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Solidification of Pcm at Low Temperature in a Cylindrical Vessel

Durai kumar.R
M.Tech (Thermal Engineering), PRIST University, Thanjavur,

ABSTRACT

The outcome of this study is to provides the data for experimental analysis of solidification of phase change material (PCM) in a cylindrical vessel. Water in pure condition was considered as a PCM, copper was identified for the cylindrical vessel and liquid nitrogen took the role of cooling fluid. The experiments carried out for dissimilar sizes of cylindrical cavities, whose dimensions were 25×25, 25×35, 40×40, 30×40 and 50×50 (diameter in mm× height in mm). At first the PCM was noted down at room temperature for all cavities. The temperature variation is presented at various time steps throughout the solidification of PCM. The result indicates the convection from the atmosphere has a notable effect on the upper surface. As the cavity's diameter changes, for the same height, then notable change in solidification time is observed when height is changed, without changing internal diameter, the change in solidification time is less significant.

Keywords: PCM, solidification, conduction and convection.

INTRODUCTION

we are dealing with the designing of experimental setup, temperature measurement and developing the idea for ice thickness measurement during the so-lidification of Phase Change Material (PCM).

Many researcher have studied the solidi-fication of Phase Change Material (PCM) but very few of them have reported the study on solidification at extreme low temperature.

Solidification is the process in which the liquid converts to solid and release some amount of energy, that energy is called the latent energy of solidification [2]. This hap-pens when the temperature of PCM is lower than its freezing point. Generally solid-ification happens at constant temperature for pure materials, but under certain con-ditions some materials, e.g impure water, solidify within a temperature range. Water being a pure material solidifies at $0^o\ C$ and releases 334 $k\ J/k\ g$ energy.

PCM can be in three states, i.e. solid, liquid and gas. It changes from one state to another state, i.e. solid to liquid, liquid to gas or gas to solid or vise-versa. Depending on this, a process may be endothermic or exothermic Sensible heat and latent heat are the important terms which are discussed in scientific articles related to solidification. Sensible heat occurs within the range of temperature not at a particular temperature.

Phase Change Material (PCM)

A number of materials are available and each have its own specific property and area of application [3]. The PCM is classified into 3 main categories i.e. organic, inorganic and eutectic PCM.Each material has its specific phase change temperature or a range of temperature at which it solidifies. The organic and inorganic PCMs are mainly used because of their properties

Analytical solution

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The analytical method can be used for some simplified problem of solidification. If the problem is one dimensional and the boundary conditions are simple then analytical methods can be used. For example, Stefan[26] solved a solidification problem for one phase and derived a non dimensional number.

$$\text{Stefan no.} = \frac{[C\,(T_S - T_m)]}{L\,H}$$

Where $L\,H$ = Latent heat

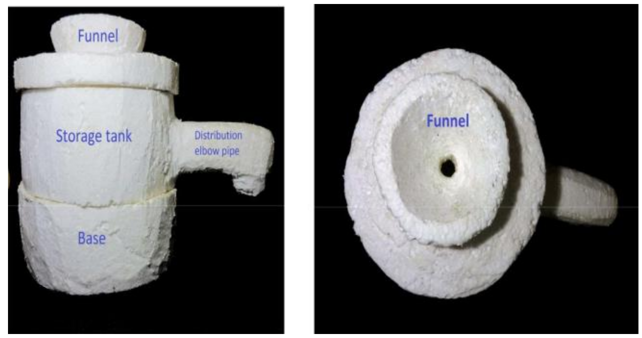
It gives the relationship between sensible heat and latent heat of PCM.

Numerical solution

As an analytical method has some limitations, researchers are giving more preference to the alternate solution, i.e. Numerical solution. Numerical methods are used to solve complex problems. There are various numerical methods to solve moving boundary problem. The numerical method can be classified into three group, i.e. fixed grid methods, variable grid methods and method of latent heat evolution. Finite volume method, finite element method and finite difference methods are the various methods used for the discritization of the governing equation

Copper containers

The cylindrical copper rod of 60 ***m m*** diameter was purchased and after some machin-ing operations, i.e. cutting, drilling, milling and turning respectively, five copper con-tainers were made each having an external diameter and height of 60 ***mm***. Each copper container has a symmetrical cylindrical cavity of different dimensions To study the effect of cavity height and diameter, they are varied as 25×25, 25×35, 40×40, 30×40 and 50×50.The cavity dimensions are expressed as diameter in ***m m***×height in ***m m***.



(a) Front view of distribution tank (b) Top view of distribution tank

Thermocouples and DAQ arrangements

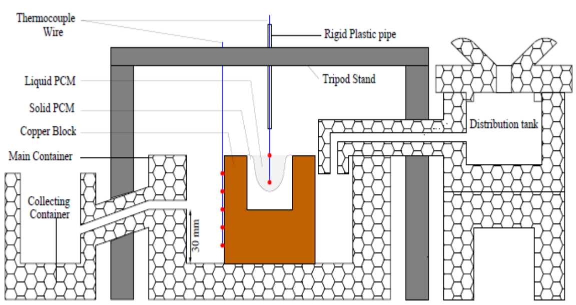
The function of the thermocouple is to measure temperature. The hardware-software arrangement is used for online monitoring of temperature variation. Seven k-type thermocouples were used for measuring the temperature of copper container and so-lidification front by placing them at several locations. The five k-type thermocouples were used for measuring the temperature variation across the height of the copper con-tainer; these were placed at the height of 10 ***m m***, 20 ***m m***, 30 ***m m***, 40 ***m m*** and 50 ***m m*** from the base. The thermocouples are fixed by using copper wire as shown in figure

Arrangement of themocouples in the copper container

. Where 1, 2, 3, 4 and 5 represent five thermocouples at 10mm, 20mm, 30mm, 40mm and 50mm from the top, respectively. Two thermocouples were used for mea-suring the temperature variation of PCM with respect to time and placed co-axially at the top and half of the internal height. To provide the rigidity to the thermocouples, these were inserted into the plastic pipe. All seven thermocouples were connected to a DAQ.

Procedures for temperature measurement

The copper container filled with distilled water is kept in a styrofoam container. The distribution tank, tripod stand with thermocouples, DAQ and container are kept in a systematic manner as shown in figure 3.6. The thermocouples were connected to PC based Data acquisition system. The distribution tank is kept filled with liquid nitrogen continuously throughout the experiment. Liquid nitrogen comes into styrofoam main cylindrical container through the connecting pipe. The main container is always filled



with liquid nitrogen up to the height of 30mm from the base and the extra liquid ni-trogen is allowed to flow to the collecting container. The level of the liquid nitrogen in the main container is kept fixed till the complete solidification of the PCM. The tem-perature was recorded by the use of thermocouple and DAQ arrangement during the experiment.

RESULTS AND DISCUSSION

Solidification temperature according to mid thermocouple

The temperature vs time graphs for the axially mid thermocouple reading is shown in the figure 4.1. The cooling medium was liquid nitrogen whose boiling point is-196^oC while initially the copper container and water were at room temperature (22^oC). Be-cause of the high heat content of liquid nitrogen, as soon as it is poured into the main container, the copper block attains the temperature of liquid nitrogen within few seconds. This heat transfer causes a high temperature gradient and that is why the tem-perature drop is fast in the initial stage of cooling

Temperature variation of copper containers and PCM

The temperature variation of all the thermocouples placed at 10, 20, 30, 40, and 50 mm from the base and axially at the mid and top of the PCM for 25×25 and 25×35 copper containers. It is seen that the copper container takes a few seconds (around 30s) to reach the liquid nitrogen temperature, i.e. half of the copper container from the base is always in contact with the liquid nitrogen, but once the liquid nitrogen reaches the 30 mm from the base, then the level of liquid nitrogen is maintained throughout. As the surface of copper container above 30 mm is always in contact with the vapour of liquid nitrogen, the temperature variation is approximately linear, which can be visualised.

Temperature variation of top and mid thermocouple

The temperature variation with time at the axial mid and top locations for the case of container size 30×40, 40×40 and 50×50. The two temperatures are de-noted by T_{mid} and T_{top} respectively. As soon as the liquid nitrogen is poured into main container, whole of the copper block is engulfed by the nitrogen vapour. This induces a strong convective heat transfer through the top surface. As a result, the temperature at the top reduces much faster than the temperature of the axial mid location, Generally, the total solidification time increases with the increase in water volume. However, it is interesting to observe that the total solidification time changes marginally when the height of the cavity is increased. But,the total solidification time changes significantly when the diameter of the cavity is increased, keeping height fixed. For example, when cavity height is increased from 20 ***m m*** to 30 ***m m*** for the same cavity diameter of 20 ***m m***, the solidification time increases by only 4.5% while it is only 3.2% when the cav-ity height is increased from 30 ***m m*** to 40 ***m m*** keeping cavity diameter fixed at 30 ***m m***. But, this figure changes to 30% and 20% when the cavity diameter is changed from 20 ***m m*** to 30 ***m m*** for the same height of 30 ***m m*** and from 30 ***m m*** to 40 ***m m*** keeping height fixed at 40 ***m m***.

CONCLUSION

As the internal diameter is increased the solidification time is observed to be in-creased by significant value as compared to the increase in internal height.

It is interesting to note that as the internal height is increased, for constant inter-nal diameter, lateral top ice thickness is reduced. But on the contrary as the internal diameter is increased, for constant internal height, the ice thickness is observed to be increased.

REFERENCES

[1] Z. Gu, H. Liu, and Y. Li, "Thermal energy recovery of air conditioning system, heat recovery system calculation and phase change materials development", *Applied Thermal Engineering*, vol. 24, pp. 2511–2526, 2004.

[2] S. C. Fok, W. Shen, and F. L. Tan, "Cooling of portable hand-held electronic de-vices using phase change materials in finned heat sinks", *International Journal of Thermal Sciences*, vol. 49, pp. 109–117, 2010.

[3] N. H. S. Tay, M. Belusko, and F. Bruno, "Designing a PCM storage system using the effectiveness number of transfer units method in low energy cooling of buildings", *Energy and Buildings*, vol. 50, pp. 234–242, 2012.

[4] H. M. S. Husseina, H. H. El-Ghetanya, and S. A. Nadab, "Experimental investiga-tion of novel indirect solar cooker with indoor PCM thermal storage and cooking unit", ***Energy Conversion and Management***, vol. 49, pp. 2237–2246, 2008.

[5] S. Mondal, "Phase change materials for smart textiles-An overview", ***Applied Ther-mal Engineering***, vol. 28, pp. 1536–1550, 2007.

[6] M. Liu, W. Saman, and F. Bruno, "Development of a novel refrigeration system for refrigerated trucks incorporating phase change material", ***Applied Energy***, vol. 92, pp. 336–342, 2012.

[7] R. Manojlovic, "Mathematical modeling of solidification process of continuous casting steel", ***Journal of Chemical Technology and Metallurgy***, vol. 48, pp. 419– 427, 2013.

[8] T. C. Hope, "Experiments and observations upon the contraction of water by heat at low temperatures", ***Transactions of the Royal Society of Edinburgh***, vol. 5, pp. 379–405, 1805.

[9] R. N. Smith, R. L. Pike, and C. M. bergs, "Numerical analysis of solidification in a thick-walled cylindrical container", ***Journal of Thermophysics and Heat Transfer***, vol. 1, pp. 90–96, 1987.