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Using Metallic Foams with Macro-encapsulated Paraffin to Enhance the Charging and DIS-charging Processes

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Abstract: *In this paper, the fabrication and development of metallic foams for an optimization of thermal and physical properties related to solar heat storage unit used paraffin waxwere explored. Macro-encapsulation comprises the inclusion of paraffin wax in some form of package such as tubes, pouches, spheres, panels or other receptacle. These containers can serve directly as heat exchangers or they can be incorporated in building products.The heat conductivity of paraffin during melting and solidification processes, the inner surface between the paraffin and the heat transfer fluid (HTF) and the heat capacity of the solar latent heat storage unit can be improved by development of the material structure in which paraffin wax filled and stored.By dispersion of ceramic nanoparticles can be enhanced heat conductivity, thermal storage performance, specific energy absorption, reduction the melting onset temperature and increasing the solidification onset temperature of paraffin wax. In addition to metallic foams, such as aluminium and copper, insertingcellular metal matrix composites reinforced with ceramic nanoparticles could also improve the features of the latent heat storage unit while charging and discharging processes.Aluminum as a matrix and ceramic nanoparticles as a reinforcement for fabrication an open cell foam structure could present a unique combination of properties, those related to metal/ceramic composites filled with phase change material (paraffin), also still associating some characteristics of cellular materials, as the low density, highheat storage capacity and good heat conductivity. This article also reviews an experimental investigations carried out on the influence of metallic and ceramic particles on charging and discharging processes of the latent heat storage unit used paraffin.*
Keywords: *Phase change materials, Cellular metals and Composites, Ceramic particles .*

I. Introduction

Fabrication and development of metals and composites with different properties increased very significantly due to development of technology and increasing new demands of industry in modern engineering applications. Advances in technologies of materials have been largely responsible for major performance improvements in engineering structures and continue to be key in determining the reliability, performance and cost effectiveness of the systems.

In recent years, the thermal energy storage (TES) by solar power has become a popular research topic. Because of the impact of day and night on solar thermal energy storage, thus, an optimization of efficient energy storage materials will directly influence the utilization efficiency of solar thermal energy storage systems. Energy storage are therefore essential to any system depends on solar energy. Energy storage unitscan help match energy supply and demand, thereby improving the system operability and utility. An optimization of efficient and cost effective thermal energy storage systems is necessary for the utilization of solar energy.

A key focus of present scientific paper is the fabrication and development of metals and composite materials for an optimization of the thermal and physical properties related to the charging and discharging processes of the latent heat storage unit using paraffin. Lightweight, high corrosion resistance, good heat conductivity, high heat storage capacity, capable of storing (PCM) paraffin and an acceptable cost an open cell foam materials are leading contenders as component materials to improve the efficiency of the latent heat storage units, and thus an optimization the heat storage system. This study paper also reviews manyresearch papers have focused on topics related to the efficiency of latent heat storage unit used paraffin as phase change material.There have been many studies carried out related to composite materials, foam metals and cellular composites, most of which focused on the mechanical and physical properties of these materials. Most of those studies have been conducted on the type of fabrication process, the type, size and distribution of reinforcement particles in the composites and their effect on microstructure, porosity, also the effect of RVR on the mechanical, physical and thermal properties of composites, as well as the mechanical and physical properties of foam metals and cellular composites, however this study will concentrate on the thermo-physical properties of metal composite materials reinforced with ceramic nanoparticles, paraffin-ceramic nanoparticles composites, foam metals and cellular composites. There were various articles accessed, however not all were completely relevant and as a result not included in this paper.

II. Latent Heat (Phase Change) Storage

A latent heat storage refers to a heat storage system that uses the energy absorbed or released during a phase transition, without a change in temperature (isothermal).

Phase change materials have high heats of fusion, which melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Temperature of PCM remains constant during the phase change, which is useful for keeping the subject at a uniform temperature. Heat is absorbed or released when the material changes from solid to liquid and vice versa, for that, these materials are classified as latent heat storage (LHS) units.

PCM's can be classified into (organic, inorganic and eutectic), which can be identified as PCM's from the point of view melting temperature and latent heat of fusion. Figure (2.1) shows a classification of latent heat storage materials.

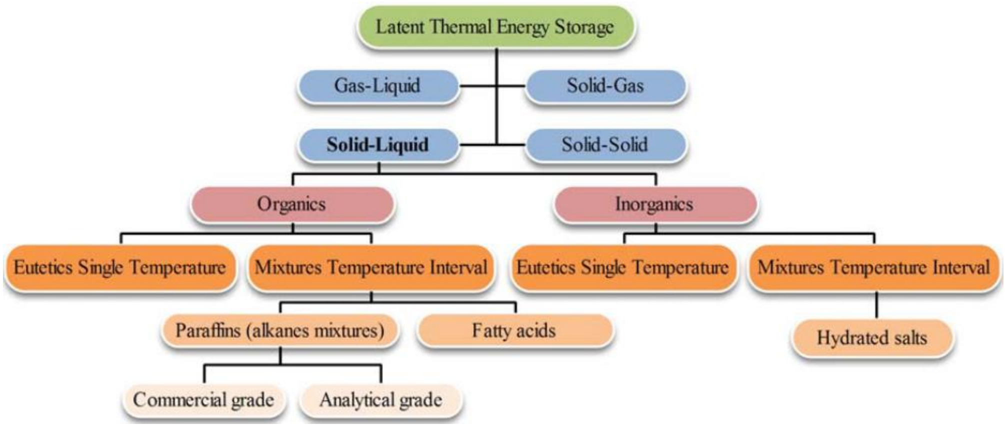


Figure (2.1): Classification of latent heat storage materials [1]

The storage capacity of the phase change materials is equal to the phase change enthalpy at the phase change temperature + sensible heat stored over the whole temperature range of the storage (Fig. 2.2). The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat [2].

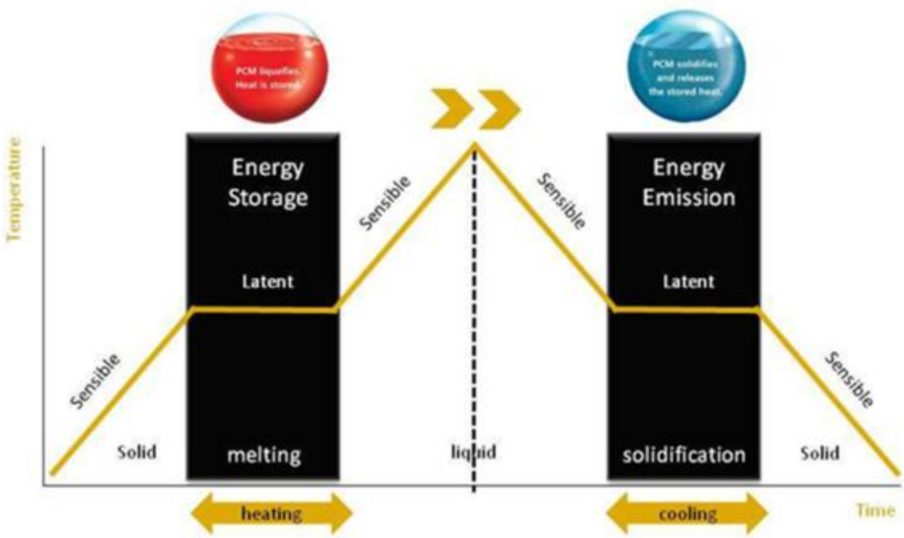


Figure (2.2): phase-change energy storage [3]

1.1. Paraffin as PCM in latent heat storage unit

There are a large number of organic and inorganic chemical materials, which can be abbreviated as PCM from the point of view melting temperature and latent heat of fusion (fig. 2.3). A large number of PCM's are available in any required temperature range from −5 up to 190 0C [2-4].

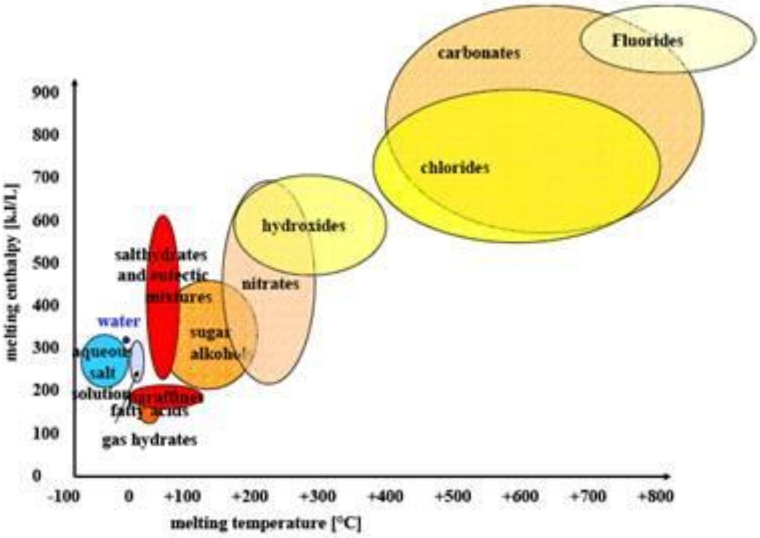
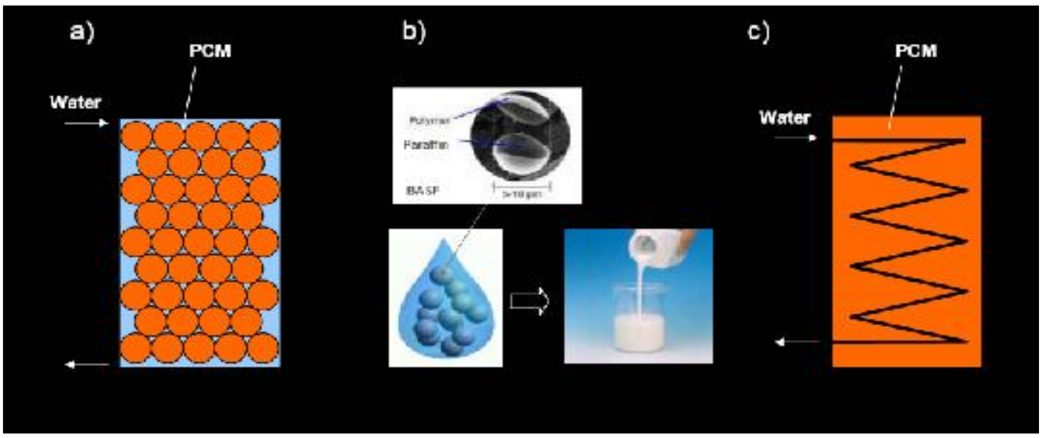


Fig. 2.3: Melting enthalpy of various phase change material groups in relation to their melting temperature [5]

An ideal phase change material must be characterized by a suitable phase change temperature and a large melting enthalpy. These features have to be fulfilled in order to store and release heat at all. However, there are more requirements for most, but not all applications. These requirements are classified into physical, technical, and economic requirements [6-1-7].

1. Physical requirements refer to the storage and release of heat and are including the suitable phase change temperature, large phase change enthalpy, reproducible phase change, also called cycling stability, little supercooling and good thermal conductivity.
2. 2.Technical requirements refer to the construction of a storage and are comprising of low vapor pressure, small volume change, chemical stability of the PCM, compatibility of the PCM with other materials and safety constraints.
3. Economic requirements refer to the development of a marketable product and are including low price and good recyclability.

   There are three possibilities for integration of phase change materials into thermal energy system: PCM in tank, immersed heat exchanger (bulk storage), PCM Macro– encapsulation and PCM Micro– encapsulation [8], as shown in fig. (2.4):



a. Macro-encapsulation, b. Micro-encapsulation ,PCM slurries, c. PCM in tank, immersed heat exchanger

Fig. 2.4: Integration of phase change materials into (TES), [9]

PCM's (Paraffins) are used for thermal storage as latent heat with high volumetric energy densities. Paraffin is an organic material with several advantages: Chemical and thermal stability, Suffer little or no supercooling, non-corrosives, non-toxic, high heat of fusion and low vapour pressure, but on the other hand it has some disadvantages which are: low thermal conductivity, high changes in volumes on phase change, inflammability, lower phase change enthalpy [10-11].

Paraffin wax typically contains primarily linear alkanes in the C_{20} to C_{40} range. It is microcrystalline, hard, brittle, and has a low affinity for oil. It melts in the range of 46-68 ^{o}C [12].

Thermal conductivity of the candidate PCM composite is of utmost importance to system performance, particularly when using low conductivity paraffin –based PCM's. Heat storage rate as well as material charge and recharge dependent on thermal conductivity.

The ability of a material to absorb and release energy determines the activeness of the PCM and the TES system as a whole [13].

For improvement of charging and discharging processes of the storage, two parameters have to be optimized, which are:

1. The inner surface between the heat transfer medium and the PCM.
2. The thermal conductivity of the PCM during melting and solidificationprocesses [14].

Encapsulation of paraffin

There are two types of PCM-encapsulation: micro-encapsulation and macro-encapsulation.

Encapsulation serves as heat transfer surface, prevents PCM from reacting with outside environment, and adds mechanical strength to the structure.

Micro-encapsulation is the process by which individual particles or droplets of solid or liquid material (the core) are surrounded or coated with a continuous film of polymeric material (the shell) to produce capsules in 1 μm to millimeter diameter range, known as microcapsules [15,16]. A large improvement in the heat transfer rate was obtained by encapsulating the PCM in small plastic spheres to form a packed bed storage unit fig. (2.5). However, the expected high pressure drop through the initial cost may be major drawbacks of such units [17].

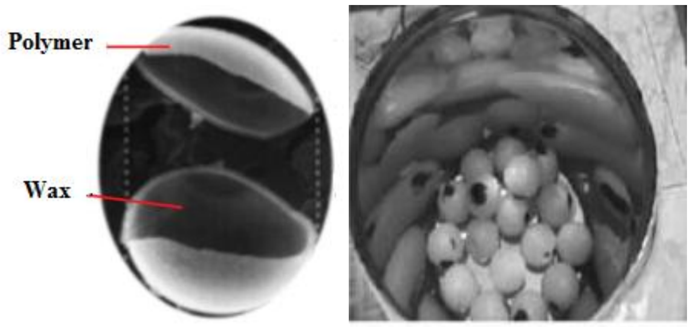


Fig. 2.5: PCM Microcapsule [4-1]

According to the core material and the deposition process of the shell, the morphology of microcapsules can be described and classified into three types as shown in fig. (2.6) [18]:

1. Mononuclear (core-shell) microcapsules contain the shell around the core.
2. Polynuclear capsules have many cores enclosed within the shell.
3. Matrix encapsulation in which the core material is distributed homogeneously into the shell material.

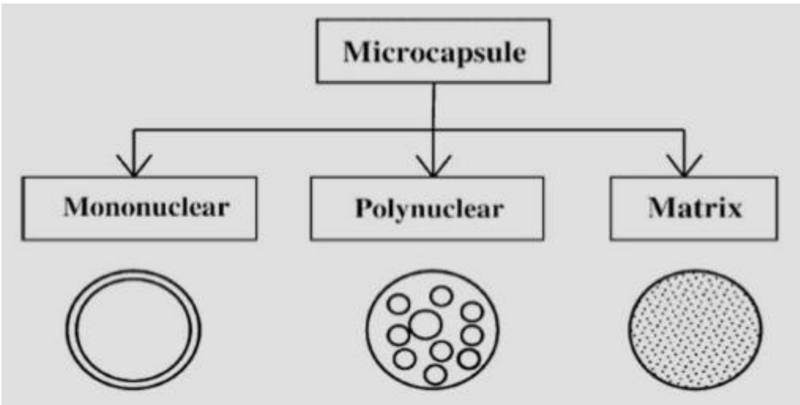


Fig. 2.6: Morphology of Microcapsules

Macro-encapsulation means filling the PCM in a macroscopic containment that fit amounts from several ml up to several liters. These are often containers and bags made of metal or plastic [15]. The advantage of the macro-encapsulation is that the possibility to apply with both liquid and air as heat transfer fluids and easier to ship and handle [17].

The macro-encapsulation is characterized by the possibility to serve directly as heat exchangers, to be incorporated in building products, possibility of using different PCM's in one tank and availability of a wide range of temperatures [19].

On other hand, it requirements for a high heat transfer rate, which means that the modules should be as small as possible and / or improvement of the thermal conductivity.

Macro-encapsulation may be achieved by a myriad techniques: ball capsules, spherical capsules, cylindrical capsules, stripe capsules, bag capsules, profiles with fins, flat and tube containers, and plates [17,20], as shown in some examples in Fig. (2.7).

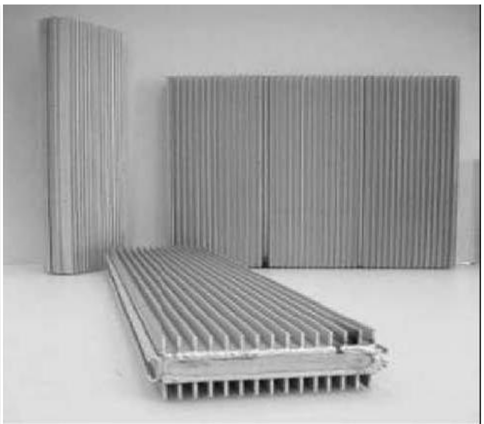
Stainless steel ball capsule, EPS LTD

Cylindrical capsule, U.K.M. (SERI)

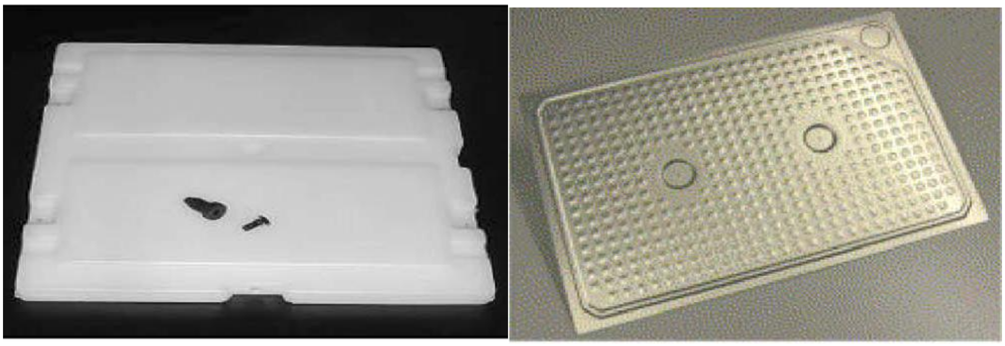
Stripe capsule (Dörken)

Spherical capsule

Bag capsule (Dörken)



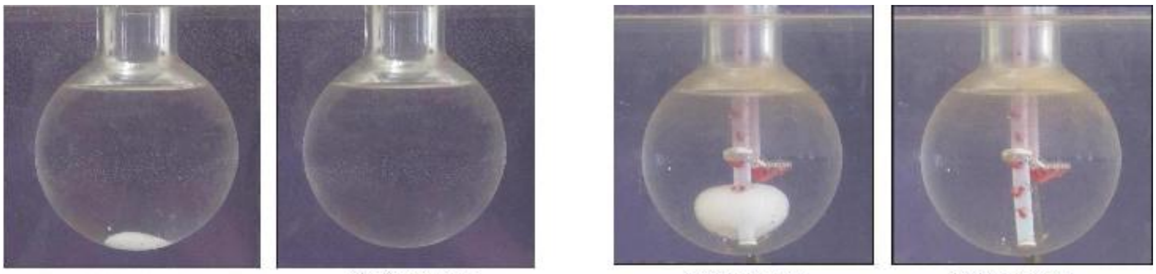
Aluminum profiles with fins (Climator)



Flat container (Kissman) Plate (Rubithem Technologies GmbH)

Fig. 2.7: Photographs of macro-encapsulation of various geometry [17]

S. Khot, N. Sane and B. Gawali investigated the constrained and unconstrained melting of PCM inside a spherical capsule using paraffin wax. The experiments are carried out with different HTF temperatures. PCM melting is constrained in spherical capsule using thermocouples used to measure the temperatures in capsule. The thermocouples are mounted inside the Teflon tube to fix up the positions. Under the constrained melting conditions, the melting occurs around the PCM inwards the centre of the capsule. The solid PCM is restricted from sinking by the tube inside the sphere. There is no contact of the solid PCM with the spherical glass. Melting is mainly through the natural convection in the liquid at the top and
bottom halves of the solid PCM.



(e) 60 minutes (f) 70 minutes (e) 70 minutes (f) 80 minutes

For the unconstrained melting, the solid PCM sinks to the bottom of the sphere. This is due to heavier density of the solid PCM than the liquid PCM. Under the same experimental condition, unconstrained melting seems to occur at a faster rate than the constrained melting. This is due to larger rate of heat transfer by conduction from the solid PCM to the spherical glass capsule [21].

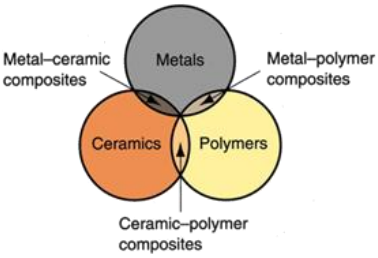
III. Multiphase Materials (Composites)

In recent years, manufacturing and development of composites with different properties increased very significantly due to development of technology and increasing new demands of industry in modern engineering applications. Composite technology combines the most important properties of the components together in order to get a material with overall properties suitable for the manufacture of the engineering part required.

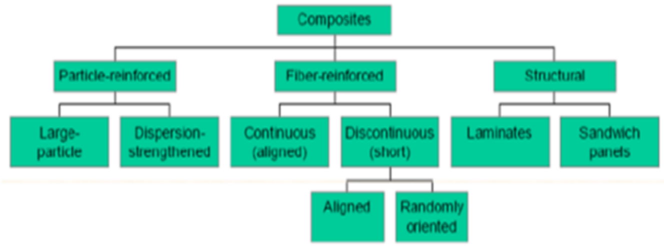
The manufacturing technique used to fabricate a composite structure is dependent upon material performance requirements, structure configuration, and production rates [22].

Matrix, reinforcement and the interface are the components of composite. The matrix, such as metal, ceramic and polymer, surrounds and supports the reinforcement materials by maintaining their relative positions and protects them from environment, the reinforcements, like carbides, oxides, organic, glass, etc., are the dispersed phases and impart special properties to enhance the matrix properties and the interface refers to the bonding and interfacial surface.

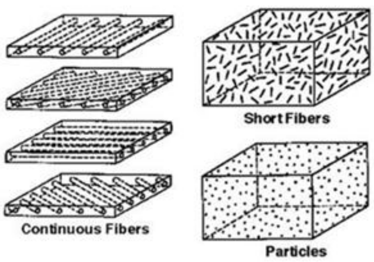
Composite materials can be classified by matrix or filler type. They are classified by matrix into meat matrix composites (MMC's), ceramic matrix composites (MMC's) and polymer matrix composites (MMC's) while by filler type are classified into particle reinforced composite, fiber reinforced composites and structural composites.Metal Matrix Composites (MMC's) is one of these materials. Aluminum, magnesium and their alloys are the most commonly used matrix materials inthe production of MMC's because of their preferred properties such as lightness and ductility. Figure (3.1) shows examples of composite reinforcements.



(a)



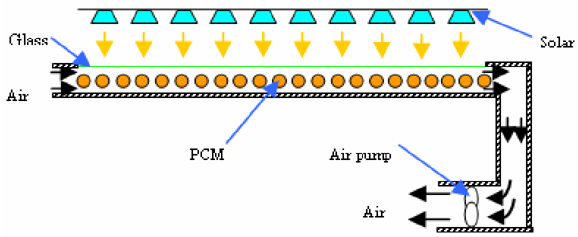
(b)



(c)

Figure (3.1): a- Classification of composites by matrix type, b- Classification of composites by filler type and c- examples of composite reinforcements.

The combination of lightweight, environmental resistance and adequate mechanical and physical properties has made aluminum and its alloys composites very popular. The melting point of aluminum is high enough to satisfy many application requirements. [23].



Cross section of the solar air collector with PCM cylinders

1.2. Aluminum metal matrix reinforced with ceramic particles

Various kinds of ceramic materials, e.g. SiC, SiO_2, Al_2O_3, MgO, ZnO, BeO, MnO_2, TiO_2, TiC, etc. are generally used as reinforcement elements. Superior properties of these materials such as refractoriness, high compressive strength and hardness, excellent wear resistance, etc. make them appropriate for use as reinforcement in MMC's [24-25-26].

Different methods such as casting, melt stirring, powder metallurgy, in-situ and infiltration can be used to produce MMC's. Melt stirring method has a good potential in all-purpose applications as it is a low cost MMC's production method [27-28].

Selection of the suitable method and material is the most important and effective criterion for manufacturing of MMC's. In addition, in case of MMC's manufacturing with melt stirring method, increased Reinforcement Volume Ratio (RVR) and decreased particle size resulted more difficult production process and increased porosity and particle agglomeration [29-30].

3.2. Metals and ceramic particles with capsulated paraffin

By mixing paraffin with alumina (Al_2O_3), titania (TiO_2), silica (SiO_2), and zinc oxide (ZnO) as the experimental samples and through heat conduction and differential scanning calorimeter experiments to evaluate the effects of varying concentrations of the nano-additives on the heat conduction performance and thermal storage characteristics of NEPCM's, their feasibility for use in thermal storage was determined, the experimental results demonstrate that TiO_2 is more effective than the other additives in enhancing both the heat conduction and thermal storage performance of paraffin for most of the experimental parameters. Furthermore, TiO_2 reduces the melting onset temperature and increases the solidification onset temperature of paraffin [31].

When brushes made of carbon fibers with a high thermal conductivity are inserted on the shell side of a heat exchanger to enhance the conductive heat transfer rates in phase change materials., the experimental results show that the brushes essentially improve the heat exchange rate during the charge and discharge processes even when the volume fractions of the fibers are about one percent [32].

A phase change material (PCM) consists of paraffin wax with 5% aluminum powder used as a thermal storage compound in a solar air heater, the compound supposed be encapsulated in cylinders as a solar absorber in cross flow of pumped air. An indoor simulation supposed that the PCM initially heated by solar simulator until liquid phase temperature (50°C) while the pumped air over the cylinders at room temperature (28°C), results show that the air temperature gained due to thermal energy discharge process decreases with increasing of air mass flow rate, and the freezing time for this compound takes long time interval for the lower mass flow rates [33].

K. karunamurthy, K. kumar and S. Suresh studied use of CuOnano-material for the improvement of thermal conductivity and performance of low temperature energy storage system of solar pond. They proved enhancement of thermal conductivity of the PCM. Also the performance of the PCM like charging and discharging time and the melting process are improved.

It is also observed that there is almost 50% reduction in charging time and discharging time of the PCM for a volume concentration of 0.16% and for all the three constant heat flux (flow rate of hot water). Further, there is a scope to determine the correct proportion of mixing the nano particle to the PCM and also there is scope to determine the better nano particle that can be dispersed with a particular type of PCM [34].

IV. Foam metals andcellular composites

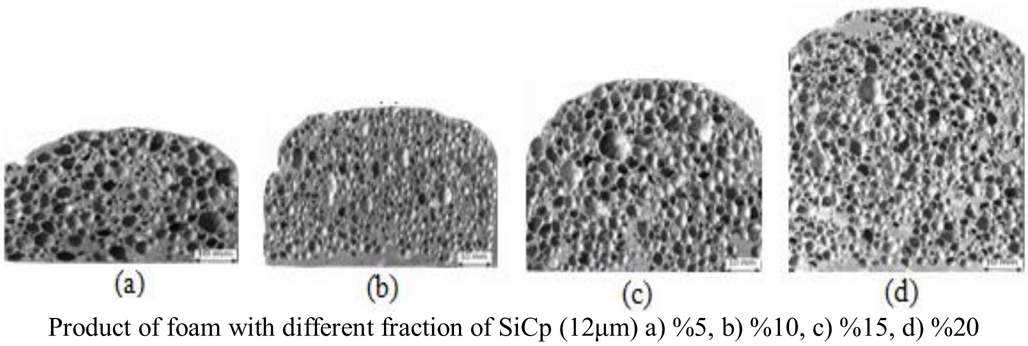
In the last two decades, another kind of material have been under increasing development and commercial utilization in different sectors of the economy such as building and architecture, mechanical, chemical industries: cellular metallic materials. These materials are highly porous, with relative density lower than 0.3, and present an interesting combination of properties, as low weight, high impact absorption, damping properties, sound and thermal insulation, etc. [35-36].

Metal foams keeping a combination of many advantageous properties of metals with low relative density, are cellular materials containing pores filled with gas. If pores insulated by metal walls from each other is referred to as closed cell metal foam. If pores interconnected with each other is referred to as open cell metal foam or metal sponge [37].

Because of consisting different physical and mechanical properties metal foams is become more popular and new applications of metal foams are brought out each passing day.

When an Al alloy AA2011 was infiltrated in the semisolid state into preforms of sintered NaCl particles, the results show the feasibility of the application of semisolid technology to produce open cell and closed cell syntactic foams, as well as low density metal matrix composites by thixoinfiltration of the alloy into removable preforms of NaCl particles or non-removable preforms of hollow glass microspheres and ceramic porous particulates. Concerning the materials produced, results show that composites containing porous reinforcements can present some mechanical characteristics of the conventional cellular metals. Taking in account this behavior associated to the low density and other specific properties inherent to composite materials, more attention must be paid to this new kind of material [38].

When a closed cell AlMg4.5Mn0.7 / SiCp composite metal foam were produced by direct foaming at semi-solid temperature, and the effects of reinforcement size and fraction on energy absorption were investigated, results show that energy absorption capability increase with increasing reinforcement ratio and decreasing reinforcement size.



Product of foam with different fraction of SiCp (12μm) a) %5, b) %10, c) %15, d) %20

It was realized that composite foam with produced by smaller size of reinforcement is more capable to absorption of energy [39].

The investigation of the thermal and acoustic properties of 6063 aluminum open cell foam prepared by the conventional precision casting method, when a water heating system and silencers were organized as a first step for its applications, as a result of heat transfer measurement, it was shown that temperature increase between the top and bottom of the foam became larger as the cell size increased.

Schematic of prototype water heater made 10 PPI 20 PPI 30 PPI
of open cell aluminum and heateropencell aluminum of 10, 20 and 30 PPI

This means that temperature rise effect is greater for larger cell size foam, even with the same amount of heat due to low density [40].

Lightweight linear cellular composite materials on basis of austenite stainless steel as matrix with reinforcements of MgO partially stabilized zirconia" ZrO_2" are described. The specimen with a zirconia fraction of 2.5 vol.% revealed the highest specific energy absorption.

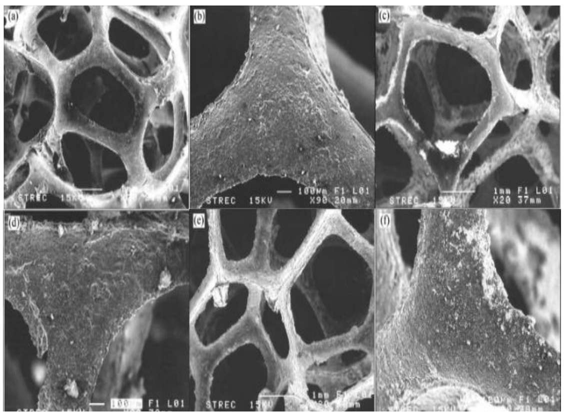
In this study, the investigated cellular stainless steel / zirconia composite material based on 2.5 vol.% Mg-partially stabilized zirconia achieved a specific energy absorption of 56 kJ/kg and 170 MJ/m^3, respectively[41].

In metallic sandwich panels with periodic, open-cell cores are important new structures, enabled by novel fabrication and topology design tools, their open cell structure allows for heat transfer into a coolant fluid, for the storage of electrical energy as a battery [42].

An example of a diamond orientation, 304 SS textile sandwich panel. The core relative density was 12.6%

When AA7075 alloy matrix reinforced with porous, lightweight and low cost $SiO_2/MgO/Al_2O_3$ ceramic particles produced by thixoinfiltration, the results show that the new cellular composite material can present low thermal conductivity, in the order of 30% of the conductivity of the alloy without reinforcement (depending on the volume fraction of reinforcement), the relative density and the thermal conductivity of the cellular composite increase with increasing the particles size [43].

Open-cell Al alloy (AC3A) composite foams with 1-5% SiC particles have been successfully produced using pressure infiltration casting method with polyurethane preform.



SEM micrographs showing structures of pure AC3A and composite foams containing
1% and 5% SiC particles: (a), (b) PureAC3A; (c), (d) AC3A+1%SiC; (e), (f) AC3A+5%SiC

Higher ceramic particle addition leads to higher volume fraction of the particles both in the matrix and on the strut surface, and results in the increased improvement of the compressive strength, energy absorption and microhardness of the foams [44].

For sponges, the typical applications of these open-cell materials so far are heat exchangers, filter elements, acoustic absorbers, stiffening elements, crash absorbers, metal matrix composites etc., because they have special properties, such as the permeability of the open-cell structure, high porosity and high ratio of surface area to volume etc. [45-46].

Those materials might be used for an optimization of the charging and discharging behavior of thermal latent heat storages by filling them with phase change materials PCM's. An advantage especially of open-cell composites structure is that the PCM even in a molten state is fixed by means of capillary forces [14].

There are number of processing methods can be used to manufacture Al foam. These methods can be classified into foaming liquid melts, gasar, infiltration, casting, foaming of powder compacts and sintering-dissolution process (SDP). Microstructure and properties of the final product depend on the manufacturing method. All these manufacturing routes have their own relative densities and cell structures. There are a variety of methods to fabricate open-celled aluminum foams, in which investment casting, pre-form infiltration and SDP are the most widely used routes[12].

1.3. Metal foams in paraffin storage unite

N. dukhan studied the thermal behavior of a small cylindrical shell phase change system. A cylindrical shell of open-cell aluminum foam was filled with Paraffin wax, after it was contained in a solid copper casing.

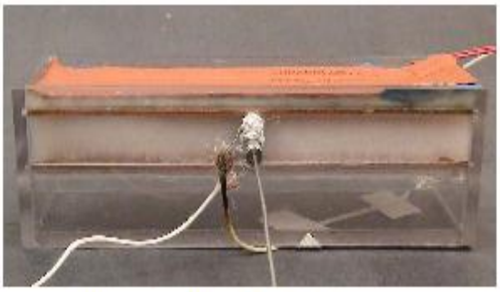
Phtograph of Aluminum foam shell

(a) (b)

Photograph of Foam Shell in Copper Casing
(a): Cross-Sectional View, (b): Outside View

The results showed that the heat transfer rate increased with increasing the airflow rate through the shell. At the maximum flow rate, the average core temperature decayed exponentially with time. Its behavior did not have the typical plateau at the solidification temperature of the wax, rather the behavior of this the core temperature mimicked that of a lumped system but with different slope. A possible explanation of this was the fact that the thickness of the core was relatively small, and that the system included other thermal mass (the copper container) [47].

The use of metal foam in thermal energy storage application was evaluated by designing and testing different thermal energy storage systems, with and without copper metal foam. The equivalent thermal conductivity of a foam-wax composite was found to be 3.8 W/mK which was 18 times higher than that of pure paraffin wax (0.21 W/mK). Copper foam reduced the time required to melt approximately the same amount of wax to 36% of that without the use of metal foam. The temperature gradients in TESS (with metal foam) while melting and solidification were significantly lower than that in a pure wax system.



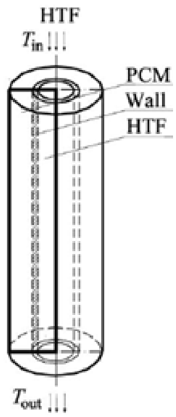
TESS with no Metal Foam

TESS with Metal Foam on wax side

The addition of metal foam on the wax side of the TESS helped to significantly increase heat transfer during melting but did not increase heat transfer to air during cooling. Hence, metal foam should be added to both wax and air sides to increase heat recovery by air. The outlet temperature of air passing through the TESS increases significantly when metal foam is placed on both wax and air sides [48].

K. Kavitha And S. Arumugam studied an experimental investigation on the thermal storage capacity for a typical composite mixture of paraffin- Graphite- Cu PCM composite. Paraffin wax was used as the base phase change material and the paraffin has been mixed with Cu turnings in different ratios 10, 50, 70 and 90 weight percentages and considered as a composite. The shiny black colour nature of graphite has been considered to provide a better absorption. The paraffin-Cu composite mixture was studied for different weight percentage 10, 20, and 30 mixture of Graphite powder. Results showed that the Paraffin copper PCM composite has higher heat transfer capacity when compared to pure paraffin. The heat charge and discharge performance of the Paraffin was found to be high, when the Cu turnings were mixed with paraffin in a smaller ratio of 10 weight percentage when compared with other weight percentage mixtures of copper.. It was also found that 20 weight percentage mixture of the graphite with paraffin-Cu had considerable better heat energy storage potential because of its expected good heat transfer property and the results have been presented.They tested this PCM composite assembly for heat exchanging property with stored volume of water which could be used as a heatreturning material due to its PCM characteristic property [49].

High conductivity porosity material-graphite foam was proposed to enhance the phase change materials, paraffin, in order to solve the problem of itslow conductivity in the latent heat storage exchanger (LHSE).The LHSE was suggested like shell-and-tube heat exchanger. Paraffin/graphite foam as the PCM filling the shell side andwater as HTF circulating inside the tube has been numerical analyzed in this study. Compared with the results of the purePCM, the phase change heat transfer can be greatly enhanced by using graphite foam in TES. The results showed also that HTF inlettemperature plays a significant role for reducing the meltingtime and liquid fraction, but the influence of flow velocity onmelting process is small although increasing velocity canreduce the melting time [50].



Schematic of the LHSE

Y. Tian and Y. Zhao investigated the effects of metal foams on heat transfer enhancement in Phase Change Materials (paraffin). The numerical investigation is based on the two-equation non-equilibrium heat transfer model, in which the coupled heat conduction and natural convection are considered at phase transition and liquid zones. They found that heat conduction rate is increased significantly by using metal foams, due to their high thermal conductivities, and that natural convection is suppressed owing to the large flow resistance in metal foams.

In spite of this suppression caused by metal foams, the overall heat transfer performance is improved when metal foams are embedded into paraffin; this implies that the enhancement of heat conduction offsets or exceeds the natural convection loss. The simulation results also indicated that metal foams with smaller pore size andporosity can achieve better heat transfer performance than those with larger pore size andporosity. In addition, a series of detailed evolutions of velocity and temperaturedistributions have been obtained; these illustrate clearly the phase change processes of theparaffin wax [51].

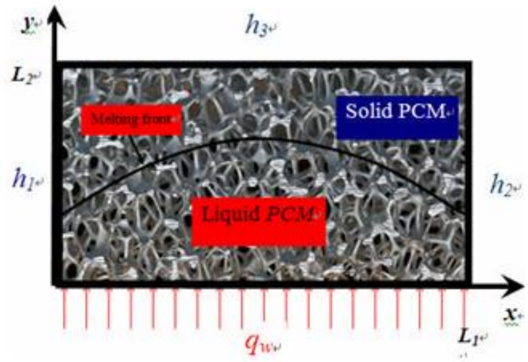


Illustration of PCMs embedded into metal foams

V. Conclusion

After review of various literature on cellular composites used in latent heat storage , the following conclusions were made:

1.4. Paraffin:

The thermal conductivity can be improved in an optimal manner by means of inserting an aluminum. Heat conductivity, thermal storage performance, specific energy absorption, reduction of the melting onset temperature and increasing of the solidification onset temperature of paraffin wax can be enhanced by addition an appropriate ceramic particles. A combination of highly porous aluminum foam and Paraffin wax enhanced the thermal conductivity of the core. The heat transfer rate increases with increasing the airflow rate though the shell. By means of inserting a copper metal foam can be improved the equivalent thermal conductivity of a foam-wax composite and reduced the time required to melt, also enhanced the temperature gradients in TESS while melting and solidification. Metal foam should be added to both PCM and HTF sides to increase heat transfer to HTF during cooling as it is during the heating. Unconstrained paraffin capsulated in spheres melts faster than those constrained paraffin., this is due to larger rate of heat transfer by conduction from the solid paraffin to the spherical capsules.

1.5. Metal matrix composites [MMC's]:

Increasing of RVR leads to an increase both porosity and energy absorption capability, and also causes a reducing of thermal conductivity. While increasing of reinforcement particles size leads to an enhancement of thermal conductivity and reducing of both porosity and energy absorption capability.

4.3. Metal Foams in Solar Cells:

A combination of highly porous aluminum foam and Paraffin wax enhanced the thermal conductivity of the core. The heat transfer rate increases with increasing the airflow rate though the shell.By means of inserting a copper metal foam can be improved the equivalent thermal conductivity of a foam-wax composite and reduced the time required to melt, also enhanced the temperature gradients in TESS while melting and solidification.Metal foam should be added to both PCM and HTF sides to increase heat transfer to HTF during cooling as it is during the heating.

4.4.Cellular composite structures:

The thermal conductivity can be greater for larger cell size foam.Reducing of reinforcement particles size results in the decrease in the relative density and thermal conductivity, also leads to an enhancement of energy absorption capability.Increasing of RVR leads to an increase of energy absorption capability and decrease of relative density.

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