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Numerical model for solidification and melting of PCM encapsulated in spherical shells

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Abstract

The study presents a numerical analysis of the flow and heat transfer on a latent heat storage device based on a phase change material (**PCM**) encapsulated in spherical shells. This kind of heat storage system is designed for passive cooling in air conditioning applications by cold accumulation through the solidification of **PCM** during the night and by cold discharge through the melting of **PCM** during the day. The numerical analysis is taking into consideration both the **PCM** solidification and melting processes. The geometry of the analysed system was taken from an experiment available in the literature and the obtained results were compared with those of the experiment. The developed mathematical model proved to be capable to describe the flow and heat transfer in such systems.

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Keywords: phase change material; sphere; air conditioning

1. Introduction

Any improvement in the energy performance of buildings has a significant impact on the reduction of the energy consumption, because buildings account for 40% of the global energy consumption in Europe [1].

The reduction of energy consumption in fresh air cooling systems is also highlighted in the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, concerning the energy performance of buildings [2]. Phase change materials (**PCM**) can be successfully used to enhance the energy efficiency of fresh air cooling

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systems of the buildings [3]. **PCM** are capable of storing and releasing large amounts of cold at relatively constant temperatures [4]. It is important to study the phase change transformations of solidification and melting because a large number of materials are capable of undergoing this transformation with negligible volume variation [5].

The analysis of technical applications in air conditioning with **PCM** requires the study of the geometry of regenerative heat exchangers also known as latent heat thermal energy storage (**LHTES**). The advantage of spherical shells as **PCM** containers is based on the high ratio between the outer surface and the quantity of material that can be encapsulated. Several studies analysed from theoretical and experimental point of view **LHTES** using packed beds [6-12].

The energy efficiency of air cooling systems can be improved by integrating **LHTES** to store the cold naturally available due to the low ambient air temperatures registered during the night, even in summers [13]. From this perspective it became important to take the outdoor air temperatures into account, when numerically simulating and predicting the behaviour of the **LHTES**.

An experimental study of the solidification process of a **PCM** contained in a spherical shell is presented in [14]. The temperature of the shell was taken into account and was found to be more important than the initial temperature of the **PCM**.

The melting process of a **PCM** was studied by both experimenting and modelling in[15] and a formula was determined to calculate the melt fraction of the **PCM**.

Both melting and solidification of **PCM** encapsulated in spherical shells were studied in [16]. The developed mathematical model was found to be in good agreement with the experiments. The behaviour of **LHTES** integrated in the air conditioning system was studied by the same authors for a house located in Slovenia [17, 18] and for houses located in six different climatic zones in Europe in [19], concluding that **LHTES** is more efficient if the phase change temperature range of the **PCM** is higher.

A mathematical model was also used in [20] to predict the behaviour of a cylindrical body filled with spherical shells containing **PCM** under a wide range of Reynolds numbers.

The influence of the spheres arrangement inside an **LHTES** was analysed in [21]. The model also takes into account the temperature variation of the **PCM** encapsulated in the spheres. The influence of the spherical shell's material on the solidification and melting process was also evaluated in the same study.

The propagation of the interface between the solid and the liquid phase inside the spheres was studied in [7].

The goal of this study is to propose a simple and accurate mathematical model capable to simulate the behaviour of a **LHTES** based on spherical shells filled with **PCM**. The model refers to both the air side and the **PCM** side and describes both phases of cold accumulation and of cold discharge. This study is continuing previous concerns in the field of energy efficiency at the Technical University of Cluj-Napoca [22-29].

2. Material and method

The study considers a **LHTES** based on spherical shells filled with **PCM**. The mathematical model used to describe the behaviour of the system during cold accumulation and cold discharge is based on the energy balance between the spheres filled with **PCM** and air flowing around the spheres. The scheme of the energy balance is presented in figure 1.

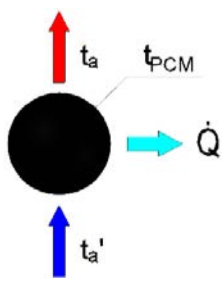

Fig. 1. The scheme of the energy balance between the spheres and the air flowing around