PHASE CHANGE HEAT STORAGE MATERIALS IN SCHEFFLER REFLECTOR: AN INSIGHTFUL SUSTAINABLE STUDY OF RENEWABLE ENERGY

Abstract

Energy is the requirement for the people to cater their basic necessities. Biomass, fossil and other carbon based fuels are the primary sources of natural energy. These carbon based fuels are limited and have negative impact on the environment. There is an urgent need of clean and environmental – friendly innovative energy technologies. Solar energy can be a feasible solution for the sustainable development especially when the world is facing environmental, population and economic growth problems. The Scheffler is a special solar concentrator device which can reach high temperature within a short interval of time. The heat retention capability of Scheffler can be increased significantly by assembling a heat storage unit in it. In this study, properties based on thermal and physical (density, thermal conductivity and melting point of different thermal storage materials (bricks, concrete, water, Phase Change Material (PCM), Latent Heat Storage Material (LHS), aluminum, iron, molten salts, silicon etc.) are compared which are used to store the heat energy for a longer period. It is observed that the heat capacity of LHS is much higher as compared to other storage materials which makes Scheffler to store heat for extended duration and using it in a sustainable way. Results and reports are highlighted in a comparative format using tables and graphs to analyze the effect of properties like melting point, thermal conductivity, and density on the specific heat of a LHS material. High heat retention material's need is predicted to rise in the future, as it can fill the energy scarcity of the people

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especially for cooking and can help in achieving the various sustainable development goals.

Keywords: Scheffler, Sustainable Development, Phase Change Materials, Latent Heat Storage, Sustainable Development Goals.

I. INTRODUCTION

The world fossil fuel reserves are limited and will be exhausted up to 2088. A large portion of the population in many countries still depends on the carbon fuels such as biomass, wood and other hydrocarbons [1]. Burning of these carbon based fuels releases a good amount of green house and other harmful gases [2]. Thousands of years are required for the formation of fossil fuels and a rapid rate of their consumption can results in their depletion. Alternates of these energy should be searched in order to meet the essential energy requirement of the people [3]. Renewable sources of energy especially solar energy can be good options, which are clean in nature and do not pollute the environment [4]. There are many ways or devices by which solar energy can be harnessed like solar heaters, panels, concentrators etc. and the combinations of these. The solar concentrator used in many applications that are using heating or cooling, generation of power, cooking and also in those areas which requires high temperature. A Scheffler reflector is a powerful solar device which is used to concentrate sunrays at a fixed focus (Refer figure 1). To maintain a fixed focus it has to track the movement of Sun daily and seasonally [5]. The tracking mechanism of Scheffler to trace the Sun's path can be manual or automatic. The sequence of operation of a Scheffler can be understood from the figure 1. The Sun rays falling on the reflector is directed towards a fixed focus (receiver), which will absorbs the incoming rays in the form of heat which can be used for various purposes. The receiver can be coated with a material having high heat retention capability. Primarily it is used for cooking but it can be used be used in cremation, power generation, process industries, desalination etc. [6], [7] also which requires high heat input. It is used in community kitchen in order to cook food for a large number of people. Brahma Kumari built the largest solar kitchen in the world which can cook 38,500 meals per day. Solar energy is the input for Scheffler, so there will be difficulty in its running during non-sunny days or during night. This problem can be mitigated by using heat storage materials, which absorbed heat for a long time and enable Scheffler's working for an extended length of time.

This research article will proceed as: Part II discusses types of heat storage materials and properties which are suited to be used in Scheffler reflector and compares the desired qualities of heat storage materials. Part III discussed challenges occurred during heat generation using Phase Change Materials. The discussion and future in this field is mentioned in last portion of this study.

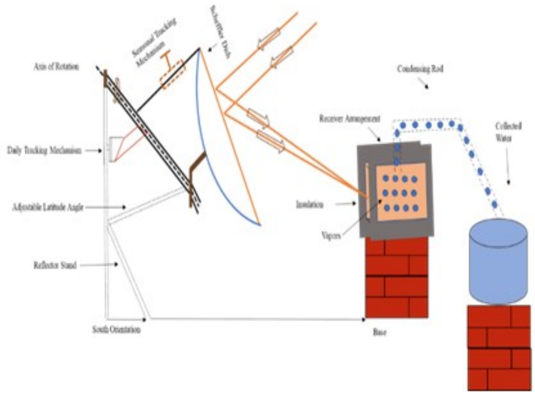

Figure1: Scheffler Reflector used for desalination of water

II. PHASE CHANGE MATERIAL IN SCHEFFLER REFLECTOR

The two methods for storing energy in form of heat : without changing phase and changing the phase [8]. Phase change heat storage seems to be more inviting than sensible heat storage techniques as it can store more heat for a given unit volume and the temperature remains unchanged during the transfer process. By adding heat to a substance its temperature increases and thermal energy is simply stored in that substance [9], [10]. This energy might be extracted from the specified medium as the temperature decreased. Additionally, they can operate in a range of temperatures and support a wide range of applications. A phase changing material contains the following properties:

- There shouldn't be much volume change as phases change.
- The material should have a high latent heat capacity [11].
- It must not react with the container in which it is contained and must not be corrosive.
- When transitioning between phases, it shouldn't lose its thermos-physical properties too soon [12].
- The environment shouldn't be harmed.
- The substance ought to be reasonably priced [13].
- It need to be simple to get to.
- It shouldn’t catch fire when operating at higher temperature.

The thermos physical characteristics heat storage of non-latent materials and those LHS are shown in Table 1, respectively. These characteristics include density, melting and boiling points, thermal conductivity, and heat capacity.

Table 1: Thermo-Physical Properties of Various Materials **[11]**

MATERIALS *(PROPERTIES)*	VALUES
BRICKS	
Density	1700 kg/m^3
Melting Point	2000 K
Thermal Conductivity	1.31 W/m-K
Heat Capacity	0.84 J/g-K
CONCRETE	
Density	2400 kg/m^3
Melting Point	1800 K
Thermal Conductivity	2.25 W/m-K
Heat Capacity	0.88J/g-K
SAND	
Density	1442 kg/m^3
Melting Point	1973 K
Thermal Conductivity	2.05 W/m-K
Heat Capacity	0.830 J/g-K
PEBBLES	
Density	(1846 & 2399.8) kg/m^3
Melting Point	1753 K
Thermal Conductivity	2.5 W/m-K
Heat Capacity	0.88050 J/g-K
ALUMINUM	
Density	2710 Kg/m^3
Melting Point	933.47 K
Thermal Conductivity	237 W/m-K
Heat Capacity	0.89 J/g-K
IRON	
Density	7874 Kg/m^3
Melting Point335	1811 K
Thermal Conductivity	79.5 W/m-K
Heat Capacity	0.450 J/g-K
MOLTEN SALTS	
Density	1549 kg/m^3
Melting Point	773 K
Thermal Conductivity	0.652–0.927 W/m-K
Heat Capacity	1.53 J/g-K
SILICON	
Density	2330 Kg/m^3
Melting Point	1687 K
Thermal Conductivity	230 W/m-K
Heat Capacity	0.71 J/g-K

Table 2: Thermo-Physical Properties of PCM [11]

PARAFFIN WAX	VALUES
Density	900 Kg/m3
Melting Point	643 K
Thermal Conductivity	7.1 W/m-k
Heat Capacity	(2.14–2.9) J/g-K
ACETAMIDE	
Density	1159 Kg/m3
Melting Point	355 K
Thermal Conductivity	0.5 W/m-K
Heat Capacity	263 J/g-K
STEARIC ACID	
Density	940 Kg/m3
Melting Point	337.5 K
Thermal Conductivity	1.60 W/m-K
Heat Capacity	196 J/g-K
MALIC ACID	
Density	860 Kg/m3
Melting Point	325 K
Thermal Conductivity	0.17 W/m-K
Heat Capacity	192 J/g-K
Calcium Chloride Hexahydrate	
Density	1710 Kg/m3
Melting Point	303 K
Thermal Conductivity	1.08 W/m-K
Heat Capacity	175 J/g-K
Magnesium Chloride Hexahydrate	
Density	1450 Kg/m3
Melting Point	390 K
Thermal Conductivity	0.570 W/m-K
Heat Capacity	168.6 J/g-K
PALMITIC ACID	
Density	942 Kg/m3
Melting Point	335 K
Thermal Conductivity	0.162 W/m-K
Heat Capacity	205 J/g-K
LAURIC ACID	
Density	862 Kg/m3
Melting Point	315 K
Thermal Conductivity	0.16 W/m-K

Heat Capacity	200 J/g-K
ERYTHRITOL	
Density	1480 Kg/m3
Melting Point	391 K
Thermal Conductivity	0.326 W/m-K
Heat Capacity	339.8 J/g-K
Sodium Dihydrogen Phosphate Dodecahydrate	
Density	1520 Kg/m3
Melting Point	313 K
Thermal Conductivity	0.476 W/m-K
Heat Capacity	279.6 J/g-K
WATER	
Density	998 kg/m3
Melting Point	373 K
Thermal Conductivity	0.598 W/m-K
Heat Capacity	4.182 J/g-K

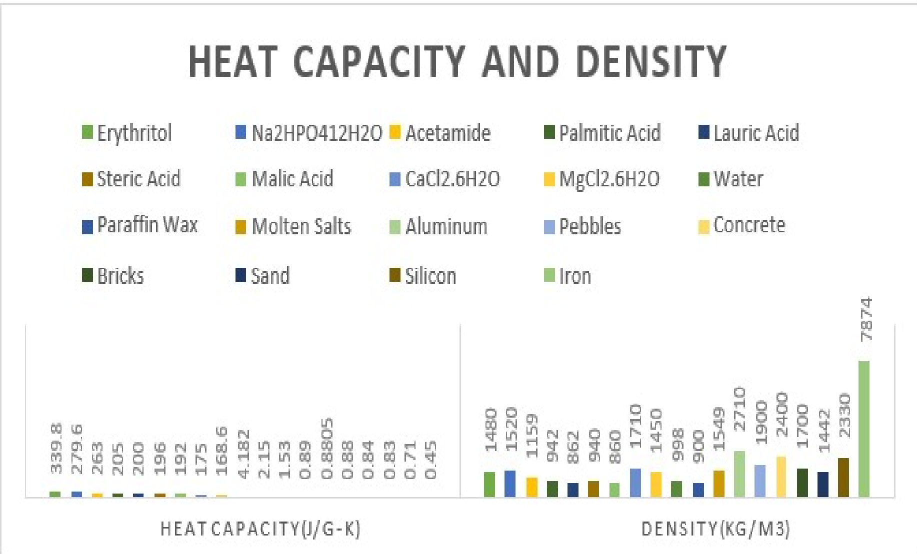

Figure 3: Graph between heat Capacity and Density

As shown in Fig. 3, the density of non LHS materials for example iron (7874 Kg/m3), aluminium, (2710 Kg/ m3) pebble (1900 Kg/ m3), silicon (Kg/m3) etc. is higher but their heat capacity is much lower (0.45 J/gK, 0.89 J/gK, 0.88 J/gK, 0.71 J/gK respectively) than the LHS materials[7], [14]. So, density is not a function of heat capacity among all the materials but a high dense material will occupy less space as compared to the less dense material as already discussed. A material (LHS) which will have good heat capacity and a compromised density like Acetamide (263 J/g-K and 1159 Kg/m3), Erythritol (339.8 J/g-K and 1480 Kg/m3), Sodium Dihydrogen Phosphate Dodecahydrate (279.6 J/g-K and 1520 Kg/m3) etc. can be a good heat storing option for a Scheffler Reflector as depicted by Table 2.

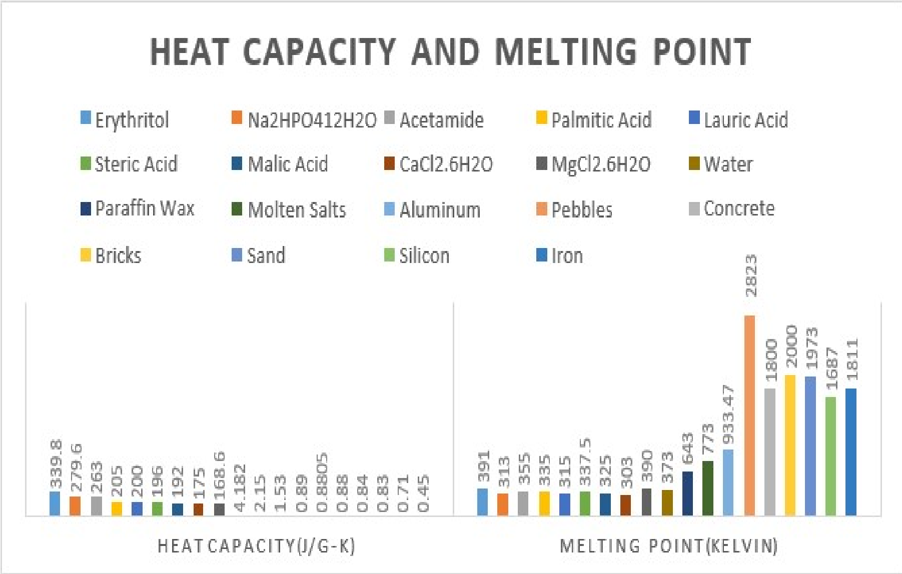

Figure 4: Graph between Heat Capacity and Melting point

From the Fig. 4 it is depicted that generally the materials having low melting point are having high heat capacity. Iron and brick are having high melting point, 1811 K and 2000 K but have low heat capacity, 0.45 J/g-K and 0.84 J/g-K. PCM materials (except water) like acetamide and lauric acid have low melting point, 355 K and 315 K but have very high heat capacity, 263 J/g-K and 200 J/g-K which makes them a good choice for applying for Scheffler as storage materials.

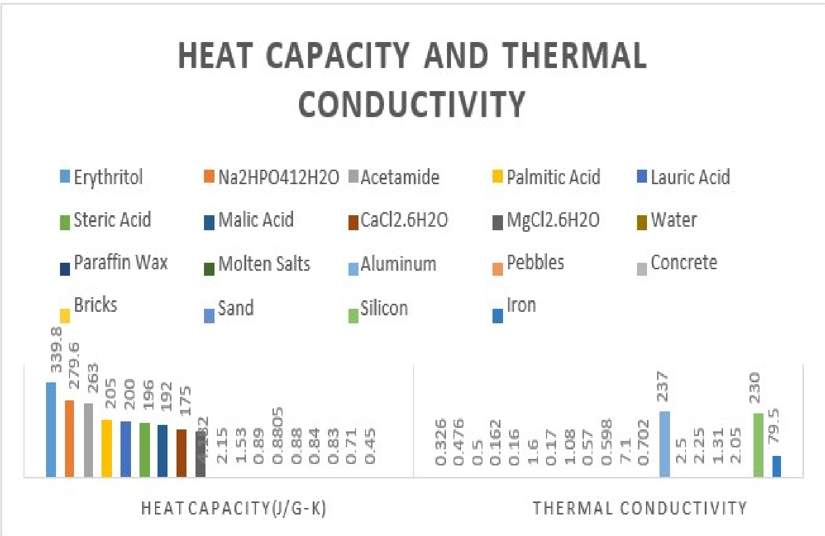

Figure 5: Graph between Heat Capacity and Thermal Conductivity

Shown in the Fig. 5, PCM material is having very low thermal conductivity as compared to other general material like aluminium (237 W/m-K), silicon (230 W/m-K), iron (79.5 W/m-K), etc. So, it has been found that the LHS material like acetamide (0.5 W/m-K) and erythritol (0.326 W/m-K) which are having good heat storage properties will have poor thermal conductivity.

III. CHALLENGES

1. **Security:** Safety is a crucial factor when choosing a heat storage material for unit, thus it makes sense to use one with superior LHS properties and greater safety [15]. Some materials with organic properties, such as non-paraffin and paraffin, are suitable LHS compounds even though they possess low ignition temperature [16]. Their application is limited up to medium range temperature..

2. **High Cost for Large Energy Density:** Due to the great density of energies it can store, thermochemical storage is one of the options, although the unit and the process are rather expensive [17]. Because it is less expensive, particularly in applications requiring solar heat, thermal absorption is preferred to it [18].

3. **PCM Selection Criterion:** A Phase change material cab be produced with characteristics of thermal and physical property [19]. While some substances, like paraffin, are more favorable for application major for low temperature range, while for high-temperature range materials like fatty acid is used [20].

4. **Storage Material Reactivity:** Although some substances, like compounds of salt[21] and alloys using metals (majorly used in heat based application in solar energy area)[22], have excellent heat storage capacity and low associated costs, their corrosiveness and rapid temperature decrease render them unsuitable for use as a heat absorbing substance for Scheffler usage[23][24].

IV. CONCLUSION

The operation of the Scheffler reflector has shown a key role in the creation of heat energy and using it as a primary source of renewable energy. In order to generate heat for applications, requiring a wide range of temperature, the dish's size can be varied. The management and control of generated heat in Scheffler also depend on the type of materials used for storing heat as unit. A number of heat storage materials were examined and contrasted with regard to thermos-physical characteristics such density, melting point, heat capacity and conductivity for thermal, for managing heat over a longer periodof time.

A Phase Change Material (PCM) is a substance that emits or store energy during a transition of phase to provide heating or cooling used to recognized for their high heat capacity, holding heat for the extended length of time. Latent heating may store the same quantity of heat in a lesser volume than specific heat storage because latent heat of a substance is substantially larger than specific heat of the same substance. According to the findings, LHS materials like acetamide, erythritol, Sodium Dihydrogen Phosphate Dodecahydrate etc. have high heat capacity as compared to other heat storage materials. From the results it is also clear that specific heat is not directly proportional to the density but a high-density material will occupy less space in thermal storage unit. So, a compromised materials like Acetamide (263 J/g-K and 1159 Kg/m^3), Erythritol (339.8 J/g-K and 1480 Kg/m^3) and Sodium Dihydrogen

Phosphate Dodecahydrate (279.6 J/g-K and 1520 Kg/m^3) etc. Are best for heat storing choice for a Reflector in Scheffler. Study also suggests that materials having low melting/boiling point will have high capacity of heat for example Acetamide and lauric acid have low melting point 355 K and 315 K respectively but have very high heat capacity 263 J/g-K and 200 J/g-K respectively. Findings highlighted materials with higher value of specific heat are having lower thermal conductivity. Hence LHS materials are capable of storing large heat and can be considered as the best choice amongst all material used in heat storage unit for Scheffler reflector.

LHS material has a lot of potential applications in the Scheffler reflector field. The industrial and innovative domain should implement exclusive awareness policies for awareness in order to improve the social visibility and practical material's applications. Although thermochemical energy storage systems have produced useful results, the technique is currently dealing with high cost to construct the making of Scheffler instrument.

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