Characterization of Erythritol as a Phase Change Material

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Abstract- *Storage of solar energy is a challenging task and has huge attention in recent years. Storage of thermal energy in the form of latent heat with the help of PCMs (Phase change materials) shows many attractive features of high energy to density and process of storage is isothermal in nature in comparison with other heat storage methods. Plenty of materials which have the characteristics of changing its phase during the process of heating and cooling are available and enormous information is published widely on the storage systems which stores heat in the form of latent. However it is still difficult to find such material for different applications at different range of temperature. This paper was presented after exhaustive literature study on characteristics of erythritol as a low temperature PCM. This paper makes convenient for the readers to know about characteristics of erythritol as a PCM for low temperature range application. In addition to this, a new design of solar heat energy storage unit, for the utilisation of thermal energy during off*

Keywords- Storage tank; latent heat; sugar alcohol.

Nomenclature			
ds	Density of PCM, solid	$C_{p}l$	Specific heat of PCM, liquid
dl	Density of PCM, liquid	$C_{p}s$	Specific heat of PCM, solid
kl	Thermal conductivity of PCM, liquid,	H	Enthalpy (kJ)
ks	Density of PCM, solid	Q	Rate of Heat Transfer (W)
m	Mass (kg)	t	Time (s)

I. INTRODUCTION

The nonstop raise, the consciousness of utilizing renewable energy sources, increased scarcity of fossil fuels and increased emission, prompted researchers to search for suitable characteristic phase change materials anticipated for the purpose of storing thermal energy at different working temperature ranges. Many parts of India are blessed with solar energy. To overcome the imbalance among requirement and delivery of the solar energy, it is necessary to develop an energy storage system.

The energy storage system plays a predominant role of providing energy conservation, improvement in system performance and reliability along with managing the imbalance between the requirement and delivery of solar energy. Hence storage system would reduce the wastage of energy and capital cost there by making system more economical and profitable. The main aim of this paper is an anthology of existing realistic information about characteristics of erythritol as a low temperature PCM. This study makes convenient to the readers to know about the characteristics of erythritol as a PCM for low temperature range applications, such as solar air heating and cooling, solar water heating, enhancement of saving heat wastages and solar cooking. A new design concept is presented to store the solar heat energy in the form of latent heat by using erythritol as a phase change material.

II. ENERGY STORAGE TECHNIQUES

Power can be reserved in three forms such as thermal, electrical and mechanical forms. The complete classification of energy reserving techniques is shown in Figure 1. The most common and effective method of storing thermal energy is sensible type and latent type. The latent type heat storage method has the largest interest and popularity over sensible heat energy method due to its large ability of collecting energy to density with a minor heat fall.

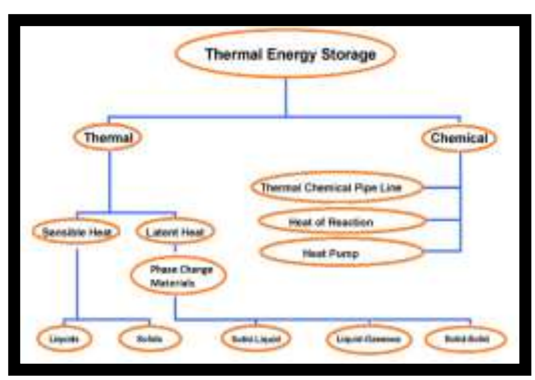

Figure 1. Thermal energy reserving techniques

An interested reader can review the literature presented by Zabla et al. [1], Farid et al. [2], Abhat [3], Zhang et al. [4], Atul Sharma et al. [5] that covers the various PCMs and properties along with applications. The available research studies have shown that the erythritol as a PCM is a good candidate for low temperature range Sharma [6]. Hence, the focus of this paper is to study the available information or literature on the characteristics of erythritol as a phase change material.

III. CHARACTERISTICS OF ERYTHRITOL

Erythritol is a general sugar alcohol which is used in most of the foodstuff since it is a low calorie sweetener or food additives. The chemical names of erythritol are Meso-Erythritol; Erythritol; Phycitol; Erythrit; Phycite etc. The Molecular formula of erythritol is $C_4H_{10}O_4$ with a molecular weight of 122.12g/mol. C.A.S. No. 149-32-6. It is white, odorless, not- attracting to the moisture and has good stability of heat. It has sweetness around 60-80% range in comparison with sucrose. At some extent it is soluble in ethanol but is easily soluble in water. Its melting temperature range is 118°C to 121°C where as its boiling temperature is 390°C. Erythritol is the most potential PCM for storage of thermal energy in low as well as medium temperature range having benefits of huge enthalpy of melting and small volume extension. It has good compatibility with the several metals like SS304, Copper, aluminum etc with low corrosiveness and high thermal cycle stability [7]. Many authors have presented the study of thermo physical characteristics of phase change material for the different working temperatures. Cohen et al. [8] have explored about the treatment of PCM in ambient environment. Kaizawa et al. [9] described that, 160°C is a maximum limit of working temperature for erythritol to store thermal energy. Lopes Jesus et al. [10] have explained that erythritol shows two dissimilar structural forms of crystal during solidified condition with dissimilar melting temperature. The maximum super cooling for small sample size of erythritol was reported as 54K, 14K, 82K, respectively by the literature [11, 12, and 13]. Shukla et al. [14] and Agyenim et al. [15] studied the thermal cycle stability of erythritol and they have reported it as, there were decrease in latent heat as well as temperature variation in melting.

IV. THERMO-PHYSICAL CHARACTERISTICS OF ERYTHRITOL

Many researchers presented the thermal characteristics of erythritol which is tabulated below in Table 1. During the test, kakuichi et al. [17] found that the change in enthalpy is as shown in Figure 2.

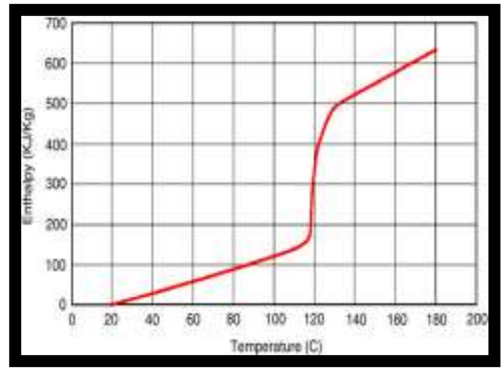

Figure 2. Change of enthalpy of erythritol

Table 1 Thermal properties of erythritol. [16]

Physical properties	Value
Melting point	117.7 ○C
Boiling point	390 ○C
Heat of fusion	339.8 kJ/ kg
Cpl	2.76 kJ/ kg K
Cps	1.38 kJ/ kg K
kl	0.326 W/ m K (140 ○C)
ks	0.733 W/ m K (20 ○C)
dl	1300 kg/ m^3 (140 ○C)
ds	1480/ m^3 (20 ○C)

V. PHASE CHANGE CHARACTERISTIC OF ERYTHRITOL

Yifei Wang et al. [18] has investigated in detail about the behavior of erythritol and concluded that, during the charging (melting) process the erythritol begins to melt and this molted erythritol collects at the top position, later on from the top it moves to the bottom by means of convection heat transfer mode. Hence natural convection takes a significant position during charging process and it is opposite in nature during solidification. Heat transfer rate depends on input temperature and heat transfer medium. Also who concluded that the relation between thermal conductivity of erythritol with respect to temperature in solid as well as in liquid state. As the temperature increases, viscosity of liquid erythritol decreases. Figure 3 shows the typical flow pattern of the PCM inside the vertical and horizontal units. Agyenim et al. [15] have practically studied behaviour of an erythritol for the Lithium bromide-water absorption refrigerator system which has inlet temperatures of 70°C- 90°C. Complete PCM melts after 8 hours and average temperature of 126.4°C was recorded in the PCM system. The time taken for discharging was recorded as 135 minutes. Hence it can be observed that time taken for discharge of erythritol was lesser compared to time taken for charging process.

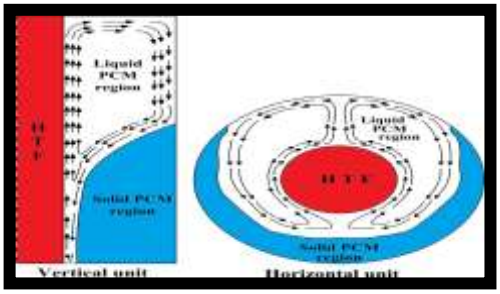

Figure 3. Flow pattern of erythritol during charging process [19, 20].

VI. THERMAL CYCLE STABILITY OF ERYTHRITOL

Erythritol were considered for 20 cycles to measure the temperature of melt and heat of fusion. The obtained results are tabulated in the following Table 2.The experimental results determines that for 20 cycles the latent heat of energy changed to 7.5%. Shukla et al. [21], showed that the sample of commercial grade erythritol was stable and does not degrade for 75 numbers of thermal cycles and it has super cooling temperature by 15°C.

Table 2. Thermal cycling results of erythritol for 20 cycles [15].

Cycles	1	2	5	10	20
Heat of fusion, kJ/kg	339.30	338.77	338.77	323.39	313.75
Melting temperature (°C)	118.39	116.49	115.56	115.29	114.39

THE EFFECT OF MASS FLOW RATE AND INLET TEMPERATURE OF HEAT TRANSFER FLUID

Agyenim et al. [15] have undertaken several charging and discharging experiments to observe the influence of varying the mass flow rate and inlet temperature of heat transfer fluid on the thermal behavior of erythritol. And the authors found that these two parameters are directly proportional to each other.

NEW DESIGN OF HEAT STORAGE UNIT USING ERYTHRITOL

A new design is presented for the development of solar heat energy storage system. An erythritol is used to store solar heat energy in the form of latent heat. The solar energy can be stored during the sunshine hours of a day and this stored energy can be utilized during evening or night time to fulfil the demand as and when required. This new system enables to serve like a power back up battery of solar energy. The stored latent heat can be used for the different application areas like water heating, crop drying, air heating, cooking etc by proper designing and integrating the end use unit to this heat storage unit. The solar heat storage unit is designed to store 5000kJ of energy using erythritol as a phase change material. The schematic diagram of the new design set up is as shown in Figure 4 and different views of storage tank are shown in Figure 5.

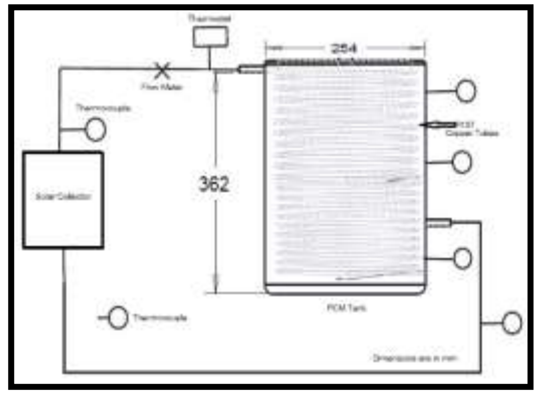

Figure 4. Schematic arrangement of solar energy storage using erythritol.

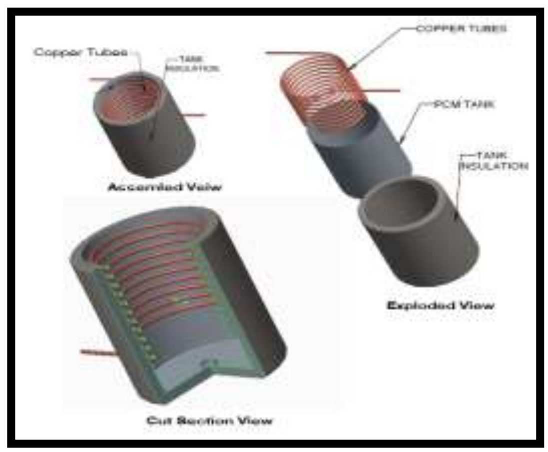

Figure 5.Different view of of storage tank

VII. CONCLUSION

The present study contributes characteristics of erythritol as a phase change material used in the context of collecting latent heat for low temperature application. This paper focused and compiled on many aspects related to erythritol which includes the thermal behavior, melting and solidification pattern and thermal stability of erythritol studied by many researchers. The readers can easily get the information on character of erythritol as a phase change material for low temperature applications. In addition to this a new design is presented to store 5000 kJ of solar energy in the form of latent heat by using erythritol as a phase change material.

REFERENCES

[1] Zalba B, Marin JM, Cabeza LF, Mehling H. Review on thermal energy storage with phase change materials, heat transfer analysis and applications, Appl. Therm. Eng. 23, 3(2003) 251–283.

[2] Farid, MM. Khudhair AM, Razack SAK, Al-Hallaj S. A review on phase change energy storage: materials and applications, Energy Convers. Manage.45, 9–10(2004)1597–1615.

[3] Abhat A. Low temperature latent heat thermal energy storage: heat storage materials, Solar Energy 30 (1983)313–332.

[4] Zhang Y, Zhou G, LinK, Zhang Q, Di H. Application of latent heat thermal energy storage in buildings: State-of-the-art and outlook, Building and Environment, 42, 6, (2007) 2197-2209.

[5] Sharma A, Tyagi VV, Chen CR, Buddhi D. Review on thermal energy storage with phase change materials and applications, Renewable and Sustainable Energy Reviews, 13, 2(2009) 318-345.

[6] Sharma SD, Kitano H, Sagra K. phase change materials for low temperature solar thermal applications. Res. Rep. Fac. Eng. Mie Univ., 29 (2004) 31- 64.

[7] Sharma SD, Sagra K. Latent heat storage materials and systems:A Review, International Journal of Green Energ (2005) 21-56.

[8] Cohen S, Marcus Y, Migron Y, Dikstein S, Shafran A. Water sorption, binding and solubility of poly J. Chem.Soc. Faraday Trans (1993) 89, 3271.

[9] Kaizawa A, Maruoka N, Kawai A, Kamano H, Jozuka T, Senda T, Akiyama T. Thermo physical and heat transfer properties of phase change material candidate for waste heat transportation system. Heat Mass Transf., 44(2007) 763–769.

[10] Lopes Jesus AJ, Nunes SCC, Ramos Silva M, Matos Beja M, Redinha JS. Erythritol: Crystal growth from the melt. Int. J.Pharm., 388 (2010) 129–135.

[11] Sari A, Eroglu R, Biçer A, Karaipekli A. Synthesis and Thermal Energy Storage Properties of Erythritol-Tetrastearate and Erythritol Tetrapalmitate. Chem. Eng. Technol., 34 (2011) 87–92.

[12] Ona EP, KojimaY, Matsuda H, Hidaka H, Kakiuchi H. Latent Heat Storage Characteristics of Erythritol-Magnesium Chloride Hexahydrate Mixtures. Asian Pac. Confed. Chem. Eng. Congr. Program Abstr., 536(2004).

[13] Rathgeber C, Miró L, Cabeza LF, Hiebler S. Measurement of enthalpy curves of phase change materials via SC and T-History: When are both methods needed to estimate the behaviour of the bulk material in applications? Thermochim. Acta, 596(2014) 79–88.

[14] Shukla A, Buddhi D, Sawhney RL. Thermal cycling tests of few selected inorganic and organic phase change materials. Renew. Energy, 33(2008) 2606–2614.

[15] Agyenim F, Eames P, Smyth M. Experimental study on the melting and solidification behaviour of a medium temperature phase change storage material (Erythritol) system augmented with fins to power a LiBr/H2O absorption cooling system. Renew. Energy, 36(2011) 108– 117.

[16] Anon. Manufacturer data sheet from Mitsubishi-Kagaku Foods Corporation (2005).

[17] Kakuichi H, Yamazaki M, Yabe M, Chihara S, Terunuma Y, Sakata Y. A study of erythritol as phase change material. In: Proceedings the 2nd workshop IEA annex 10, phase change materials and chemical reactions for thermal energy storage, Sofia, Bulgaria (1998) 11– 13.

[18] Yifei Wang, Liang Wang, Ningning Xie, Xipeng Lin, Haisheng Chen Experimental study on the melting and Solidification behaviour of erythritol in a vertical shell-and-tube latent heat thermal storage unit, International Journal of Heat and Mass Transfer 99,(2016) 770–781.

[19] Longeon M, Soupart A, Fourmigue JF, Bruch A, Marty P. Experimental and numerical study of annular PCM storage in the presence of natural convection, Appl. Energy 112(2013) 175–184.

[20] Ng KW, Gong ZX, Mujumdar AS. Heat transfer in free convection dominated melting of phase change Material in horizontal annulus, Int.Commun. Heat Mass Transfer 25, 5(1998) 631–640.

[21] Shukla A, Buddhi D, Sharma SD, Sagara K. Accelerated thermal cycle test of erythritol for the latent heat storage application. In: Proceedings of the EM4 Indore workshop IEA ECES IA annex 17, Indore, India (2003) 21–24.