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Evaluation of thermal energy storage and recovery for an electrical energy mediator system

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ABSTRACT

Energy storage both electrical and thermal is a rapidly emerging field of interest toward the development of more sustainable energy systems. The inherent inefficiencies associate with electrical storage can be partially overcome when thermal storage that collects and storage the waste thermal energy for alternative uses is integrated. Consequently, thermal energy storage systems are an enabling technology that will allow increased energy efficiency of a community, permit load levelling to reduce peak electricity demand. In order to facilitate a technology evaluation, a sizing strategy is developed for a phase change material (PCM) thermal storage system that determines system requirements under given thermal energy capture and recovery cycles. The sizing process utilizes a simplified one-dimensional heat transfer model that estimates melt times for a phase change material thickness without detailed geometry information. This melt time estimate allows the proportion of phase change material to fluid routing materials to be calculated, giving an estimate of material cost for the thermal storage cell to determine economic feasibility. The model is compared to both experimental data and computational fluid dynamics models in order to determine its limitations. Through a specific example of hydrogen based distributed electrical energy mediator system, the utility of the sizing model in determining the estimated cost of thermal energy storage is demonstrated.

1. Introduction

With the shift of focus in the energy industry towards more efficient and sustainable generation, transmission and use of power, reducing waste has become a major area of research. As inefficiency eventually manifests itself as thermal energy, rather than releasing this thermal energy into the atmosphere, which is wasteful and can be potentially harmful to the environment, the goal is to store it and use it for heating needs. This also has the benefits of decreasing the use of fossil fuels to satisfy hot water and building heating needs, as well as reducing the associated emissions from the hydrocarbon combustion process. This type of cogeneration is not widely used in Canada due the low cost of electricity and natural gas and the lack of economical thermal energy storage technologies to allow the production of heat to be decoupled in space and time from its use [9]. It is therefore necessary to develop systems that will allow storage and transport of thermal energy. In addition to this technology, a model that allows potential users to quickly and effectively evaluate such a system could facilitate a wider use of thermal storage technologies.

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Nomenclature

A	area (m^2)
Cp	heat capacity (J/kg K)
E	energy (J)
h	heat transfer coefficient (W/m^2 K)
h_{sf}	latent heat of fusion (J/kg)
k	thermal conductivity (W/m K)
l	length (m)
M	mass (kg)
Q	rate of heat transfer (W)
q”	heat flux (W/m^2)
s	position of the solid–liquid interface (m)
t	time (s)
T	temperature (K)
U	temperature distribution (K)
V	volume (m^3)
x	position (m)
γ	melt fraction (–)
ρ	density (kg/m^3)

Subscripts

c	capture
CS	cross-sectional
Eff	effective
f	fluid
i	initial
n	time interval
m	melt
PCM	phase change material
R	recovery
SC	subcooling
SH	superheat
sf	solid/fluid
ss	stainless steel
s	solid
Store	storage value
tube1	tube inner wall
tube2	tube outer wall
w	wall value

Thermal storage is by no means a new concept. In addition to centuries of use of ice houses, thermal storage units have also been studied extensively for use of solar energy at night. In the summary of thermal storage technologies by Zalba et al. [12], many applications that use storage of thermal energy during times of abundance or low cost for use in times of high cost or low availability are listed. The other major category of items pertains to temporary thermal protection of goods and a variety of stabilization applications including thermal control of electronics [5]. In terms of efficiency of existing systems, the application that is of most interest in this investigation is the harvesting of thermal energy from a “capture process”, storage of the energy for a suitable amount of time and then transfer to a “recovery process” with the goal of increasing overall energy efficiency.

While many mathematical models currently exist for predicting melt and solidification times in specific phase change material-heat transfer surface configurations [10,14,12] for a preliminary assessment they are typically challenging primarily due to their dependence on specific geometry information and associated size of most existing systems. Typically electronics thermal management and solar heating applications have been the focus of thermal storage development. The models reviewed by Verma et al. [10] use an energy balance to determine temperature and heat flux profiles throughout the phase change material and surrounding components and a second law of thermodynamics analysis, which use the principle entropy generation. Wirtz et al. [11] developed a model that simulates the performance of a cooler/heater storage unit. Alawadhi and Amon [1] numerically studied the time dependence of PCM thermal storage unit under various operating conditions for electronics applications in particular the thermal balance effectiveness is a function of the varying power magnitude, period and PCM quantity. Zheng and Wirtz [13] developed a set of thermal performance figures of merit and a thermal model for optimizing the design of a plate-type thermal energy storage unit.