Study of Solidification at Intense Low Temperature in a Spherical Container

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Abstract- Texture produced on the surface of hydrodynamic journal bearing have certain changes in the coefficient of friction, load carrying capacity, wear rate, stiffness and damping of the two surfaces which are matting with each other. By creating texture or micro dimple on a hydrodynamic journal bearing, pressure increases and significant improvement has been achieved in its load carrying capacity, lubricant flow rate, coefficient of friction etc. In a present work numerical analysis has been carried out to determine the effect of using negative spherical surface texture on hydrodynamic journal bearing surface and it is compared with normal journal bearing i.e. journal bearing without texture. We can take any other profile also but spherical profile is easy to fabricate by laser technology or etching process. The Reynolds equation is solved numerically with the help of central finite difference method and analysis is done on the effect of texture height, asperity ratio and number of textures on the journal bearing. Here we also determine the behavior of parameters of hydrodynamic journal bearing (texture and without texture) with increase in eccentricity ratio. Texture journal bearing has a great importance in journal bearing because in vertical journal bearing initially it provides converging part which helps in increasing load carrying capacity which is not present in plain journal bearing. The author believes that such detail analysis of texture on journal bearing surface to study different tribological behavior under different condition will help researchers around the world.
Keywords:- Tribological Behavior, Texture and Without Texture

I. INTRODUCTION

In this thesis, we are dealing with the designing of experimental setup, temperature measurement and developing the idea for ice thickness measurement during the solidification of Phase Change Material (PCM). Many researchers have studied the solidification 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. This happens when the temperature of PCM is lower than its freezing point. Generally solidification happens at constant temperature for pure materials, but under certain conditions some materials, e.g. impure water, solidify within a temperature range. Water being a pure material solidifies at 0^oC and releases 334 k J /kg 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 vice-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.

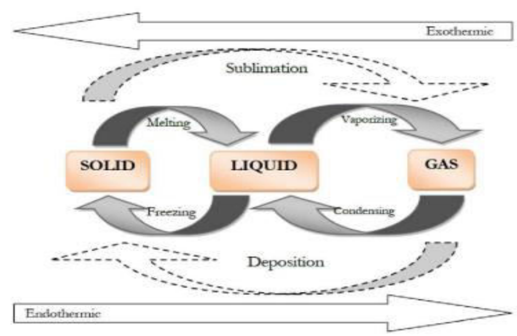


Figure 1: PCM Transformation Phases

II. LITERATURE SURVEY

Daabo et al. [2019] analyzed the impact of collector calculation on the optical execution of a limited scale sunlight based depression recipient for illustrative dish applications by dissecting three distinct calculations viz., tube shaped, circular and tapered hole beneficiaries on the optical proficiency perspective, yet in addition the transition dissemination in particular calculations. The connection between the transition dispersion and the optical effectiveness of the collectors is gotten as the outcome from this review. The conelike beneficiary found to have great retention and high intelligent transition energy. The state of the recipient and beneficiary absorptive chooses the point of convergence area models. At last, the trial results are contrasted and mathematical models.

Zhao et al. [2019] concentrated on the cyclic warm portrayal of a liquid salt pressed bed TES for concentrating sunlight based power. Liquid salt stuffed bed thermo cline nuclear power stockpiling was viewed as the expense cutthroat nuclear power stockpiling type concentrated sun oriented plant. The reproductions were finished by a one-layered enthalpy strategy scattered concentric model. The warm exhibition of the presented fractional charge cycles and resulting full charge cycles are assessed in ideal working circumstances. The fractional charge impact is gotten by making varieties in thermo cline advancement and energy stockpiling or delivery limit. Embodied PCMs containing arrangements are of more prominent opposition and more grounded recoverability to the variety in energy capacity or delivery limit. What's more, areas of strength for the of the stuffed bed stockpiling relies upon the warm way of behaving of the stockpiling mediums inside the district.

Smith et al. [2019] concentrated on the hardening of PCM mathematically inside a thick wall barrel shaped compartment involving a rotating course verifiable strategy for taking care of the overseeing equation. A comparative issue for certain extra differing boundaries. The enthalpy strategy for the mathematical investigation of hardening in a round calculation and contrasted their outcomes and the intensity balance vital technique (HBIM) for an extensive variety of Stefan numbers.

Tan and Leong [2018] have done a trial investigation of the form cementing interaction of n-octa decane as the stage change material inside a thick barrel shaped shape considering consistent base temperature for various superheated PCMs. They have thought about two distinct materials, for example metal and tempered steel, for their examinations and found that the cementing system is quicker in metal when contrasted with treated steel. They inferred that the hardening mass part is straightforwardly relative to the shape foundation of cementing time for sub-cooled wall condition.

Lipnicki [2018] has done an exploratory examination of hardening of water with blue methylene in an annular nook. He contrasted the exploratory outcome and the systematically result and gave a decent relationship between's them. For the most part CFD assists with following the hardening front, yet Lipniki utilized a straightforward round and hollow medium and a double arrangement of water with methylene blue for representation of cementing front.

Smith and Meeks [2017] have done trial and mathematical examinations to give quantitative information to a basic complex cementing cycle of n-octadecan (PCM) in a nook. They introduced the state of the stage front profile.

Jones et al. [2016] have done exploratory estimations during the liquefying of a moderate-Prandtl number material (paraffin wax, n-eicosane) in a tube shaped enclosure and gave the benchmark trial estimations for approval of mathematical codes. With respect to the mathematical arrangement, limited volume technique is utilized and a second request verifiable plan was utilized for the transient term while the subsequent request upwind plan was utilized for the convective term and focal separating was utilized for the diffusive/conductive term. The multi-block strategy was utilized for strong and fluid districts.

Kamkari et al. [2016] have done exploratory examination of softening of stage change material yet learned at specific three points, for example 0o ,45o and 90o , and figured out that the liquefying opportunity expected for 45o and 0o was 35% and 53% not exactly the time expected for 90o nook. A portion of the creators researched softening of PCM tentatively and mathematically.

Shrivastava et al. [2014] have done mathematical examination of softening utilizing computational liquid elements (CFD) in an upward round and hollow calculation thinking about the inward intensity age. They additionally acquired the exploratory consequence of softening.

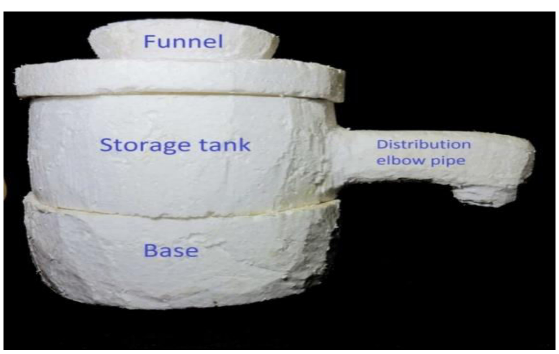
Shmueli et al. [2013] contrasted the mathematical arrangement with the past exploratory arrangement of softening of a PCM in an upward roundabout cylinder. Albeit numerous analysts have concentrated on the cementing or liquefying of PCM in various calculations like chamber, annular cylinder, round shells, and so on. In any case, none of the examinations detailed hardening of a PCM in a tube shaped holder whose surface is kept up with at a very lower temperature.

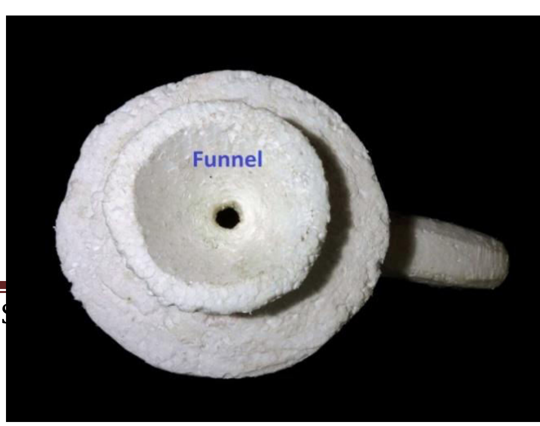
Riahi et al. [2013] This paper researches hardening of a PCM in a round and hollow holder by a low limit fluid as an intensity move liquid. The aim of the current work is to explore and foresee tentatively the warm way of behaving of stage change material during the cementing system inside a round and hollow holder at outrageous lower temperature limit condition, for example low edge of boiling over fluid (fluid nitrogen).

III. PROBLEM IDENTIFICATION

This Experimental work mainly comprises of three sections are as follows:-

- Design and development of experimental setup.
- Studying the heat transfer and temperature variation in the PCM and periphery of copper blocks.
- Developing an idea for measuring the ice thickness in the cavity at various time step during the solidification.





IV. RESEARCH OBJECTIVES

The main objective of this study is to measure the ice thickness experimentally.

- The ice thickness for the each container was recorded at the 40% and 65% of solidification.
- As the internal diameter is increased the solidification time is observed to be increased by significant value as compared to the increase in internal height.
- Atmospheric convection dominates at the upper surface. The expansion of the ice looks like a hemispherical shape.

V. MODELLING AND EXPERIMENTAL ANALYSIS

As for maintaining all boundary condition the setup was prepared. It satisfies all conditions, according to the requirement. The study of solidification is done in several copper containers; therefore five copper blocks are machined. The setup consists of four main parts, i.e. distribution tank, double cylindrical Styrofoam container, tripod stand, thermocouples with DAQ arrangement.

The cylindrical copper rod of 60 mm diameter was purchased and after some machining operations, i.e. cutting, drilling, milling and turning respectively, five copper containers were made each having an external diameter and height of 60 mm. Each copper container has a symmetrical cylindrical cavity of different dimensions which was used for the experiments as shown in figure 3.1. To study the effect of cavity height and diameter, they are varied as 20 × 20, 20 × 30, 30 × 30, 30 × 40 and 40 × 40. The cavity dimensions are expressed as diameter in mm×height in mm.

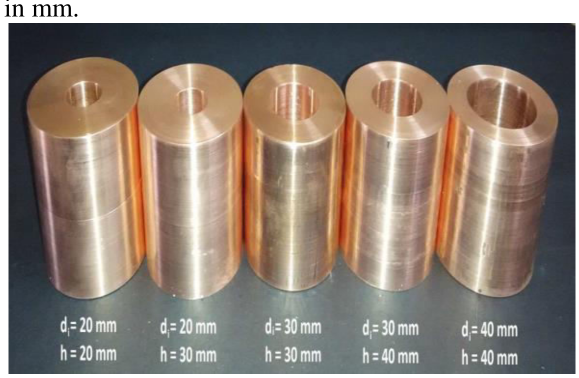


Figure 2: Copper Containers

Figure 3: Distribution Tank

The distribution tank made from the 70mm thick styro foam slab. The function of the distribution tank is to provide continuous and uniform flow of liquid nitrogen to main cylindrical styro foam container. The other simple way is to provide the liquid nitrogen through a small diameter pipe, but in this case the outlet pressure and velocity will not be uniform and also some particle of liquid nitrogen spitting on the upper surface of copper blocks. So for avoiding this problem and maintaining a boundary condition distribution tank was prepared. It consists of three parts base, small capacity storage tank with distribution elbow pipe and a funnel as shown in figure.

The small storage tank is open only at inlet and outlet. The storage tank is mounted on the base and the head of the storage tank connect to funnel while the other end is the extended part in the form of an elbow pipe. The internal diameter of the elbow pipe is 5 mm. The internal height of the storage tank in 50mm and the distribution pipe is extended from above the 10mm of the base of the storage tank so that outlet liquid nitrogen as minimum as possible of turbulent nature and also uniform flow rate throughout the experiment. The function of the funnel is to provide liquid nitrogen to the storage tank without any wastage. The liquid nitrogen was chosen as a heat transfer fluid and maintains extremely low and constant temperature at the periphery of the copper container.

The double cylindrical Styrofoam container is made from 70 mm thick Styrofoam slab. The main objective of making the double cylindrical Styrofoam container is to maintain the level of the liquid nitrogen to a particular height i.e. 30mm from the base. Although single cylindrical container is enough for liquid nitrogen to be in contact with the copper blocks, this will cause the level of liquid nitrogen in the container which will not be constant. It level will vary continuously about the mean height (30mm from the base) during the experiment. A passage was given at the height of 30mm from the base of the copper block between two cylindrical containers so that extra liquid nitrogen goes out from the main cylindrical container and delivers it to collecting container, as the level of liquid nitrogen is more than the mean height. The thickness of the double cylindrical container was made 15mm.

There are many materials available with low thermal conductivity but Styrofoam is cheaper and easily available material. It is also called expandable Polystyrene. It was invented by Ray McIntire during World War II. As the boiling point of the liquid nitrogen is around−196oC and the atmospheric temperature is around22oC to 23oC. The temperature difference between atmosphere and liquid nitrogen is very high and this causes high vaporization. It is difficult to maintain the level of liquid nitrogen in the double cylindrical Styrofoam container. It also reduces the vaporization of liquid nitrogen.

Some characteristics of Styrofoam are –

1. Lightweight
2. Good formability
3. Good insulator (thermal conductivity = 0.032 to 0.038W /mK)
4. Enough rigidity and shock absorber
5. Easily available

As the aim is to online monitoring and record the temperature history during the whole experiment and ice thickness at different time step that is why there is little change between procedures for the temperature measurement and procedure for the ice thickness measurement. Both the procedures are written ahead.

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. 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 nitrogen 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 temperature was recorded by the use of thermocouple and DAQ arrangement during the experiment.

VI. RESULTS AND ANALYSIS

As mentioned above, this paper reports an experimental study of the solidification of water inside the copper containers. This section presents some results like temperature history during solidification process, solidified zone at different time instants and the phase front profile at different times for all the studied cases. Altogether five copper blocks have been taken with varying internal cavity dimensions as 20×20, 20×30, 30×30, 30×40 and 40×40.

A. TEMPERATURE VARIATION

The temperature vs time graphs for the axially mid thermocouple reading is shown in the figure the cooling medium was liquid nitrogen whose boiling point is−196°C while initially the copper container and water were at room temperature (22°C). Because 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 temperature drop is fast in the initial stage of cooling. From the graph, the temperature profile of the PCM for all the containers decreases continuously and follows approximately same pattern up to 100 s.

The temperature profile for the 20×20 and 20×30 follows the same pattern, but the 20×30 copper container has taken a little more time. It is noticed that the solidification time increases with increase in the water volume. It is also interesting to observe that the solidification time is not that much influenced with the increase in water height; however it does increase significantly when diameter is increased.

As in the case of 20×20 and 20×30 or 30×30 and 30×40 containers the change in solidification time is little, i.e. the change in solidification time in 20×20 and 20×30 is 15 s and the change in solidification time for 30×30 and 30×40 is 20s. With the passage of time, the temperature gradient decreases. Also, the convection due to buoyancy helps in decreasing the temperature gradient which ultimately results in slow temperature change with time. But, once the temperature reaches the phase change temperature of water, there is a sudden change in temperature which is a typical characteristics of the phase change process. After the solidification of water, maintain the level of the liquid nitrogen for some time and found that the temperature profile of ice decrease suddenly for all the containers. This suddenly temperature drops happened because the conductivity of the ice increase with the decrease the temperature of ice.

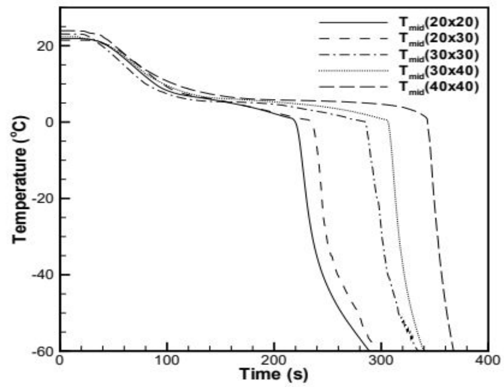


FIGURE 4: TEMPERATURE HISTORY FOR THE SOLIDIFICATION OF PCM IN DIFFERENT CONTAINERS FOR MID THERMOCOUPLE

B. 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 20×20 and 20×30 copper containers. It is seen that the copper container takes a few seconds (around 30 s) 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 the experiment as represented by the graph of T 10, T 20 and T 30. As the surface of copper container above 30 mm is always in contact with the vapor of liquid nitrogen, the temperature variation is approximately linear, which can be visualized from the graph of T 40 and T 50.

C. 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 30×30, 30×40 and 40×40. The two temperatures are denoted by T mi d 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 vapor. 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, which can be clearly seen in the figure.

For example, when cavity height is increased from 20 mm to 30 mm for the same cavity diameter of 20 mm, the solidification time increases by only 3.8% while it is only 2.7% when the cavity height is increased from 30 mm to 40 mm keeping cavity diameter fixed at 30 mm. But, this figure changes to 35% and 15% when the cavity diameter is changed from 20 mm to 30 mm for the same height of 30 mm and from 30 mm to 40 mm keeping height fixed at 40 mm.

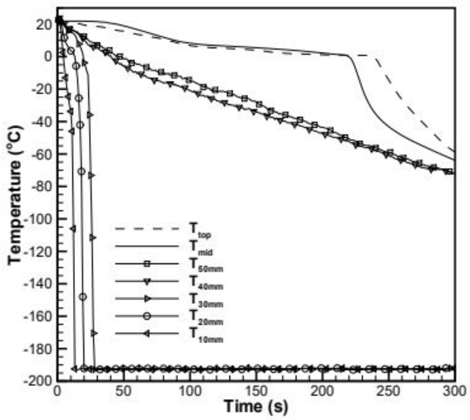


Figure 5: Temperature History for 20×20 Copper Container

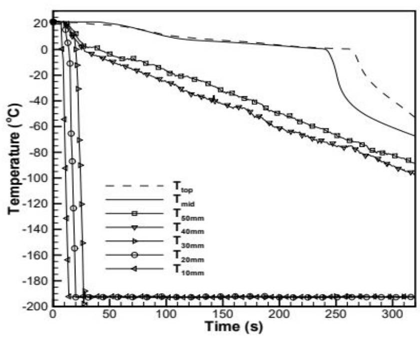


Figure 6: Temperature History for 20×30 Copper Container

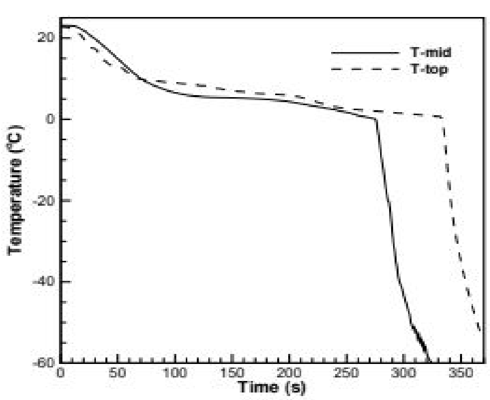


Figure 7: Temperature Variation of The PCM in a Cavity of 30×30

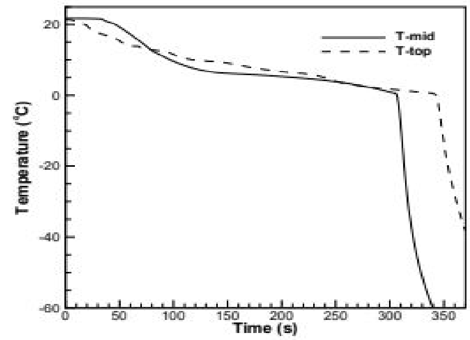


Figure 8: Temperature Variation of PCM in a Cavity of 30×40

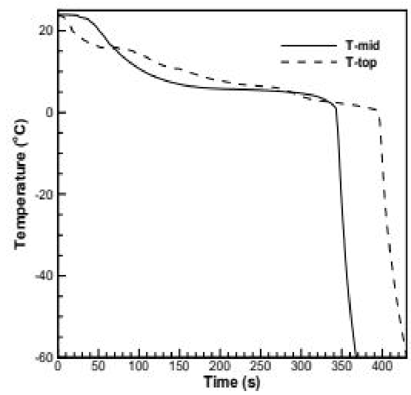


Figure 9: Temperature Variation of PCM in a Cavity of 40×40

CONTAINERS	TIME (S)
20×20	238
20×30	247
30×30	334
30×40	343
40×40	396

Table 1: Total Solidification Time for all the Container

VII. CONCLUSIONS

It is concluded that as the internal diameter is increased the solidification time is observed to be increased 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 internal 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.

It is also found that when the depth increases from 20mm to 30mm for the same internal diameter (20mm), the solidification time increases by only 3.78% and when the depth increases from 30mm to 40mm, the solidification time increases by 2.69%. But when the internal diameter increases for the same height, there are more change in the solidification time. For example, as the internal diameter increases from 20mm to 30mm and 30mm to 40mm for the same height of 30mm and 40mm respectively, the change in the solidification time is 35% and 15% respectively.

The experiment was done with the aim that the result can be used for cryo-preservation but experiment with the tissue was not done. Now it is very difficult to say that what happens when tissue is used in the PCM. The experiment is done in the open atmosphere, but when the tissue is to be used, it has to be in a closed environment. These results are valid under the specific boundary condition.

The relation between depth and internal diameter of solidification is good when the copper container is in contact with extremely low temperature. This experiment was done with the copper container, in future it can be done with some other material. The variation of the size of the container can be studied in detail. For ice tracking, some temperature sensing instrument can be used so that experiment can be done in one step and results are more accurate.

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