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Thermal energy storage systems

[1] Sunkara Ravi, [2] MV Sirisha, [3] M Mastanaiah

[1] M. Tech Student Department of Mechanical Engineering, Dr. Samuel George institute of engineering and technology, Markapuram, Prakasam Dist. Andhra Pradesh, India.
[2] Assistant Professor Department of Mechanical Engineering, Dr. Samuel George institute of engineering and technology, Markapuram, Prakasam Dist. Andhra Pradesh, India.
[3] Professor Department of Mechanical Engineering, Dr. Samuel George institute of engineering and technology, Markapuram, Prakasam Dist. Andhra Pradesh, India.

Abstract

The objective of this paper is twofold: First, a computational model is presented for predicting the thermal behavior of a packed bed LHTES unit consisting of spherical capsules containing PCM with HTF flowing across them. Second, parametric studies are performed to access the effects of geometric and operating parameters on the thermal behavior of the system

The developed model can be used to predict the energy storage behavior of different phase-change materials used with different heat transfer fluids, flow rates and temperatures. Numerical solutions have been obtained for the case where the phase change material is Paraffin wax [RT60] and the heat transfer fluid is water.

Keywords: Thermal energy, storage systems, heat transfer fluids, Paraffin wax

1. Introduction

Energy storage (ES) has only recently been developed to a point where it can have a significant impact on modern technology. In particular, ES is critically important to the success of any intermittent energy source in meeting demand. For example, the need for storage for solar energy applications is severe, especially when the solar availability is lowest, namely in winter.

ES systems can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use in building heating and cooling, aerospace power, and power utility applications. The use of ES systems often results in such significant benefits as

- reduced energy costs,
- reduced energy consumption,
- reduced equipment size,
- more efficient and effective utilization of equipment,
- conservation of fossil fuels (by facilitating more efficient energy use and/or fuel substitution), and
- reduced pollutant emissions (e.g. CO_2 and CFC_S).

ES systems have an enormous potential to increase the effectiveness of energy-conversion equipment use and for facilitating large-scale fuel substitutions in the world's economy. ES is complex and cannot be evaluated properly without a detailed understanding of energy supplies and end-use considerations. In general, a coordinated set of actions is needed in several sectors of the energy system for the maximum potential benefits of storage to be realized. The opportunities for energy storage are not confined to industries and utilities. Storage at the point of energy consumption, as in residences and commercial buildings, will likely be essential to the future use of solar heating and cooling systems, and may prove important in lessening the peak-demand loads imposed by conventional electrical, space-conditioning systems. In the personal transportation sector, now dominated by gasoline-powered vehicles, adequate electrical storage systems might encourage the use of large numbers of electric vehicles, reducing the demand for petroleum.

In particular, decisions on whether to use energy storage systems will likely be made on the basis of prospective cost savings in the production or use of energy, unless legislative or regulatory constraints are imposed. Thus, among criteria necessary for the commercialization of ES systems, potential economic viability is a major parameter.

2. Modeling of latent heat Thermal energy storage systems

Modeling of solid-liquid phase change heat transfer has received considerable research attention over the last two decades. This is not surprising considering its numerous application in processes such as the melting of ice and freezing of water, metal casting, welding coating and purification of metals, crystal growth from melts and solutions; freeze-drying of foodstuffs, nuclear reactor safety, aerodynamic heating of re-entry bodies and thermal spacecraft control. Modeling of solid-liquid phase change is also relevant to the design and development of efficient, cost effective Latent Heat Thermal Energy Storage (LHTES) systems. Indeed, the latent heat-of-fusion energy storage concept, which involves storing and recovering heat through the solid-liquid phase change process, has two undeniable advantages. First, the latent heat of most materials is much higher than their sensible heat, thus requiring a smaller mass of storage medium for storing/recovering a given quantity of thermal energy. Second, the thermal storage process occurs at a nearly constant temperature, which is desirable for efficient operation of most thermal systems. A good understanding of the heat transfer processes involved is essential for accurately predicting the thermal performance of the system and for avoiding costly system overdesign.

Modeling the thermal behavior of LHTES systems is, however, much more complex than the modeling of sensible heat storage systems. There are problems associated with the nonlinear motion of the solid-liquid interface, the possible presence of buoyancy driven flows in the melt, the conjugate heat transfer between the encapsulated PCM and the Heat Transfer Fluid (HTF) in the flow channels and the volume expansion of the PCM upon melting/solidification. Several investigators have studied, theoretically and experimentally, the advantage of thermal energy storage employing a phase-change material in a varity of geometries and developed computational models for predicting the thermal behaviour of LHTES

Farid and Kanzawa (1989) developed a mathematical model to predict the transient behaviour of a phase-change thermal storage unit consisting of bundle of tubes filled with PCM with air flowing across them. The model was based on solving the heat conduction equation in both melt and solid phases in cylindrical co-ordinates, taking into account the radial temperature distribution in both phases. A highly accurate and efficient finite-difference method for phase-change problems with multiple moving boundaries of irregular shape was developed using co-ordinate transformation method was presented by Kim and Kavlany (1990) [5]. The accuracy and flexibility of this numerical methods were verified by solving some phase-change problems and comparing the results with existing analytical, semi-analytical and numerical solutions. Results indicated that one and two-dimensional phase-change problems can be handled easily with excellent accuracies. The modeling of the heat transient process in a phase-change storage medium consisting of parallel flow channels was presented by Majumdar and Saidbakhsh (1990) [9]. A finite difference solution was obtained for the developed mathematical model and used to carry out a parametric study of the PCM storage for various non-dimensional parameters and operating conditions.

Table 1: Thermophysical properties of PCM (Paraffin wax)

Material Properties	Paraffin wax (RT60)
Latent Heat of Fusion (λ), kJ/kg	209
Density (ρ_{ps}), kg/m^3	861
Density (ρ_{pl}), kg/m^3	778
c_{ps} solid, J/kg ^{0}C	1850
c_{pl} liquid, J/kg ^{0}C	2384
k_{ps}, W/m ^{0}C	0.4
k_{pl}, W/m ^{0}C	0.15
Melting point temperature (T_{pm}) ^{0}C	60

Table 2: Properties of HTF (water) at 80 ^{o}C

Properties	*Water*
Density (ρ), kg/m^3	974
Kinematic viscosity, m^2/sec	0.364X10^{-6}
Thermal conductivity (k), W/m K	0.6687
Specific heat (c_p), J/kg k	4195
Dynamic viscosity (μ), kg/ms	0.00035

3. Results and Discussion

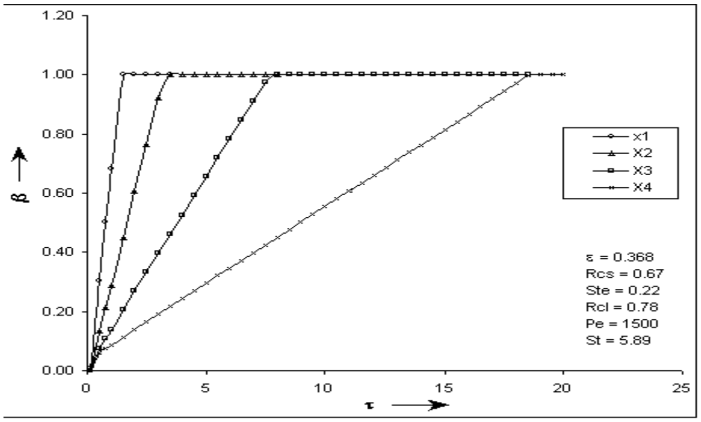

Fig 1: for ε = 0.368

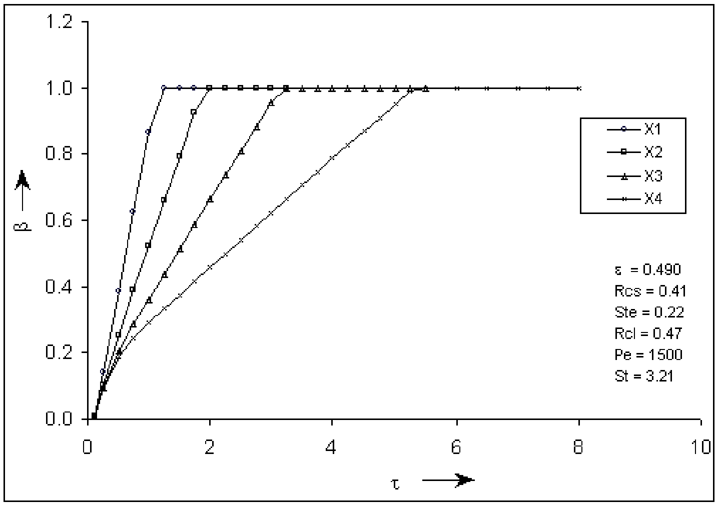

Fig 2: Timewise variation of melted mass fraction, (β) at various axial locations

4. Conclusion

A one-dimensional computer model based on the porous medium approach is developed to predict the thermal behaviour of a packed bed LHTES unit that consists of spherical capsules containing PCM with HTF flowing across them for heat exchange. The model is based on the conservation equations of energy for the PCM and the HTF. The governing equations for the time dependent temperature distributions in both HTF and PCM are solved using finite difference scheme.

Parametric studies are performed to examine the effects of various geometric parameters and operating conditions on the thermal behaviour of the unit. Numerical solutions have been obtained for the case where the phase change material is Paraffin wax [RT60] and the heat transfer fluid is water. The variation of the dimensionless temperatures of the HTF & the PCM, the melted mass fraction (β) of the PCM during the phase change process and instantaneous heat stored, with dimensionless time, for different values of porosity, Stefan number, Stanton number and the flow parameter have been studied.

5. References

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