Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(5) (2022) 237-240
DOI: 10.22060/mej.2022.20390.7224

Melting Process of Phase Change Materials in a Triplex-Tube: Arrangement, Newtonian and Non-Newtonian

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ABSTRACT: In this paper, a numerical study is presented on the investigation of heat transfer and melting process of phase change material in a finned triplex tube. The non-Newtonian Power-Law model is used to simulate the non-Newtonian fluid and the enthalpy-porosity method is used to simulate the melting process. The results show that the melting process in the case of using Newtonian fluid is more than in the case of using non-Newtonian fluid. Thus, the average value of the melting fraction of the phase change material in 5000 seconds is about 3.03% higher for the Newtonian phase change material. The effect of the two-layer composition of the Newtonian & non-Newtonian phase change material and how they are placed in the middle and outer tubes on the melting process has been investigated. For this purpose, two arrangements have been considered according to the way the fluids are placed in the middle-outer tube: 1. Newtonian & non-Newtonian fluid and 2. Non-Newtonian fluid - Newtonian. The melting process for the Newton-non-Newtonian fluid state is faster than for the non-Newtonian-Newtonian fluid state. The melting fraction in the Newtonian & non-Newtonian fluid states is about 10.32% higher than in the other state. The amount of melting fraction decreases with increasing Consistency index and decreasing Power-law index. The Nusselt number changes are similar to the melting fraction changes.

Review History:

Received: Aug. 10, 2021
Revised: Nov. 12, 2021
Accepted: Jan. 01, 2022
Available Online: Jan. 08, 2022

Keywords:

Melting
Phase change material
Triplex tube
Non-Newtonian fluid
Arrangement

1- Introduction

Increasing levels of pollution through the production of greenhouse gases and a significant increase in fuel prices have increased the potential for greater use of renewable energy sources. One of the most important challenges of technology today is to store energy in suitable forms that can be converted into the required forms. Energy storage not only balances energy supply and demand but also improves the efficiency of energy systems and plays a special role in saving energy consumption [1]. Most active solar heating systems provide storage for hours of the day. Many heat storage devices store heat in the summer on a seasonal basis to heat the environment in the winter. Therefore, these energy systems can be improved by using thermal energy storage. One of the methods of energy storage is latent heat energy storage. This storage is formed by a series of materials that are capable of melting and freezing. These materials are called phase change materials, which have a high melting point and can be used to store or release energy without changing their temperature. Various researches on the phase change process and improvement of heat transfer have been carried out using phase change materials in Newtonian and non-Newtonian chambers with chambers of different geometries with fins. The arrangement of phase change materials with different melting points has a significant effect on improving the melting and freezing process and has been studied in various studies. Jasem et al. [2] have numerically investigated the simulation of latent thermal energy storage for a shell and tube converter with phase change materials using the finite volume method. Their results show that the use of states with two and three-phase change agents has increased the speed of the freezing process compared to the state of one-phase change material by 2.5 and 8.2%, respectively. Fang and Chen [3] investigated a numerical model for storing latent heat energy using several layers of phase-change material in series in a finite element shell-and-tube converter system. They found that the difference in melting temperature between the phase change materials and the order in which they were arranged had a significant effect on the overall process of heat transfer and storage of latent heat energy despite the phase change material. Adineh and El Qarnia [4] have numerically investigated a latent heat storage unit in a shell and tube heat exchanger using a combination of two-phase change materials in series. P116 and octadecan are used as phase change materials to combine the series. The results of their research show that the use of two series of different phase change materials produces 57% more heat transfer rate than the single layer state.

In the present study, the process of melting the phase change material as a Newtonian and non-Newtonian fluid in a finned three-tube chamber has been investigated numerically. The effect of the arrangement of phase change material as Newtonian and non-Newtonian fluid in the space of inner

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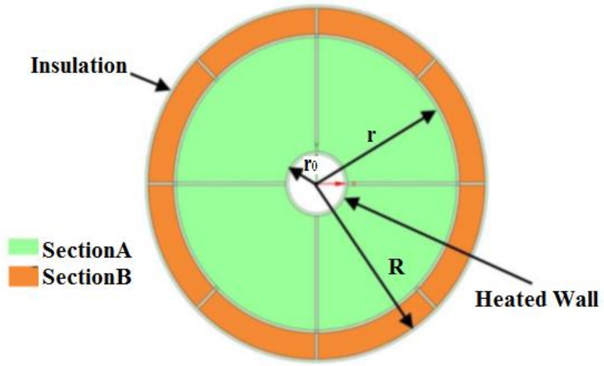

Fig. 1. A schematic of the case study

and middle pipes on the melting process and heat transfer of phase change material have been investigated. Numerical simulation is based on the finite volume method and is performed using ANSYS Fluent commercial software. The enthalpy-porosity method was used to model the melting and freezing process and the power model was used to simulate the non-Newtonian fluid. The results of the present study can be used to improve solar equipment such as solar collectors, solar air heaters, solar water desalinators, etc.

2- Methodology

A schematic of the thermal energy storage chamber is shown in Fig. 1. The thickness of the chamber and the fins used is fixed and equal to 1 mm. The fins are made of aluminum and the phase change material is lauric acid. r, r_0, R, and H represent the radius of the middle, inner, outer cylinder, and the length of the fin in the outer cylinder, respectively, and their values are R-r, 60, 10, and 50 mm, respectively. The constant temperature boundary condition of 333 K is applied to the inner wall of the chamber and the adiabatic condition is applied to the outer wall of the chamber. The initial temperature of the phase change material, fines, and the chamber is 300 K. For numerical simulation, the latent thermal energy storage process with phase change materials, the enthalpy-porosity method based on the finite volume method is used. In this method, the melting fluid fraction is calculated at each iteration. The paste region is the region in which the porosity increases from 0 to 1 with the melting of the phase change material. When an area is completely frozen, the porosity is zero and the flow velocity in this area decreases to zero. Natural convection occurs within the fluid regions of the phase change material. The effect of natural convection during the melting and freezing process is considered using the Boussinesq approximation for the density of the phase change material. The effect of the arrangement of phase change materials in the form of Newton and non-Newton in the inner and outer parts of the storage chamber on the melting process and heat transfer has been investigated. In the present numerical study, the governing equations are solved using ANSYS Fluent software based on the finite volume method. The laminar flow model and the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm are used to couple the velocity and pressure fields. The coefficients for correction of velocity, pressure, thermal energy, and liquid fraction are equal to 0.4, 0.3, 1, and 0.9, respectively. Ten different modes are considered for how the phase change material is placed in the Newtonian and non-Newtonian form inside the inner parts (section A) and the outer part of the chamber (section B) during the simulation.

Fig. 2 shows the changes in the melting fraction of the phase change material for the case where only the Newton and non-Newton phase change material is used in both the inner and outer parts of the storage chamber. The results show that the amount of melting fraction for the time when both inner and outer parts of the chamber are surrounded by non-Newtonian fluid (Type 2) is greater than the time when both parts of Newtonian fluid are surrounded (Type 1). The reason for this thermal behavior is that non-Newtonian fluid has a higher density and heat capacity compared to Newtonian fluid. Also, the effect of heat transfer due to natural convection in the non-Newtonian fluid is greater than in Newtonian fluid, so the average melting fraction for Type 2 mode has increased by 3.03% compared to Type 1 mode up to 5000 seconds. When the temperature of the solid phase change material increases due to the heat transferred from the hot surfaces, the phase change material begins to melt. In the initial stage, a thin layer of liquid phase change material is formed parallel to the inner surface under heat, and consequently, heat transfer appears between the phase change material and heat surfaces, and over time the phase change material near the heat surface, it melts completely. Thus, the shape of the melting fraction curve shows the natural convection process and the heat transfer process during the simulation. At the beginning of the process, the share of conductive heat transfer that reaches the phase change material through the heated wall by the fins is high, but over time, the share of natural heat transfer due to natural convection overrides the conductive heat transfer. The phase change in the initial and final times is different as shown in Fig. 2.

3- Conclusion

In the present study, the effect of the arrangement of phase change materials in the form of Newtonian and non-Newtonian fluids in the inner and outer parts of the storage chamber on the melting process and heat transfer during the simulation has been investigated. The amount of melting fraction is greater when both inner and outer parts of the chamber are surrounded by non-Newtonian fluid than when both parts are filled with Newtonian fluid. The amount of melting fraction is higher for the cases where the Newtonian fluid is in the inner part and the non-Newtonian fluid is in the outer part of the chamber than in the case where the non-Newtonian fluid is in the inner part and the non-Newtonian fluid is in the outer part of the chamber. For cases where non-Newtonian phase change material has been used, the amount of melting has decreased by increasing the parameter of the non-Newtonian fluid compatibility index and decreasing the non-Newtonian fluid index.

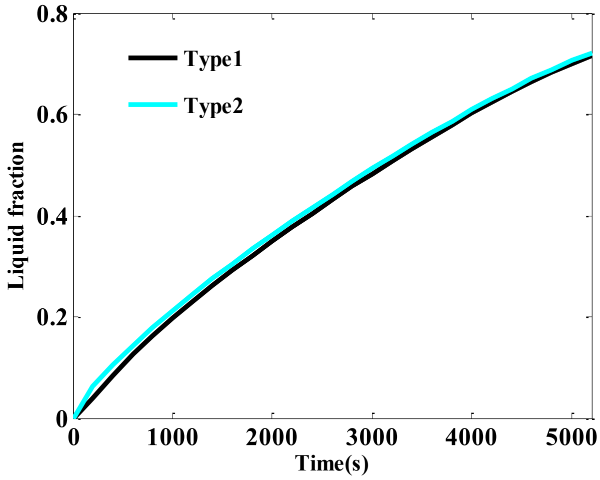

Fig. 2. Melting fraction changes of phase change material for a different arrangement

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HOW TO CITE THIS ARTICLE
S. Davoodabadi Farahani , A. Davoodabadi Farahani, F. Tayebzadeh , Melting Process of Phase Change Materials in a Triplex-Tube: Arrangement, Newtonian and Non-Newtonian, Amirkabir J. Mech Eng., 54(5) (2022) 237-240.

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