# Development Of Heat Storage System For Solar Cooker

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***Abstract*—The use of a latent heat storage system using Phase Change Materials (PCM) is an effective way of storing thermal energy in solar cookers. It has been demonstrated that, for the development of a latent heat storage system, choice of the PCM plays an important role. In this paper, we make an effort to test few ionic liquids tetra ethyl ammonium cation [N+2222] with inorganic anions like BF4-, PF6- for solar cooker. DSC tests of both mentioned materials were carried out to get the amount of heat storage capacity of them. An empty cooker test was also performed for comparison. The cooker was tested with power supply and the heating and cooling time was measured.**

***Keywords- Phase change material, solar energy, Latent heat storage system, hybridized solar cooker, ionic liquids.***

## I. INTRODUCTION *(HEADING 1)*

Solar energy is one of the most promising sources of renewable energy which is free, environment friendly and available almost everywhere. The use of solar energy for cooking is one of the simplest attractive option [1].But as it is intermittent, unpredictable, and available only during the day so its optimum utilization requires efficient thermal energy storage systems. The heat stored during the phase change process (melting process) of the material is called latent heat. Latent heat storage has two main advantages: (i) it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density; (ii) because the change of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations. The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached. Sharma et.al has published many papers on Solar Cooking using PCMs for evening and night cooking [2]. The Phase changing materials (PCM) can be used for heat storage as they absorb the heat to melt and store this heat in the form of latent heat. The PCMs with high specific heat capacity can also collect heat in the form of sensible heat after melting. Attempts are also being made in storing different forms of energy which can be released at a desired time [3, 4]. Thermal energy is one such energy which is of interest to researchers worldwide [5]. During the past few decades, many articles reporting investigations of solar thermal energy storage systems and their applications have been reported. Emphasis has mainly been put on performance evaluations, design fundamentals, transient behavior and thermal analyses as well as system process optimization [6].The most popular applications of PCMs found in solar-energy storage systems are for water heating, greenhouses, space heating and cooling and cooking [3,4,7-11]. The use of solar cookers is limited due to lack of energy storage facility. It cannot be used on cloudy days or in the late evening or night time. Solar cookers with PCM as Heat storage devices can be used during the day time as well as night time too. The design, testing methodology and utility of a box type solar cooker are well developed [12]. Sharma and et.al has developed number of cookers with PCM as heat storage , as it is possible to store large amount of heat with only small temperature changes and therefore have a 5 to 10 times higher storage density [13-17].

The authors have designed and developed a small scale solar cooker and tested the performance for $BF_4^-$ and $PF_6^-$ materials. The tests were performed in fully controlled conditions in the laboratory itself. These materials were selected because of their compatibility of material with container, thermal stability, phase separation, non-flammability and economic factors.

## II. MATERIALS AND METHOD

*A.* Melting points were measured using capillary tube apparatus, and are quoted as the visual observation onset of the melt. The thermometers used in the entire study had an uncertainty of ± 0.5 °C. The water content in the ILs was determined using Karl-Fisher titration technique. Each of the samples exhibited water content below 100 ppm. Density (ρ) of the materials was measured using specific gravity bottle methods at their melting temperatures. The uncertainty of measurement for the bottles used was 0.00001g/ml. Infrared spectra were recorded on a GX FT-IR PERKIN ELMER instrument. All samples were examined as KBr pellets. Thermo gravimetric Analysis (TGA) was conducted using Perkin Elmer between 30 °C to 300 °C with the temperature rate 10 °C $min^{-1}$. The instrument was calibrated using melting points of indium, tin, lead and zinc. Aluminium pans were used in all the experiments. The uncertainty of measurement of the tube was 0.0001g/ml. The linear volume expansion in the temperature interval of 10 °C above and below the melting point was then calculated using the equation 1.

$$\alpha=\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p \quad (1)$$

The thermal conductivity of ILs was calculated using a known method [16].

$$k_s=\frac{\left[1+\frac{C_p(T_m-T_{oil})}{\Delta H_m}\right]}{4\left[\frac{t_{fs}(T_m-T_{oil})}{\rho R^2\Delta H_m}\right]} \quad (2)$$

A reverse experiment in which the oil temperature was maintained at 120 °C was conducted to obtain the thermal conductivity of ILs in liquid state.

1) Differential Scanning Calorimetry (DSC).

In power compensated DSC, the sample and a reference material are maintained at the same temperature through the controlled temperature programme. Any energy difference in the independent supplies to the sample and reference is then recorded against the programmed temperature. The Perkin Elmer, Model Pyris 1 DSC shown in figure 1 was used to get the DSC of both the mentioned ionic liquids. Exactly 2.5 mg sample was weighed in aluminium pan. Sample pan was kept in sample cell against reference cell. For low temperature analysis, Liquid nitrogen was used. Analysis was started once equilibrium has reached up to desired temperature (10°C). Once the run completed, delta H, Peak height, Area was calculated by software. Programme set for sample analysis 10°C to 250°C at 10°C heating rate per min with 20ml/min flow rate of Nitrogen gas.

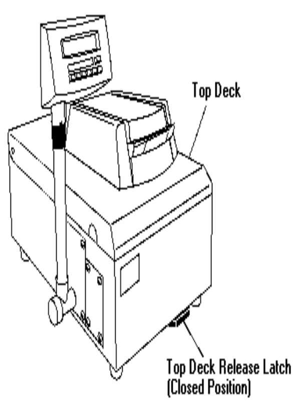


Fig. 1(a) Schematic diagram of DSC Perkin Elmer, Model: Pyris 1 DSC Fig. 1(b) Photograph of DSC

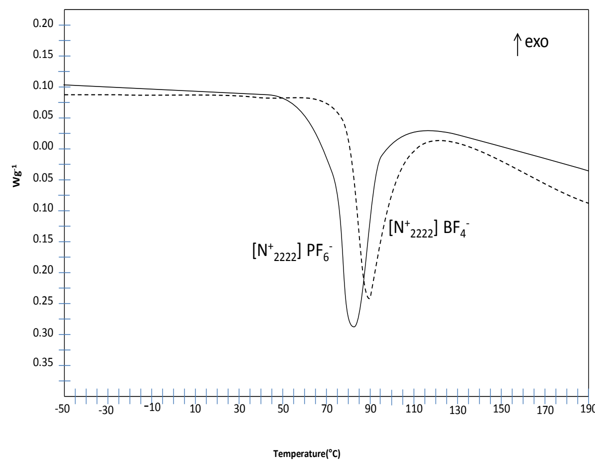


Figure 2: DSC thermogram of BF4- & PF6- materials

Figure 2 and 3 shows the DSC thermograms and TGA of BF4-, PF6- respectively. These tests were conducted at Sophisticated Instrumentation center for applied Research and Testing, SICART, Vallabh Vidyanagar, Gujarat, India.

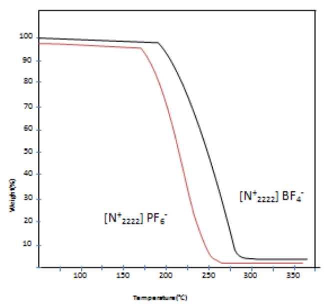


Fig 3: TGA of BF4- and PF6- materials

All the thermal characteristics of the samples under present investigation are shown in table 1. The thermal data of the salts were derived from TGA and DSC. A wide range of melting points (46 °C to 170°C) has been observed. This broad range is heartening as it permits a variable usable temperature range.

The decomposition temperatures of all the samples were obtained from TGA thermogram. The absence of moisture in ILs was confirmed by the lack of weight loss around 100 °C in TGA thermograms. All the samples registered a thermal stability at least up to 220°C. The ILs displayed a weight loss around 225 °C. A close proximity in the density values was observed in the samples under present investigation (table 1). These values were found to be in the range of 1023 to 1157 kg/m3 which clearly indicates the superiority of these materials over water. Materials with high density occupy less space and can have a high energy storage capacity.

*B* ***Heats of fusion.***

Heat of fusion is the amount of energy required during phase change of solid to liquids. It is one of the most important properties for a potential TES device. These Values of heat of fusion were calculated from the area enclosed in the DSC melting endotherm. Large values of heat of fusion are indicative of greater effectiveness in TES applications. The broadness of the final melting peak of a DSC thermogram in some cases also indicates the onset of one or more solid-solid transitions coincident with melting point. Heat capacity and density can be calculated by DSC and densitometery respectively. Thermal energy storage capacity can be calculated in the usable temperature range using equation (1) [17].

**Heat capacity and thermal energy storage capacity.** Heat capacities of all the ILs reported were calculated from the DSC thermograms. These values were calculated in the temperature range of first and last transitions. The values of heat capacity were found in the range of 0.70 to 1.70 kJ/kg °C. These values were found to be near the higher end in case of iodate, bicarbonate and nitrite containing ILs. The bromate and nitrate moieties showed the least value for heat capacity. The standalone value of heat capacity was not of much significance as the more important property, thermal energy storage capacity depends on temperature range and density also. Thermal energy storage capacities were calculated in the usable temperature range ($T_{decomp}$ - $T_m$) using the following equation (3) [11].

$$E = \rho\, C_p (T_{decomp} - T_m) \qquad 3$$

Most of the ILs registered a significantly higher value of thermal energy storage capacity in the diversity of 0.695 to 2.293 × $10^5$ kJ/$m^3$. Once again, the iodate, nitrite and bicarbonate moieties exhibited the highest values of thermal energy storage capacity across the series. The least value was registered by the IL containing nitrate anion.

| ILS | $[N^+_{2222}][BF_4^-]$ | $[N^+_{2222}][PF_6^-]$ |
|---|---|---|
| $T_m$ °C | 91 | 82 |
| $T_{decomp}$ °C | 190 | 170 |
| α $10^{-3}$ /°C | 0.71 | 0.57 |
| ρ kg/$m^3$ | 1132 | 1074 |
| $C_p$ kJ/kg °C | 1.00 | 1.40 |
| E $10^5$ kJ/$m^3$ | 1.121 | 1.323 |
| $\Delta H_m$ kJ/kg | 102.08 | 132.00 |
| $t_{fs}$ s ($t_{fl}$ s) | 64 (52) | 62 (32) |
| $k_s$ & ($k_l$) w/m°C | 0.42 (0.72) | 0.36 (0.74) |

Table: 1 Thermal Charecteristics of ILs in usable temperature Range

**Thermal conductivity.** All the samples registered several fold high values of thermal conductivity in liquid state as compared to that of the solid state. These values really become important when the material is to be used as a heat transfer liquid or a TES device. Higher values of thermal conductivity in liquid state permit efficient heat transfer while lower values in solid state offer better heat retention. These values showed a considerable variation both on state to state basis and sample to sample basis.

$$E = \rho C_p (T_2 - T_1) \quad (4)$$

The heat storage can be calculated as

$$E = V \rho c_p dt \quad (5)$$
$$= m c_p dt$$

Heat of fusion is the amount of energy required during phase change of solid to liquids. It is one of the most important properties for a potential TES device. These Values of heat of fusion were calculated from the area enclosed in the DSC melting endotherm. Large values of heat of fusion are indicative of greater effectiveness in TES applications. The broadness of the final melting peak of a DSC thermo gram in some cases also indicates the onset of one or more solid-solid transitions coincident with melting point. In the present study, such transitions near to the melting points are not distinguished and are considered to be solely due to phase change.

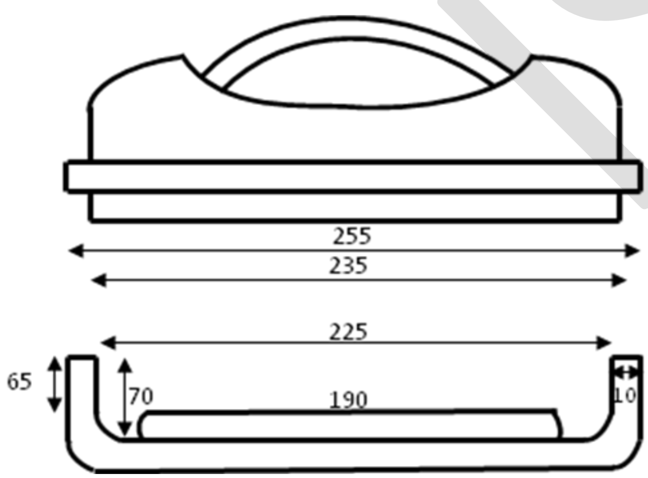


Fig.4 schematic diagram of Photovoltaic and Thermal hybridized solar cooker [9]

Fig. 4 shows a sketch of casserole solar cooker. Both the outer and inner boxes are cylindrical in shape and made up of stainless steel. The gap between both the boxes was filled with polyurethane foam (PUF) which served as insulating material. A separate air tight fixed cover made up of stainless steel without any glass cover fits well with the casserole pot. A dish type heater running with direct current is fitted in the inner box of the cooker. It does not need any glass material or mirror as the cooker is designed for indoor cooking. Fig.5 shows the temperature profile of an empty cooker. The empty cooker took nearly 110 minutes to reach 200 °C.

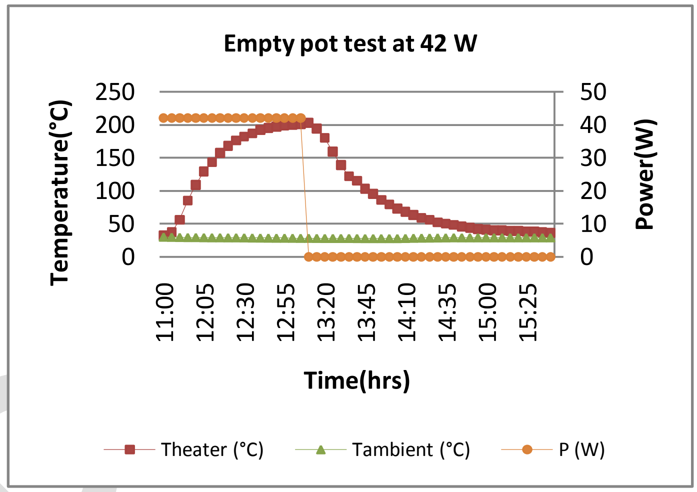


Figure 5 time vs. temperature plot for empty pot

Fig.6 shows the temperature profile of the ionic liquid containing $BF_4^-$ anion. 20 gram of the sample of $BF_4^-$ material was taken for the testing. The initial temperature of ionic liquid was 27.4 °C and it became 117.4 °C within fifteen minutes. The maximum temperature was 226 °C after 70 minutes then the power supply was switched off. Ambient temperature and humidity were 25.7 and 52 respectively which were found nearly constant as it was controlled testing inside the laboratory.

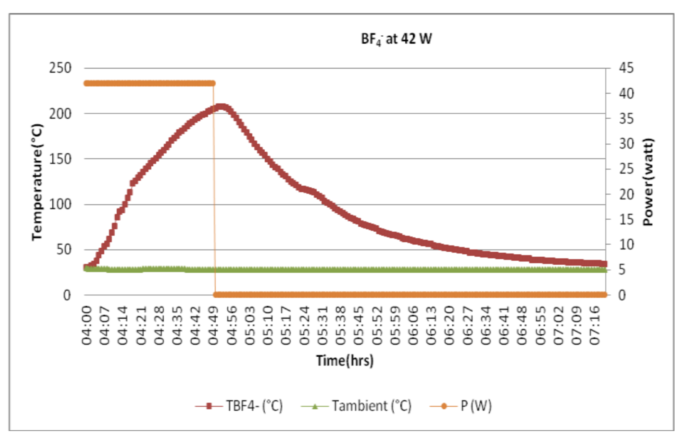


Figure 6 time vs. temperature plot for $BF_4^-$

Fig.7 shows the testing of one of the ionic liquid $PF_6^-$. 20 grams of ionic liquid containing $PF_6^-$ anion was taken in a pot for testing. The initial temperature of the ionic liquid was 28 °C and it was raised 99.9 °C within 15 minutes and the maximum temperature was up to 211 °C after 70 minutes. Then the supply was switched off.

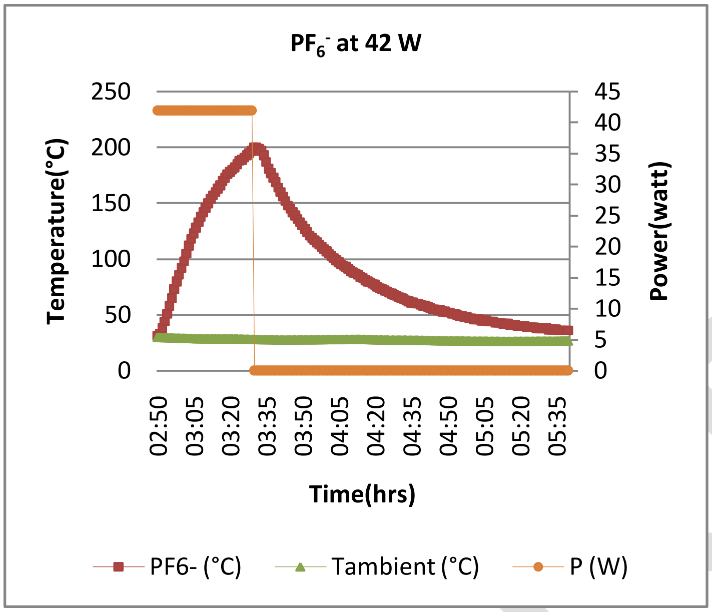


Figure 7 time vs. temperature plot for $PF_6^-$

of the current designations.

ACKNOWLEDGMENT *(HEADING 5)*

The authors thank Director SICART for DSC of the materials. We also thank Mr. Shreelal Jha, Department of Physics for instrumental support.

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