Applied Thermal Engineering 84 (2015) 138–149

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Parametrical analysis of latent heat and cold storage for heating and cooling of rooms☆

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HIGHLIGHTS

- Thermal properties of paraffin RT22HC were measured.
- Flow visualization was carried out and velocity between plates was measured.
- Thermal and pressure drop analysis were performed.
- Melting times are too long however, use of storage tank for heating and cooling looks promising.

ARTICLE INFO

Article history:
Received 15 July 2014
Accepted 20 February 2015
Available online 31 March 2015

Keywords:
PCM
Thermal energy storage
Plates
Free cooling
Heating
Solar air collector

ABSTRACT

One of the problems we are facing today is the energy consumption minimization, while maintaining the indoor thermal comfort in buildings. A potential solution to this issue is use of phase change materials (PCMs) in thermal energy storage (TES), where cold gets accumulated during the summer nights in order to reduce cooling load during the day. In winter, on the other hand, heat from solar air collector is stored for evening and morning hours when solar radiation is not available. The main objective of the paper is to examine experimentally whether it is possible to use such a storage unit for heating as well as for cooling. For this purpose 30 plates filled with paraffin (melting point around 22°C) were positioned into TES and applied with the same initial and boundary conditions as they are expected in reality. Experimental work covered flow visualization, measurements of air velocity in the channels between the plates, parametric analysis in conjunction with TES thermal response and measurements of the pressure drops. The results indicate that this type of storage technology could be advantageously used in real conditions. For optimized thermal behavior, only plate thickness should be reduced.

1. Introduction

In the last few years there has been a growing interest in reducing energy use in buildings, which is also stated in the European directive [1]. The literature on this topic shows a variety of approaches towards achieving this goal. This article concentrates on energy storage using phase change materials (PCM). Principle of operation of all systems with PCM is that the energy is stored when it is available and is released later when the energy demand arises. In order to achieve thermal comfort in buildings it is necessary to deliver a certain amount of heat or cold. The source can be conventional systems or more advanced technologies, proposed by researchers in recent years. Promising are two principles: one for cooling and the other one for heating. For cooling needs in summer, the idea is to store outdoor cold during the night and supply it to the indoor environment during the day. This type of cooling is suitable for climates where the diurnal temperature range is at least 15 K [2]. For the heating requirement, energy from the sun can be exploited in conjunction with solar air collectors [3]. It happens often that the heating during the day is not needed, because of relatively high ambient temperature and solar gains. Heating load increases after sunset, so in such cases day-cycle TES can be advantageously used. When the available energy exceeds the energy demand, energy is stored, later it is released and so it completely or partially replaces conventional systems. The advantage of such systems is that they can operate in a relatively small temperature

☆ This document is a collaborative effort.

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http://dx.doi.org/10.1016/j.applthermaleng.2015.02.081
1359-4311/© 2015 Published by Elsevier Ltd.

Nomenclature

Roman symbols

c	specific heat [kJ/(kg K)]
D	hydraulic diameter [m]
f	friction factor [/]
h	specific enthalpy [kJ/(kg]
K	loss factor [/]
L	length of pipe [m]
m	mass flow [kg/s]
P	thermal power [W]
Q	heat [J]
T	temperature [°C]
U	the overall heat transfer coeffiecient [W/(m^2 K)]
v	mean velocity of flow [m/s]

Abbreviations

EPS	expanded polystyrene
HTF	heat transfer fluid
PMMA	polymethylmethacrylat
TES	thermal energy storage

Subscripts

a	air
al	aluminum
amb	ambient
avg	average
ch	channel
cs	cross-section
end	end of cycle
EPS	expanded polystyrene
h	holder
in	inlet
init	initial
out	outlet
PMMA	polymethylmethacrylat

range and the amount of energy is greater than in the case of sensible heat storage.

Several publications have appeared in recent years documenting different types of TES such as capsules [4–6], tube banks [7], hybrid systems with fins [8,9], heat pipes [10], shell and tube [11], plates [12–14]. All of them use air as HTF. Experimental studies, where plates were used, can be divided into two groups, namely for cooling and for heating. Research work on former will be presented first.

One of the first examples was presented in paper by Zalba et al. [15]. They outlined the development of an installation for free cooling that allows testing the performance of PCMs. Experiments were performed using 3 kg of paraffin (RT25, Rubitherm GmbH) which means a storage density of 28 kWh/m^3. The main focus of the study was on: the ratio of energy/volume in capsules, load/unload rate of the storage, and cost of the installation. The results obtained suggest that the thickness of the encapsulation, the inlet temperature of the air and the air flow have significant influence on the solidification and melting process. Study carried out by Waqas and Kumar [16] was conducted to investigate thermal performance of the latent heat storage for free cooling of buildings in a dry and hot climate. 13 kg of PCM (SP29, Rubitherm GmbH) was encapsulated in the containers of the galvanized steel. The authors concentrated on the influence of air flow and the air inlet temperature on cold accumulation and it was shown that solidification of PCM was more sensitive to the charging air temperature compared to the air flow rate. Heat exchanger with two different geometries was investigated by Lazaro et al. [17,18] who developed empirical and numerical models. They proposed a modular structure and identified the required number of modules and the melting temperature to meet the specific cooling demand over time. In experiment 135 kg of paraffin (RT27, Rubitherm GmbH) was encapsulated in 10 mm thick aluminum plates.

Second group are applications for space heating where Saman et al. [19] used experimental data for validation. They analyzed effects of different parameters (such as the air flow rate, the PCM slab thickness or the air gap) on TES performance. Melting temperature of calcium chloride hexahydrate (PCM29) was around 29 °C. Labat et al. [20] presented a prototype which provided a 1 kW heating power during 2 h. It consisted of 34 aluminum containers filled with 28 kg of paraffin (Microtek 37D). Its melting range was between 31 °C and 34 °C. Their results revealed that enough energy was stored but the heating power was lower than 1 kW in the first 2 h. In another study carried out by Charvat et al. [21] larger heat storage unit was investigated. They used 100 aluminum plates filled with a paraffin (RT42, Rubitherm GmbH) with the melting temperature around 40 °C. Experimental results served as a means of validation. Data from each of the above mentioned experiments are collected in Table 1. Compactness refers to the ratio of plate's surface area to plate's volume, whereas energy density refers to the ratio of stored energy to volume of storage unit.

The novelty of the paper is local storage unit for heating and cooling. In Table 1 different studies are presented, but none of them unites these two options. However, some studies [23] address both of them, but those are larger systems that are meant to operate more or less as central systems. In these systems more plates were positioned one after another along the flow. In this manner the area for heat transfer increased significantly and, consequently, the characteristics and thermal response of larger storage tank differed from the smaller one. With proposed system low exergy sources could be utilized throughout the year. Overall delivered energy for cooling and heating demands would increase, and consequently the energy demand from conventional systems would decrease. TES would operate in summer and winter, and thus would not be constrained to one season as are other systems in relevant literature.

The objectives of the paper are to study the effects of inlet air temperature, air flow and air gap on the melting and solidification processes, to check the total energy exchanged between air and PCM for each case, to assess the required time to perform the phase-change process, to carry out flow analysis in the tank, since none of the previous studies addressed problems with uniform flow and nobody presented distribution of flow between channels and to determine thermal properties of paraffin and investigate if hysteresis and subcooling are present.

2. Experimental setup

2.1. Description of TES unit

In order to achieve the target set in the introduction, an experimental rig for testing TES's thermal response was set up.