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Parametric study on the effect of using cold thermal storage energy of phase change material on the performance of air-conditioning unit

M.A. Said[a,b], Hamdy Hassan[a,c,*]

[a] Egypt-Japan University of Science and Technology, Alexandria, Egypt
[b] Department of Mech. Eng., Faculty of Engineering, Benha University, Benha, Egypt
[c] Mech. Engineering Department, Faculty of Eng., Assiut University, Assiut, Egypt

HIGHLIGHTS

- New technique of using phase change material with air-conditioning is presented.
- Outlet air temperature and charge time are reduced with rising inlet air velocity.
- Longer and thinner phase change material plates is suitable for short cooling time.
- The rise of the coefficient of performance of air-conditioning unit is about 14%.
- Saved power per ton refrigeration for each kg of phase change material is 0.16 KW.

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ABSTRACT

This paper presents a study on a new technique of using thermal energy storage of phase change material system with conventional air-conditioning unit to increase its cooling performance. The technique is based on integrating plates of phase change material with the condenser of the air-conditioning unit. The phase change material plates use its cold storage energy during the night time to increase the cooling performance of the unit during the daytime. The air is used to transfer the cold storage energy from the phase change material plates to the air-conditioning unit during the daytime. The study is performed during charging the phase change material with cold storage energy at night and discharging this energy to the air-conditioning unit at daytime. A theoretical transient model for the phase change material with air heat exchanger is constructed and a numerical solution of the theoretical model is presented. The numerical solution of the theoretical model is validated with an experimental work. The effect of the phase change material plates configurations and the inlet velocity and temperature of the air inlet to the phase change material plates on the charging and discharging process is carried out. Also, the effect of these parameters on the air-conditioning unit performance is presented. The results show that the longer and thinner phase change material plates configuration has the lower charging and discharging time. The discharging time and the outlet cold air temperature from the phase change material plates are decreased with increasing inlet air velocity and temperature. The charging time is decreased with decreasing inlet air temperature and rising inlet velocity. The maximum increase of the coefficient of performance of the air-conditioning unit with phase change material for the different configurations compared to the conventional one for inlet air temperature 35 °C, is 14%, 13% and 12% for inlet air velocity 0.96 m/s, 1.2 m/s and 1.44 m/s respectively. The discharging and charging time and the outlet cold air temperature from the phase change material plates are decreased with increasing inlet air velocity and temperature respectively. Also, at inlet air temperature 45 °C, and velocity 1.44 m/s, the maximum useful cooling power per kg of the phase change material is 46, 50, 54, 55, and 67 W for the configurations 2, 5, 4, 1 and 3 respectively. The results illustrate that, at air inlet velocity 0.96 m/s, the maximum percentage of the saved power per ton refrigeration for each kg phase change material with respect to conventional AC unit is about 11.6%, 6.7% and 5.4% for inlet air temperature 45 °C, 40 °C and 35 °C respectively.

* Corresponding author at: Egypt-Japan University of Science and Technology, Alexandria, Egypt.
E-mail address: hamdyaboali@yahoo.com (H. Hassan).

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Nomenclature

A	area [m^2]
C	mushy zone coefficient
C_p	specific heat [J/kg K]
g	acceleration gravity [m/s^2]
G	generation of turbulence kinetic energy
H	total enthalpy [J]
h	specific enthalpy [J/kg]
k	thermal conductivity [W/m K]
L	latent heat [J/kg]
m	mass [kg]
Q	heat flux [W/m^2]
p	pressure [pa]
T	temperature [K]
u	velocity [m/s]
V	inlet velocity [m/s]
S_i	darcy's law damping coefficient
W	power consumption [W]

Greek symbol

ρ	density [kg/m^3]
μ	dynamics viscosity
μ	m/s^2 β
μ	melting fraction
ΔH	latent heat content

Subscripts

in	inlet
out	outlet

Abbreviations

AC	air conditioning
CCT	complete cooling time
CMT	complete melting time
COP	coefficient of performance
CST	complete solidification time
PCM	phase change material

1. Introduction

Using of air-conditioning (AC) systems is increasing rapidly everywhere of the world with rising the world populations and cities modernization. The COP of AC and refrigeration units rises with decreasing condenser or increasing evaporator temperatures, which results in a decrease in the unit energy consumption [1]. Researches showed that for the air-cooled AC unit, if the on-coil temperature of the condenser is raised by 12 °C, the COP of the AC unit drops by about 3% [2]. Therefore, reducing AC condenser's operating temperature will be highly beneficial for the AC's performance and efficiency. This attracted great efforts from researchers, such as using new types of refrigerant [3], optimizing condenser placement [2] and investigating the effect of temperature stack [4]. Cold thermal energy storage of phase change material (PCM) is an effective way to use of night cold energy in reducing the AC power consumption during the daytime. PCM depends on the phase change enthalpy of the PCM to accumulate heat within a temperature range, resulting a higher energy density than the obtainable energy from sensible heat storage for the same temperature range [5]. One of the concepts of using phase change material (PCM) in AC purpose is called "free cooling" or "night ventilation system" where thermal energy storage of the PCMs can be used for free cooling. PCM is one type of latent heat thermal energy storage system used for cooling applications [6]. The aim of using PCM is to reduce the energy consumption and the peak time problem. In using PCM approach for cooling, low ambient temperature at night is used to store cold energy by solidifying the PCM during the night. Then, during the next daytime, the cold storage energy is used in the cooling process by exchanging heat with the low temperature of the solidified PCM. The PCMs have been used in ventilation, heating, cooling and AC systems for different applications. Using ice thermal energy storage with AC system was carried out by Lee et al. [7] and pu et al. [8]. They found that using ice PCM decreases the required power, but it has a disadvantage of its low melting temperature. Vakiloroaya et al. [9] investigated and discussed different technologies and approaches, and established their capability to improve the performance of the heating, ventilation, and AC systems to reduce the energy consumption. In some applications, the air was used as the heat transfer medium in both charging and discharging processes for the most intensely thermal energy storage system [10,11]. Wang et al. [10] developed and studied the using of two heat

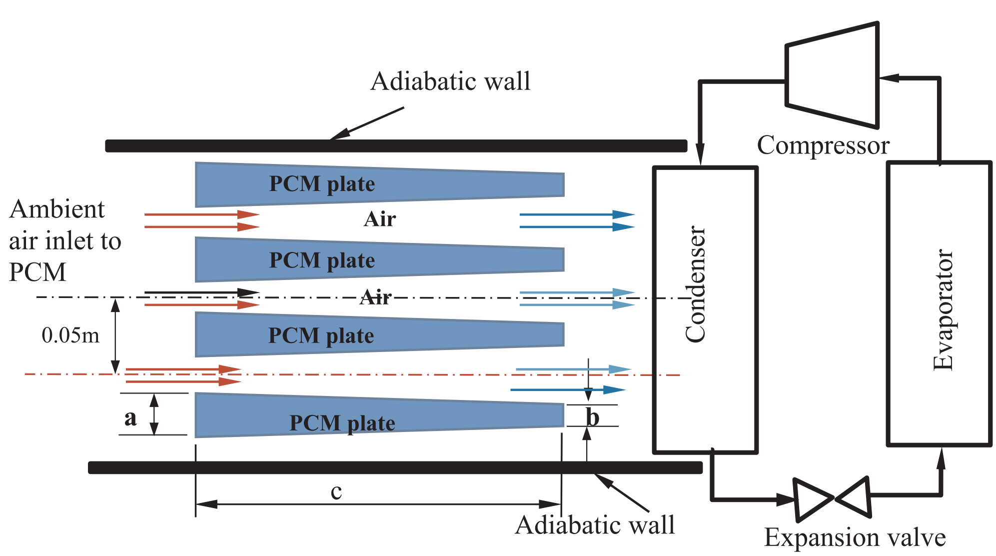

Fig. 1. Physical model of the PCM heat exchanger with AC unit.