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Review of current state of research on energy storage, toxicity, health hazards and commercialization of phase changing materials

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ABSTRACT

Phase change materials (PCM) are widely used for energy storage applications worldwide. The objective of the study is to review the current state of research on PCM materials, energy storage, environmental aspects and identifying potential research areas which needs focus to make this technology widely marketable and economically promising. The paper presents PCM research status, material properties, microencapsulation, shape stabilization techniques, commercial applications and environmental issues and also covers areas which have not been given much attention in previous studies like toxicity, health hazards, fire retardation techniques and current market scenario. The study shows that salt hydrates are safe if carefully handled and commercial grade paraffins being flammable, release toxic vapors thus are potential health hazard so need to be used carefully. Further research on fire retardation of PCM is found lacking in literature. Critical issues to ensure long term performance, are discussed which will help researchers to identify appropriate PCM for different commercial applications. New innovative PCM materials are identified although these are not used in real applications as yet. The commercial potential of PCM products is presented which shows that these materials have promising solutions for textiles, heat or cold storage during transits, pain relief packs, vaccine and blood storage where maintenance of a critical temperature is important. These materials could significantly cut down the air conditioning demands in future provided the current challenges are met. With increased awareness and stricter environmental regulations in future, PCM market potential is expected to rise.

Contents

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1. Introduction

Phase change materials (PCM) absorb large amount of heat thus increasing the internal molecular energy at a nearly constant temperature and release heat during phase transition. This characteristic makes these materials attractive for thermal and solar energy storage applications. Phase transitions could be solid-liquid, liquid-gas or solid-gas but PCMs with solid-liquid phase transitions are most widely used since they offer wide range of temperatures suitable for large range of applications, high storage capacities and limited volume changes during the phase transition. The PCMx with liquid-gas transition also a have high energy storage capacity but large volume changes limit their use [1]. Solid-solid PCMs store energy due to change in the crystalline state of the material and are particularly attractive as they do not require any containment. However, their storage capacity is far lower than other two types of phase transitions [2–4]. Most commonly used phase change materials include paraffin wax, salt hydrates, fatty acids and eutectics.

The objective of the study is to review the current research on energy storage, environmental aspects, health hazards and applications of phase changing materials along with identifying materials which are non-toxic and environmentally safe, This paper presents current research status of PCM technologies by a detailed literature review on encapsulation, shape stabilization, fire retardation techniques, toxicity, health hazards and environmental issues associated with the use of PCMs. The motive is to identify research gaps which need future research effort to make this technology more economically promising. The problems are described with respect to their potential in building application since market research suggests that this is one area in which this technology is yet not very successful and the applications are restricted to few flagship projects. Some retrofit wallboards and panels are however available in the market and are used.

The paper is organized as follows: Section 2 highlights the properties of the PCM and various concerns like toxicity, health hazards and possible impact on the environment. Section 3 provides an overview of different encapsulation techniques. Section 4 presents a detailed literature review on microencapsulation, shape stabilization techniques, container requirements and state of research on fire retardation of PCM along with discussing unsolved problems and major findings. This is followed by a market survey of PCM to analyze the current market scenario.

2. Phase changing material-basics and properties

2.1. Energy storage techniques

2.1.1. Sensible heat storage

Sensible heat storage is in the form of rise in the temperature of PCM which is a function of the specific heat capacity and mass of the material. The materials generally used are water, pebbles, rocks, concrete and sand etc. They have low energy density and require large volume for storage which considerably increase the unit size and therefore preferred for small applications where economics is a major concern.

2.1.2. Latent heat storage

This form of energy storage is based on the phase change enthalpy of the material without any change in temperature. The material may undergo solid-liquid, liquid-gas or solid-gas phase transitions. Latent heat storage technique is attractive over sensible heat storage methods due to its higher energy storage capacity per unit volume and nearly constant temperature during the heat storage. Further these are available in wide range of temperatures to suit different applications. The present work is focused on solid-liquid phase change materials as these are widely used for various applications like air conditioning, cold-chains, solar cookers, packaging, vaccinations etc.

2.1.3. PCMs as attractive latent heat storage materials

In order to use PCM as heat storage material, it should have melting temperature lying within the range of mean temperature of the system, high latent heat capacity, compatibility with the container, lower volume changes, stability of properties with the melt freeze cycles, non-toxic, environmentally safe, non- inflammable, cost effective and easily available. The essential properties for a material to be used as PCM are summarized in Table 1.

2.1.4. Storage through chemical means

This form of energy storage is due to the energy associated with the molecules bonded to each other. Energy is released when the bonds break or new bonds are formed. It is dependent on the type of reaction, the materials involved and extent of the reaction.

2.2. Classification of PCM materials - their toxicity health hazards and environmental effects

PCMs are broadly classified as organic, inorganic and the eutectic.

2.2.1. Organic PCMs

These include paraffins which are open chain saturated alkanes, fatty acids and vegetable oils. They have high latent heat capacity, are non-reactive, do not undergo phase segregation and super cooling with melt freeze cycles and have good nucleation property. They however suffer from low thermal conductivities and are flammable in nature. Because of this, salt hydrates are preferred over them in spite of the problems with phase segregation and poor nucleation associated with them.