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

Alptug Yataganbaba [a], Bengi Ozkahraman [b], Irfan Kurtbas [a,*]

[a] Hitit University, Faculty of Engineering, Department of Mechanical Engineering, North Campus, Corum 19030, Turkey
[b] Hitit University, Faculty of Engineering, Department of Polymer Engineering, North Campus, Corum 19030, Turkey

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.

Contents

* Corresponding author.
E-mail address: ikurtbas@gmail.com (I. Kurtbas).

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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

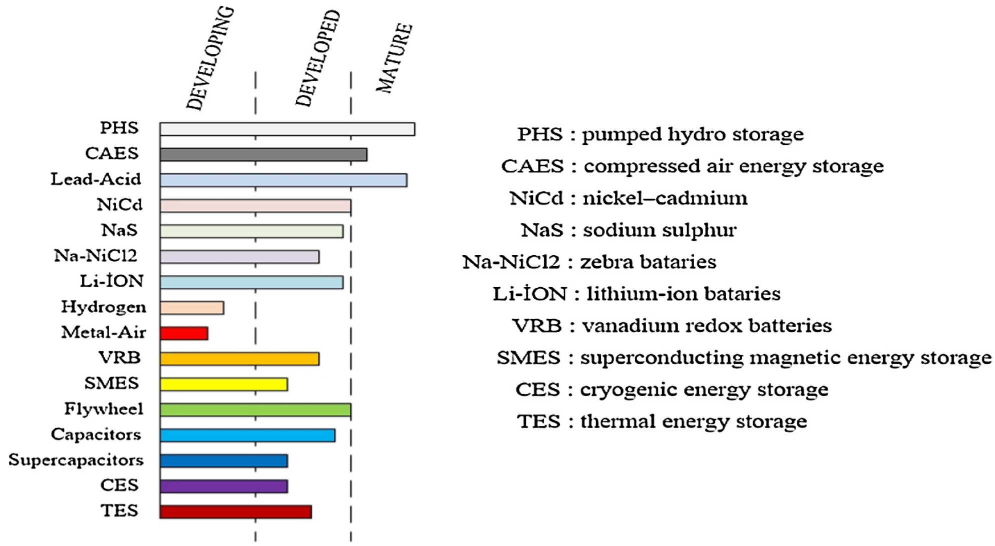


Fig. 1. Energy storage technologies and their development stages [5].

Table 1
Summary of important studies as heat transfer enhancement method on PCM.

Authors	PCM Materials and properties	Type of enhancement method	Type of study	Observations
Fang et al. [8]	T_m = 393 K, k = 0.326 W/mK L = 339.8 kJ/kg	Internal aluminium(Al) and copper (Cu) fins k(Al) = 202.4 and k(Cu) = 387.6 W/mK	Numerical	Small fin-ratio can reduce melting time, the angle between neighbour fins has little and the outer tube conductivity has great impact on melting process
Sharifi et al. [9]	Paraffin (octadecane) T_m = 303 K, k = 0.2 W/mK L = 125 kJ/kg	Internal copper fins, k(Cu) = 401 W/mK	Numerical	Rapid melting occurs during the early stages of the phase change with horizontal fins
Yang et al. [10]	Paraffin wax, T_m = 321–323 K k(s) = 0.3 W/mK, L = 136 kJ/kg	Copper foam (20PPI) and a bottom fin	Experimental	Completely melting the PCM in composite takes over 1/3 less time than that of pure paraffin under the same operating conditions
Yataganbaba and Kurtbas [11]	Paraffin (n-heptacosane) T_m = 332–334 K k = 0.21 W/mK, L = 236 kJ/kg	10PPI, 20PPI aluminium foams	Experimental	The effect of metal foam on the solid/liquid phase change heat transfer is significant, particularly for the top-heating case
Şahan et al. [12]	Paraffin, T_m = 319–321 K k = 0.21 W/mK	Paraffin–nanomagnetite (Fe_3O_4) composites	Experimental	The addition of Fe_3O_4 nanoparticles is an efficient and cost effective method to enhance the heat transfer properties of paraffin
Sarı et al. [13]	Paraffin (n-octacosane)	Polymethylmethacrylate (PMMA) microcapsules	Experimental	Microcapsules have good thermal reliability and have good energy storage potential
Karaipekli [14]	Stearic palmitic acid T_m = 340–343 K	Expanded graphite (particle size of 35–75 µm) and carbon fiber (filament diameter of 6 µm)	Experimental	The melting times of composite PCMs were reduced significantly with respect to that of pure stearic acid
Ji et al. [15]	Palmitic acid	Carbon nanotube(diameter range 20–40 nm and length of 10–15 mm)	Experimental	The thermal conductivity of the composite is significantly enhanced
Mills et al. [16]	Paraffin	Porous graphite matrices	Experimental	Using the PCM-composite as a passive thermal management system for a lithium ion battery pack discharged at high rates

(the shell). There are considered as potential materials reported that as core materials such n-eicosane [17,18], n-octadecane [13,19–25], n-dodeconal [26,45], paraffin wax [27,28], n-tetracosane [29]. In addition, the polymers can be used as shell materials poly(styrene) [21,30,31], poly(methyl methacrylate) [32–35], poly(melamine formaldehyde) [21–23,36], poly(n-butyl methacrylate) [37,38], poly(ethylacrylate) [39,40]. Table 2 summarizes the core-shall materials and the particle size based on publications for the year of 1990–2015.

3.2. Classification of encapsulation methods

Encapsulation is one of the techniques used for enhancing the holding the liquid/solid phase and stability developed in 1940s and 1950s. It is defined as an advanced technology of PCMs with smart building materials [24], spacecraft thermal systems, medical application, food agroindustry, thermal protection of electronic devices, thermal comfort vehicles, fabrics, insulation panel [49–53] by which small droplets of liquid or solid particles are coated with a shell. The technologies of several kinds of microencapsulated PCMs, interfacial polymerization, emulsion polymerization, miniemulsion polymerization, in situ polymerization, sol-gel methods, and complex coacervation method are discussed in this review. Nano-micro encapsulation of polymerization methods and applications are also shown in Table 2.

3.2.1. Interfacial polymerization

Interfacial polymerization technique has been widely studied since it was first reported by Morgan [49] in 1965. In Interfacial polymerization technique, the two reactants in a polycondensation meet at an interface and react rapidly. The methods of interfacial polymerization two monomer is reacted at the interface between

Table 2
Summary of major parameters for encapsulation methods of PCM.

Authors	Polymerization method	Size		Core/Shell materials	Applications
		Type	Distribution		
Fang et al. [20]	Miniemulsion in-situ polymerization	Nano	100–123 nm	n-octadecane/St/butyl acrylate	Synthesis and characterization
Zhang et al. [21]	In-situ polymerization	Nano/micro	200–340 nm	Melamine-formaldehyde/n-octadecane	Fabrication
Fan et al. [22]	In-situ polymerization	Micro	100 nm	Melamine-formaldehyde/n-octadecane	Synthesis and characterization
Lee et al. [24]	In-situ polymerization	Micro	5000–20,000 nm	Melamine-resin/hexadecane or n-octadecane	PCM building materials
Chen et al. [26]	Miniemulsion polymerization	Nano	150 nm	Poly(methylmethacrylate)/n-dodecanol	Great potential for energy storage
Silva et al. [27]	Suspension-like homopolymerization	Nano/micro	500 μm	Polyvinylpyrrolidone/paraffin wax	Textile applications
Sarı et al. [30]	Miniemulsion polymerization	Nano/micro	1–15 μm -1–12 μm -1–20 μm	Poly(styrene)/n-heptadecane	Temperature regulating applications in textile, building, food storage, medical and electronic fields
Sarı et al. [31]	Emulsion polymerization	Nano/micro	0.01–35 μm	Poly(methyl methacrylate)/n-nonadecane	Solar thermal controlling of building envelopes thermal protecting of vehicle battery systems, and thermal regulating applications
Sarı et al. [32]	Emulsion polymerization	Nano/micro	1.3 μm	Polymethylmethacrylate(PMMA)/capric–stearic eutectic	Used to fabricate new building components
Qiu et al. [37]	Suspension polymerization	Micro		Poly(butyl methacrylate-co-methacrylic acid)/n-alkane-n-octadecane	Good potentials for thermal energy storage, such as building materials
Qiu et al. [38]	Suspension polymerization	Micro	1.45–0.43 μm	Poly(methylmethacrylate)/n-octadecane	Show a good potential as a solar-energy storage material
Sarı et al. [13]	Emulsion polymerization	Micro	0.25 μm	Poly(methylmethacrylate-allymethacrylate)/n-octacosane	Good energy storage potential
Sarı et al. [41]	Emulsion polymerization	Micro	0.14–0.40 μm	Poly(methylmethacrylate)/n-heptadecane	The development and applications of such type micro PCMs may provide to widespread use of the PCMs
Liang et al. [42]	Interfacial polycondensation	Micro	20–35 μm	Butyl stearate/ethylenediamine-toluene2,4-diisocyanate	Packing rate of micro PCMs is good
Konuklu et al. [43]	Suspension polymerization	Micro	200 nm-1.5 μm	Urea-melamine formaldehyde resin/caprylic acid	Thermal energy storage
Jamekhorshid et al. [44]	Suspension polymerization	Micro	100–300 μm	Poly(styrene)/paraffin wax	Thermal energy storage
Xia et al. [45]	Mini-emulsion polymerizations	Nano	605 nm	Cypermethrin	–
Qiu et al. [46]	Suspension polymerizations	Micro	4–15 μm	Poly(butylmethacrylate)/n-octadecane	Excellent thermal stabilities and great thermal reliabilities
Giro-Paloma et al. [47]	Suspension polymerizations	Micro	4–15 μm	Poly(methylmethacrylate)/paraffin wax	Building applications
Al-Shannaq et al. [48]	Suspension polymerization	Micro	5 μm	Poly(methyl methacrylate)/RUBITHERM®	Thermal storage properties

the monomers at two liquid phases. The interfacial polymerization processes that specific point is facilitated the addition of different surfactant agents, either positively or negatively charged and also to hydrophilic surfactant agents in the aqueous phase. The methods of the interfacial polymerization, microcapsule coating of the polymeric products is composed from two monomers in distinct phases (organic phase and an aqueous phase) that monomer in the interface of both phases, during of microencapsulation. The interfacial technique has several advantages which high-molecular-weight polymers are obtained by the process. It is more stable than the possibility for high temperature polymers synthesized at lower temperatures [50–55].

3.2.2. Emulsion polymerization method

Emulsion polymerization is the most largely used methods for micro/nanoparticle preparation. Emulsion polymerization is a type of free-radical polymerization. The polymerization systems usually contains hydrophobic monomers, surfactants and a water-soluble radical initiator. The monomers are emulsified in water of the emulsion large size droplets that stabilized by the surfactant. There are also surfactants dissolving in the water and excessing surfactant present in micelles. As polymerization continues, monomer is added to the growing micelles. This polymerization is a chain reaction initiated by the decomposition of an initiator molecule. About 50–80% conversion monomer droplets disappear and the micelles become large polymer-containing droplets the particle growth stage ends. The final product is a water-based system with a low viscosity polymer latex. The emulsion polymerization has more advantages in comparison to solution polymerization. First of all, much higher molecular weight polymers can be synthesis. High solid content (50% or higher) polymers can be produced with emulsion polymerization. Another advantage is that the polymer has low viscosity, thus allowing fast air drying by evaporation of water [27,32,33,55–61].

3.2.3. Mini-emulsion polymerization method

Mini-emulsion polymerization is a convenient one step encapsulation technique for preparing microcapsules since 1980. It was assumed that the polymerization mechanism of emulsion polymerization of hydrophobic monomers. The water-in-oil (w/o) or oil-in-water (o/w) mini-emulsion droplets are involved for the high conversion and the shape properties of microlatex particles. In the beginning phases of mini-emulsion polymerization, the polydispersity of the droplets is still quite high, but the size and polydispersity decrease until the mini-emulsion determined stability. The main ingredients of mini-emulsion polymerization monomer, surfactant, co-stabilizer and initiator. Mini-emulsion polymerization technique was used only a small amount of surfactant and a feature of surfactant residual in the polymer latex. Recently, many useful polymeric materials have been improved by the mini-emulsion polymerization [20,26,30,55–61].

3.2.4. In situ polymerization method

In situ polymerization have been one of the chemical microencapsulation technics, became in oil-in-water (o/w) polymer mixture. The products have fine smooth morphology and spherical microcapsules with transparent polymeric pressure or temperature sensitive microcapsule films. Based on the microencapsulation processes synthesized from amine and aldehyde groups of monomers which it was called precondensates. The condensation products are hydrophilic which are prone to interact strongly with water molecules. These obstacles can be overcome by reacting the hydroxymethyl groups with lower alcohols to form alkoxymethyl compounds. In the in situ polymerization methods, first of all a core material is prepared and then the reaction of the prepolymers. The prepolymer is drop wised in the emulsion in which it is precipitated during the polymerization. The reaction mixture is cooled down and filtered, obtaining the microcapsules, which have to be dried [21–24,55–59].

3.2.5. Sol-gel method

The sol-gel polymerization methods have been the polycondensation reactions which the colloidal suspension (sol) is precursors and sol particles condense into a continuous liquid phase (gel). The sol-gel process is a room temperature technique for synthesizing porous materials. The methods can be generally three stages are used to describe the sol-gel process. The first stage is the hydrolysis reaction and polycondensation reactions of alcohol is gelation of colloidal particles in second stage, the last stage is polymerization drying process at room temperatures. The sol-gel process has many advantages such as better mixing of the starting materials and perfect chemical properties in the polymeric materials [60–63].

3.2.6. Complex coacervation method

Coacervation method is a one of the microencapsulation method that is defined as the separation into two liquid phases in colloidal systems. This technic is divided into two categories: simple coacervation method and complex coacervation methods. Simple coacervation technics usually interests only with one colloid solute and includes the addition of a strongly hydrophilic compound to a less hydrophilic colloidal dispersion. It generates two layers: one rich in colloid droplets, and the other deficient in such droplets. On the other hand, complex coacervation involves more than one colloid and caused by the interaction of two oppositely charged colloids between a poly-anion and a poly-cation, both water-soluble. The complex coacervation methods were significantly affected by the pH of the solution, since pH determines the charge density on ampholytes. [64–67,57].

4. Bibliometric literature analysis

This paper attempts to find worldwide trends on encapsulation of phase change material in scientific studies. Data for this purpose were retrospectively collected from Scopus database. Published studies were identified using a search strategy to shed light on trends. According to practical viewpoint, this paper does not provide a comprehensive review of PCM or encapsulation. However, there are several important points where this study makes an original contribution to researchers who study in thermal energy storage field. There are two primary aims for authors of this study: 1. To determine the trends dominating the related research in the field of heat transfer enhancement methods of PCMs, especially nano-encapsulation. 2. To perform a new experimental study which aims to increase heat transfer performance of PCM with using encapsulation method in the light of obtained data. The following titles constitute the backbone of the bibliometric analysis; number of publications, type of publications, leading journals, authors, institutions, and countries, etc.

Pritchard [68] defined firstly the term bibliometrics in 1969 as ‘‘the application of mathematical and statistical methods to books and other media of communication”. In addition to explanation of Pritchard, it comprises components from social sciences, natural sciences, engineering and even life sciences. Therefore, bibliometrics has become an interdisciplinary research field from that day to this. Especially, the past ten years have seen increasingly rapid advances in the field of bibliometrics [69–74].

The researcher should bear in mind that there are a number of limitations associated with bibliometric analysis [75,76];

- Direct comparison cannot be made between citations because of they can differ greatly between disciplines.
- Bibliometric analysis cannot be seen a complete response of quality measurement. For instance, the number of times research is cited does not automatically mean that a paper is of high quality. Citation counts only measure the impact, or usefulness.
- The bibliometric databases do not cover all research areas and do not index all publications. So, time is needed before a meaningful citation analysis.
- There is an incontrovertible tendency that English is the language of science. Therefore, many database do not cover publications published in different languages.
- Database consist of some risks for separating the data in a reliable way (researchers who share the same surname and initials, meaning that citation counts may be inflated).

The bibliometric research is still one of the methods to understand the research trends to the contrary of the limitations and mistakes associated with indicators since each method balances the weaknesses of the other [77–79].

The initial step of the bibliometric literature analysis, we adopted Scopus database as the data source of this study. Scopus web site [80] claims ‘‘...the largest abstract and citation database of peer-reviewed literature: scientific journals (more than 60 million), books (more than 113.000) and conference proceedings (7.2 million)”. Publications on ‘phase change material and encapsulation’ were searched for and retrieved from this database with great care. Bibliometric literature analysis was carried out by using some indicators, such as descriptive (year of publication, subject categories, journal counts), relational (collaborations among authors, countries, institutions) and qualitative (citations, impact factors) whose title included the following main keyword: ‘‘phase change material”, sub-keywords ‘‘encapsulation, nano-encapsulation, miniemulsion polymerization”. Publications containing these keywords in title, abstract, keywords were retrieved for further analysis. Research areas were further refined by excluding ‘‘Engineering, Chemical Engineering, Chemistry, Energy”. The data were retrieved in May 2016 including a time span from 1990 to 2015.

The search strategy involved the following search query:

TITLE-ABS KEY(phase change material) AND SUBJAREA (mult OR ceng OR CHEM OR comp OR eart OR ener OR engi OR envi OR mate OR math OR phys) AND PUBYEAR > 1989 AND PUBYEAR < 2016 AND (LIMIT-TO(SUBJAREA,‘‘ENGI”) OR LIMIT-TO(SUB JAREA,‘‘CHEM”) OR LIMIT-TO (SUBJAREA,‘‘CENG”) OR LIMIT-TO (SUBJAREA, ‘‘ENER”).

After the retrieving process of raw data (RIS Format), some general procedures were applied to eliminate some duplicates by using BibExcel software [81] before carrying out any analysis. BibExcel software was developed by Professor Olle Persson at Umeå University, Sweden. It is a great tool for helping with bibliometric analysis, and citation studies in particular. Pajek and Vosviewer softwares [82,83] were used in the social network analysis for the visualization of networks.

5. Worldwide trends

Fig. 2 shows the variations in scientific production between 1990 and 2015. As can be observed, the number of publications by year has gone increasing. Therefore, relevant topics have attracted an increasing interest in the scientific community. As a result of search from Scopus database with using "phase change material" keyword, it is observed that 34,626 publications on

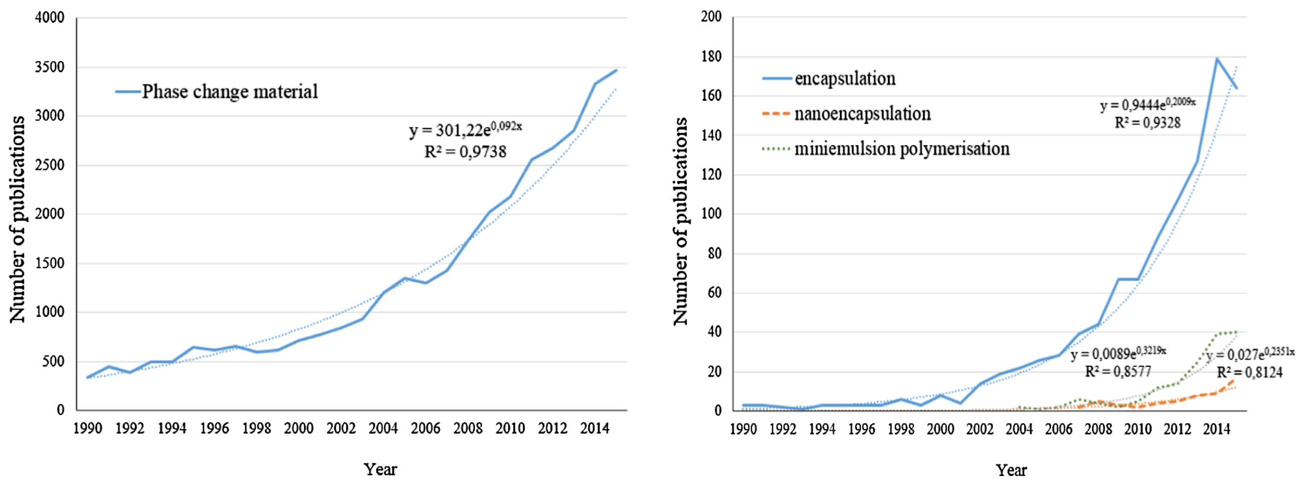


Fig. 2. Number of publications per year between the period 1990–2015.

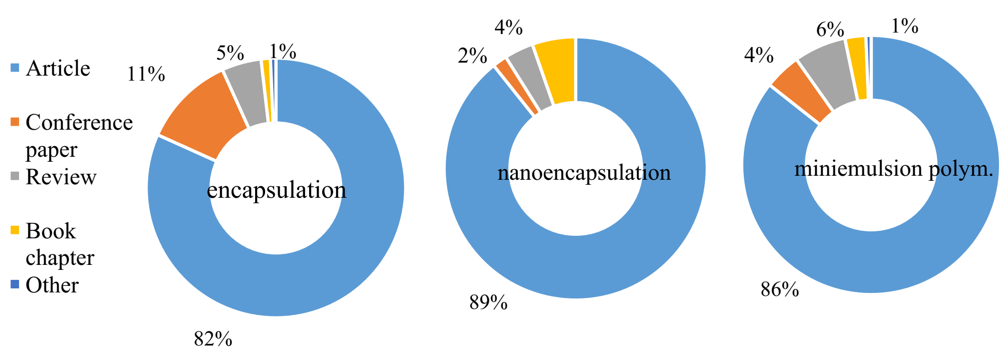


Fig. 3. Most common document types.

Table 3
Breakdown of scientific production by country.

Country	Number of publications: Encapsulation	Nanoencapsulation	Miniemulsion polymerization	% of total (encp.)	TC* (encp.)	h-index (encp.) (R)
China	370	25	83	38.06	5898	42 (1)
United States	253	8	20	26.03	5557	33 (2)
India	65	5	4	6.68	2824	20 (4)
United Kingdom	58	3	5	5.97	1463	22 (3)
Germany	47	1	9	4.84	1001	16 (6)
Japan	45	3	3	4.63	897	14 (8)
Turkey	39	5	8	4.01	2102	18 (5)
South Korea	35	5	7	3.60	771	15 (7)
Spain	33	4	4	3.39	1637	18 (5)
France	27	1	3	2.78	580	14 (8)
Total	972	60	146	100	22,730	

TC = Total number of citations (2000–2015).
R = Rank.
Encp = Encapsulation.
Note: % (Percentage) refers to the ratio of one country's publications to total number of encapsulation publications.

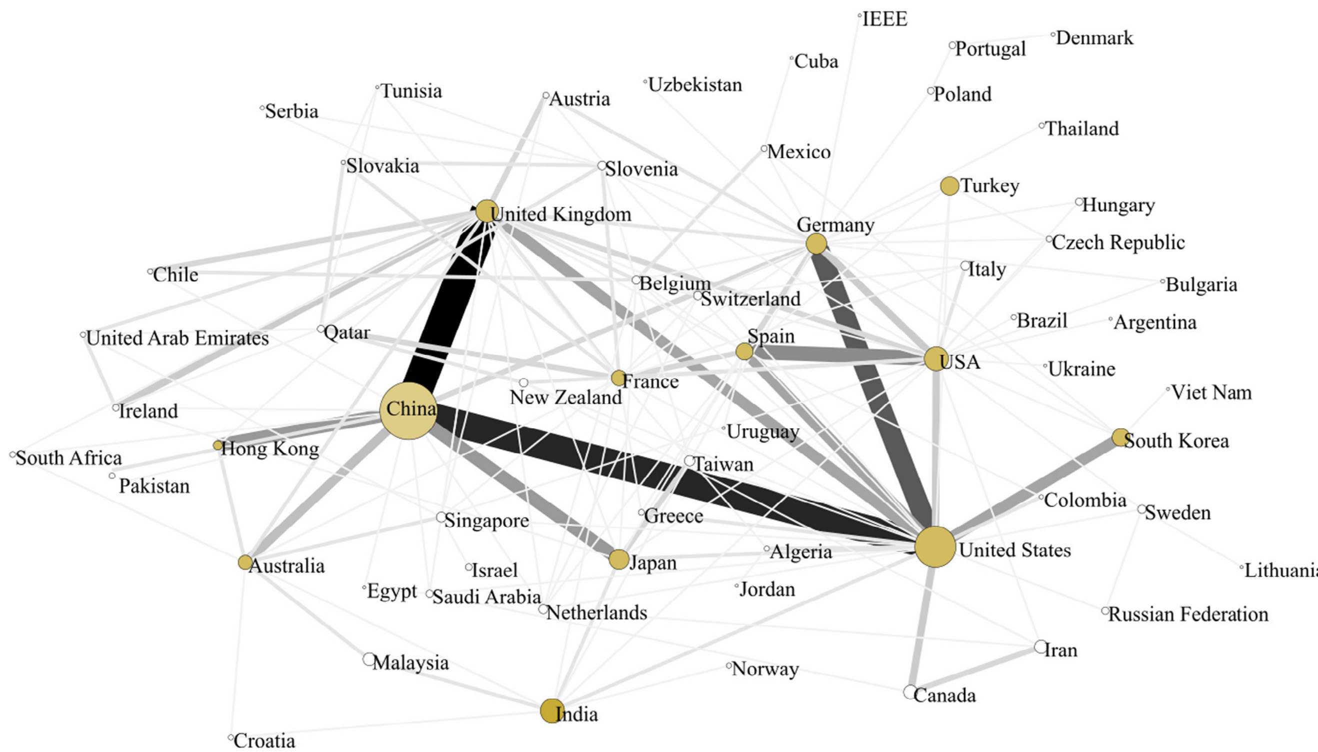


Fig. 4. Collaboration network between countries for encapsulation.

Table 4
Authors with the highest rate of productivity.

Authors	Number of publications: Encapsulation	Nanoencapsulation	Miniemulsion polymerization	TC* (encp.)	C/A** (encp.)	h-index (encp.)
Xiaodong Wang (China)	30	1	7	155	5.16	6
Yinping Zhang (China)	23	2	10	254	11.04	3
Ahmet Sarı (Turkey)	21	1	4	1449	69	13
Wei Li (China)	20	2	9	295	14.75	8
Guoyi Tang (China)	18	2	8	433	24.05	10
Xü Liu (China)	16	1	2	124	7.75	5
Shuangfeng Wang (China)	16	1	3	–	–	–
Cemil Alkan (Turkey)	16	1	4	842	52.62	10
Zhengguo Zhang (China)	15	4	10	128	8.53	4
Jianhua Wang (China)	15	4	11	–	–	–
Guolin Song (China)	13	1	5	342	26.30	9
J.Francisco Rodriguez (Spain)	13	1	1	603	46.38	11
Xuenong Gao (China)	4	5	8	36	8.5	2
Yutang Fang (China)	5	4	6	151	30.2	4
M.S. Karthikeyan (India)	3	3	1	7	2.33	2

TC = the total number of citations.
C/A = the average citations per article.

phase change material were published in the field of Engineering, Energy, Chemistry and Chemical Engineering. Publication production increased very fast after the year 2000. R&D activities have been considered one of the most dominant factor for evaluating the increment. The number of publications related to phase change material grew by 108.82% between 1990 and 2000, and by 207.04% from 2000 to 2010, and 58.94% from 2010 to 2015, respectively. A new search was performed to obtain more specific results within the phase change material publications (34,626) in the literature. 1034 publications for "encapsulation" keyword, 56 publications for "nanoencapsulation" keyword and 153 publications for "miniemulsion polymerization" keyword were determined. Fig. 2. also represents the exponential increase, giving an idea of the

Table 5
The most frequently used words in paper titles.

Word	Frequency	Word	Frequency
Phase	437	Microencapsulated	107
Change	413	Characterization	94
Thermal	351	Microcapsules	68
Materials	272	Composite	63
Storage	255	Synthesis	63
Energy	215	pcm	55
Material	167	System	52
Properties	138	Containing	52
Preparation	127	Encapsulated	50
Heat	125	Paraffin	50

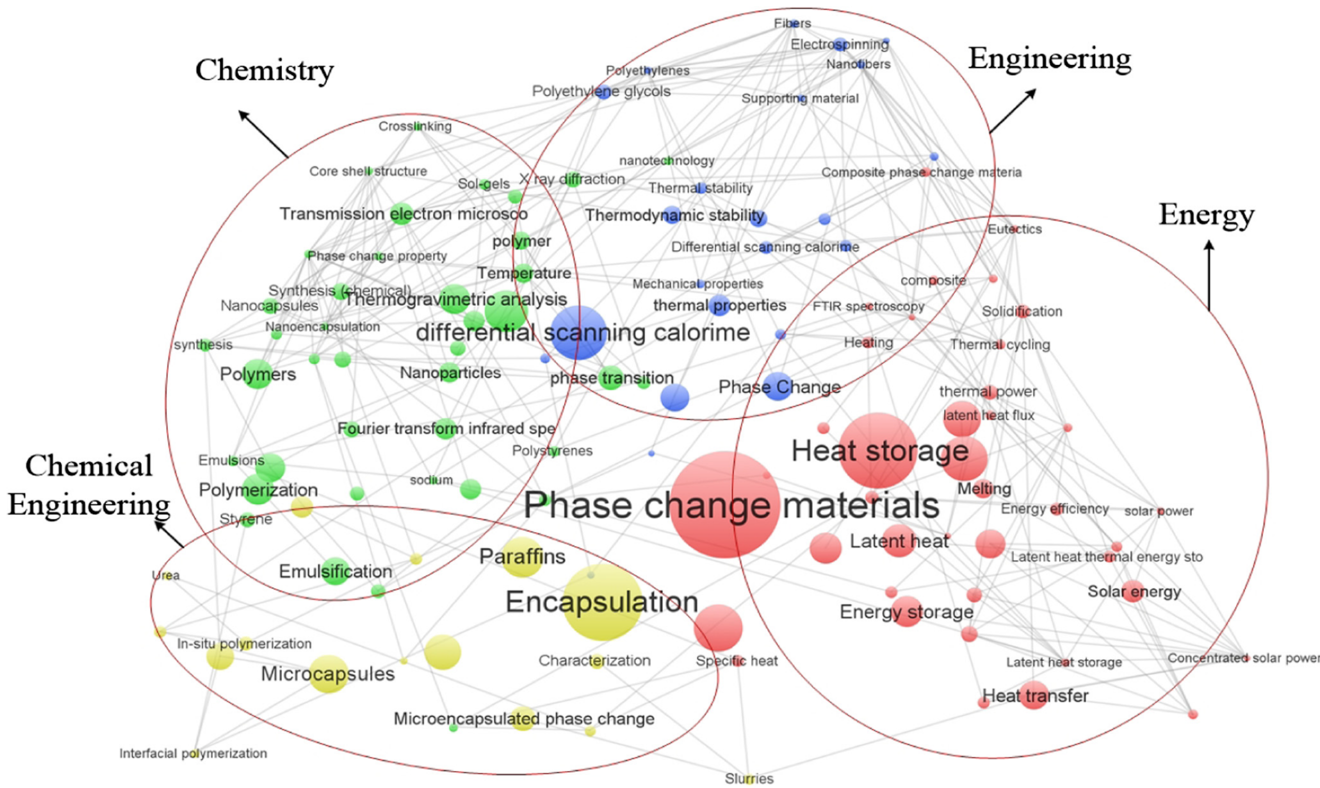


Fig. 5. Keyword map for encapsulation.

growth rate. x represents the year, and y represents the number of publications. The relationship between x and y was found to be $y = 301.22e^{0.092x}$ ($R^2 = 0.9738$) for phase change material, $y = 0.944e^{0.2009x}$ ($R^2 = 0.9328$) for encapsulation, $y = 0.0089e^{0.3219x}$ ($R^2 = 0.8577$) for nanoencapsulation, and $y = 0.027e^{0.2351x}$ ($R^2 = 0.8124$) for miniemulsion polymerization.

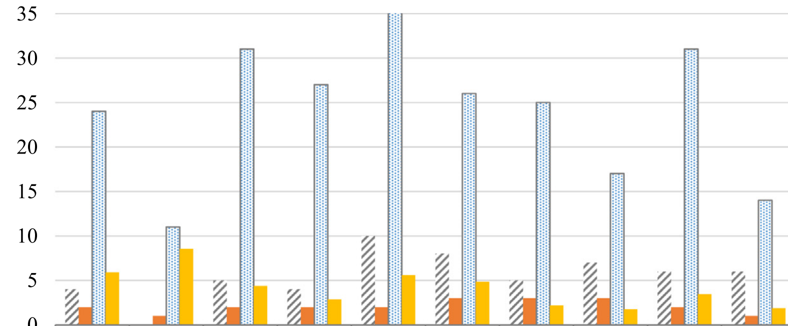
One of the important factors to be considered in the bibliometric study carried out for scientific publications is the type of publication. It is known that assessment made by the type of publications both in academic advancement and publication incentives in many countries. Fig. 3 shows that the article is the most frequently used type of research representing above 80% for all keywords. 845 articles with 'encapsulation', 50 articles with 'nan o-encapsulation', and 131 articles with 'miniemulsion polymerization' keyword were detected. Proceedings are the next most common publications with totally 127, reviews (totally 63 publications).

Table 3 shows the most prolific countries according to publications. China is first ranking with the 370 publications (38.06%) related to encapsulation with 972 total citations, 25 publications (41.66%) related to nano-encapsulation, and 83 (56.84%) publications related to miniemulsion polymerization between 1990 and 2015. The next most productive countries are United States and India, with 253 (5557 TC) and 65 publications (2824 TC), respectively. Despite Turkey produced fewer publications (39), the total number of received citations of these publications are 2102, more than many countries compared to number of publications. It shows that these publications are of a high quality. Besides, another indicator for publications to measure the quality of research depending on the number of citations received is h-index. The countries with the highest h-index are the China, United States, and United Kingdom. The collaboration between countries (62 nations) was visualized using Pajek as shown in Fig. 4. Each countries are presented as a node and the size of nodes is proportional to the total number of collaboration, the thickness demonstrates the strength of collaboration. China-United States collaborations ranked first, followed by China-United Kingdom and United States-Germany. The cooperation network between EU countries seems to be very dense. While the US acts like an EU country by building a cooperation network, China has become the most important partner of the US in terms of international cooperation network.

Authors who publish the most on the topic (encapsulation) are Xiaodong Wang, Yinping Zhang and Ahmet Sarı with 30, 23 and 21 publications, respectively (Table 4). However, the authors with most citations are Ahmet Sarı, Cemil Alkan and J.Francisco Rodriguez. It should be noted that these authors have coauthored with each other a large number of these papers. Especially, Ahmet Sarı is the most productive author considering the average citations per article with 69 point.

The top 20 words used in the paper titles are summarized in Table 5. During the time period between 1990 and 2015, the most frequently preferred word in publication titles is "phase" (437) and "change" (413) and "thermal" (351). In addition to most used word, the co-occurrence relationships among most frequently used keywords are also visualized (Fig. 5). Keyword analysis in research papers is very interesting in order to follow and search the trends in the science and engineering branches. Keyword analysis was carried out with author keywords in the field of encapsulation. As a result of our work, a total of 8883 different keywords were identified from 1990 to 2015 in the field of encapsulation. The Fig. 5 shows that four main clusters (denoted by the green[1], blue, yellow and red colours) are characterized by the most used keywords in the encapsulation area.

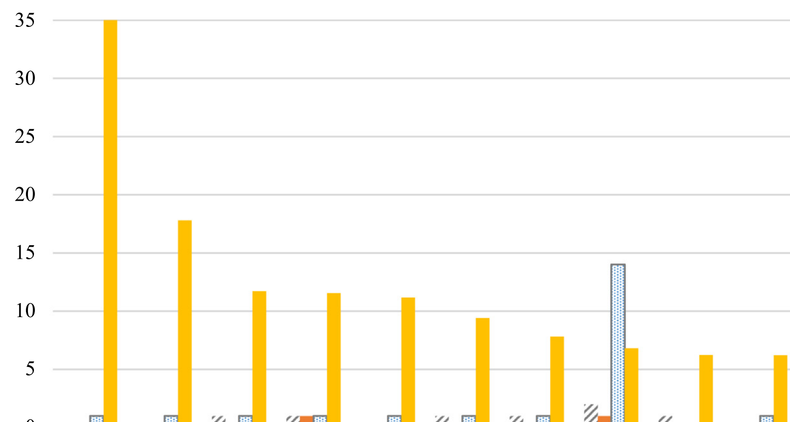
[1] For interpretation of color in Fig. 5, the reader is referred to the web version of this article.



	Renew Sustain Energy Rev	Biomaterials	Energy Convers. Manage.	Energy Build.	Appl. Energy	Energy	Thermochim Acta	J. Appl. Polym. Sci.	Sol Energ Mater Sol Cells	Colloid Polym Sci.
Miniemulsion polymerization	4	0	5	4	10	8	5	7	6	6
Nanoencapsulation	2	1	2	2	2	3	3	3	2	1
Encapsulation	24	11	31	27	39	26	25	17	31	14
Impact factor *	5.901	8.557	4.38	2.884	5.613	4.844	2.184	1.768	3.469	1.865

*2015 Journal Citation Reports® by Thomson Reuters

Fig. 6. The top 10 publishing journals (total publications).



	Chem Rev	Mater Today	Angew Chem	Nano Energy	Ann Rev Fluid Mech	Chem Mater	Adv Coll Interface Sci	Renew Sustain Energy Rev	Curr Opin Colloid Interface Sci	Polym Rev
Miniemulsion polymerization			1	1		1	1	2	1	
Nanoencapsulation				1				1		
Encapsulation	1	1	1	1	1	1	1	14		1
Impact factor *	37.369	17.793	11.709	11.553	11.163	9.407	7.813	6.798	6.234	6.216

*2015 Journal Citation Reports® by Thomson Reuters

Fig. 7. The top 10 publishing journals (reviews).

Fig. 6 presents the 10 most productive journals. There are also additional journal statistics that are not shown in Fig. 3. Three remarkable journals are: Applied Energy with 39 publications, Solar Energy Materials and Solar Cells with 31 publications, and Energy and Buildings with 27 publications for "encapsulation" keyword. Thermochemical Acta, Energy, and Journal of Applied Polymer Science are the leading journals with 3 publications for ' 'nanoencapsulation" keyword. Applied Energy is the journal which has by far the largest number of publications (10) on miniemulsion polymerization. According to the impact factor analysis for 2015, Biomaterials, Renewable and Sustainable Energy Reviews and Applied Energy is scored above 5. Over 91.89% of the publications were published in English, while only 6.86% were published in Chinese. The remainder consisted of publications written in Japanese, Slovene, and Turkish representing less than 1% each. Similarly, Fig. 7. presents the 10 most productive journals based on review type publications. Journals were taken into account which have impact factor above 6. Renewable and Sustainable Energy Reviews is the most preferred journal among others with 14 reviews for 'encapsulation' keyword and 2 reviews for 'miniemulsion polymerization' keyword. According to the impact factor value obtained from Journal Citation Reports® by Thomson Reuters for 2015, Chemical Reviews, Materials Today, Angewandte Chemie, Nano Energy and Annual Review of Fluid Mechanics is scored above 10.

Table 6 shows the top 10 institutes' statistical information based on the number of papers according to selected keywords. Among the top 10 institutes, six originated from the China. It is followed by Turkey, Spain, India and Germany. Compared with Table 2, United States and United Kingdom positioned second and fourth rank, respectively, however, they had no institutes in

Table 6
The top 10 productive institutions.

Intuitions (Country)	Number of publications			TC (encp.)	% of total (encp.)	h-index (encp.) (R)
	Encapsulation	Nanoencapsulation	Miniemulsion polymerization			
Tsinghua University (China)	32	2	10	836	18.39	13
South China University of Technology (China)	25	6	12	229	14.36	8
Tianjin Polytechnic University (China)	23	2	8	317	13.22	9
Gaziosmanpasa University (Turkey)	22	1	4	1445	12.64	13
Beijing Uni. of Chemical Technology (China)	20	–	4	653	11.49	11
Nanjing University (China)	18	–	3	348	10.34	11
Universidad de Castilla-La Mancha (Spain)	15	1	2	601	8.6	11
University of Science and Technology (China)	13	2	5	175	7.4	6
Karpagam Institute of Technology (India)	3	3	1	7	1.7	2
Max Plank Institute for Polymer Research (Germany)	3	2	5	58	1.7	2
Total	174	19	54	4669	100	

TC = Total number of citations.
R = Rank, Encp = Encapsulation.
Note: % (Percentage) refers to the ratio of one country's publications to total number of encapsulation publications.

the list of the top 10 most productive institutes. Tsinghua University and South China University of Technology from China are the most important institutions related to encapsulation.

6. Conclusions

The present study makes several noteworthy contributions to phase change material and encapsulation subjects via the bibliometric technique. The findings obtained from bibliometric analysis provide insights for future research. Based on the raw data from Scopus database, the publication characteristics such as quantity and quality were analysed by using the bibliometric analyse techniques over the past 25 years. This is the first study reporting worldwide trends related to phase change material and encapsulation when evaluated in this respect. Throughout this paper, the main keyword 'phase change material' and sub keywords 'encapsulation, nanoencapsulation, miniemulsion polymerization' will refer to bibliometric analysis.

The most obvious findings emerged from this study are:

- A total of 34,626 publications with the keyword "phase change material" and 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 are the most productive countries according to the total publication criteria.
- While Xiaodong Wang from China is the most productive author, Ahmet Sarı is the most productive author considering the average citations per article with 69 point.
- The most preferred keywords are phase change material, encapsulation and heat storage.
- Over 91.89% of the publications were published in English.
- Applied Energy takes place on the top with 39 publications and 5.613 impact factor.
- If the debate is to be moved forward, a better understanding of bibliometric analysis needs to be developed. More information on this type of research would help us to establish a greater degree of accuracy on this matter.

References

[1] International Energy Agency in World Energy Outlook 2011, 546–7. Retrieved from: http://www.worldenergyoutlook.org (International Energy Agency, 2011).
[2] Petroleum British. BP Energy Outlook 2016;2016:98. http://dx.doi.org/10.1017/CBO9781107415324.004.
[3] International Energy Agency. World Energy Outlook 2015. Executive Summary. Int Energy Agency Books Online 2015:1–9. http://dx.doi.org/10.1787/weo-2005-en.
[4] Chu S, Majumdar A. Opportunities and challenges for a sustainable energy future. Nature 2012;488:294–303. http://dx.doi.org/10.1038/nature11475.
[5] Chen H, Cong TN, Yang W, Tan C, Li Y, Ding Y. Progress in electrical energy storage system: a critical review. Prog Nat Sci 2009;19:291–312. http://dx.doi.org/10.1016/j.pnsc.2008.07.014.
[6] Dincer I, Rosen MA. Thermal energy storage: systems and applications. John Wiley & Sons Ltd; 2002.
[7] Ehid R, Fleischer AS. Development and characterization of paraffin-based shape stabilized energy storage materials. Energy Convers Manage 2012;53:84–91. http://dx.doi.org/10.1016/j.enconman.2011.08.003.
[8] Wang P, Yao H, Lan Z, Peng Z, Huang Y, Ding Y. Numerical investigation of PCM melting process in sleeve tube with internal fins. Energy Convers Manage 2016;110:428–35. http://dx.doi.org/10.1016/j.enconman.2015.12.042.
[9] Sharifi N, Bergman TL, Faghri A. Enhancement of PCM melting in enclosures with horizontally finned internal surfaces. Int J Heat Mass Transf 2011;54:4182–92. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2011.05.027.
[10] Yang J, Yang L, Xu C, Du X. Experimental study on enhancement of thermal energy storage with phase-change material. Appl Energy 2016;169:164–76. http://dx.doi.org/10.1016/j.apenergy.2016.02.028.
[11] Yatağanbaba A, Kurtbaş İ. Effect of heating position on thermal energy storage in cavity with/without open-cell metallic foams. Exp Heat Transf 2016;29:355–77. http://dx.doi.org/10.1080/08916152.2014.989376.
[12] Nurten Ş, Fois M, Paksoy H. Solar energy materials & solar cells improving thermal conductivity phase change materials-a study of paraffin nanomagnetite composites. Sol Energy Mater Sol Cells 2015;137:61–7. http://dx.doi.org/10.1016/j.solmat.2015.01.027.
[13] Sari A, Alkan C, Karaipekli A, Uzun O. Microencapsulated n-octacosane as phase change material for thermal energy storage. Sol Energy 2009;83:1757–63. http://dx.doi.org/10.1016/j.solener.2009.05.008.
[14] Karaipekli A, Sari A, Kaygusuz K. Thermal conductivity improvement of stearic acid using expanded graphite and carbon fiber for energy storage applications. Renew Energy 2007;32:2201–10. http://dx.doi.org/10.1016/j.renene.2006.11.011.
[15] Ji P, Sun H, Zhong Y, Feng W. Improvement of the thermal conductivity of a phase change material by the functionalized carbon nanotubes. Chem Eng Sci 2012;81:140–5. http://dx.doi.org/10.1016/j.ces.2012.07.002.
[16] Mills A, Farid M, Selman JR, Al-Hallaj S. Thermal conductivity enhancement of phase change materials using a graphite matrix. Appl Therm Eng 2006;26:1652–61. http://dx.doi.org/10.1016/j.applthermaleng.2005.11.022.
[17] Alkan C, Sari A, Karaipekli A. Preparation, thermal properties and thermal reliability of microencapsulated n-eicosane as novel phase change material for thermal energy storage. Energy Convers Manage 2011;52:687–92. http://dx.doi.org/10.1016/j.enconman.2010.07.047.
[18] Jiang F, Wang X, Wu D. Design and synthesis of magnetic microcapsules based on n-eicosane core and Fe_3O_4/SiO_2 hybrid shell for dual-functional phase change. Appl Energy 2014;134:456–68. http://dx.doi.org/10.1016/j.apenergy.2014.08.061.
[19] Li W, Song G, Tang G, Chu X, Ma S, Liu C. Morphology, structure and thermal stability of microencapsulated phase change material with copolymer shell. Energy 2011;36:785–91. http://dx.doi.org/10.1016/j.energy.2010.12.041.
[20] Fang Y, Kuang S, Gao X, Zhang Z. Preparation and characterization of novel nanoencapsulated phase change materials. Energy Convers Manage 2008;49:3704–7. http://dx.doi.org/10.1016/j.enconman.2008.06.027.

[21] Zhang XX, Fan YF, Tao XM, Yick KL. Fabrication and properties of microcapsules and nanocapsules containing n-octadecane. Mater Chem Phys 2004;88:300–7. http://dx.doi.org/10.1016/j.matchemphys.2004.06.043.

[22] Fan YF, Zhang XX, Wang XC, Li J, Zhu QB. Super-cooling prevention of microencapsulated phase change material. Thermochim Acta 2004;413:1–6. http://dx.doi.org/10.1016/j.tca.2003.11.006.

[23] Konuklu Y, Paksoy HO, Unal M, Konuklu S. Microencapsulation of a fatty acid with poly(melamine–urea–formaldehyde). Energy Convers Manage 2014;80:382–90. http://dx.doi.org/10.1016/j.enconman.2014.01.042.

[24] Lee SH, Yoon SJ, Kim YG, Choi YC, Kim JH, Lee JG. Development of building materials by using micro-encapsulated phase change material. Korean J Chem Eng 2007;24:332–5.

[25] Yu S, Wang X, Wu D. Microencapsulation of *n*-octadecane phase change material with calcium carbonate shell for enhancement of thermal conductivity and serving durability: synthesis, microstructure, and performance evaluation. Appl Energy 2014;114:632–43. http://dx.doi.org/10.1016/j.apenergy.2013.10.029.

[26] Chen ZH, Yu F, Zeng XR, Zhang ZG. Preparation, characterization and thermal properties of nanocapsules containing phase change material n-dodecanol by miniemulsion polymerization with polymerizable emulsifier. Appl Energy 2012;91:7–12. http://dx.doi.org/10.1016/j.apenergy.2011.08.041.

[27] Sánchez-Silva L, Tsavalas J, Sundberg D, Sánchez P, Rodriguez JF. Synthesis and characterization of paraffin wax microcapsules with acrylic-based polymer shells. Ind Eng Chem Res 2010;49:12204–11. http://dx.doi.org/10.1021/ie101727b.

[28] Jiang X, Luo R, Peng F, Fang Y, Akiyama T, Wang S. Synthesis, characterization and thermal properties of paraffin microcapsules modified with nano-Al_2O_3. Appl Energy 2015;137:731–7. http://dx.doi.org/10.1016/j.apenergy.2014.09.028.

[29] Sari A, Alkan C, Döğüşcü DK, Kızıl Ç. Micro/nano encapsulated n-tetracosane and n-octadecane eutectic mixture with polystyrene shell for low-temperature latent heat thermal energy storage applications. Sol Energy 2015;115:195–203. http://dx.doi.org/10.1016/j.solener.2015.02.035.

[30] Sari A, Alkan C, Döğüşcü KD, Biçer A. Micro/nano-encapsulated n-heptadecane with polystyrene shell for latent heat thermal energy storage. Sol Energy Mater Sol Cells 2014;126:42–50. http://dx.doi.org/10.1016/j.solmat.2014.03.023.

[31] Paloma JG, Konuklu Y, Fernandez AI. Preparation and exhaustive characterization of paraffin or palmitic acid microcapsules as novel phase change material. Sol Energy 2015;112:300–9. http://dx.doi.org/10.1016/j.solener.2014.12.008.

[32] Alkan C, Sari A. Fatty acid/poly(methyl methacrylate) (PMMA) blends as form-stable phase change materials for latent heat thermal energy storage. Sol Energy 2008;82:118–24. http://dx.doi.org/10.1016/j.solener.2007.07.001.

[33] Sari A, Alkan C, Özcan AN. Synthesis and characterization of micro/nano capsules of PMMA/capric-stearic acid eutectic mixture for low temperature-thermal energy storage in buildings. Energy Build 2015;90:106–13. http://dx.doi.org/10.1016/j.enbuild.2015.01.013.

[34] Sari A, Alkan C, Biçer A, Altuntaş A, Bilgin C. Micro/nanoencapsulated n-nonadecane with poly(methyl methacrylate) shell for thermal energy storage. Energy Convers Manage 2014;86:614–21. http://dx.doi.org/10.1016/j.enconman.2014.05.092.

[35] Sari A, Alkan C, Bilgin C. Micro/nano encapsulation of some paraffin eutectic mixtures with poly(methyl methacrylate) shell: preparation, characterization and latent heat thermal energy storage properties. Appl Energy 2014;136:217–27. http://dx.doi.org/10.1016/j.apenergy.2014.09.047.

[36] Cao F, Yang B. Supercooling suppression of microencapsulated phase change materials by optimizing shell composition and structure. Appl Energy 2014;113:1512–8. http://dx.doi.org/10.1016/j.apenergy.2013.08.048.

[37] Qiu X, Song G, Chu X, Li X, Tang G. Microencapsulated n-alkane with p(n-butyl methacrylate-co-methacrylic acid) shell as phase change materials for thermal energy storage. Sol Energy 2013;91:212–20. http://dx.doi.org/10.1016/j.solener.2013.01.022.

[38] Qiu X, Li W, Song G, Chu X, Tang G. Microencapsulated n-octadecane with different methylmethacrylate-based copolymer shells as phase change materials for thermal energy storage. Energy 2012;46:188–99. http://dx.doi.org/10.1016/j.energy.2012.08.037.

[39] Konuklu Y. Microencapsulation of phase change material with poly (ethylacrylate) shell for thermal energy storage. Int J Energy Res 2014;38:2019–29. http://dx.doi.org/10.1002/er.3216.

[40] Konuklu Y, Paksoy HO, Unal M. Nanoencapsulation of n-alkanes with poly (styrene-co-ethylacrylate) shells for thermal energy storage. Appl Energy 2015;150:335–40. http://dx.doi.org/10.1016/j.apenergy.2014.11.066.

[41] Sari A, Alkan C, Karaipekli A. Preparation, characterization and thermal properties of PMMA/n-heptadecane microcapsules as novel solid-liquid microPCM for thermal energy storage. Appl Energy 2010;87:1529–34. http://dx.doi.org/10.1016/j.apenergy.2009.10.011.

[42] Liang C, Lingling X, Hongbo S, Zhibin Z. Microencapsulation of butyl stearate as a phase change material by interfacial polycondensation in a polyurea system. Energy Convers Manage 2009;50:723–9. http://dx.doi.org/10.1016/j.enconman.2008.09.044.

[43] Konuklu Y, Unal M, Paksoy HO. Microencapsulation of caprylic acid with different wall materials as phase change material for thermal energy storage. Sol Energy Mater Sol Cells 2014;120:536–42. http://dx.doi.org/10.1016/j.solmat.2013.09.035.

[44] Jamekhorshid A, Sadrameli SM, Bahramian AR. Process optimization and modeling of microencapsulated phase change material using response surface methodology. Appl Therm Eng 2014;70:183–9. http://dx.doi.org/10.1016/j.applthermaleng.2014.05.011.

[45] Xia CM, Zhou YF, Nie WY, Song LY, Dai MD, Xu XL, et al. Fabrication and characterization of cypermethrin nanocapsules in miniemulsion polymerization system. J Appl Polym Sci 2012;126:1859–66. http://dx.doi.org/10.1002/app.36866.

[46] Qiu X, Song G, Chu X, Li X, Tang G. Preparation, thermal properties and thermal reliabilities of microencapsulated n-octadecane with acrylic-based polymer shells for thermal energy storage. Thermochim Acta 2013;551:136–44. http://dx.doi.org/10.1016/j.tca.2012.10.027.

[47] Giro-Paloma J, Al-Shannaq R, Fernández AI, Farid MM. Preparation and characterization of microencapsulated phase change materials for use in building applications. Materials (Basel) 2016;9(1):1–13. http://dx.doi.org/10.3390/ma9010011.

[48] Al-Shannaq R, Farid M, Al-Muhtaseb S, Kurdi J. Emulsion stability and cross-linking of PMMA microcapsules containing phase change materials. Sol Energy Mater Sol Cells 2015;132:311–8. http://dx.doi.org/10.1016/j.solmat.2014.08.036.

[49] Morgan PW. Condensation polymers: by interfacial and solution methods. Polym Rev., vol. 10. New York: Wiley; 1965.

[50] Zalba B, Marín JM, Cabeza LF, Mehling H. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. Appl Therm Eng 2003;23:251–83. http://dx.doi.org/10.1016/S1359-4311(02)00192-8.

[51] Cabeza LF, Mehling H, Hiebler S, Ziegler F. Heat transfer enhancement in water when used as PCM in thermal energy storage. Appl Therm Eng 2002;22:1141–51. http://dx.doi.org/10.1016/S1359-4311(02)00035-2.

[52] Bansode SS, Banarjee SK, Gaikwad DD, Jadhav SL, Thorat RM. Microencapsulation: a review. Int J Pharma Bio Sci 2010;1(2):38–43. http://dx.doi.org/10.1007/BF00569928.

[53] Jacob R, Bruno F. Review on shell materials used in the encapsulation of phase change materials for high temperature thermal energy storage. Renew Sustain Energy Rev 2015;48:79–87. http://dx.doi.org/10.1016/j.rser.2015.03.038.

[54] Sharma A, Tyagi VV, Chen CR, Buddhi D. Review on thermal energy storage with phase change materials and applications. Renew Sustain Energy Rev 2009;13:318–45. http://dx.doi.org/10.1016/j.rser.2007.10.005.

[55] Zhao CY, Zhang GH. Review on microencapsulated phase change materials (MEPCMs): fabrication, characterization and applications. Renew Sustain Energy Rev 2011;15:3813–32. http://dx.doi.org/10.1016/j.rser.2011.07.019.

[56] Tyagi VV, Kaushik SC, Tyagi SK, Akiyama T. Development of phase change materials based microencapsulated technology for buildings: a review. Renew Sustain Energy Rev 2011;15:1373–91. http://dx.doi.org/10.1016/j.rser.2010.10.006.

[57] Jamekhorshid A, Sadrameli SM, Farid M. A review of microencapsulation methods of phase change materials (PCMs) as a thermal energy storage (TES) medium. Renew Sustain Energy Rev 2014;31:531–42. http://dx.doi.org/10.1016/j.rser.2013.12.033.

[58] Delgado M, Lázaro A, Mazo J, Zalba B. Review on phase change material emulsions and microencapsulated phase change material slurries: materials, heat transfer studies and applications. Renew Sustain Energy Rev 2012;16:253–73. http://dx.doi.org/10.1016/j.rser.2011.07.152.

[59] Boh B, Knez E, Staresinic M. Microencapsulation of higher hydrocarbon phase change materials by in situ polymerization. J Microencapsul 2005;22:715–35. http://dx.doi.org/10.1080/02652040500162139.

[60] Zhang H, Wang X, Wu D. Silica encapsulation of n-octadecane via sol-gel process: a novel microencapsulated phase-change material with enhanced thermal conductivity and performance. J Colloid Interface Sci 2010;343:246–55. http://dx.doi.org/10.1016/j.jcis.2009.11.036.

[61] Wang LY, Tsai PS, Yang YM. Preparation of silica microspheres encapsulating phase-change material by sol-gel method in O/W emulsion. J Microencapsul 2006;23:3–14. http://dx.doi.org/10.1080/02652040500286045.

[62] Chen Z, Qin M, Yang J. Synthesis and characteristics of hygroscopic phase change material: composite microencapsulated phase change material (MPCM) and diatomite. Energy Build 2015;106:175–82. http://dx.doi.org/10.1016/j.egypro.2015.11.140.

[63] Latibari ST, Mehrali M, Mehrali M, Afifi ABM, Mahlia TMI, Akhiani AR, et al. Facile synthesis and thermal performances of stearic acid/titania core/shell nanocapsules by sol–gel method. Energy 2015;85:635–44. http://dx.doi.org/10.1016/j.energy.2015.04.008.

[64] Hawlader MNA, Uddin MS, Khin MM. Microencapsulated PCM thermal-energy storage system. Appl Energy 2003;74:195–202. http://dx.doi.org/10.1016/S0306-2619(02)00146-0.

[65] Huang HJ, Chen XD, Yuan WK. Microencapsulation based on emulsification for producing pharmaceutical products: a literature review. Dev Chem Eng Mineral Process 2006;14:515–44. http://dx.doi.org/10.1002/apj.5500140318.

[66] Kruif CG, Weinbreck F, Vries D. Complex coacervation of proteins and anionic polysaccharides. Curr Opin Colloid In 2004;9:340–9. http://dx.doi.org/10.1016/j.cocis.2004.09.006.

[67] Doublier JL, Garnier C, Renard D, Sanchez C. Protein-polysaccharide interactions. Curr Opin Colloid In 2000;5:202–14. http://dx.doi.org/10.1016/S1359-0294(00)00054-6.

[68] Pritchard A. Statistical bibliography or bibliometrics? J Doc 1969;24:348–9.

[69] Raban DR, Gordon A. The effect of technology on learning research trends: a bibliometric analysis over five decades. Scientometrics 2015;105:665–81. http://dx.doi.org/10.1007/s11192-015-1690-7.
[70] Ellegaard O, Wallin JA. The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 2015;105:1809–31. http://dx.doi.org/10.1007/s11192-015-1645-z.
[71] Yang J, Vannier MW, Wang F, Deng Y, Ou F, Bennett J, et al. A bibliometric analysis of academic publication and NIH funding. J Informetr 2013;7:318–24. http://dx.doi.org/10.1016/j.joi.2012.11.006.
[72] Cobo MJ, Martínez MA, Gutiérrez-salcedo M, Fujita H, Herrera-viedma E. Knowledge-based systems 25 years at knowledge-based systems: a bibliometric analysis. Knowledge-Based Syst 2015;80:3–13. http://dx.doi.org/10.1016/j.knosys.2014.12.035.
[73] Yataganbaba A, Kurtbaş I. A scientific approach with bibliometric analysis related to brick and tile drying: a review. Renew Sustain Energy Rev 2016;59:206–24. http://dx.doi.org/10.1016/j.rser.2015.12.357.
[74] https://library.leeds.ac.uk/info/467/bibliometrics/307/what_is_bibliometrics/2.
[75] Young J, Chi R. Intercultural relations: a bibliometric survey. Int J of Intercult Rel 2013;37:133–45. http://dx.doi.org/10.1016/j.ijintrel.2012.11.005.
[76] Belter CW. Bibliometric indicators : opportunities and limits. J Med Lib Assoc 2015;103(4):219–21. http://dx.doi.org/10.3163/1536-5050.103.4.014.
[77] Heradio R, Morago HP, Amoros DF, Cabrerizo FJ, Viedma EH. A bibliometric analysis of 20 years of research on software product lines. Inform Softw Tech 2016;72:1–15. http://dx.doi.org/10.1016/j.infsof.2015.11.004.
[78] Chen H, Ho YS. Highly cited articles in biomass research: a bibliometric analysis. Renew Sustain Energy Rev 2015;49:12–20. http://dx.doi.org/10.1016/j.rser.2015.04.060.
[79] Healey P, Rothman H, Hoch PK. An experiment in science mapping for research planning. Res Policy 1986;15:233–51. http://dx.doi.org/10.1016/0048-7333(86)90024-7.
[80] https://www.elsevier.com/solutions/scopus.
[81] Persson O, Danell R, Schneider JW. How to use Bibexcel for various types of bibliometric analysis. In: Celebrating scholarly communication studies: a Festschrift for Olle Persson at his 60th Birthday. International Society for Scientometrics and Informetrics, Aalborg, Copenhagen, Umeå and Sydney, 2009. p. 9–24. Retrieved From: <http://issi-society.org/ollepersson60/ollepersson60.pdf>.
[82] http://vlado.fmf.uni-lj.si/pub/networks/pajek/.
[83] http://www.vosviewer.com/.