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Analyses of a Phase Change Material based Thermal Energy Storage System

KEYWORDS: kCl, eutectic, Bi, Fo

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ABSTRACT *For the development of the economical heat storage medium, the 2 % by weight eutectic of kCl / water is among the most suitable heat storage material. The freezing point of this eutectic mixture is -6.0 oC. This temperature is sufficient to store pharmaceuticals and other heat sensitive materials. In this study the kCl / water eutectic mixture is prepared. The modeling of kCl / water eutectic mixture is studied and a mathematical correlation developed. The parameter, Biot number, bi. is studied and the variation of the dimensionless temperatures, with dimensionless time, Fo, are achieved for different values of the parameter (Bi).*

1. Introduction
Energy plays a central role in all human activities without which, the socio-economic development of a country would come to a stand-still. Energy storage of all types plays an important role in energy conservation. Energy storage is essential whenever the supply or consumption of energy varies independently with time. An example of this is solar energy, which is available during the day only and hence its application require an efficient thermal storage so that the excess heat collected during sunshine hours may be stored for later use during night hours. One method of storing energy is by a latent –heat storage system (LHSS). This method is particularly attractive due to its high energy- storage density. The use of phase change materials (PCMs) for thermal energy storage in solar heating systems has received considerable attention. The most studied phase- change materials (PCMs) include ice, paraffins, calcium chloride hexahydrate, sodium thiosulfate pentahydrate, sodium carbonate decahydrate, fattic acid and Glauber salt.

An experimental and theoretical study to evaluate the performance for a closed latent heat energy storage system using energy and energy analyses was conducted by Kaygusuz, K. et al. (2000). They concluded from their study that an energy analysis is a powerful tool for the evaluation of the performance of a thermal energy storage system. Kondepudi, S. et al. (2003) developed a theoretical model to predict the energy storage behavior of different phase-change materials used with different heat transfer fluids, flow geometries, flow rates and temperatures. An important observation was made by Kaygusuz, K. et al. (2006) that the flow rate and inlet temperature of the heat transfer fluid to the PCM tube in the experimented range has an insignificant effect on the phase change processes and the the melting and solidification of the PCM can be reduced significantly by placing the tube containing the PCM in a horizontal position.

2. Experimental
2.1 Materials used
1. Potassium Chloride Pure Merck
2. Methanol BDH analyzer Assay: 99.8%

Double Distilled water was used for making kCl/H2O eutectic.

2.2 Preparation of kCl/H2O Eutectic Composition
In this study, thermometric method was used to determine the transition temperature. Initially a number of eutectic test compositions were made at constant intervals. 10 gm of the sample was taken in a test tube having a tight fitted cork with a hole for the thermometer for recording the temperature. These test samples were put in a cryostat which was maintained at a temperature somewhere below the freezing point.

The pattern of fall of temperature of test sample was noted as; initially the test sample lost heat to the cryostat fluid (methanol) which is maintained at a temperature somewhere below the freezing point. Then there was a rapid increase of temperature, due to the release of latent heat and maximum temperature reached while the increase of temperature was marked and of the various test samples whichever showed a highest increase in temperature was the composition to be tested for the evaluation of heat transfer characteristics.

2.3 Determination of Heat Transfer Characteristics of the Eutectics
Methanol was circulated through the heat exchanger maintaining a constant flow rate. Thermocouple readings at 12 different points were noted down in the interval of 15 minutes. At every time interval the crystal growth was measured with the help of syringe attached to the heat exchanger and graph paper.

2.3 Experimental Setup
The apparatus used in the experiment consists of a heat exchanger, a cryostat and a temperature indicator as shown in figure 1:

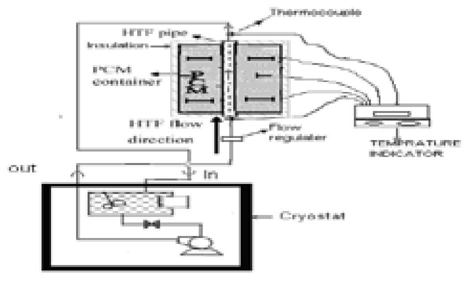

Figure 1: Heat Exchanger

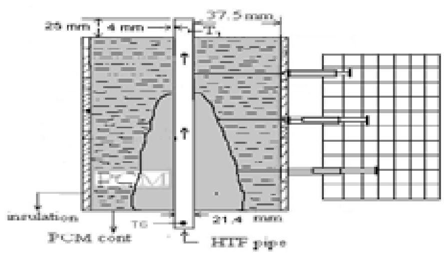

Figure 2: Arrangement of thermocouples in Heat Exchanger

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To measure the temperature at various points in the heat exchanger, copper constant thermocouples were incorporated into the heat exchanger at 12 different points. The output of all these were fed into a temperature indicator. To measure the inlet and outlet temperatures of methanol two thermocouples are fixed at the inlet and outlet.

In order to prevent the heat losses to the environment from the lines carrying methanol & Heat Exchanger a lagging of glass wool was used. To maintain the temperature constant in the cryostat liquid nitrogen was used.

Table 1: Distances of different thermocouples from the glass wall:

Thermocouple No.	Distance from glass wall cm
1	1.25
2	2.5
3	1.0
4	1.5
5	0.9
6	Inlet
7	Outlet
8	2.3
9	1.0
10	1.0
11	0.8
12	2.0

3. Results and Discussions

The various weight percent compositions potassium chloride and water were prepared and it was found that eutectic was formed at -6.0 oC with the composition of 2 % by weight. The experimental data were interpreted as follows:

- The freezing temperature Tf was plotted against composition of potassium chloride in water by weight. It is evident from Figure 3 that the freezing temperature first decreases with composition and then increases with increase in composition, the curve takes a lower most dip or touches the minima at a temperature of –6.0 oC and corresponding composition of the eutectic potassium chloride / water was 2 % (by weight),and after this the curve rises.

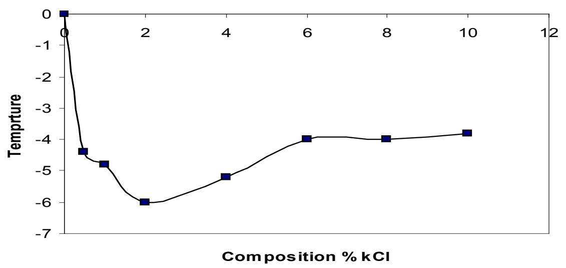

Figure 3: Freezing Temperature vs. Composition of kCl in Water

- The curve from Figure 5 for inlet and outlet temperature of methanol as a function of time shows two distinct regions. One represents the unsteady state that is the region, as when the experiment is just started there will be heat flow from the outlet methanol to inlet methanol, which was initially at 17oC from the phase change material across the copper tube and there are some heat gains in the pipe. After around 20 minutes, there is a remarkable difference between the inlet and outlet temperature curves as the heat is extracted from the PCM and this difference continues till 270 minutes as evident from Figure 4

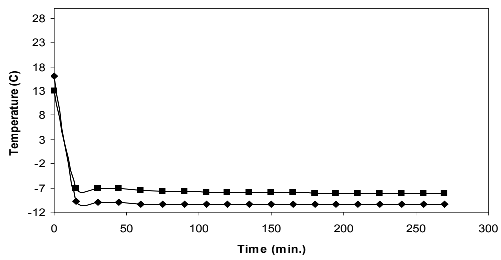

Figure 4: Inlet and Outlet temperature of methanol as a function of time

(■) Outlet Temperature, (◆) Inlet Temperature

- Radial temperature profile

In this eight thermocouples output i.e. temperature readings were monitored.

T1 & T2; T8 & T9: These are the thermocouples positioned in the uppermost region of the shell, thus the methanol entering from the copper tube will first gain heat from the various other regions. The readings are not so smooth due to the irregularities in the convective currents, which are set up in the exchanger due to the release of latent heat of fusion by the growing solid interface. They are accumulated in the upper region of the glass shell as evident from the Figures 5a & 5b. But after sometime the curves become parallel.

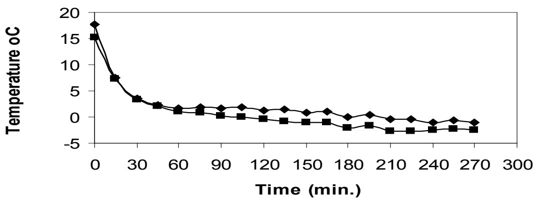

Figure 5a: Radial Temperature Profile

(◆) T1 , (■) T2

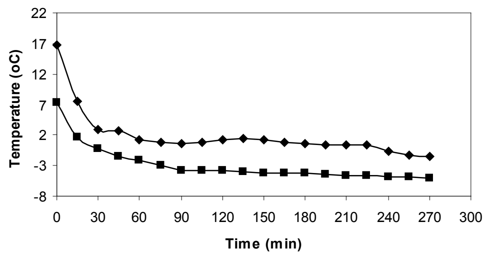

Figure 5b: Radial Temperature Profile

(■) T8 , (◆) T9

T4 & T5; T11 & T12: As these are present in the lowermost region of the shell, thus the heat extraction rate is higher in this region. Temperature drops to a minimum of about – 6oC i.e. the lower most among the various thermocouple readings as evident from Figures 6a &6b.

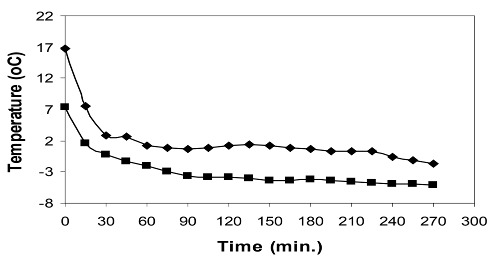

Figure 6a: Radial Temperature Profile

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(■) T4, (◆) T5

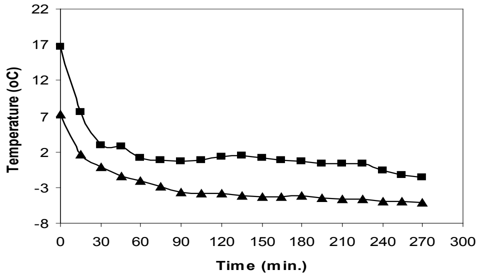

Figure 6b: Radial Temperature Profile

(■) T11, (◆) T12

- Vertical temperature profile

Under this head 10 thermocouple readings were monitored i.e.

T2 & T4; T8 & T12: This sequence of thermocouple represents the innermost column of thermocouples, i.e., the thermocouples that are nearest to the copper wall. Thus, the rate of fall of these will be the steepest and the lowermost thermocouple reading i.e. that of T2 reaches a minimum temperature of – 6oC as seen from the Figures 7a & 7b.

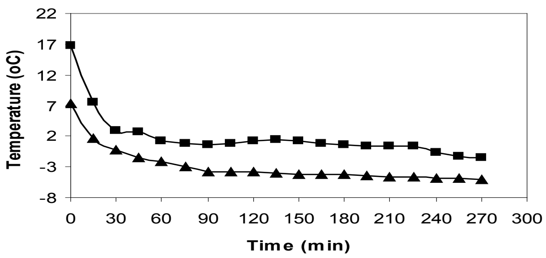

Figure 7a: Vertical Temperature Profile

(■) T2, (◆) T4

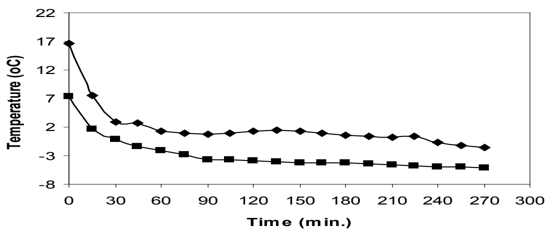

Figure 7b: Vertical Temperature Profile

(■) T8, (◆) T12

T1, T3 & T5; T9, T10, T11: This sequence of thermocouple represents the outermost column of thermocouples. Thermocouple T9 shows the highest reading as it is situated in the uppermost region as well as is far from the copper tube as seen from the Figures 8a & 8b.

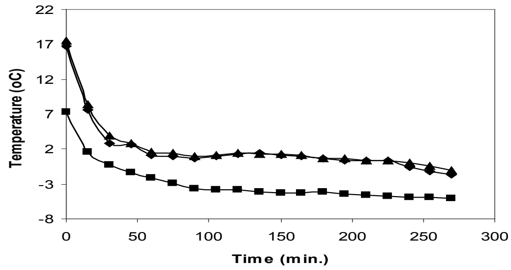

Figure 8a: Vertical Temperature Profile

(■) T1, (◆) T3, (▲) T5

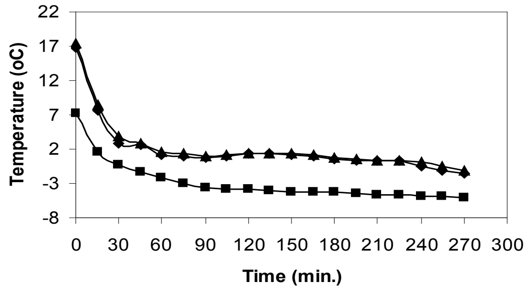

Figure 8b: Vertical Temperature Profile

(■) T9, (◆) T10, (▲) T11

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