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Improving the energy efficiency in buildings by using phase change materials

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Summary

Phase change materials are chemical substances which have the ability to store thermal energy and release it as latent heat because they have a small range between their melting and solidification point.

There is a wide variety of phase change materials and based on their type and melting point they can be used in many applications in order to improve the energy efficiency of a building.

This paper follows three main aspects. The first section presents types of phase change materials, the second contains encapsulation techniques and the last part includes information about the applicability of these materials.

Keywords: Phase change materials, Encapsulation, Latent heat, Energy efficiency, Heat storage.

1. INTRODUCTION

Decreasing the energy consumption by using renewable sources of energy is an intensely discussed problem these days. In the developed countries, the building sector uses between 20-40% of the total amount of energy produced, and these numbers are growing annually.

Storing thermal energy may have a significant impact upon a building's energy consumption. Using phase change materials is a solution for these requirements because it can store energy and release it as latent heat when the energy source becomes unavailable. For the most types of renewable energy, storing thermal energy is the key to the system's efficiency.

One of the first research regarding the integration of phase change materials in building sector began in 1940 when Dr. Maria Telkes built the so-called „Dover house". The 135m^2 of the house were split among 5 rooms. 18 black absorbent panels were collecting the solar radiation which was then stored in 3 containers filled with 21 tons of phase change material (Glauber's Salt).

A series of analysis showed that out of 20.000 phase change materials, only 1% can be efficiently used in the building sector. The most important are paraffin wax and salt hydrate for applications which use temperatures below 100 ^{o}C.

2. MATERIALS AND RESEARCH METHODOLOGY

2.1 Types of phase change materials

Based on their state, phase change materials can be solid-solid, solid-liquid, solid-gas or liquid-gas. The ones involving gas are less used because they need a high volume of storage. The most effective ones are the solid-liquid ones which they can be organic, inorganic and mixtures.

The organic ones, like paraffin wax or n-octadecane, have a wide range of working temperatures and a better chemical stability. The inorganic ones like water or salt hydrate have a better thermal conductivity and a smaller volume variation during the phase change, but they get cold quicker and they are corrosive.

Figure 1. Paraffin wax sold by Rubitherm
(https://www.rubitherm.eu/en/index.php/productcategory/organische-pcm-rt)

2.2 Encapsulating phase change materials

During the phase change, when the material goes from a solid state to a liquid one, it has the tendency to leak. A proper encapsulation becomes necessary in order to prevent that. The encapsulation is the technique to keep the phase change material in a sealed container.

The phase change material and the polymer (or the inorganic material) work as a core and a shell, creating a capsule. Besides of keeping the core from leaking, the

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shell also has the role of increasing the thermal conductivity of the capsule. Several encapsulated phase change materials with their proprieties are presented in Table 1.

Table 1. Various encapsulations of phase change materials

Core (PCM)	Thermal conductivity of PCM (W/m*K)	Shell	Thermal conductivity of shell (W/m*K)	Encapsulation efficiency (%)	Thermal conductivity of encaspsulation (W/m*K)
n-octadecane	0.153(solid)	CaCO3	2.467	40.04	1.264
n-octadecane	0.1505	Silica	1.296	57.7	0.6213
n-octadecane	0.152	Zirconia	2.560	64.52	0.906
RT 42	0.369	CaCO3	-	-	0.814
Paraffin	0.265	Silica	-	50.8	1.031
RT 21	0.15	Polymethyl methacrylate	0.192	-	2.41

One of the materials commonly used for the shell is calcium carbonate ($CaCO_3$). This type of shell was used to encapsulate n-octadecane[14] or mixtures of paraffin RT28 and RT42[12], in order to check the behavior and the efficiency of the encapsulation.

The polymers are also often used as the shell for the encapsulations. But because of their low thermal conductivity, polymers are usually modified in order to increase their capacity to transfer thermal energy. Some tests regarding this matter were made using paraffin RT21 as core and polymethyl methacrylate as shell, which afterward was coated in a silver layer [1].

3. RESULTS AND INTERPRETATIONS

The experimental results of n-octadecane in the calcium carbonate shell showed that the encapsulation's thermal conductivity gets higher with the shell's thickness. The thermal conductivity of the encapsulation becomes 1.264 W/m*K compared to just 0.153 W/m*K, which is the thermal conductivity of the pure n-octadecane [14].

Similar, the encapsulation of paraffin in the calcium carbonate shell revealed an increase of the thermal conductivity up to 3 times compared to regular paraffin [12]. Beside this improvement, the shell is also protecting the phase change material in order to increase its lifetime.

Regarding the encapsulation of paraffin RT21 in the polymethyl methacrylate shell, there were two main aspects which were studied: the behavior of the encapsulation with different sizes of the particles and its behavior with different thicknesses for the coating layer. As expected, the thermal conductivity of the

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encapsulation increases proportionally with the thickness of the silver coating. There is also a downside of the process if the coating is too thick, the enthalpy of the phase change material will decrease [1].

Protecting the environment and conserving energy required the implementation of new sources of energy such as solar energy or wind energy. The downside of these renewable sources is their fluctuating regime. Phase change materials can improve the efficiency of the processes which harvest these types of energy because of their capability of keeping a constant temperature during the phase change transition.

3.1 Phase change materials used for solar energy system

The solar radiation is considered to be an almost infinite source of energy but it can only be used during sunny days. Phase change materials can store solar energy during the day and they can supply the demand during the night or cloudy days, therefore, they are often used in this field. There are two main types of solar powered energy producing systems, solar water heating system and solar thermal power generation system.

3.1.1 Solar water heating system

A solar water heating system is decreasing a significant amount out of a building's energy requirement and they are environmentally friendly. The conventional systems are ineffective during bad weather or nighttime, and that's where the phase change materials bring the improvement.

Storing solar energy in paraffin was analyzed for a hot water producing system, made out of a solar energy collector with six copper pipes with a diameter of 80mm. The experiment took place during the clear and sunny days of January, February, and March. It was noticed that the change of temperature between the system with phase change materials and the system without it is different. The temperature of the first one increases from the entrance to two and a half meters and the remaining seven and a half meters remains constant. Without the presence of the sun, the system cools off and the phase change materials in the liquid state start the solidification process and become the heat source for the water [6].

3.1.2 Solar thermal power generation system

Phase change materials are also effective in producing thermal energy. For example, for a solar energy power plant located in Shiraz, Iran, there were investigated the energy performance with and without the integration of phase change materials. The results showed that the efficiency of the system without phase change material is 30% for energy and 10% for exergy, but by introducing them in the solar collectors, the exergy efficiency rises up to 30% because of the phase change material's property of storing latent heat. The exergy percent rises with the melting point of the materials that are used [7].

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3.2 Phase change materials in buildings

A higher quality of life requires an increase of the demand for thermal comfort in buildings, resulting in a higher amount of energy required especially during summer and winter. By integrating phase change materials in buildings, we can decrease the amount of energy demanded. And increase the thermal comfort.

To analyze their efficiency, phase change materials were integrated into gypsum boards to improve the thermal proprieties of buildings. The proprieties of the improved gypsum boards were investigated in several different cities. The results showed that the efficiency of the phase change material depends on the external temperature. The assumptions were confirmed, the improvement had a great impact upon the energy conservation and the gypsum boards can be used for both new and old buildings [10].

3.3 Phase change materials in heat recovery system

Heat recovery has a major impact regarding energy savings and reducing CO_2 emissions, but in general, there is a time gap between heat release and heat demand points. This problem can be solved by introducing phase change materials in these types of system as phase change materials possess an outstanding latent heat storage capacity.

An example of this type of improvement is the implementation of paraffin RT 20 as the phase change material in a heat pipe heat exchanger. The primary agent is used water inside a building. The role of the phase change material is to store the thermal energy recovered from the primary agent and release it to the secondary agent when the heat source is gone. The secondary agent can be used for hot water preparation or preheat the thermal agent for the building's heating source [2].

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

Phase change materials can significantly improve the energy efficiency of a building. Their encapsulation prevents leakings or affecting the phase change material and improves the thermal conductivity.

Introducing them in construction materials, hot water, and thermal energy preparation or heat recovery system will decrease both the energy requirements of buildings and the CO_2 emissions, which will have a great impact on the environment.

As future developments, we can introduce phase change materials in several other types of heat recovery system in order to increase their efficiency. These types of heat recovery systems could reduce the energy consumption inside a building up to 12% during winter and 30% during summer when it's used only for hot water preparation. Also, phase change materials will increase the efficiency of heat pipes used for some applications, because their melting/solidification point can be similar to the heat pipe's temperature working regime.

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