Polyethylene Glycol-600 as PCM to Enhance Efficiency of Thermal Device

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Abstract— PCMs are divided mainly into organic and inorganic materials [9,10,11]. Many researchers have described about PCMs and their types, Researchers have found that organic PCMs properties and characteristics are more advantageous than inorganic PCMs. Organic PCMs having high latent heat, low volume change, less corrosive, high chemical stability, high thermal stability than inorganic PCMs. In recent times, studies of PCMs are more attractive in the respect of their melting point temperature as useful for thermal energy storage. The melting point is main criteria in the selection of PCMs according to different type of applications. Some researchers have investigated the addition of PCM in different cold storage systems and units in order to enhance food quality and, to reduce electricity consumption during storage and transportation [ref]. Also several applications for thermal protection of biomedical products (such as organs and blood) during transport and storage have been studied over the years [ref]. In these applications the PCM are normally encapsulated in containers, hence the interest remains in designing a light weight, high conductive, non-corrossive, and low cost container.

Keywords: Polyethylene Glycol-600, PCMs, Thermal Device

I. INTRODUCTION

The requirement of energy in the field of cold storage, thermal storage, air conditioning and building sector is very high[1]. Due to transformation in life style of human being and requirement of energy to full fill the daily need human being are using huge amount of energy[2]. Nowadays the maximum energy generation is based on non- renewable sources. So the phase change materials are alternative source to save the energy and are capable to stop the exploitation of non-renewable source of energy [3]. Among the different type of thermal energy storage methods, latent heat thermal energy storage, which employs (PCMs) as the energy storage medium, is much meaningful as its high energy storage density and isothermal energy storage. Since few decades the use of PCMs is increasing in the field of cooling termed as cold thermal energy storage. Therefore cold thermal energy storage is an active area in research nowadays. The cold energy storage applications can be building air-conditioning, fresh/frozen food storage, heating, cooling, refrigeration(VAR and VCRS) systems[5,6,7,8]. Nowadays PCMs are using in building as latent heat thermal energy storage to maintain the desired room temperature. If PCM is used to maintain indoor temperature of buildings then we can minimize the peak load of electricity in summer season. Different types of PCM-based thermal energy storage techniques for building cooling applications have been reported.

II. EXPERIMENTAL SECTION

A. Material

Polyethylene glycol-600 was analysed in this paper. PCM is 98% pure and was in liquid state at room temperature. PEG-600 was used without any further purification.

B. DSC

DSC was performed by using a Mettler Toledo DSC 822e. The preliminary calibration for heat flow and temperature was performed using In and Zn as references. N_2 was used as the purge gas at a flow rate of 50ml/min. Approximately 10 mg of sample was sealed in a Al pan, and an empty pan was used as a reference. The samples were subjected to three consecutive heating and cooling cycles between 0 and 70°C. The result of final cycle was used to determine the thermal properties, such as melting temperature and LHF.

C. Endothermic and exothermic curves

The sample (10 g) was heated to 60°C in a water bath in a test tube. A thermocouple connected with the data logger was fixed inside the test tube with the PCM. when the endothermic process ended, the test tube was kept in the water bath at 70°C for the next endothermic process.

D. Thermal cycle tests

Thermal cycle tests on the PCM sample were conducted to study the thermal stability, change in melting point, and LHF after repeated melting and freezing cycles. The PCM was kept in a cold bath below its freezing point in a glass container to freeze the sample, which was followed by a hot bath above its melting point to melt the sample. This process was continued up to 1000 cycles, and samples were drawn from the test tube after every 200 cycles.

E. FTIR spectroscopy

IR spectra were recorded by using a thermo Avatar 370 FTIR spectrometer. A single drop of liquid- phase PCM was poured onto a KBr pellet (diameter 13 mm) prepared by using a hydraulic press with the application of a pressure 7 tonnes. Spectra were collected over a range of 4000-450 cm-1 resolution with an interferogram of 32 scans.

F. TGA

The thermal stability of the eutectic mixture was tested by using a TGA instrument was calibrated using a reference material. Samples (10 mg) in a Al pan were subjected to a heating rate a 10°C min^{-1} under a constant stream of N_2. Values were recorded to find the weight loss of PEG-600.

G. Corrosion test

Three common metals were selected as PCM containers: copper, aluminium, stainless steel. Metal samples used had

the dimensions of 50 mm in length, 10 mm in length, and a thickness of 0.5 mm.

III. METHODOLOGY

The experimental methodology was divided in three steps:
Preparation of the sample.
Corrosion and degradation test for metal.
Sample cleaning-up.

Metal samples were obtained from cutting big plates; therefore they had to be cleaned with acetone in order to remove the oil coming from the cutting process. All samples were weighted in a precision balance (3 decimal digits) from Mettler -Toledo before starting the experimental process.

Once the samples were weighted, they were immersed inside the glass test tubes containing PCM in order to combine each metal. Then the glass tubes were covered with plastic paraffin to avoid contact with environmental agents. The phase change temperature of PCM tested was around 21ºC, the experimentation was done at ambient temperature (23ºC), ensuring that during all the processes the PCM was in liquid phase.

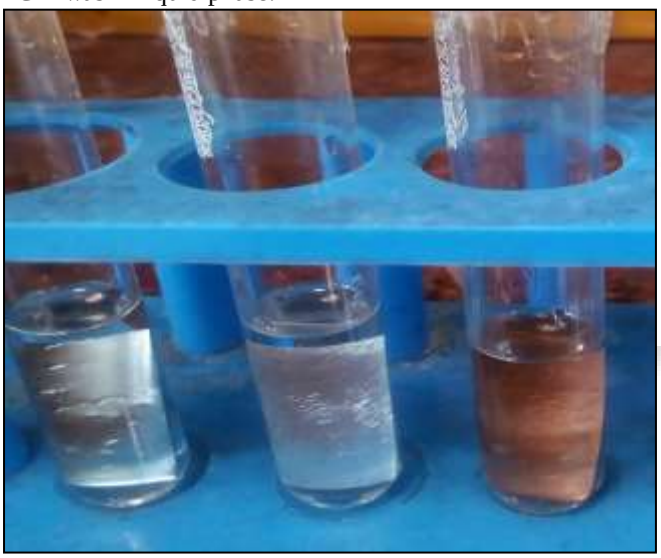

Fig. 1: S.S, Al, Cu samples dipped in PEF-600

Metals were removed from the test tubes after 1 week (7 days), 4 weeks (28 days), and 12 weeks (84 days), in order to see the evolution of corrosion rate in time. PH measurements with litmus paper were also carried out. Before reweighted samples were cleaned and dried.

Based on previous methodology the data obtained from experimentation were further evaluated. Hence corrosion rate of metal samples were calculated. In the case of metals mass loss (gm) were calculated with equation (1), considering the initial mass, $m(t_1)$, and mass measured after 1, 4, 12 weeks, $m(t_2)$, respectively.

$$\Delta m = m(t_1) - m(t_2)$$

Corrosion rate CR (mg/cm^{2}Yr) takes into account the mass loss (Δm), the area of the metal sample (A), and the experimental time (t_1-t_2) as is shown in the following:

$$CR = \frac{\Delta m}{A.(t1-t2)}$$

IV. RESULTS AND DISCUSSION

A. *Pure components*

The DSC curves of pure PEG-600 is shown in Figure 1. For PEG-600 one endotherm is observed upon heating, which corresponds to melting, and one exotherm is observed upon cooling, which corresponds to freezing.

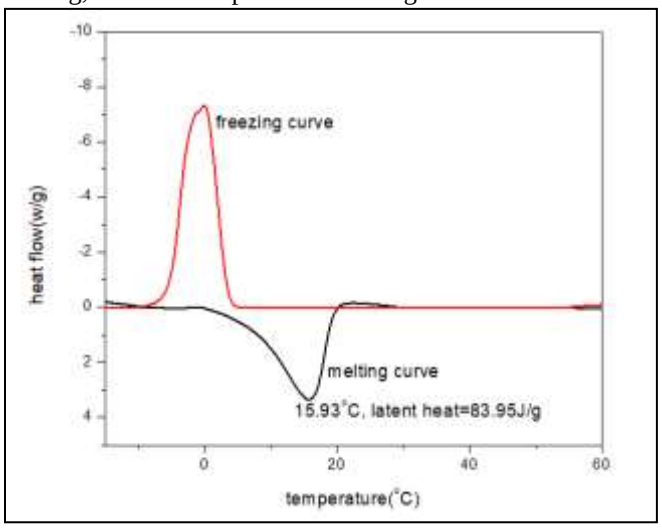

Fig. 2: DSC curve of PEG-600.

From the DSC curve, the peak melting and freezing temperatures are 15.93ºC and 0ºC. The corresponding change in enthalpy during melting and freezing is 83.95J/g and -130.53J/g respectively.

The temperature- time curve of the PEG-600 is shown in Fig 3. During the endothermic process, the temperature is almost the same. The horizontal section of the curve represents the melting point of the binary mixture, which is close to the theoretical value.

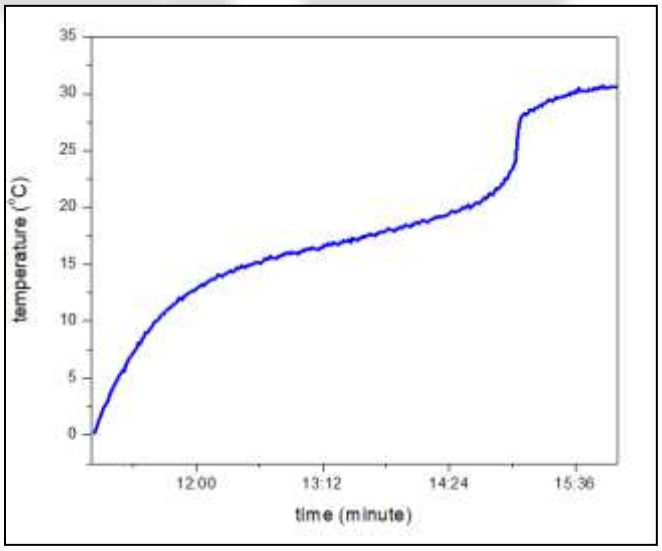

Fig. 4: Temperature-time curve for melting

B. *Accelerated thermal cycling test*

The melting point and LHF were measured for the PCM between 0 and 1000 thermal cycles at a regular interval of 200 cycles (Fig 4). The DSC curves of the PCM after 0, 200, 400, 600, 800, 1000 cycles are shown in Figure 5. After 1000 thermal cycles, the melting point of the PCM decreased to

14.76ºC and the LHF increased to 86.60 J/g. The results of the zeroth cycle are used as a reference,

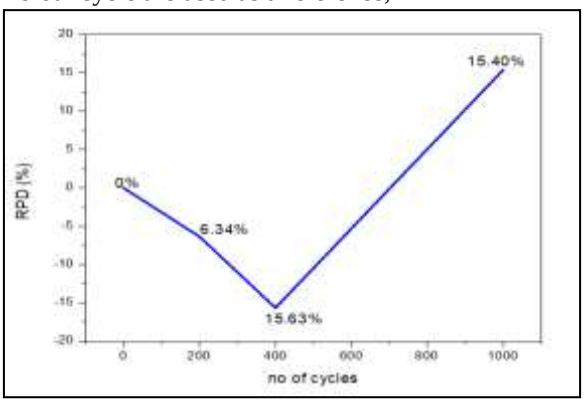

Fig. 5: Variation of melting point after thermal cycling.

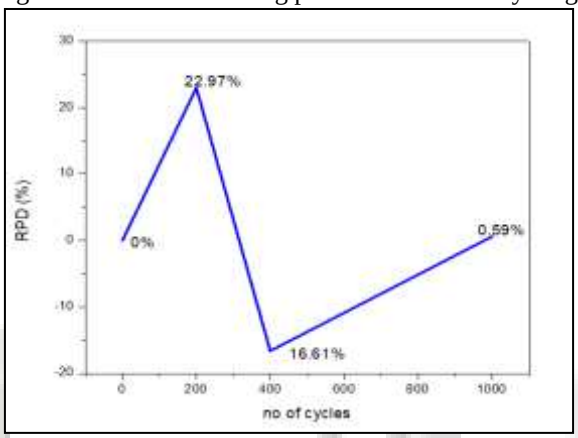

Fig. 6: Variation of the latent heat after thermal cycling.

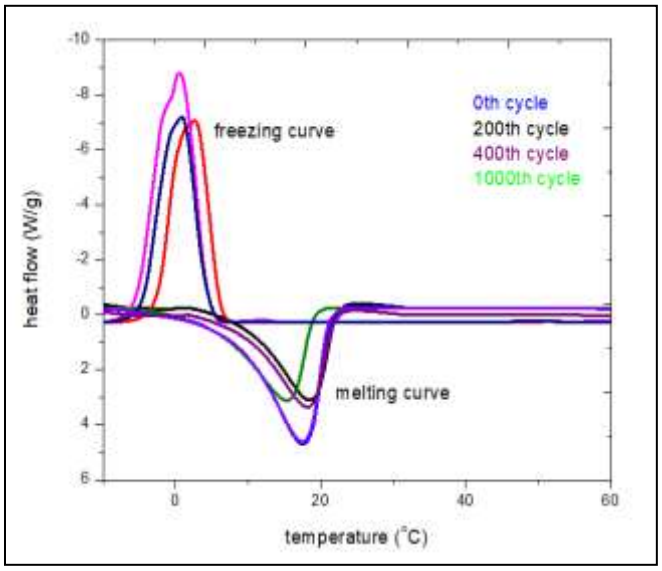

Fig. 7: DSC curves of the PCM 0, 200, 400, 1000 thermal cycles.

and the relative percentage difference (RPD) was calculated using equation

$$\text{RPD} = (\boldsymbol{Xn,i} - \boldsymbol{Xo,i})/\boldsymbol{Xo,i} \times 100$$

In which i is the property of the PCM, such as melting point or LHF, and $X_{n,i}$ and $X_{o,i}$ are the values after the n^{th} and 0^{th} cycles. The melting point and LHF with their corresponding RPD values for cycled samples are presented in Table 1. After thermal cycling, the melting point varies by a maximum of 15.63% and the LHF varies by a maximum of 22.97%. The variation in the properties is negligible compared with the reference values. Therefore, the PCM possesses a good thermal stability even up to 1000 thermal cycles and it can be used as a promising thermal energy storage material for cold thermal energy storage as cold storage.

Melting point and LHF with RPD after thermal cycling according to DSC CURVE

cycles	Tm (ºC)	RPD of melting point[%]	ΔH [J/g]	RPD of LHF[%]
0	15.93	0	83.95	0
200	14.92	- 6.34	103.24	22.97
400	12.79	- 15.63	86.09	- 16.61
1000	14.76	15.40	86.60	0.59

V. FTIR SPECTROSCOPY

Fourier – transformation infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high-spectral-resolution data over a wide spectral range. The term FTIR originates from the fact that a Fourier transform is required to convert the raw data into the actual spectrum.

FTIR absorption spectra of PEG-600 at initial condition and after 1000 cycles are presented in below figure. The FTIR spectra were similar before and after 1000 cycles. In the spectrum of PEG-600, peaks at 3385.70 and 3556.46 cm^{-1} are caused by the O-H and C-O stretching vibrations. The C=O and $–CH_2$ stretches appear at 1936.38cm^{-1} and

1643.49cm^{-1} respectively. The absorption peaks at 1936.38 and 554.59 cm^{-1} represent C-O stretching.

After 1000 thermal cycles we can see that the PCM is stable and there are no structural changes. The PCM is stable over continuous thermal cycling, which shows that PCM can be used for long term thermal energy storage applications.

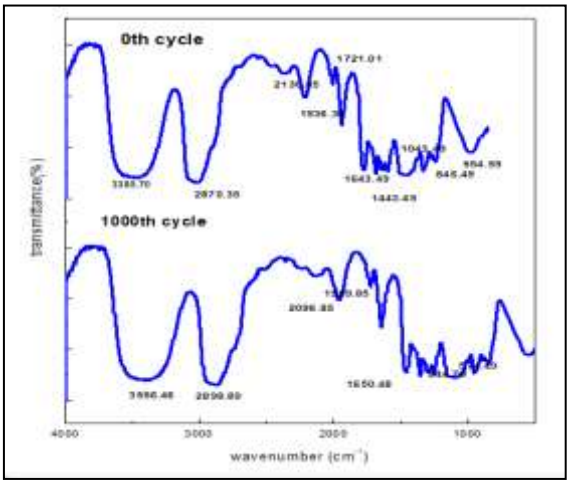

Fig. 8: FTIR spectra of PEG-600 after 0 and 1000 cycle.

VI. TGA (THERMAL GRAVIMETRIC ANALYSIS)

TGA is a method of thermal analysis in which the mass of a sample is measured over time as the temperature changes. This measurement provides information about physical phenomena, such as phase transitions, absorption, desorption as well as chemical phenomena including thermal decomposition and solid gas reactions.

A. Application

Thermal stability

TGA can be used to evaluate the thermal stability of a material. In a desired temperature range, if a species is thermally stable, there will be no observed mass change. Negligible mass loss correspond to little or no slope in the TGA trace. TGA also gives the upper use temperature of a material. Beyond this temperature the material will begin to degrade. Most polymers melt or degrade before 200ºC. However there is a class thermally stable polymers that are able to withstand temperatures of at least 300ºC in air and 500ºC in inert gases without structural changes or strength loss, which can analysed by TGA.

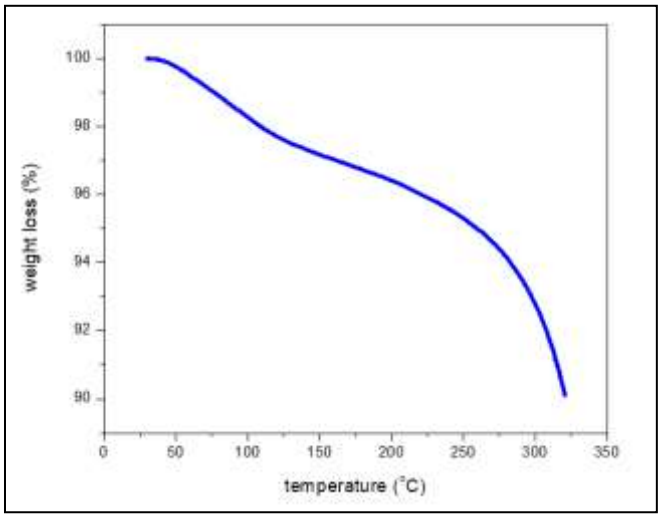

Fig. 9: TGA curve of PEG-600

This TGA graph is showing slope that means PEG-600 is degrading after 75ºC temperature. The slope in this graph indicates the weight loss after a definite temperature. Up to temperature range 75ºC PEG-600 can be used .PEG-600 is thermal stable up to 75ºC temperature range.

VII. THERMAL CONDUCTIVITY

Phase change materials are widely used in energy-efficiency initiatives for thermal energy storage. PCMs are interesting because they store the thermal energy of a phase change called the latent heat of phase change on heating and cooled, they can give off the stored heat by reversing the phase change.

The ideal PCM is stable, chemically inert, and nonflammable. As well it also has a high latent heat of phase change, remains solid through the phase change and has thermal conductivity to maximize the efficiency of the heat transfer during the phase change. Thermal conductivity being a key performance metric of the materials. A key performance metric of PCM is its ability to exchange heat with its surroundings – a metric which is often referred to as thermal inertia or more commonly thermal effusivity. Thermal effusivity is governed by $e = (\rho \cdot Cp \cdot k)^{1/2}$ where e is the thermal effusivity. Cp is the specific heat capacity at constant pressure, k is the thermal conductivity. Thermal effusivity unit is in $ws^{1/2}/m^2k$.

Temperature^{o}c	10ºC	20ºC	30ºC	40ºC
Thermal Conductivity W/Mk	0.352	0.481	0.185	0.187
Thermal Conductivity W/Mk	0.261	0.537	0.202	0.186

Above table is showing thermal conductivity at different temperature in two phases. The graph plotted according to data is given below.

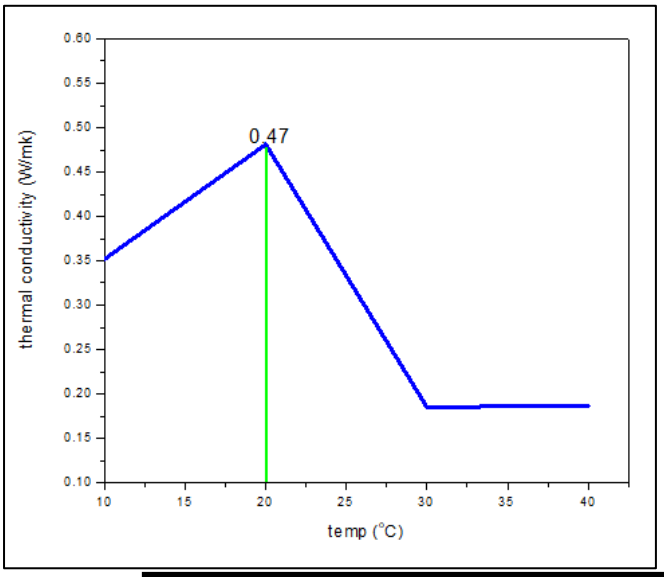

Fig. 10: Thermal conductivity graph for PEG-600

According to graph the maximum thermal conductivity is at 20°C. Starting from 10°C when temperature is increasing then thermal conductivity is increasing as usually it increases with temperature rises in liquids. It is maximum at 20°C for PEG-600.

VIII. CORROSION STUDIES

The corrosion results for Cu, Al, and stainless steel with the PCM are presented in the Table after 1, 4, 12 weeks. If we used the PCM with a Cu

CORROSION RATE OF METAL SAMPLES IN CONTACT WITH PCM

Material	corrosion rate(mg/cm^2 /year	CR= [(initial – final)/ (area.time)].100
	after 1 week	after 4 weeks
Cu	0.014	0.007
Al	0	0.014
Stainless steel	0	0

Plate a black deposit was absorbed over the surface of the metal sample as a result of corrosion and it shows a higher corrosion rate than the other metal samples. If we used Al samples a black deposit over the metal surface was detected, which evidence of corrosion. In the case of stainless steel no corrosion. The metal samples before and after the corrosion studies are shown in figures respectively. The corrosion rate calculated from the mass loss during the corrosion analysis is presented in above Table. The corrosion rate of Cu decreased considerably with the increase of the time of the metal samples to the PCM with the metal surface and the PCM that prevents the direct contact of the PCM with the metal surface. The same phenomenon was found for the Al sample, stainless steel show a mass loss after 1 week in the presence of dust particles on the surface even after cleaning , which was reduced after 4 and 12 weeks.

Fig. 11: Cu, Al, and stainless steel 316 specimen before testing.

IX. CONCLUSIONS

A new phase change material (PCM) was identified for cold thermal energy storage applications. The sample was analyzed by using differential scanning calorimetry. The melting point of the PCM was found 15.93ºC and freezing point was 0.3ºC respectively. And the corresponding latent heat values were 83.95J/g and -130.53J/g respectively. The measured melting point is in the thermal comfort range, and the PCM can be used for cold thermal storage systems. The result of thermogravimetric analysis showed the good thermal stability of the PCM. The difference between the phase change temperature and decomposition temperature is high, and the PCM is safe and stable for use in real world applications. After 1000 thermal cycling, there was a negligible change of melting point and latent heat of fusion of the PCM. We confirmed that the PCM was chemically stable even after 1000 thermal cycles by using FTIR spectroscopy, and no notable structural variations were there. More over the corrosion results proved that the PCM was compatible with Al and stainless steel and recommended for long term use. However use of PCM with Cu shows corrosion, and Cu is not recommended for use as a constructional material. Therefore, the PCM is a potential cold thermal storage material that can be used.

REFERENCES

[1] Thermal energy storage design manual by www.pcmproducts.net
[2] U.S. Energy Information Administration, Annual Energy Outlook with projections to 2050, 2017.
[3] BP Statistical Review of World Energy 2018, 67th ed., London, 2018.
[4] Akhtar Hussain, Syed Muhammad Arif, Muhammad Aslam, Emerging renewable and sustainable energy technologies: state of the art, Renew, sustain, Energy Rev. 71 (2017) 12 – 28.
[5] Rubitherm GmbH 1993. https://www.rubitherm.eu/en/ (accessed July 29, 2018).
[6] PureTemp – Global Authority on Phase Change Material 2007. http://www. puretemp.com/ (accessed July 29, 2018).
[7] T. Silva, R. Vicente, F. Rodrigues, Literature review on the use of phase change materials in glazing and shading solutions , Renew, sustain Energy Rev.53(2016) 515-535.
[8] T. Silva, R. Vicente, F. Rodrigues, Literature review on the use of phase change materials in glazing and shading solutions,
[9] S. Devahastin, S. Pitaksuriyarat, Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product, Appl. Therm. Eng. 26 (2006) 1705–1713. during drying and its effect on drying kinetics of a food product, Appl. Therm. Eng. 26 (2006) 1705–1713
[10] Y.L. Lu, W.H. Zhang, P. Yuan, M.D. Xue, Z.G. Qu, W.Q. Tao, Experimental study of heat transfer intensification by using a novel combined shelf in food refrigerated display cabinets (Experimental study of a novel cabinets), Appl. Therm. Eng. 30 (2010) 85–9
[11] J.H. Johnston, J.E. Grindrod, M. Dodds, K. Schimitschek, Composite nanostructured calcium silicate phase change materials for thermal buffering in food packaging, Curr. Appl. Phys. 8 (2008) 508–511

