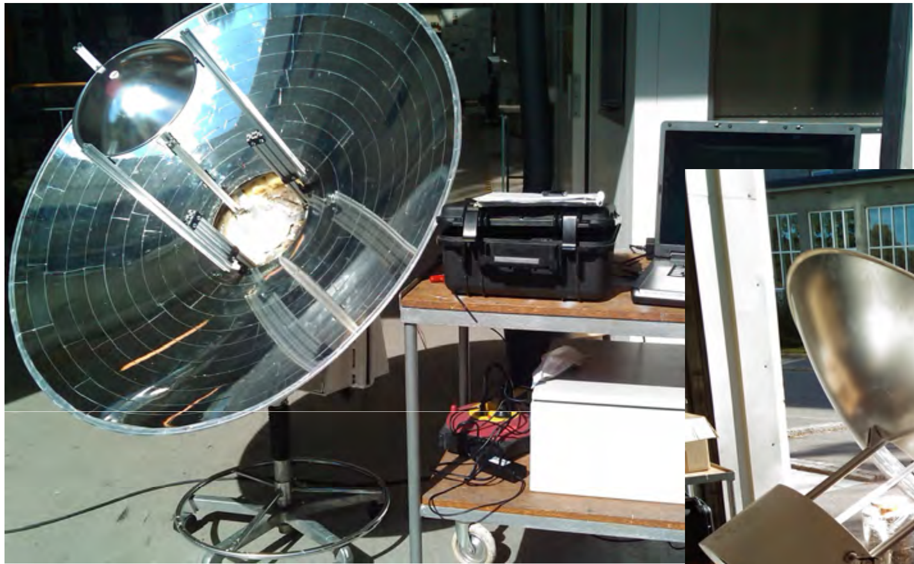
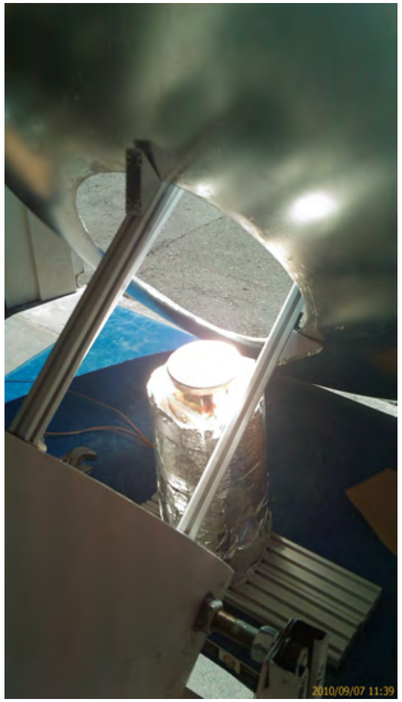
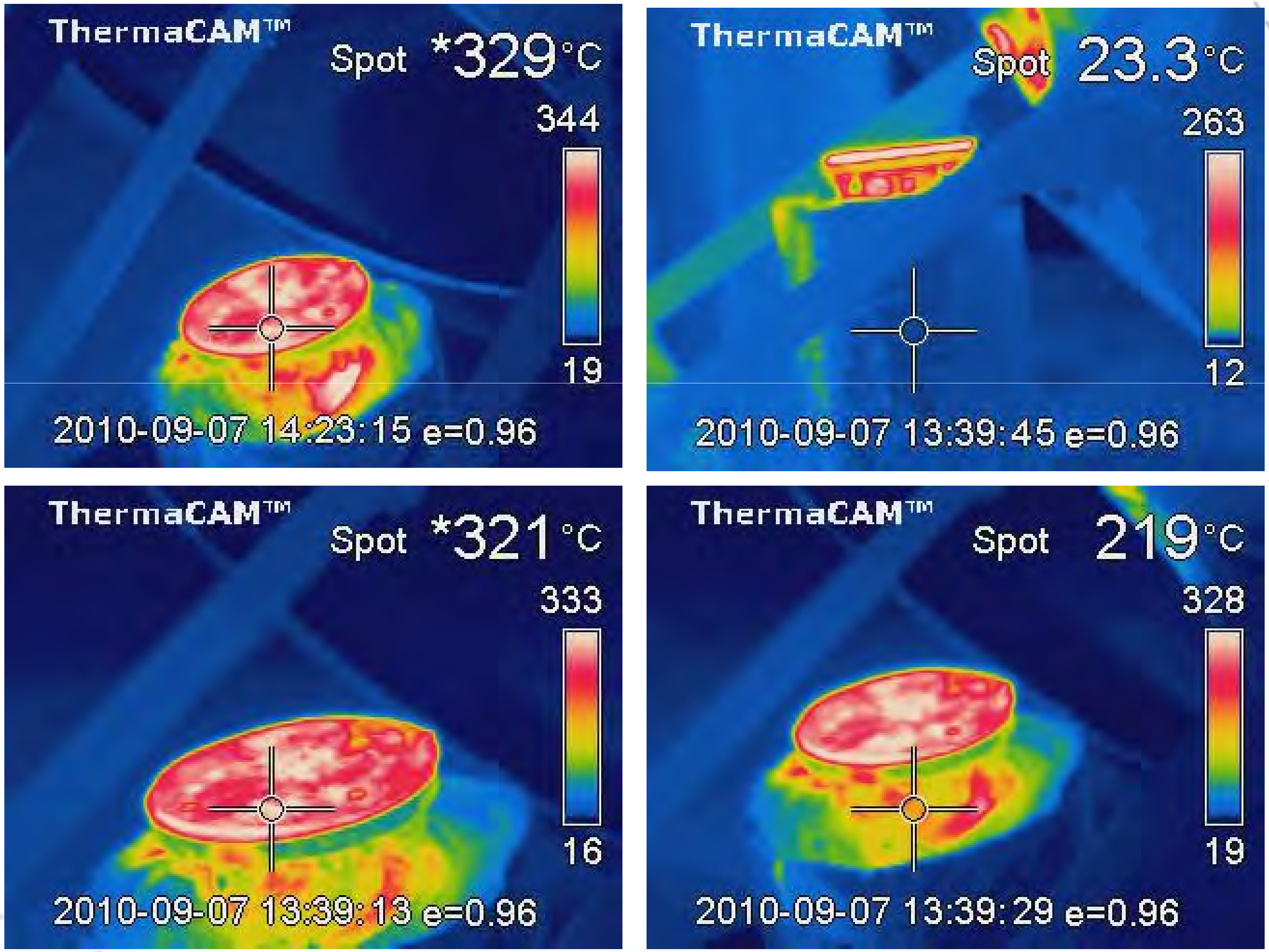




Double-reflector solar system (PCM)



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COMSOL simulation

The simulations of the latent heat storage unit were carried out using COMSOL Multiphysics 3.5a.

A 2D model with transient analysis was chosen to solve the problem.

The governing equation for the heat transfer process within the PCM is the energy equation for conduction and convection. However, the effect of convection heat transfer within the PCM can be neglected when the volume of PCM used in between the fins is small.

COMSOL simulation

$$\rho C_p \left(\frac{\partial T}{\partial t} \right) = \nabla (k \nabla T)$$

Solving the solid-liquid interface is one of the major problems in heat transfer calculations.

In this study, the phase change problem is solved using the effective heat capacity method.

Effective heat capacity, C_{eff}

$$C_{eff} = \frac{L}{T_1 - T_2} + C_p$$

where L is the latent heat of fusion, T1 is the onset temperature of phase transition and T2 is the end temperature of phase transition.

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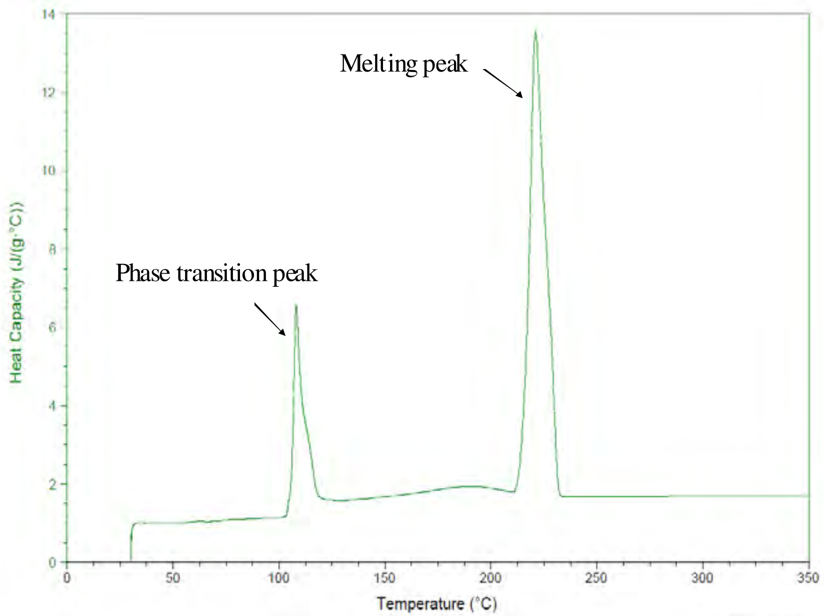
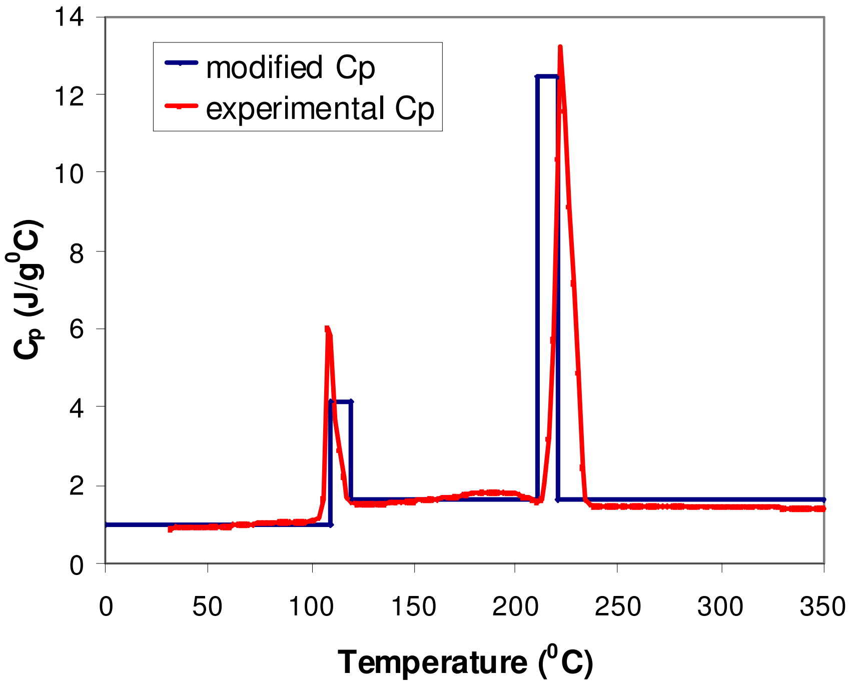
COMSOL simulation





Thermal measurement of the $NaNO_3$-KNO_3 system using DSC.

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COMSOL simulation

The phase transition enthalpy and enthalpy of fusion were incorporated in the modified heat capacity

$$C_p \text{ (kJ/kg)} = \begin{cases} 1 & T \prec 383K \\ 4.128 & 383K \le T \le 393K \\ 1.6 & 393K \prec T \prec 483K \\ 12.463 & 483K \le T \le 493K \\ 1.6 & T \succ 493K \end{cases}$$

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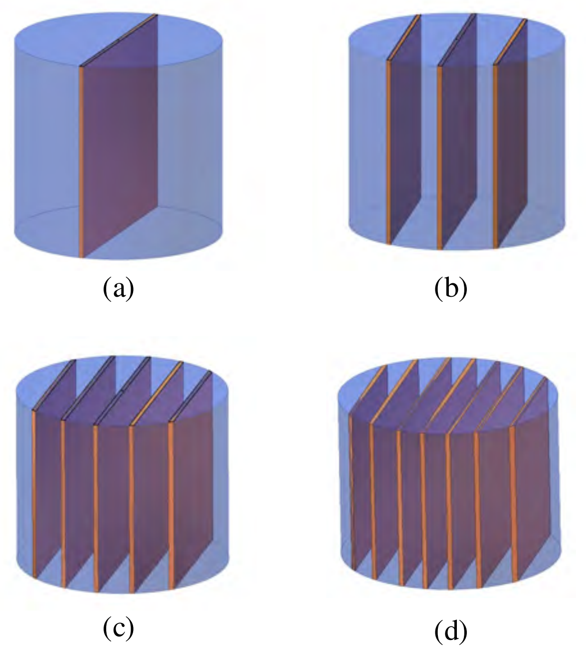
COMSOL simulation



Latent heat thermal storage container with different number of aluminum fin; (a) 1 fin, (b) 3 fins, (c) 5 fins, (d) 7 fins.

Thermophysical properties of the $NaNO_3$ - KNO_3 mixture (60:40 mol%)

Parameter	Value
Thermal conductivity (W/m·K)	0.5
Density (kg/m^3)	2000
Enthalpy of fusion (kJ/kg)	108.67
Phase transition enthalpy (kJ/kg)	31.91

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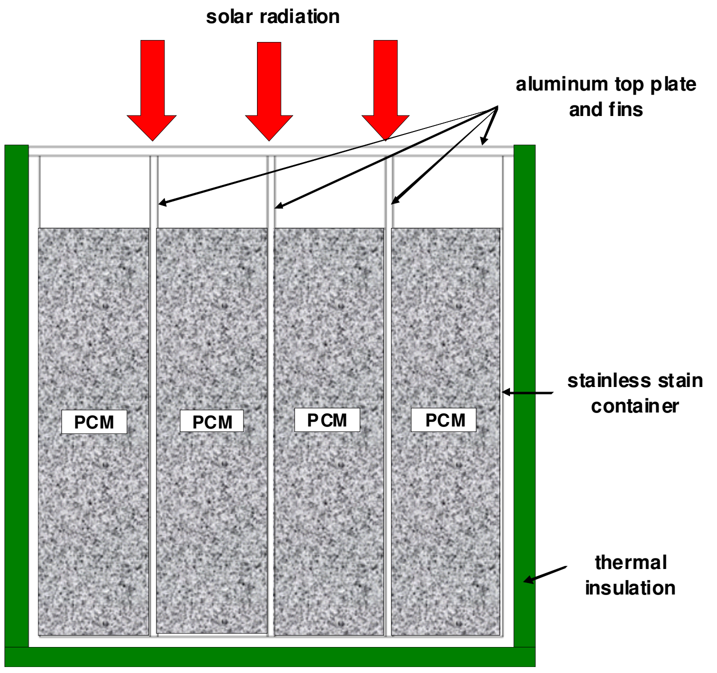
COMSOL simulation



The initial and boundary conditions are as follow:

• The top plate surface is subjected to constant solar radiation and convection heat loss.

• A constant room temperature at 296 K and the heat transfer coefficient, h is assumed to be 10 $W/m^2 \cdot K$.

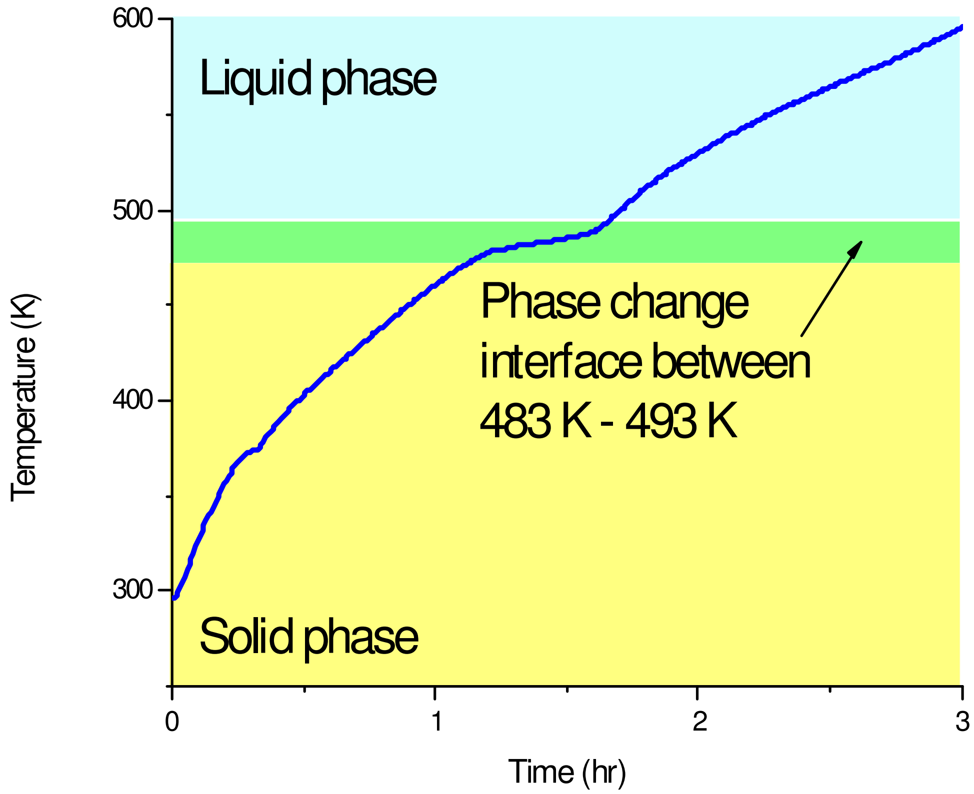
• The initial temperature of the thermal storage unit including PCM was 296 K.

• All other outside surfaces are thermally insulated.

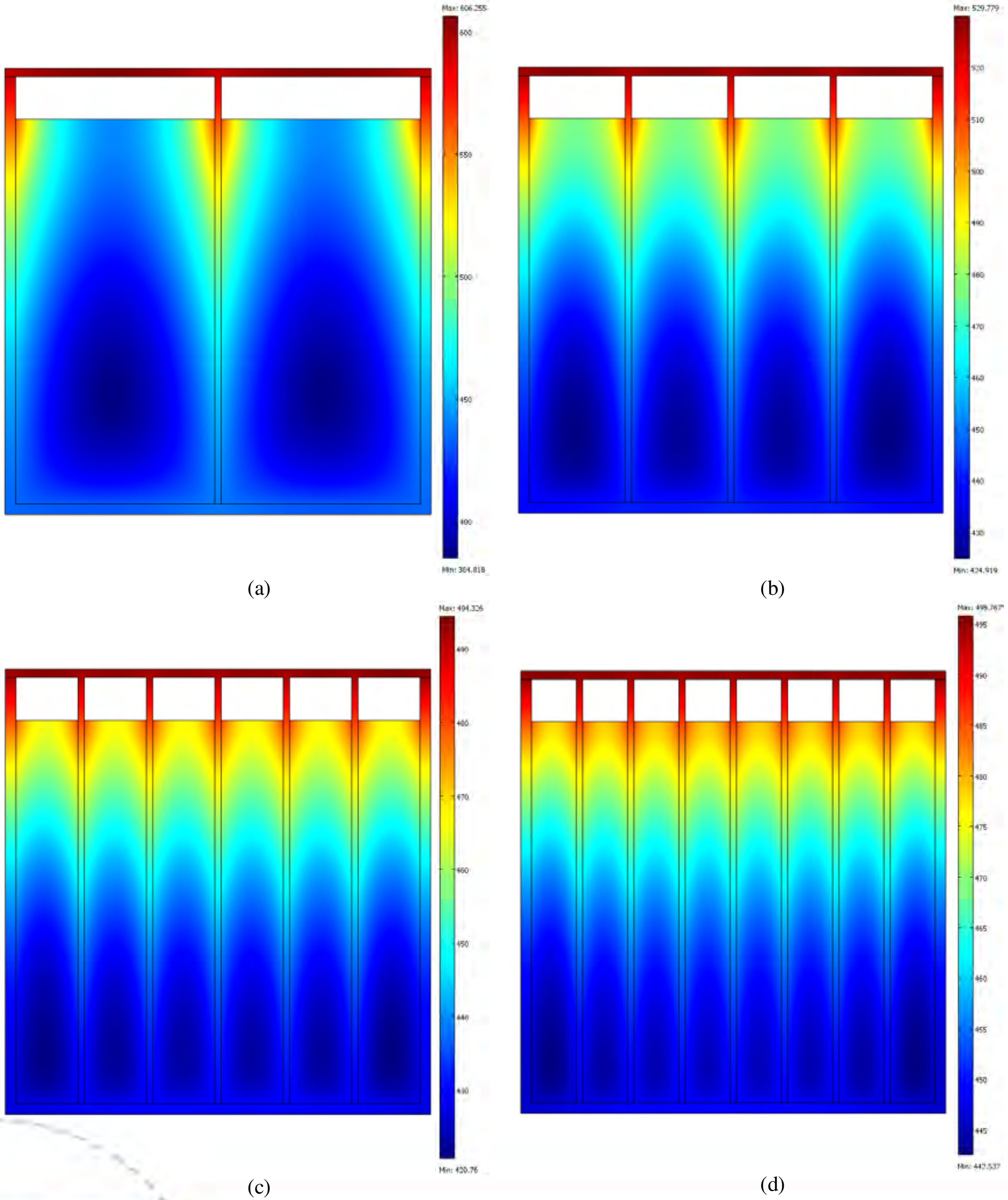
Conductivity and density of the PCM are assumed to be constant.

The solar intensity and the overall system efficiency are assumed to be at 850 W/m^2 and 35% respectively.

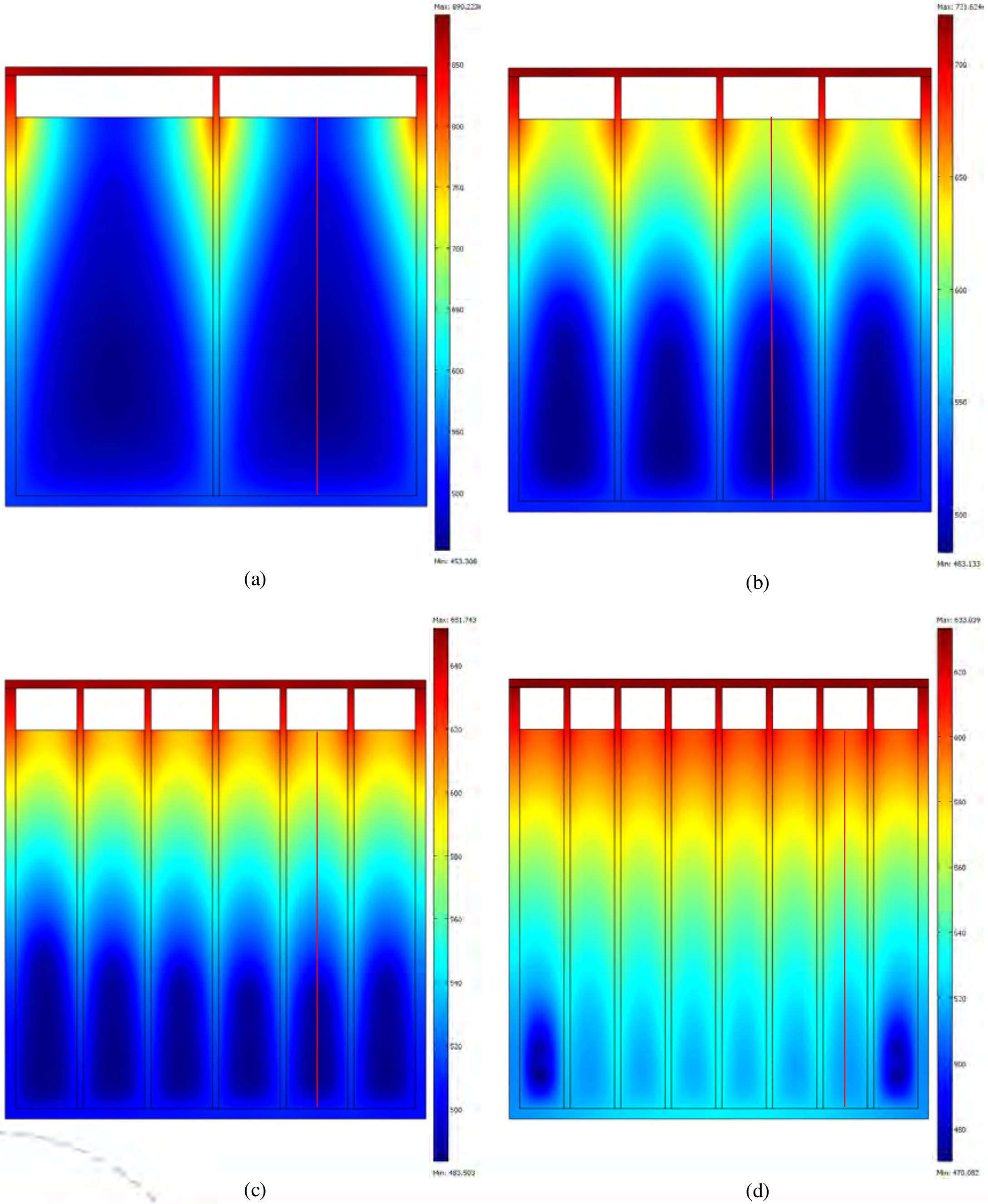
COMSOL simulation



Computed temperature profile of the $NaNO_3$-KNO_3 system during charging process.



Temperature profiles of the PCM thermal storage unit at time = 3 hours and surface heat flux of 10 kW/m^2; (a) 1 fin, (b) 3 fins, (c) 5 fins, (d) 7 fins.



Temperature profiles of the PCM thermal storage unit at time = 3 hours and surface heat flux of 20 kW/m^2; (a) 1 fin, (b) 3 fins, (c) 5 fins, (d) 7 fins.

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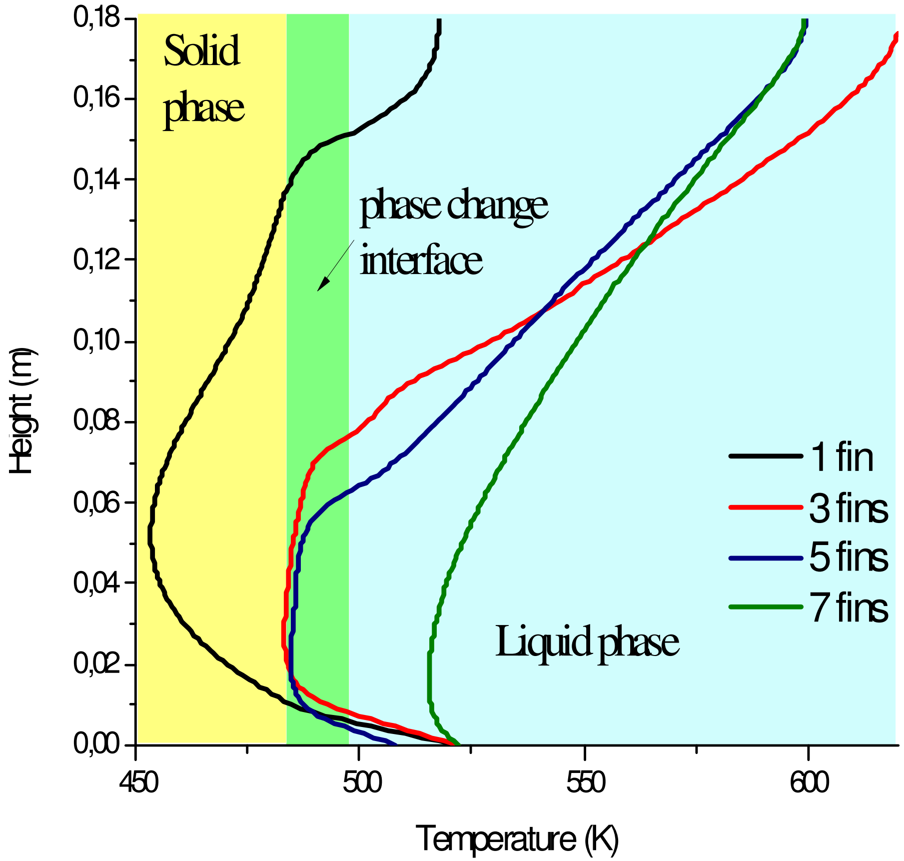
COMSOL simulation



Vertical temperature profiles of the PCM at heat flux 20 kW/m².

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Conclusions

- The latent heat storage unit was modeled numerically using COMSOL Multiphysics.
- Effective heat capacity method was used to simulate the phase change process.
- It demonstrates how the model can be used to determine the number of fins and heat flux required in order to melt the PCM completely within 3 hours.
- For future works, optimization will be done on fin thickness, container dimension, and includes radiation heat loss.

Thank you…

Background

There are different principles for concentrating solar systems such as parabolic trough, parabolic dish, and central receiver. CSP systems will be large, suitable for national grid supply. Heat only systems can be mass produced at smaller scale giving the major fraction of energy use in areas where the solar resource is good. Most of the developing countries are situated inside the sunbelt 400 north and 400 south. Therefore, solar energy can contribute to alleviate the energy problem in these countries.