International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 19 (2018) pp. 14365-14371

Performance analysis by Implementation of Microencapsulated PCM in Domestic Refrigerator: A novel Approach

Prashant Geete[1], H P Singh[2], Sunil K Somani[3]

[1] *Research Scholar, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.*

[2] *Dr. (Commodore) Pro-President, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.*

[3] *Professor (Vice- Chancellor), Medi-Caps University, Indore, Madhya Pradesh, India.*

Abstract

The use of Microencapsulated phase change materials (PCMs) to accumulate thermal energy in domestic refrigerators is a new solution to improve the energy efficiency of these appliances. Energy storage not only reduces the mismatch between supply and demand but also improves the performance. Experimental investigation has been carried out to enhance the performance of refrigerator by use of MEPCM. R134a refrigerant has been used for the investigation and Compressor power was 1/8HP, Air cooled condenser of length 11m and capillary tube of 0.036inch as expansion device. The test has been carried out at different load like 0.25, 0.5, 1 to 3 kg with and without PCM. The experimental result clearly shows that Phase change material can raise the performance of evaporator by maintaining the constant temperature by 6-8 hours and reduction of upto 1-2ºC for every one hour.

Keywords: phase change materials, energy efficiency, COP, Expansion device, Evaporator

INTRODUCTION

In Past 10 years, the energy demand constantly increases in India especially in cooling sector due to population growth and living standards improvement. Currently, the fossil fuels satisfy 85% of the total energy needs, and their direct impact on the climate is alarming. Currently every household uses at least one refrigeration system for domestic food preservation or in the building's mechanical ventilation system to provide the required indoor thermal environment. Refrigeration and air conditioning systems consume 15% of all electricity produced worldwide, as estimated by the International Institute of refrigeration (IIR) [1].

Storage of energy as thermal energy in Phase changing materials is a new research area it has large interest among technologists. Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy [2, 3]. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. For example, storage would improve the performance of a power generation plant by load leveling and higher efficiency would lead to energy conservation and lesser generation cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs).

The emerging technology of TES using PCMs presents itself as a suitable candidate for making these improvements. Storing large amounts of thermal energy that would previously have been lost or rejected, then recalling it for later use will enable. Even though the thermal conductivity of phase change materials (PCM) is usually not high, it is sufficient to enhance the global heat transfer conditions of an evaporator with air as external fluid and natural convection as heat transfer mechanism.

Use of Phase change material (PCM) for the latent heat storage in household refrigerators is one of the upcoming technologies in the field of refrigeration. Many researchers investigated on Dynamic model of vapour compression refrigeration system using Phase change material as latent heat storage medium show that the addition of thermal inertia globally enhances heat transfer from the evaporator and allows a higher evaporating temperature, which increases the energy efficiency of the system. The energy stored in the PCM is yielded to the refrigerator cell during the off cycle and allows for several hours of continuous operation without power supply [4]. An Experimental tests carried out to investigate the performance of a house hold refrigerator using a Phase change material (PCM). The PCM is located on the back side of the evaporator in order to improve its efficiency and to provide a storage capacity allowing several hours of refrigeration without power supply. The system has been tested with water and eutectic mixture (freezing point -30c) and for various operating conditions (PCM thickness, ambient temperature, and thermal loads). A 10-30% increase in COP depending on the thermal load is observed, and 5-8 hrs of continuous operation without power supply[5].

Types of PCM

PCMs can be broadly classified into two types: Organic PCMs e.g. Paraffin Wax and Inorganic PCMs e.g. Salt Hydrates [6-8].

Early efforts in the development of latent TES materials used inorganic PCMs. These materials are salt hydrates, including Glauber's salt (sodium sulphate decahydrate), which was studied extensively in the early stages of research into PCMs [9,10].

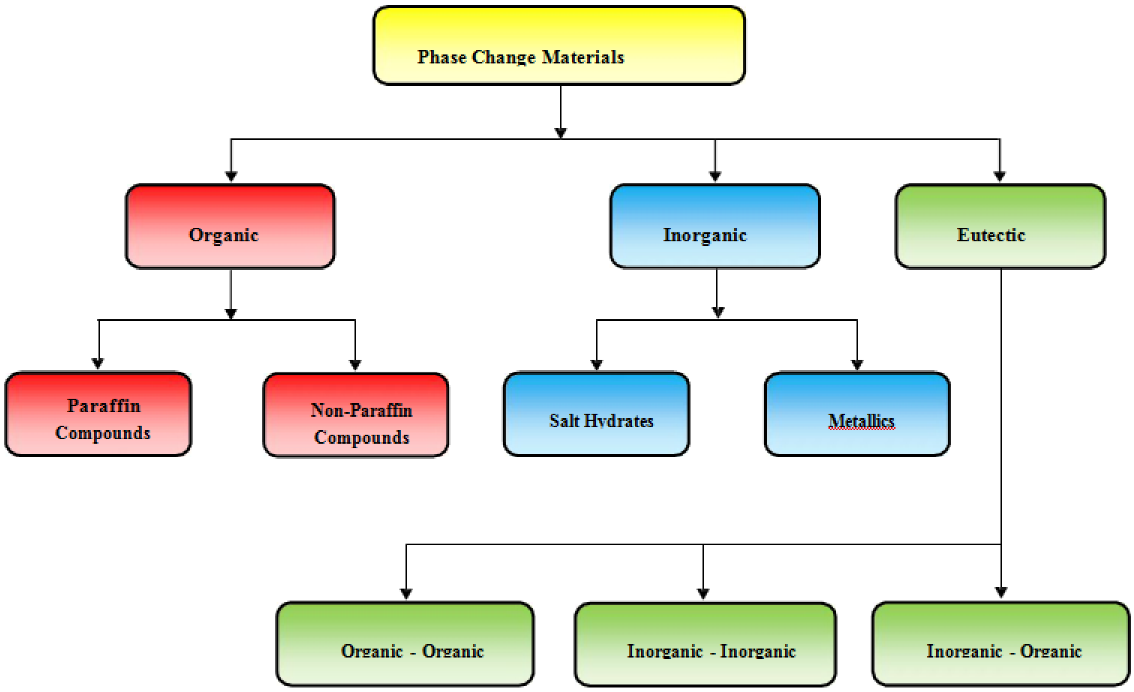

Figure 1 Classification of phase change materials

Encapsulation

Encapsulation is a process of engulfing the materials of solids or droplets of liquids or gases in a compatible thin solid wall. The material inside the capsules is referred to as the core, internal phase, or fill, whereas the wall is sometimes called a shell, coating, or membrane. Normally, encapsulation materials are classified as nanocapsules, microcapsules and macrocapsules based on the capsule size diameter.

Micro and Macro Encapsulation Methods

PCMs have a relatively low thermal conductivity and in principle there are two ways of solving this problem. On one hand the distances for heat transfer by conduction in the PCM can be shortened. This can be done by encapsulating the material into relatively small capsules or by highly dispersed heat exchangers with low distances between fins or pipes. On the other hand the thermal conductivity can be enhanced by embedding structures of materials with high conductivity into the PCM.

There are two principal means of encapsulation: micro and macro encapsulation. Micro-encapsulation enables to handle the PCMs independently of being solid or liquid. The microcapsules are tiny particles of solid, liquid or gas with diameters smaller than 1 mm and larger than 1 μ m (ussualy5–10 μ m in diameter), which surround the paraffinic PCM core material individually with a hard polymeric shell.The second containment method is macro-encapsulation, which comprises the inclusion of PCM 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 PCM must be encapsulated so that it does not adversely affect the function of the construction material.Both methods of PCM encapsulation in concrete (micro- and macro-encapsulation) may have some drawbacks. Plastic or metallic encapsulation of the PCM is expensive but safe, as the PCM is not in contact with the concrete. Microencapsulation by impregnating the PCM in the concrete is very effective, but it may affect the mechanical strength of the concrete [20].

Phase change material (PCM) could be a great option for enhancing the performance of refrigerator by reducing temperature fluctuation inside the evaporator cabinet. A phase change material (PCM) is a latent heat thermal energy storage system. These PCM melts and solidifies at a certain temperature. During the phase change time the material is capable of storing and releasing large amounts of heat energy. There is no artificial energy associated with the thermal energy storage using PCM.

Properties for phase change materials

Thermal properties

- Phase change temperature suitable to the desired operating range
- High latent heat per unit mass
- High specific heat
- High thermal conductivity in both solid and liquid phases

Physical properties

- High density
- Low density variation during phase change
- Little or no supercooling during freezing

Chemical properties

- Chemical stability
- No chemical decomposition
- Compatibility with container materials
- Non-poisonous, non-inflammable and non-explosive

Economic factors

- Available in large quantities
- Inexpensive

MATERIAL AND METHODS

In the present study, A refrigerator test rig has been fabricated and a separate evaporator freezing compartment is considered. The Performance of this device has been characterized by measurements of cooling capacity, electrical consumption, and evaporation and condensation temperatures. The average electrical consumption is about 650Wh per day for an internal temperature of 4°C and an external temperature of 22°C. The heat losses are characterized by a measured global heat transfer coefficient of 0.34 $Wm^{-2}C^{-1.}$ The phase change material considered here is Ethylene Glycol whose temperature range between -51ºC to 121ºC. The MEPCM slab is about 0.03 m x 0.45 m x 0.5 m The device is located on one side of the evaporator. In this study, a simple dynamic model of the refrigerating system is developed with and without a phase change material on the evaporator, for a better understanding of the effect of the storage device on the energy performance.

As evaporator coil and phase change material (PCM) are present in one panel, the PCM will absorbs the energy as evaporator coil cools and stores the energy by changing its phase. During power cuts or off peak time the PCM will releases its energy and maintains the cold cabin at constant require temperature for -10°C for about 6-8 hours depending upon the outside condition as it is proved by experiment. Thus a small difference in temperature can be used for storing energy and releasing the stored energy. In order to avoid the above stated problem, in this paper it is clearly analyzed experimentally that the thermal storage capacity can be improved by using phase change material panels incorporated in the walls of the cold storage.

Experimental test Rig.

Refrigerator with R134a having mass of 150g. Compressor power was 1/8HP, Aircooled condenser of length 11m and capillary tube of 0.036inch as expansion device.

Measuring Devices

As the measurement of variables affect the test results, care is taken to choose the best instrument at our premises.

Thermocouple:

The temperature at various points of the system is measured using thermocouples. The thermocouples used are Chromel-Alumel (known as K type thermocouples). The thermocouple tip is attached on various points of the copper refrigerant lines to note down the respective temperature

Pressure Gauge:

The pressure gauges used in this rig are of Bourdon tube type pressure gauges. Using copper tubes, tapings are taken from various points and the gauges are fixed on the panel board. For the high-pressure side, gauge with maximum pressure of 55Kg/cm^2 is used and at low-pressure side, gauge with maximum pressure of 17.5Kg/ cm2 is used.

Digital Energy meter:

In the experimental setup single phase digital energy meter is used for measuring the power input to the compressor.

Figure 2. Set-up of Experimental Test rig of in Refrigeration lab

1. **Compressor details:**

- Compressor Power = 0.167 H.P

1 H.P = 746 W

Therefore Power = 0.167×746=124.582 W

We use Reciprocating piston type compressor. The specifications of the compressor are as follows:

Table 3: Specification of Compressor

Phase	***Volts***	***Current***	***Speed***	***Cycles***	***Temperature***
Single	160/250	4 amp	2850 rpm	50 Hz	40ºC

Theoretical tonne of refrigeration system is 0.5 Ton.

2. Condenser Fan details:

Table 4: Specification of Condenser

Type	*Volts*	*Power*	*Speed*	*Current*	*Cycles*
Suction	*220/240*	*5W*	*1300 r.p.m*	*0.21 A*	*50/60Hz*

1. Condenser details:

Fine type 9 inch double row condenser is used
Heat extracted in the condenser = m c_p ΔT

= m c_p $(T_2 - T_1)$

2. Expander details:

- Diameter of capillary tube = 0.036 inch.
- Length of capillary tube = 2 M

3. Evaporator:

- Length of the evaporator coil = 11m
- Diameter of the evaporating coil = 1/4 inch

Result and Discussion

The performance of the test rig under different load with and without PCM is tested. Then the. Temperature limits are set between --25 ºC and 4 ºC of the evaporator. This is the usual temperature limit as this ensures the preservation of perishables inside freezer. After completing these tests, keeping those readings as the basis the refrigerator is tested with PCM at different conditions (varying loads, varying quantity of PCM etc.) Since our prime aim was not to modify the existing refrigerator, PCM was inserted inside the evaporator chamber. Here, we are assuming that the conduction losses through evaporator walls are negligible.

With PCM, the air temperature is kept constant at - 10°C for 6 hours, compared to without PCM where the air temperature rises continuously and rises above -10°C in just 1 hour. The PCM temperature rises slowly as the PCM melts over this 6 hour period. Once the PCM has finished melting, the air and PCM temperatures rise steeply.

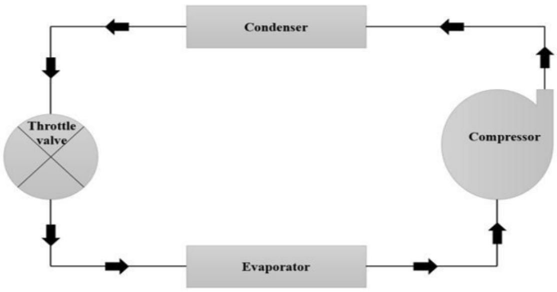

Figure 3 simple refrigeration cycle [11]

Table 1: C.O.P at different loads without PCM in evaporator

S.No	*Load (kg)*	*ΔT*	*Time (sec)*	*Heat Rejected Kw*	*Current (Amps)*	*Power (Kw)*	*C.O. P*
1	0.25	18	70	0.27	1.3	0.26312	1.026148
2	0.5	18	80	0.4725	1.5	0.3036	1.556324
3	0.75	18	110	0.515455	1.6	0.32384	1.591695
4	1	18	130	0.581538	1.7	0.34408	1.690126
5	1.5	18	145	0.782069	1.9	0.38456	2.033672
6	2	18	160	0.945	2.5	0.506	1.867589
7	2.5	18	180	1.05	3	0.6072	1.729249
8	3	18	195	1.163077	3.5	0.7084	1.641836

Table 2: Temperature variation at different time frame without PCM

S.No	*Time (hr)*	*Temperature (°C)*	*S.No*	*Time (hr)*	*Temperature (°C)*
1	0	-25	7	6	0
2	1	-20	8	7	4
3	2	-16			
4	3	-13			
5	4	-8			
6	5	-5			

Table 3: C.O.P at different loads without PCM in evaporator

S.No	*Load (kg)*	*ΔT*	*Time (sec)*	*Heat Rejected Kw*	*Current (Amps)*	*Power (Kw)*	*C.O. P*
1	0.25	18	45	0.42	1.3	0.26312	1.59623
2	0.5	18	60	0.63	1.5	0.3036	2.075099
3	0.75	18	75	0.756	1.6	0.32384	2.334486
4	1	18	105	0.72	1.7	0.34408	2.092537
5	1.5	18	150	0.756	1.9	0.38456	1.965883
6	2	18	195	0.775385	2.5	0.506	1.532381
7	2.5	18	240	0.7875	3	0.6072	1.296937
8	3	18	285	0.795789	3.5	0.7084	1.123362

Table 4: Temperature variation at different time frame without PCM

S.No	*Time (hr)*	*Temperature (°C)*	*S.No*	*Time (hr)*	*Temperature (°C)*
1	0	-25	14	13	-8
2	1	-23	15	14	-8
3	2	-22	16	15	-7
4	3	-21	17	16	-7
5	4	-20	18	17	-5
6	5	-19	19	18	-5
7	6	-17	20	19	-4
8	7	-17	21	20	-4
9	8	-15	22	21	-3
10	9	-12	23	22	-3
11	10	-10	24	23	0
12	11	-9	25	24	4
13	12	-9			

By incorporating this, set up in refrigeration system the co-efficient performance can be increased more than the systems that have not this set up. Phase change material is very effective in protecting the temperature rise in evaporator when there is power loss. For hours there is only 1-2 degree rise in temperature

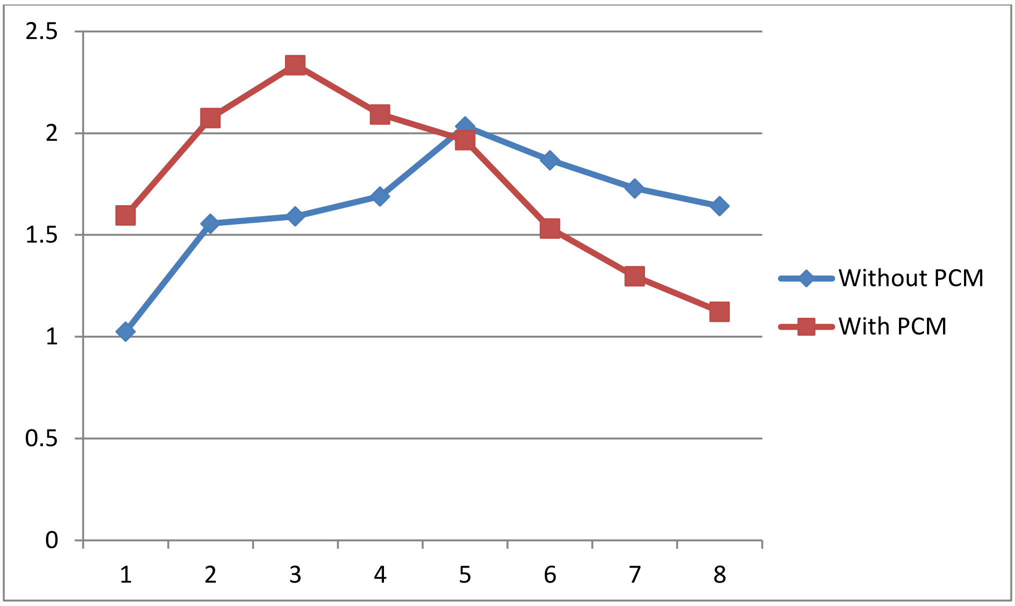

Figure 3. Comparison of COP at different load with and without CPM

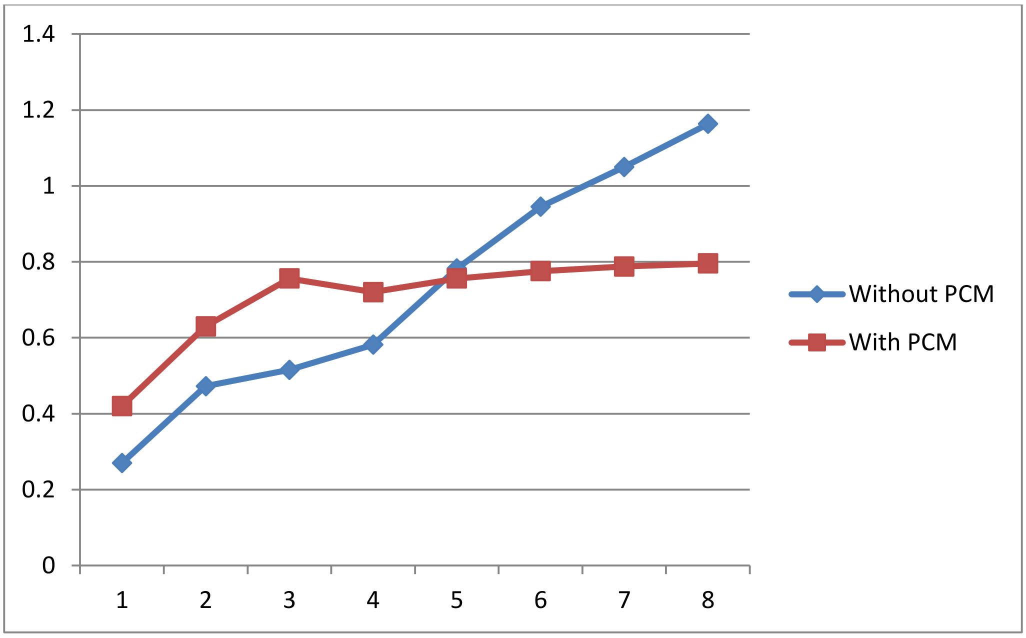

Figure 4. Comparison of Heat rejected at different load with and without PCM

CONCLUSION

Experimental investigation has been carried out to enhance the performance of refrigerator by use of PCM. R134a refrigerant has been used for the investigation and Compressor power was 1/8HP, Air cooled condenser of length 11m and capillary tube of 0.036inch as expansion device.

The test has been carried out at different load like 0.25, 0.5, 1 to 3 kg with and without PCM. The Temperature limits are set between --25 °C and 4 °C of the evaporator.

A notable improvement in the efficiency of the refrigerator was found out upon the addition of PCM material. The following conclusions were drawn based on the experimental result

- Phase change material can raise the performance of evaporator by maintain the constant temperature by 6-8 hours.

- In evaporator by using PCM it has been observed that temperature reduction is almost constant for number of hours and reduction of upto 1-2ºC for every one hour.
- It has been observed that up to 20% of COP improvement has been achieved by the phase change material with respect to without phase change material.
- Depending on the thermal load with phase change material the average compressor running time per cycle is reduced significantly and it is found about 17% to 30% as compared to without phase change material.
- The COP is calculated at different loads and it has been observed that the coefficient of performance (COP) is optimum at 1 Kg of thermal load while it decreases with the increase of thermal loads.

REFERENCE

[1] I.I.o. Refrigeration. Refrigeration Drives Sustainable Development – State of the Art – report card,. (2007).

[2] Garg HP, Mullick SC, Bhargava AK. Solar thermal energy storage. D.Reidel Publishing Co; 1985.

[3] Project Report. Energy conservation through thermal energy storage. An AICTE project.

[4] K. Azzouza, D. Leducq, D. Gobin, 2007. Performance enhancement of a household refrigerator by addition of latent heat storage. International journal of refrigeration , Elsevier, 208 pp.-892-901

[5] Azzouz K, D. Leduq and D. Gobin, “Enhancing the performance of household refrigerators with latent heat storage: An experimental investigation”, Int. J. Refrigeration, 2009, pp. 1634-1644.

[6] Ravikumar M., Srinivasan Dr.Pss., Phase change material as a thermal energy storage material for cooling of building, Journal of Theoretical and Applied Information Technology, 2005-2008, 4(6), p. 503-512.

[7] Ravikumar M., Srinivasan Dr.Pss, Natural cooling of building using phase change material, International Journal of Engineering and Technology, 2008, 5(1), p. 1-10.

[8] Zalba B., Marın J.M., Cabeza L.F., Mehling H., Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, Applied Thermal Engineering 23, 2003, p.251–283.

[9] Patil N.D., Design and Analysis of Phase Change Material based thermal energy storage for active building cooling: a Review, International Journal of Engineering Science and Technology (IJEST), 2012, 4(6), p.2502-2509.

[10] Khudhair A.M., Farid M.M., A review on energy conservation in building applications with thermal storage by latent heat using phase change materials, Energy Conversion and Management 2004, 45, p. 263-275.

[11] Castellon C., Medrano M., Roca J., Nogues M., Castell A., Cabeza L.F., Use of Microencapsulated Phase Change Materials in Building Applications, http://www.ornl.gov/sci/buildings

[12] Atul S, Tyagi VV, Chen CR, et al. Review on thermal energy storage with phase change materials and applications. Renew Sustain Energy Rev 2009;13:318–45.

[13] Hastings R, Wall M. Sustainable Solar Housing: Exemplary Buildings and Technologies. IEA Energy Conservation in Buildings & Community Systems Programme. Earthscan, 2007.

[14] Bales C. Solar Energy Research Center (SERC). Chemical and sorption heat storage. In: Proceedings of DANVAK Seminar, DANVAK Seminar (Solar Heating Systems – Combisystems – Heat Storage), 2006.

[15] Hadorn J-C (ed). Thermal Energy Storage for Solar and Low Energy Buildings—State of the Art. Servei de Publicacions de la Universitat de Lleida, 2005.

[16] Darkwa K, Ianakiev A, O’Callaghan PW. Modelling and simulation of adsorption process in a fluidised bed thermochemical energy reactor. Appl Therm Eng 2006;26:838–45.

[17] Perry RH, Green DW. Perry’s Chemical Engineers’ Handbook, 8nd edn. McGraw-Hill Professional Publishing, 1984.

[18] Kato Y. Chemical energy conversion technologies for efficient energy use. In: Paksoy H (ed.) Thermal Energy Storage for Sustainable Energy Consumption. NATO Science Series, 234, PART VI, Springer, 2007, 377–91.

[19] Justin Ning-Wei Chiu - Heat Transfer Aspects of Using Phase Change Material in Thermal Energy Storage Applications journal – 2011

[20] Farid, M.M., Khudhair, A.M., Siddique, A.K.R., Said, A., 2004 - A review on phase change energy storage: materials and applications, Energy. Covers. Manage vol. 45, no. 9-10: p. 1597-1615.