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PERFORMANCE ANALYSIS OF ROTATING LATENT HEAT STORAGE SYSTEM

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Abstract. *In recent years, shell and tube latent heat thermal energy storage system (LHTESS) with phase changing materials (PCM) are used to store energy. The major drawback of latent heat storage system is due to low thermal conductivity of PCM the heat transfer is low. In this study, a 2-dimensional horizontal shell and tube latent heat storage system is considered, the rotation is implemented to accelerate charging process of the system. ANSYS FLUENT 2022 R2 software is used for the simulation and calculation. Paraffin wax (n-octadecane) and water are used as PCM and hot fluid (HTF) respectively. The simulation and calculation are carried out for 0.5 rpm, 1 rpm and 1.5 rpm and these results are compared with stationary counterpart. The result show that rotation accelerate melting process. The percentage thermal enhancement between rotation and stand stand still for 0.5 rpm, 1 rpm and 1.5 rpm are 8%, 18.61% and 25.38% respectively.*

Keywords: *Rotating latent heat storage system; ANSYS; Paraffin wax (n-octadecane).*

1. Introduction

A rotating latent heat storage system (RLHSS) is an innovative thermal energy storage technology that utilizes phase change materials (PCMs) to store and release thermal energy. Rotating latent heat storage system consist of a cylindrical container filled with PCMs that is rotate around its axis to enhance heat transfer during charging cycle. The PCMs undergo phase change (solid-liquid or liquid-solid) during thermal energy storage and release, resulting in high energy density and efficient heat transfer. RLHSS has potential application in various fields, such as solar energy storage, waste heat recovery and thermal management of buildings. The Latent heat storage system stores heat in a storage medium in the form of potential energy between the particles of the substance. The conversion between the heat and the potential energy within the substance involves a phase change thus heat storage occurs without significant temperature changes in the storage medium. Digant S.Metha, Bhavesh Vaghela, Manish K. Rathod studied about the heat transfer intensification technique by imparting eccentricity and imparting rotation and providing multi hot fluid tube [1]. Stearic acid (5.57–56.6º C) is the melting time is reduced by 47.75%. Binjian Nie, Xiaohuishe studied about compact thermal storage device containing phase change material is designed and experimentally investigated two types of fins were used serrated and perforated fins. The efficiency is increased by 43.3%[2]. Teng Xiong, Long Zhung Flat plate collector and evacuated tube collectors are used Phase changing material used is Ethylene glycol and Aluminium fins were used [3]. Lihar Asipkhan, Muhammad Khan investigated the heat of latent heat storage system with shell and tube heat exchange. The shell consist of annular fin Performance is increased by 10% [4]. Alberto Pizzolato (2017): This paper presents a unique solution to the problem of heat transfer in shell-and-tube latent heat thermal energy storage units by means of high conducting _ns [5]. We developed a design approach using topology optimization and multi-phase computational fluid dynamics. No assumption is made about the _ns layout, which freely evolves along the optimization process resulting in more efficient non-trivial geometries. At each optimization iteration, the fluid-dynamic response in the phase change material is computed by solving the transient Navier-Stokes equations augmented with a phase-change porosity term. Coupling large design freedom to detailed physics modeling allowed studying the effect of convective transport on both design and performance of latent heat thermal storage units. Results indicate that accounting for fluid design optimization studies is crucial for performance. It is shown that melting and solidification can be enhanced remarkably through natural convection by using well engineered with specific design features, that could hardly be revealed with alternative design routes. These features make designs optimized for melting fundamentally from those optimized for solidification. Mr. K. Manikandan (2021): Convective heat transfer between a surface and the surrounding has been a major issue and a topic of study for a long time [6]. In this project, the heat transfer performance of fin is analyzed by ANSYS workbench. Various design configuration are performed such as Cylindrical configuration, Square configuration, and Rectangular configuration. The heat transfer performance of fin with same base temperature having various geometry is compared. In this thermal analysis Aluminium was used as the base metal for the fin material and for various configuration. Fin is major component used in many systems for increasing the rate of heat transfer. In order to cool the system fins are provided on the surface of the system to increase the rate of heat transfer. By doing thermal analysis on the fins , It is helpful to know the heat dissipation and rate of heat transfer in different types of fins. By increasing the surface area of fin configuration we can increase the heat dissipation rate of this process, so designing the large complex is very difficult. A fin for the Circular, Square, Rectangular and conical surface that extends from a fin configuration to increase the rate of heat transfer. Azeem Anzar (2016): The present work is a numerical study consisting of thermal analysis of various configurations of finned heat sink with PCM [7]. The configurations considered are finned heat sink with PCM and without PCM, fin filled with half PCM material, towards the fin tip side and cases which includes forced convection for systems which continuously operates. The transient nature of problems were recorded for performing unsteady analyses. Evaluation of design operational time and characteristics of PCM are carried out. By analyzing these different configurations and valid picture of the physics of heat transfer in PCM based heat sink is imaged out. Pawar Shreekant Prabhakar (2015): Modern portable electronic devices are becoming more compact in space, the exponential increase in thermal load in air cooling devices require the thermal management system (i.e. heat sink) to be optimized to attain the highest performance in the given space [8]. In this work, experimentation is performed for high heat flux condition. The heat sink mounted on the hot component for cooling the component under forced convection. The two different orientation of fan i.e. “fan-on-top” and “fan-on-side” are tested for different air mass flow rate and cooling rate is validated with numerical results for the same amount of heat flux. The numerical simulation are performed using computational fluid dynamics (CFD). The primary goal of this work is to do the thermal analysis and comparison of fan orientation on cooling efficiency and to find the optimum parameters for a natural air-cooled heat sink at which the system will continue its operation in natural convection mode (i.e. fan-failed condition). The CFD simulations are performed for optimization of heat sink parameters with objective function of maximization of heat transfer coefficient. In this study, CPU cooling has been investigated in the acrylic cabinet with chosen heat sink and the performance of the heat sink is investigated experimentally and then validated using CFD. P. M. Deshpande & Dr. S. Dawande studied horizontal zigzag coil tube (HSTC) for various forces (viscous, buoyancy and centrifugal force) acting on fluid element in coil; of which the centrifugal force is predominant and results in secondary flow [9]. This phenomenon also depends on the physical fluid at a given temperature. They also concluded that as the coil diameter reduces the curvature ratio increase that increases the pressure drop. [10]Yan Ke, G. P. Qi, et al. [10]. They had analyze transverse vibration of conical zigzag tube bundle. The effect of the external fluid flow on the transverse vibration of tube bundle is studied with the combination of experimental data, empirical correlations and FEM. The external fluid flow has a significant effect on the frequency of the tube’s transverse vibration, which are decreased by about 18% to 24% when the external fluid flow speed is 0.3 m/s. [11]Dr. M. S. Tandale & S. M. Joshi provided analytical model to design of zigzag tube heat exchanger and experiments were performed [11]. The experimental results show that the deviation between calculated values of overall heat transfer coefficient from the experimental results and theoretical values obtained from the analytical model are within 12%. Also, the accuracy is found to be within ±8 % in approximation. The pressure drop estimated is also compared with actual values observed during experimentation, which is found in acceptable range. R. K. Patil, & B. W. Shende et al. proposed that heat transfer rate of helical coil heat exchanger is better to compare another types of heat exchanger [12]. In the helical coil heat exchanger space is limited so not enough straight pipes should be laid. The helical tube heat exchangers consist of helical coil fabricated out metal pipe that is fitted in the annular portion of two concentric cylinders. M. P. Nueza & G. T. Polley provides the design space where the available options that meet the heat duty and allowable pressure drops are displayed for the various geometrical parameters. the design space is determined considering standard exchanger by a set of set of three curves: a curve that represents the heat duty (thermal length) and two curves that represent the pressure drop on the hot and cold streams [13]. They conclude that the graphical representation of the design parameters that fulfil the process heat load and pressure drops. They refer to the selection of the exchanger dimensions that will meet the heat duty within the limitations of pressure drop and the space between the streams is same.

2. Need of the study

The major drawback of latent heat storage system is due to low thermal conductivity of PCM, heat transfer is low. So PCM takes more time to melt. To overcome this rotation is implemented to accelerate the charging process of the system. Simulation and calculation are carried out for three different rotational speed such as 0.5 rpm, 1 rpm and 1.5 rpm.

3. Research methodology

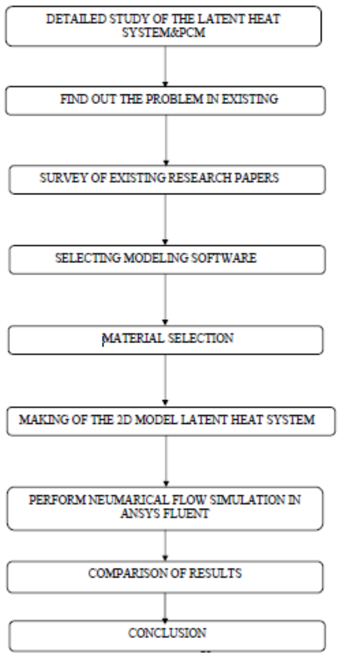


Fig. 1 Research methodology

4. Design configuration

A cross section of the shell-and-tube LHTES unit is considered. LHTES is made of copper. Water flows through the inner pipe while the PCM fills the external shell. The pipe has an external diameter of 13 mm, while the shell has a diameter of 30 mm. The charging process was considered in the analysis. That is, the PCM melting process. In such a case, PCM is initially solid and at temperature below the melting point. When water flows through the pipe at a temperature higher than the PCM melting point then heat is transfer to the PCM delivered. The process proceeds until PCM is completely melts and the energy is stored in PCM. A paraffin wax (n-octadecane) was considered as PCM. Its thermo-physical properties are listed below Design of the latent heat storage system is created with help of Ansys design modeler.

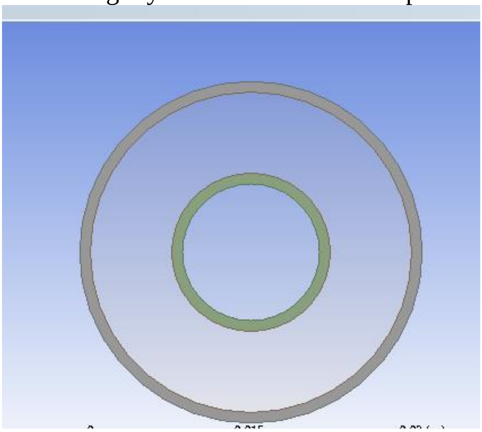


Fig 2. Design of latent heat storage system

Properties of phase changing material (PCM) are treated as temperature dependent by adopting polynomial and power law functions. The temperature dependent properties are PCM are taken from J.C.Kuria et al. /Applied Thermal Engineering 50 (2013) 896-907 [14].

4.1 Properties of Paraffin Wax:

- The density **ρpcm** is given by **ρpcm = 750/(0.001(T-319.15)+1) ,**where T is the temperature of PCM.
- Thermal conductivity of PCM is estimated by **K_{pcm} = [0.21 if T<Tsolidius or 0.12 if T>Tliquidius].**
- The PCM viscosity is defined as **μpcm = 0.001exp(-4.25+1790/T).**
- Specific heat **C_p = 2890 J/Kg K.**

- Melting point of PCM = **28 to 30ºC.**

Properties that depend on temperature were fed as user defined function.

4.2 Assumptions for Simulation:

For carrying out numerical simulations, some assumptions are made and simplifications are applied to the system. The liquid phase of PCM is considered as incompressible, Newtonian, homogenous, and isotropic medium, and the radiation heat transfer is considered negligible as compared to natural convection heat transfer. The buoyancy force due to temperature-dependent density variations during the melting of PCM is modeled by Boussinesq approximation. Considering Boussinesq approximation, the volume expansions of the PCM are also neglected, and natural convection is assumed laminar . The two-dimensional enthalpy porosity method is used to solve the problem numerically.

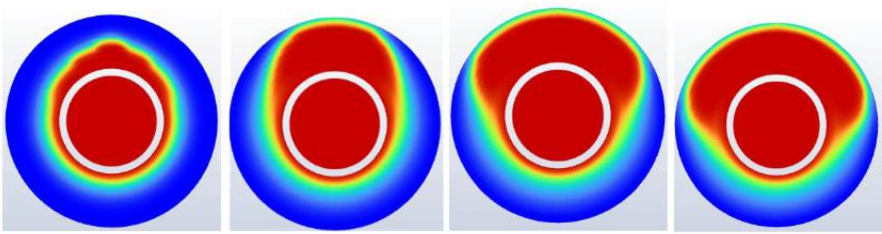
Set of under relaxation factors that is suitable to avoid divergence, for pressure, density, body forces were 0.3, 0.8, 1, while momentum, liquid fraction and energy were 0.3, 0.1, and 0.9. (from soibam J 2017) .

At step of solution the pressure was corrected using PRESTO scheme and pressure velocity coupling is implemented by semi implicit pressure linked equation (SIMPLE) algorithm .

4.3 Boundary conditions:

The initial temperature of the system for all cases was assumed to be298k. The outer wall is assumed to thermally insulated. Hot fluid(water) enters the storage at 305k.

5. Liquid Fraction Contours for Stationary Case:



Time = 500 s. Time = 1000 s. Time = 2000 s. Time = 3000 s.

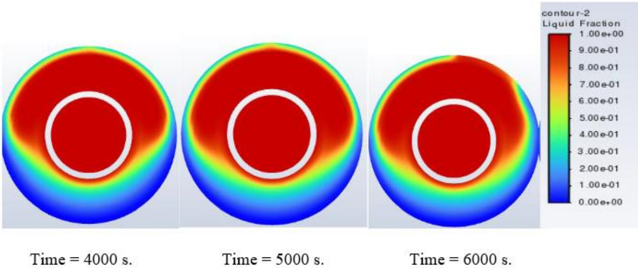


Fig. 3 Liquid Fraction Contours for Stationary Case

Temperature Contours for Stationary Case:

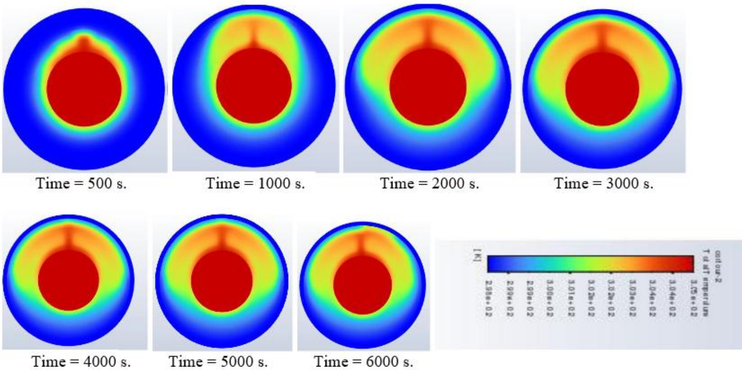


Fig 4. Temperature Contours for Stationary Case

Liquid Fraction Contours for 0.5 Rpm Rotation Case:

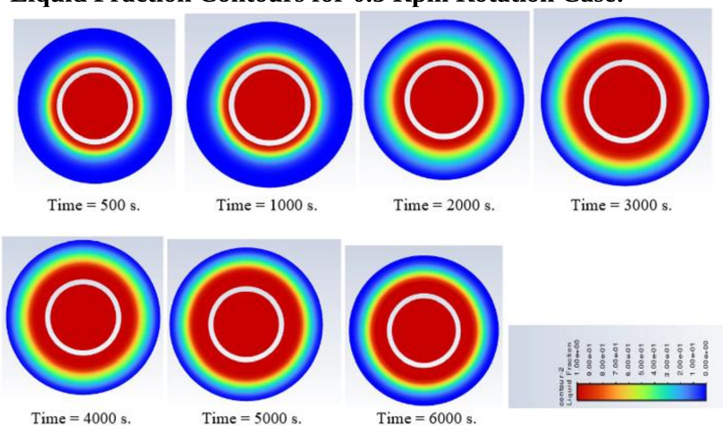


Fig. 5 Liquid Fraction Contours for 0.5 rpm Rotation Case

Temperature Contours for 0.5 rpm Rotation Case:

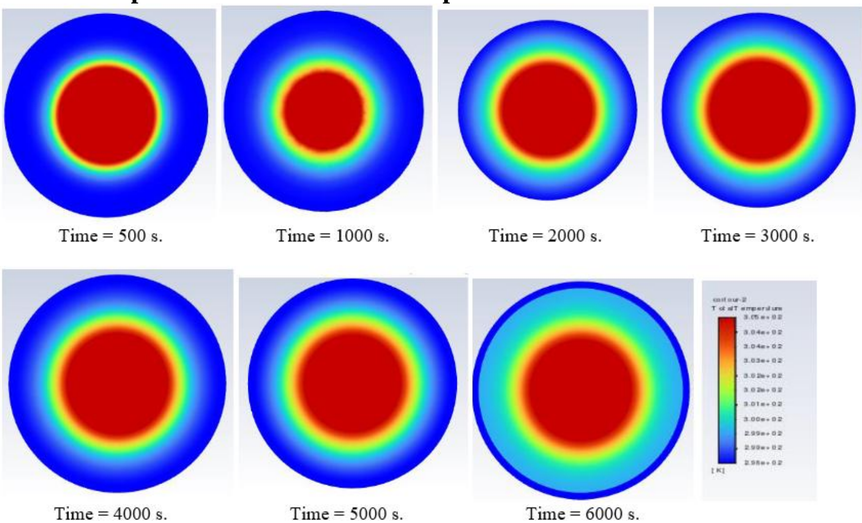


Fig. 6 Temperature Contours for 0.5 rpm Rotation Case

Liquid Fraction Contours for 1rpm Rotation Case:

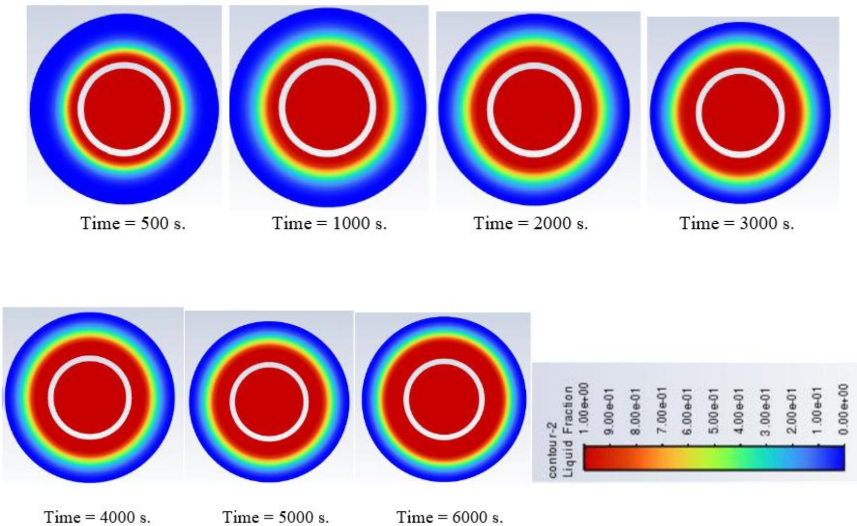


Fig. 7 Liquid Fraction Contours for 1rpm Rotation Case

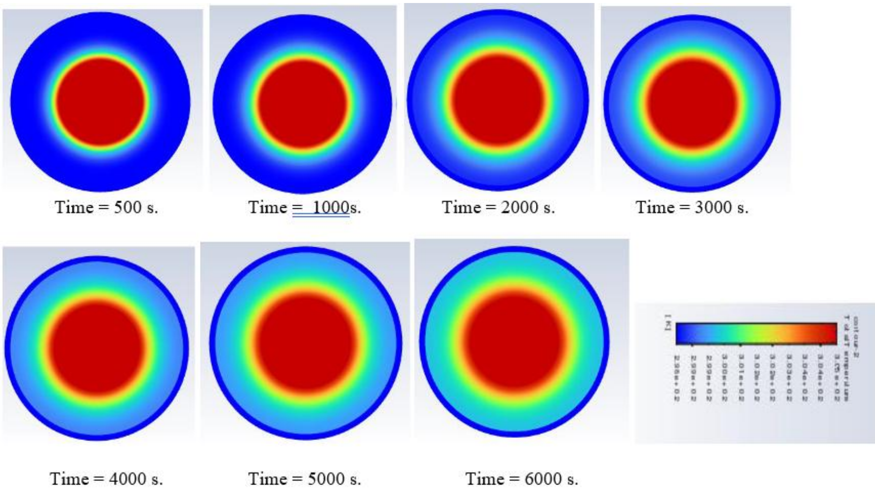


Fig. 8 Temperature Contours for 1 rpm Rotation Case

Liquid Fraction Contours for 1.5 rpm Rotation Case:

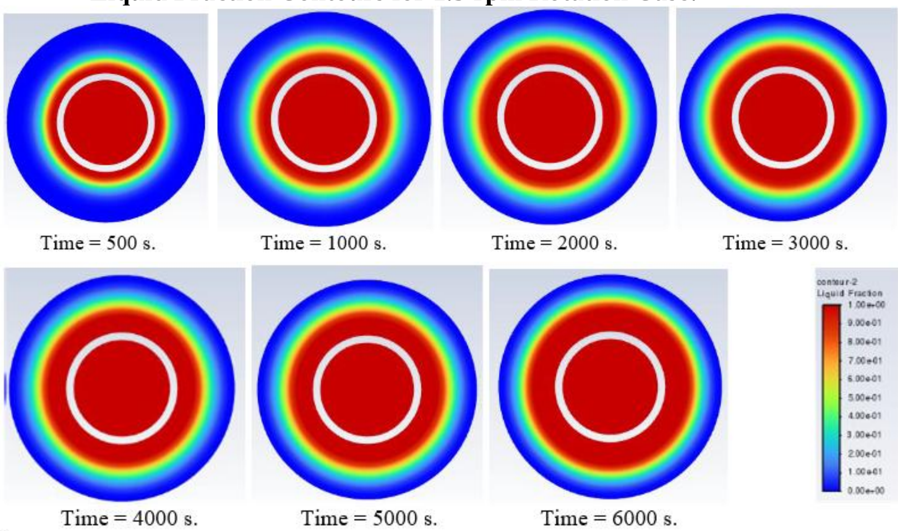


Fig. 9 Liquid Fraction Contours for 1.5 rpm Rotation Case

Temperature Contours for 1.5 rpm Rotation Case:

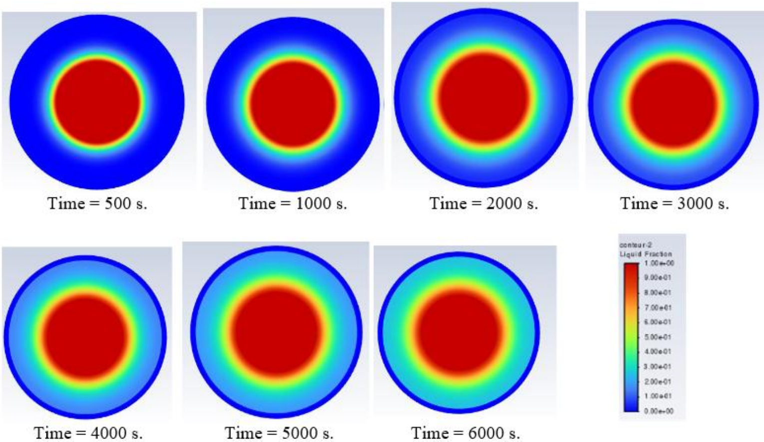


Fig. 10 Temperature Contours for 1.5 rpm Rotation Case

6. Table1: Volume Average of Liquid Fraction for Different Rotation Speed and Stand still Case:

S.No	Time (s)	Stand still case (0 rpm)	Rotation With (0.5 rpm)	Rotation With (1rpm)	Rotation With (1.5 rpm)
1	500	0.240	0.200	0.222	0.232
2	1000	0.343	0.318	0.328	0.331
3	2000	0.411	0.442	0.463	0.487
4	3000	0.515	0.528	0.530	0.613
5	4000	0.573	0.637	0.658	0.672
6	5000	0.641	0.662	0.715	0.746
7	6000	0.650	0.702	0.771	0.815

7. Calculation of Percentage of Thermal Enhancement

Percentage of Thermal Enhancement = liquid fraction of rotation - liquid fraction of stand still/liquidfraction of stand still*100

- Volume average of liquid fraction for stand stand still case = 0.650
- Volume average of liquid fraction for rotation with 0.5 rpm= 0.702
- Volume average of liquid fraction for rotation with 1 rpm = 0.771
- Volume average of liquid fraction for rotation with 1.5 rpm = 0.815

Percentage enhancement between stand still and rotation with 0.5 case = 0.702–0.650 *100/ 0.650

Percentage enhancement between stand still and rotation with 0.5 rpm case = 8%

Percentage enhancement between stand still and rotationwith1rpm case = 0.771–0.650 *100 /0.650

Percentage enhancement between stand still and rotation with 1 rpm case = 18.61%

Percentage enhancement between stand still and rotationwith1.5 rpm case = 0.815–0.650 *100 /0.650

Percentage enhancement between stand still and rotation with 1.5 rpm case = 25.38%

8. Graph:

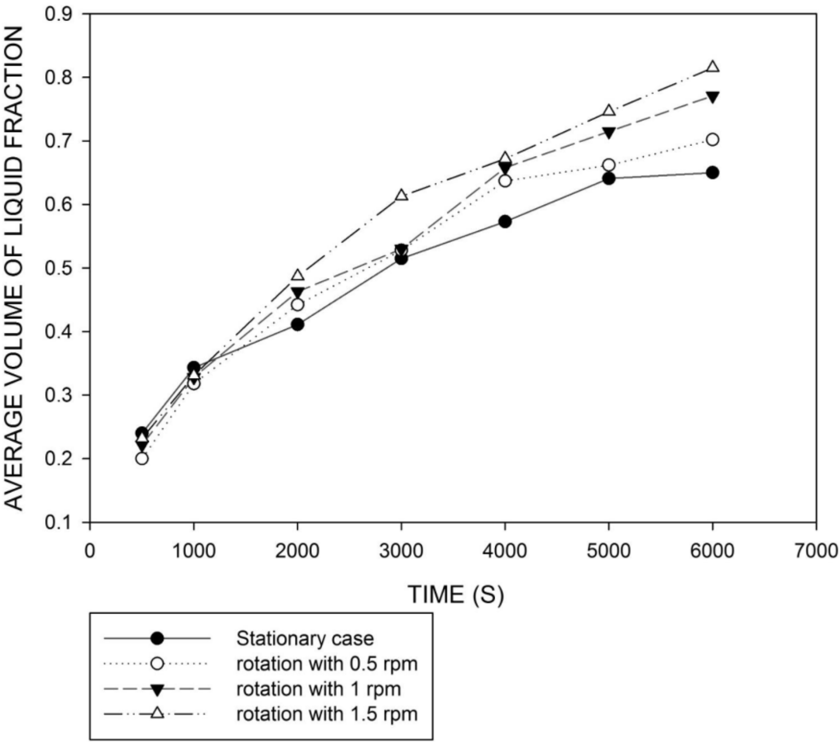


Fig. 11 Time Vs Volume Average of Liquid Fraction

9. Result and Discussion:

Stand stand still case

From the contours , when the hot water flows through hot fluid tube, the phase changing material starts melting. At, the beginning small layer of molten PCM is formed around the hot fluid tube. As, the melting goes on PCM is heated, it expands and become less dense, causing it to rise. As it rise, it carries heat away from the heat source and transfer it to cooler regions of the PCM. At the same time ,cooler, denser PCM sinks down to replace the rising molten PCM. This result in faster melting of PCM in the upper region of storage unit. The effect of buoyancy is negligible in the lower region of storage unit. The heat transfer in the lower region of the system is mainly due to conduction. Hence the melting is slow in region below the hot fluid tube. In stand still case the natural convection makes the molten PCM to rise on the upper region of latent heat storage unit. Thus a high rise in temperature is noted on the upper half of latent heat storage unit .

Rotation case

Rotation is implemented to enhance the heat transfer. In this study three rotational speeds are evaluated 0.5 rpm, 1 rpm,1.5 rpm. Performances of these cases are compared with stationary case. Rotation seems to have negative effect on the beginning of melting of PCM. In rotation latent heat storage system, the phase changing material (PCM) is subjected to centrifugal forces due to rotation of system. This can result in an angular component of the PCM, which affects the heat transfer and melting process of the PCM. Because of centrifugal forces on PCM, the PCM is pushed outwards towards the outer wall of the system. Once the sufficient melted liquid PCM available (time = 2000 s.) because of rotation, molten PCM starts circulating in the system. The rotation promote mixing of PCM. This helps to eliminate any regions of PCM that are cooler or denser than others. This result in more uniform melting of PCM in the latent heat storage system. The effectiveness of this method is calculated by percentage of thermal enhancement between stand still case and rotation case. The percentage of thermal enhancement between stand still case and rotation case for 0.5 rpm, 1 rpm and 1.5 rpm are 8%, 18.61% and 25.38% respectively. When the faster rotational speed is given the parasitic load will be higher and the advantage of having rotation may vanish. Hence the rotational speed should be maintain low to minimize parasitic load for rotating latent heat storage system.

10. Conclusion

A shell and tube latent heat storage system was numerically studied to inspect the effect of rotation in the melting process. The system was simulated as 2D model. ANSYS FLUENT 2022 VERSION R2 was used to simulate and calculate the solution. The system was studied with three different rotational speeds 0.5 rpm, 1 rpm and 1.5 rpm as well as stand still case. Paraffin wax (n-octadecane) was used as PCM while the water is used as hot tube fluid. The conclusions drawn from the study are:

• Rotation will have negative effect until sufficient amount of molten PCM is formed.

• When enough molten PCM is formed because of rotation the molten PCM starts circulating, this promotes of mixing of PCM. This helps to eliminate any regions of PCM that are cooler or denser than others.

• This result in more uniform melting of PCM in the latent heat storage system.

• The percentage of enhancement for 0.5 rpm,1 rpm and 1.5 rpm are 8%, 18.61% and 25.38% respectively for 6000 seconds of charging process.

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АНАЛІЗ ПРОДУКТИВНОСТІ ОБЕРТОВОЇ СИСТЕМИ НАКОПИЧЕННЯ ПРИХОВАНОГО ТЕПЛА

Анотація. *В останні роки для зберігання енергії використовуються кожухові та трубчасті приховані теплові системи накопичення теплової енергії (LHTESS) з матеріалами, що змінюють фазу (PCM). Основним недоліком прихованої системи накопичення тепла є те, що через низьку теплопровідність PCM теплопередача низька. У даному дослідженні розглядається 2-вимірна горизонтальна оболонка і трубчаста система прихованого зберігання тепла, обертання якої реалізовано для прискорення процесу зарядки системи. Для моделювання та розрахунку використовується програмне забезпечення ANSYS FLUENT2022 R2. Парафін (n-октадекан) і вода використовуються як PCM і гаряча рідина (HTF) відповідно. Для проведення чисельного моделювання робляться деякі припущення і застосовуються спрощення до системи. Рідка фаза PCM розглядається як нестисливе, ньютонівське, гомогенне і ізотропне середовище, а радіаційна теплопередача вважається незначною в порівнянні з природним конвекційним теплообміном. Сила плавучості через зміну щільності в залежності від температури під час плавлення PCM моделюється за допомогою наближення Буссінеска. З огляду на наближення Буссінеска, обсягними розширеннями PCM також нехтують, і природна конвекція приймається ламінарною. Для розв'язання задачі чисельним способом використовується метод двовимірної ентальпійної пористості. Моделювання та розрахунок проводяться для 0,5 об/хв, 1 об/хв та 1,5 об/хв і ці результати порівнюються зі стаціонарним аналогом . Отримані результати показують, що обертання прискорює процес плавлення. Висновки, зроблені в результаті дослідження свідчать про те, що обертання матиме негативний ефект до тих пір, поки не утвориться достатня кількість розплавленого PCM. Коли в результаті обертання утворюється достатня кількість розплавленого PCM, розплавлений PCM починає циркулювати, це сприяє перемішуванню PCM. Це допомагає усунути будь-які області PCM, які є холоднішими або щільнішими за інші. Це призводить до більш рівномірного плавлення PCM в прихованій системі накопичення тепла. Відсоток посилення для 0,5 об/хв, 1 об/хв та 1,5 об/хв становить 8%, 18,61% та 25,38% відповідно за 6000 секунд процесу заряджання.*

Ключові слова: *обертова система накопичення прихованого тепла; ANSYS; парафін (н-октадекан).*