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Thermophysical properties of some organic phase change materials for latent heat storage. A review

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Abstract

Past three decades are characterized by intensive investigations and the development of phase change materials for thermal energy storage. Latent heat storage is one of the most perspective methods of increasing efficiency in energy conservation and effective using sources of heat. Among available latent heat storage materials, the organic materials draw the attention of many researchers. It should be noted that the development of phase change materials advances the investigations of their thermophysical properties sufficiently. Knowledge of thermophysical properties is necessary condition for practical applications. The data on thermophysical properties of potential latent heat storage materials is dissipated in many scientific sources that are inaccessible, in many cases, for potential consumers of phase change thermal energy storage materials. This paper summarizes the results of previous investigations on transitions temperatures, heat of fusion, heat capacity, and thermal conductivity, long-term characteristics of many organic substances, their compositions, and compounds.

Keywords: n-Alkanes; Paraffins; Fatty acids; Fatty acid esters; High molecular alcohols; Benzene compounds

1. Introduction

Continuous growth of level of greenhouse gases emissions into the atmosphere and a high cost of fossil fuel are the basic motive forces for more effective utilization of energy in all spheres of humankind activity. Commercial buildings and housing apartments are the most energy-intensive consumers. So, for example, in 2005, 38.9% of all energy which has been consumed in the USA (Buildings Energy Datebook, 2006) was used for heating, air-conditioning and illumination of buildings. The similar situation is observed in the European Union where buildings consume now 40% of all energy used in these countries (Kornevall, 2008). These examples show us how important it is to use energy effectively in buildings.

Thermal energy storage is one of the most perspective methods for increasing efficiency in energy conservation of available sources of heat. Thermal energy can be stored by using sensible energy of solids or liquids, latent heat of phase change materials or chemical reaction of some chemicals. The main requirements and fields of applications of thermal energy storage (TES) systems are generalized in Schaetzle et al. (1980), Schmidt (1981), Beckmann and Gill (1984), Garg et al. (1985), Hadorn (1990) and Dinçer and Rosen (2011)). Among TES methods, in many cases, latent heat storage (LHS) is more preferable (Lane, 1983, 1986; Mehling and Cabeza, 2008). LHS differs in high density of accumulated energy at constant temperature

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Nomenclature

T_m	melting point (°C or K)
T_f	freezing temperature (°C or K)
T_{tr}	solid–solid transition temperature (°C or K)
ΔH_m	heat of fusion (J/g)
ΔH_f	heat of solidification (J/g)
ΔH_{tr}	heat of solid–solid transition (J/g)
C_p	specific heat capacity (J/g°C)
ρ	density (g/cm^3)
λ	thermal conductivity (mW/m°C or W/m°C)
α	thermal diffusivity (mm^2/s)
N_c	number of carbon atoms

Abbreviation

AMPL	aminoglycol (2-Amino-2-methyl-1,3-propanediol)
CA	capric acid
comp.	compound
DSC	differential scanning calorimetry
DTA	differential thermal analysis
eut.	eutectic
LA	lauric acid
LHS	latent heat storage
NPG	neopentyl glycol (2,2-Dimethyl-1,3-propanediol)
MA	myristic acid
MM	molar mass (g/mol)
PA	palmitic acid
PE	pentaerythritol (2-2-Bis(hydroxymethyl)1.3-propanediol)
PCM	phase change material
PG = TME	pentaglycerine = Trimethylolethane (2-hydroximethyl)-2-methylpropane-1,3-diol)
SA	stearic acid
TES	thermal energy storage
TRIS	2-Amino-2-hydroximethyl-propane-1,3-diol
TMP = TRMP	Trimemethylolpropane ((2-hydroxymethyl)-2-ethylpropane-1,3-diol)

and narrow temperature region. At present, a lot of solid–liquid phase change materials (PCM) have been studied and they are commercially produced for different purposes (Kenisarin, 1993; Zalba et al., 2003; Sharma and Sagara, 2005; Kenisarin and Mahkamov, 2007; Agyenim et al., 2010; Kuznik et al., 2011; Tatsidjodoung et al., 2013).

The basic problems connected with the use of salt hydrates were practically solved in the seventies and eighties of the last century (Lane, 1983, 1986; Abhat, 1980, 1983). In order to use PCMs for thermal energy storage in wide scale, designers of heat storage systems are needed aside from stable chemical viability of PCMs, the following reliable thermophysical properties: melting point, heat of fusion, heat capacity, density, heat conductivity of latent heat storage materials in neighborhood of their melting point (±15 °C) as well as volume change at phase transition. The known thermophysical properties of salt hydrates were generalized in (Mozgovoy et al., 1990). It was established that the thermophysical properties of salt hydrates were studied insufficiently. The manufacturers of commercially produced phase change heat storage materials supplied their products only with data on melting point and heat of fusion. These data are not enough for potential consumers. Last two decades are characterized with high intensity studies of potential organic materials that can be used as LHS materials. A lot of organic materials which have been investigated have suitable melting point and high heat of fusion. Recently Sarier and Onder (2012) published a review on application of PCMs relating to improving heat storage ability of textile materials.

Among organic materials perspective for latent heat storage, the pure n-alkanes and their blends, fatty acids, their compositions and esters it should be noted. The data on thermophysical properties of organic PCMs available in (Lane, 1983, 1986; Mehling and Cabeza, 2008; Kenisarin, 1993; Zalba et al., 2003; Sharma and Sagara, 2005; Kenisarin and Mahkamov, 2007; Agyenim et al., 2010; Kuznik et al., 2011; Tatsidjodoung et al., 2013, etc.) are very limited. The present paper summarizes and analyses the available data on thermophysical properties of some perspective organic PCMs.

2. n-Alkanes and their compositions

2.1. Pure alkanes

Thermodynamic properties of pure normal alkanes have been the subject of many investigations. These properties are necessary for developing phase diagrams with alkanes that allow preparing blends and compositions in the required range of temperatures with high heat of fusion. The pure alkanes and their compositions are very attractive for using as phase change thermal energy materials. Himran et al. (1994) for the first time systematized the data on some thermophysical properties of pure alkanes and paraffin waxes for application as latent heat storage materials. However the generalized data has not been supplied by the used references. Several years later Dirand with his colleagues (2002) summarized the temperatures and enthalpies of (solid + solid) and (solid + liquid) transitions of more than 60 pure normal alkanes as well as their