Forum doctoral 2017

Convection and Radiation During Melting of a Phase Change Material: A Simplified Model for Engineering Applications

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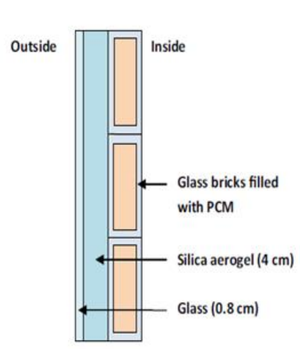
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Abstract

A simplified model for combined natural convection and radiation during melting process of a phase change material (PCM) is presented. First, the simplified model for natural convection during melting is validated using a CFD model, in addition to experimental and numerical benchmark solutions for a test case. Then, the simplified model for both natural convection and radiation is applied to the melting of a fatty acid eutectic filled in glass bricks and validated against lattice Boltzmann-discrete ordinate method (LBM-DOM). Finally, the complete model is applied to study the thermal behavior of a translucent wall; then validated experimentally using a full-scale building located in southern France.

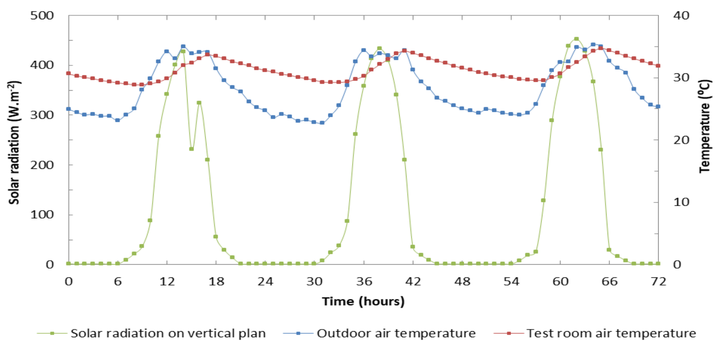
Numerical study

Layout of the INERTRANS wall and PCM filled in glass bricks

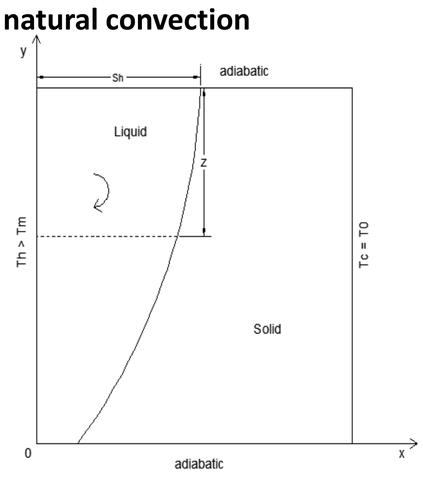




Temperatures and solar radiation for three consecutive days in summer 3, 4, 5 August 2017 from experimental data



1) Melting of Octadecane with natural convection



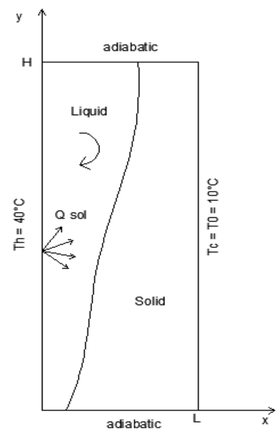
For the simplified model :

- a fixed-grid modified "enthalpy" method is used to solve phase change problem
- The absorption solar radiation is divided equally between the nodes representing each layer. Considering N nodes in the PCM cavity, the absorbed solar radiation to be added as a source term to the energy equation at the node P is then given as:

$$\emptyset_{sol} = \frac{Q_{sol}\,\alpha_{PCM}}{N}$$

- The nodal optical properties such as the transmissivity and absorptivity of the PCM are evaluated function of the transient liquid fraction.

2) Melting of fatty acid with natural convection and radiation

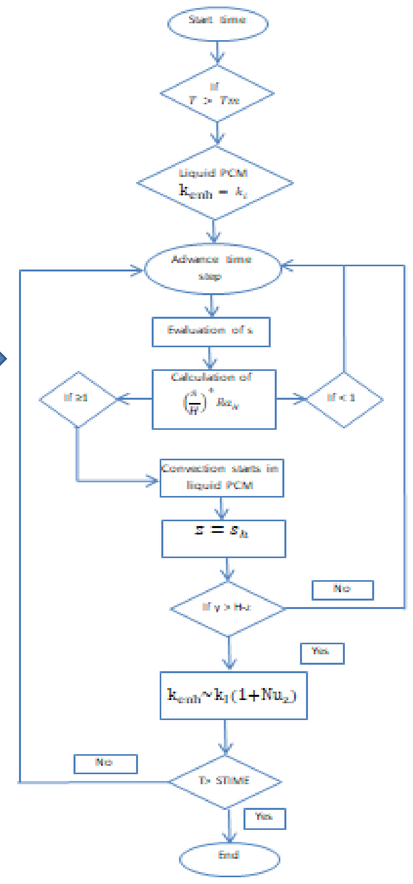


The energy equation, with natural convection and radiation, is given as:

$$\rho\frac{\partial H}{\partial t} = div(kgrad\,T) + \emptyset_{sol}$$

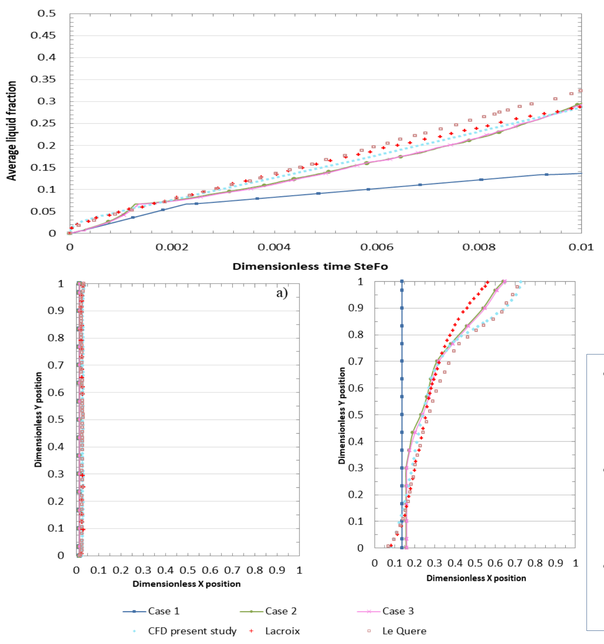
Convection effect in the liquid PCM is accounted for using the enhanced conductivity method coupled with the scaling theory approach (Simplified model)

CFD model is created and implemented in COMSOL Multiphysics 4.4 solver. The modified heat capacity method is employed.

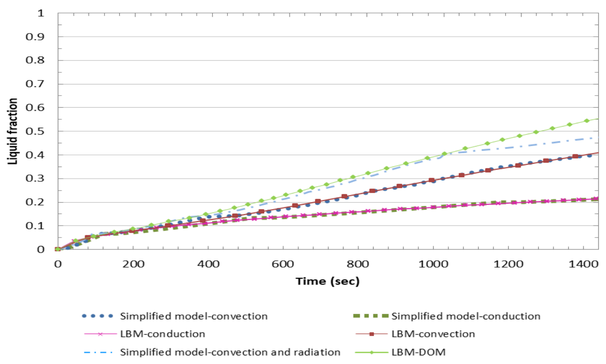


Results

1) Melting with natural convection

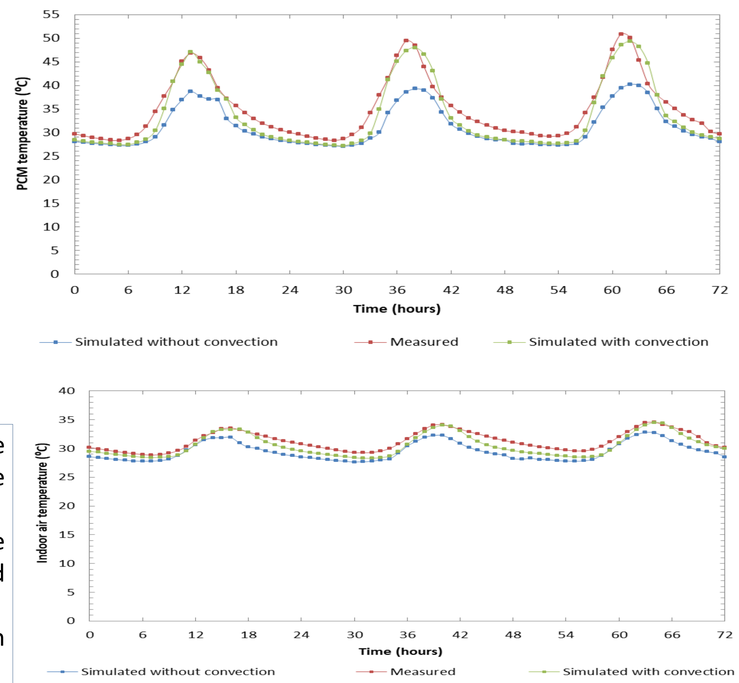


2) Application to the melting of fatty acid with natural convection and radiation



- The results of the simplified model in terms of the average liquid fraction are in very good agreement compared to those of LBM-DOM model.
- convection enhances liquid fraction by 35% compared to the conduction only model and shortwave radiation raises liquid fraction by around 20% compared to the convection model.
- the simplified model simulations run significantly faster than those conducted using CFD and LBM-DOM

3) Application to the TIM-PCM wall



$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(s_i - e_i)^2}$$

$$PRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{s_i - e_i}{e_i}\right)^2}$$

- The comparison between the numerical results and the experimental data demonstrates the good ability of the numerical model to simulate the TIM-PCM wall.
- to obtain this good agreement the natural convection effect must be taken into account.
- the purpose of the verified TIM-PCM model is to propose a technological solution for the overheating problem inside the test room providing thermal comfort for the occupants.

- Very good agreement between the proposed simplified model and the CFD model in terms of the average liquid fraction and position of melting front.
- Considering convection during melting enhances the average melting front position by about 55% at SteFo = 0.01.
- Simulations of the simplified model run 45 times faster than the CFD model.

Temperature	Model	RMSE	PRMSE
Indoor air temperature	Model with convection	0.90 °C	2.94 %
	Model without convection	1.89 °C	6.03 %
PCM temperature	Model with convection	2.09 °C	6.13 %
	Model without convection	4.70 °C	11.57 %

Conclusions

- The proposed simplified model is simple to implement and its simulations run significantly faster than those of CFD models and LBM-DOM model. Consequently, it can be easily integrated into an energy simulation tool for yearly performance evaluation,
- During PCM melting process, natural convection has a noteworthy role as it enhances the average fraction of liquid and the position of the melting front,
- Shortwave radiation enhances the average liquid fraction,
- To be closer to reality, natural convection and radiation during melting must be considered.