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Worldwide trends on encapsulation of phase change materials: A bibliometric analysis (1990–2015)

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HIGHLIGHTS

- 1034 papers with the keyword "encapsulation" were determined from 1990 to 2015.
- Article type comes into prominence as dominant species in terms of type of publication.
- China and United States is the most productive countries.
- Ahmet Sarı is the most productive author considering the average citations per article.
- Over 91.89% of the publications were published in English.

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ABSTRACT

Context: Science is not static! In light of this basic approach, it can be expressed clearly that bibliometric methods or analysis has become an indispensable guide to be draw scientific and technological roadmaps in their research areas for researchers especially in recent years. The present study is planned as the first step of the study which will be conducted by authors on nano-encapsulation of phase change materials.
Objective: This study combines a traditional literature review with data mining procedures by using bibliometric approach to identify the evolution of the knowledge structure related to encapsulation of phase change materials. Papers published from 1990 to 2015 in all journals indexed by the Scopus database were considered.
Method: Bibliometric methods and knowledge visualization technologies were employed to investigate publication activities based on the following indicators: year of publication, document type, language, country, institution, author, journal, keyword, number of citations.
Results: As a result of bibliometric analysis; 34,626 papers were determined with the keyword "phase change material" and 1034 papers with the keyword "encapsulation". The number of publications on encapsulation of phase change materials have increased significantly after 2000. China, the United States and India are the most productive countries, while Tsinghua University and South China University of Technology from China are the most important institutions related to encapsulation. Applied Energy (39) is the most productive journal followed by Energy Conversation and Management (31).
Conclusion: This is the first bibliometric analysis study on encapsulation of phase change materials. The results of this research support the idea that this type of bibliometric analysis would be a fruitful area as a first step for further works, not only associated with phase change materials. Further investigations into research fields are strongly recommended.

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1. Introduction

The main issue that drew attention by the energy statistic reports regularly published every year by different institutions in worldwide is the increasing demand for more energy day by day. Population growth is the key driving factor behind growing demand for energy. The world's energy demand will reach 17–18 billion tonne oil equivalents (t.o.e.) according to reports published by International Energy Agency (IEA) [1]. Besides, the inability of the amount of production to meet this demand, increase in carbon emission values resulting from fossil fuels and ever increasing financial crisis and political instabilities push countries to develop new energy policies. At this point, renewable energy technologies and energy efficiency have become prominent topics in recent years. Renewables are projected to be the fastest growing power source (approximately 6%) to 2035 [2], and it is expected that efficiency measures reduce demand growth to 60% in OECD countries [3]. The world needs a revolution in which energy is affordable, accessible and sustainable. Energy efficiency and conservation constitute an undeniable step in this revolution [4]. Therefore, the storage and efficient usage of energy has become priority for researchers and energy industry especially in order to overcome the imbalance between energy supply and demand. Fig. 1 presents a summary of various energy storage technologies and their development stages.

Although different type of energy can be stored (mechanical, electrical, thermal etc), only thermal energy storage (TES) will be discussed in this study. TES is described by Dincer and Rosen [6], as"... an advanced energy technology that is attracting increasing interest for thermal applications such as space and water heating, cooling, and air conditioning". Three types of TES methods can be mentioned; (i) sensible heat storage process occurs a change of temperature. It is the simplest and common form of storing thermal energy, (ii) latent heat storage is a low cost method for thermal energy storage. It is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa, (iii) thermochemical heat storage is a relatively new and promising alternative to traditional sensible heat storage methods. However, requirement of efficient chemical reaction is one the limitations. In the present study, it was focused on latent heat storage materials (also known as phase-change materials (PCM).

2. Phase change material (PCM)

PCM is a promising unique material which allows for the storage/release of thermal energy as latent heat form at almost constant temperature. The latent heat transfers during the phase change process, for example; from solid to liquid, liquid to solid. PCM can absorb large amount of thermal energy from the environment when it melts, conversely, it releases an equal amount of energy when it freezes. Therefore, PCM is an ideal solution for thermal management due to this property. The best example that can be given to PCM is water/ice. Ice stores a large quantity of heat and maintain temperature at 0 °C when it melts. However, the solidification temperature of water is fixed at 0 °C, which makes it unsuitable for most thermal energy storage applications. To overcome this unwanted situation, various PCMs having a broad range of phase change temperature have been developed by producers. Generally, PCMs can be classified in three main categories; organic and inorganic materials, and eutectic mixtures. Among many available organic PCM, paraffin wax (characterized by C_nH_{2n+2}) is the most preferred one due to better chemical stability, low cost, high thermal energy storage capacity, 200–250 kJ/kg depending on the particular paraffin selected, and repeatable melt/solidify cycles without degradation [7]. However, they have undesirable properties apart from favourable characteristics such as: low thermal conductivity, flammability, large volumetric change. Contrary to organic materials, inorganic PCMs have much higher latent heat per unit volume, higher conductivity, and non-flammable. Although PCMs have many advantages compared with sensible heat storage material, there is still need for research to overcome some shortcomings such as; incongruent melting, supercooling and low thermal conductivity. Researchers have focused on two main subjects to solve these problems; (i) discovering more kinds of PCMs have a wide range of transition temperature, (ii) enhancing heat transfer to promote melting and solidification. Some of the research in the literature especially conducted to increase heat transfer performance of PCMs were discussed in the following section.

2.1. Heat transfer enhancement techniques

Enhancement of heat transfer characteristics of PCM is one of the most attractive topics for researchers in recent years. This is a critical step for thermal energy storage applications, because the low thermal conductivity is the most important barrier to high storage capacity of PCM. There is a large volume of published studies describing the role of various methods as heat transfer enhancement (Table 1).

3. Encapsulation of PCM

3.1. Material selection/type of materials

Micro or nano encapsulation is the process by which individual particles or droplets of solids or liquid materials (the core) are surrounded or coated with a continuous film of polymeric materials