SOLAR DRYING BY USING PHASE CHANGE MATERIAL: A REVIEW

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ABSTRACT
Solar energy is one of the purest form of energy which we get from nature. Solar energy is hazel free from of energy. It does not create any type of pollution in environment. Many methods are used to collect solar radiation into useful form. Usage of collectors integrated to any system can enhance the already efficient working of a solar energy utilizing system. This solar energy is used for various form during day time. During off sunshine time like cloudy day or night time, when solar radiations are not present it is difficult to use it. To overcome this disadvantage research is being carried out in this field for many years. A method to overcome this problem is usage of thermal storage systems. This paper contains the different solar dryer collector study, the study of solar dryer heat storage system and solar dryer techno economic study. For eatable like vegetables, fruit like potato, onion, cashew, raisin, banana paraffin wax is considered as best option for using as Phase change material. Some research also includes study of solar dryer of vegetables and fruits using PCM. Also comparison is made without using PCM. Paraffin wax is better choice as thermal storage material. But there is a disadvantage of Paraffin wax that is low thermal-conductivity (K), to improve that many research paper have technology like metal beads, metal fins, metal foam, graphite foam, usage of metal powder etc.

Keywords: phase change materials, dryer, solar, paraffin.

1. INTRODUCTION:
Due to increase in the population of the world there is a large demand of energy. Continuous use of conventional energy can extinguish it early. This shortage of energy can only be fulfilled by renewable form of energy like solar energy. One of the most prominent way of using solar energy is by drying process. Use of solar radiation in drying can be done for vegetable, fruit etc. It reduces the total cost, efforts, uses less space, reduces use of nonrenewable energy and saves time. Earlier drying process was carried out by keeping things in open sun or by burning wood and passing that energy (heat) in drying chamber. But this methods have its own disadvantages as open drying cause hygiene problems, large open space for drying purpose **Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.**burning cause fuel extenuation as well as pollution.

2. STUDY OF VARIOUS TYPES OF SOLAR COLLECTOR
Solar collectors are used since ages, among them some of the type of collectors are flat plate collector, parabolic collector, scheffler collector, evacuated tube collector, Fresnel lens collector etc. Among the collector flat plate collector can be made of glazed material or of collector absorbing plate. Sun tracking collectors are also available like parabolic trough collector, linear Fresnel lens collector, parabolic dish reflector, heliostat field collector. Thermal and economic analyses of this collector are carried out and accordingly application is being decided. This solar collector was used in different area like solar water heating, solar refrigeration, solar drying, solar desalination, solar thermal based power plant etc. each place the collector can be selected according to the need. Like in drying only 60 to 70 ºC is needed so we can use flat plate collector but for solar power plant we need more temperature so we can use

scheffler or Fresnel lens. So this was review about solar collector its type and usage by kalogirous (2004)[14]

[15] Ayompe (2011) presented work of a year record of observation of data and result of two solar water heaters with 5 m^2**flat plate** and 4 m^2 **evacuated tube** collectors which were kept under same atmospherically condition. The reading of the two heaters was recorded on daily, monthly and yearly basis. After year it was calculated that flat plate collector produced energy of about 489 kWh/m^2 and evacuated tube collector produced 678 kWh/m^2. The yearly average collector efficiencies of flat plate collector were 45% and 61% of evacuated tube collector. Hence it was observed that the ETC are more efficient in water heating then Flat plate collector.

Tyagi (2012) [16] Research was done using paraffin wax and without using wax in different items like oil. Efficiency were calculated based on the experimental data. It was seen that efficiencies in case of heat storage material/fluid are significantly higher than the efficiency of heater of without Heat storage device. Efficiency of solar heater in which thermal storage material was used as paraffin wax was more than then material in which hytherm oil was used.

Tain Zhao (2013) had provided information on a review of various solar collectors and thermal storage methods. Information on the existing and future solar power stations was also given. According to the paper in solar collector thermal energy is absorbed from the radiation by the working fluid which can be air, wax, water or oil. Usually paraffin is used as thermal storage material but it is not so effective as the thermal conductivity of wax is very less. Tain has suggested to enhance this thermal property by adding metal powder, metal beads or metallic fins in collector. Graphite composite or metal foams are used to enhance thermal conductivity. [17]

Drying of food material also depends upon different drying kinematics. The thickness of the banana slices which will be efficient for drying purpose was mentioned in [26]. According to [28] for optimal drying or removal of moisture banana should be slices of 20 mm thickness.

Normally according to the study it is clear that active drying of materials are giving more result quick. [29] [30] [31] [32] Describes that how by drying red chilies through solar fan near collector inlet helps to enhance drying process.

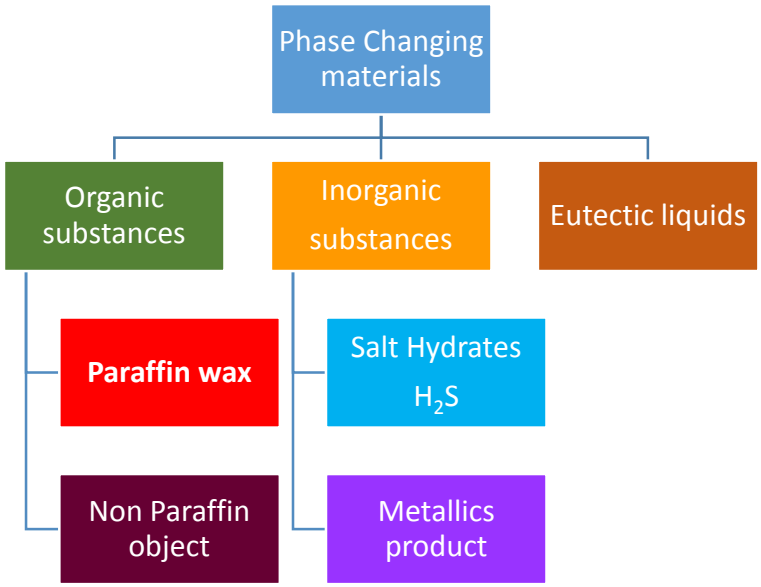
3. PHASE CHANGE MATERIAL (PCM) IN SOLAR DRYER

The solar energy is only available during day time. There is no technic to store the large amount of sun energy which we are getting in conventional way like we us electricity. But there is a way to store it in thermal storage materials. PCMs are used as thermal storage materials **Error! Reference source not found.**.

Thermal energy storage devices are used for storing solar energy in night and cloudy days. The PCMs absorbs the surplus amount of the radiation which is been delivered by sun. the best thermal storage device is made by latent heat storage devices like PCMs. The only disadvantage of using PCMs are its higher volume change. Study are carried on inorganic and organic materials as PCM **Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.**. The higher price of PCM is again a draw back.

[8] Also shown experimental study of solar dryer in which sensible heat storage device and phase changing material was used. It was observed that 12.30 pm pebble temperature was 65ºC were as Paraffin temperature was 60 ºC.

PCMs are the material which absorbs and releases energy by melting and solidifying respectively. The PCMs absorbs and releases energy in form of latent heat of a substance. PCMs are seen to be more effective and better then sensible heat storage material. They are more convenient to use as they provide high energy storage density per unit volume.



3.1 Comparison between different PCM.

TYPE	ADVANTAGE	DISADVANTAGE
Organic	**Super cooling is not seen.** Thermal conductivity is moderately good when it is in liquid state. **It melts as well as freezes evenly**. Availability in large temperature range **Chemical properties are stable at high temperature also**. Normally heat of fusion is high. **Materials are less reactive and safe to use even for food items drying**. It can be reused mostly.	**In solid state thermal conductivity is very low**. Water cannot dissolve many organic materials. **It can catch fire easily, so at high temperature there is a risk.** It has low density, so we ned more volume to fill more mass. Hence the size of dryer increases. **If the chamber is not closed properly it can easily vaporise as it is mostly volatile**. It costly than other TES materials.
Inorganic	**Thermal conductivity is normally high**. Specific heat storage capacity is higher. **Inorganic materials are less expensive and easily available** It cannot catch fire even at high temperature. **Material can be recycled for many time**.	**High degree of super cooling** Melting takes place unevenly. **Materials like stone contains heavy weight**. Many times material like water can corrode the other metallic part of dryer. **Proper container is needed for filling and keeping material**.
Eutectic	Sharp melting temperature High volumetric thermal storage density No phase segregation and congruent phase change	Lack of currently available test data of thermo-physical properties Low total latent heat capacity Some of eutectics suffer from super-cooling effect Strong Odour Costly

3.2 Use of PCM in Solar Dryer

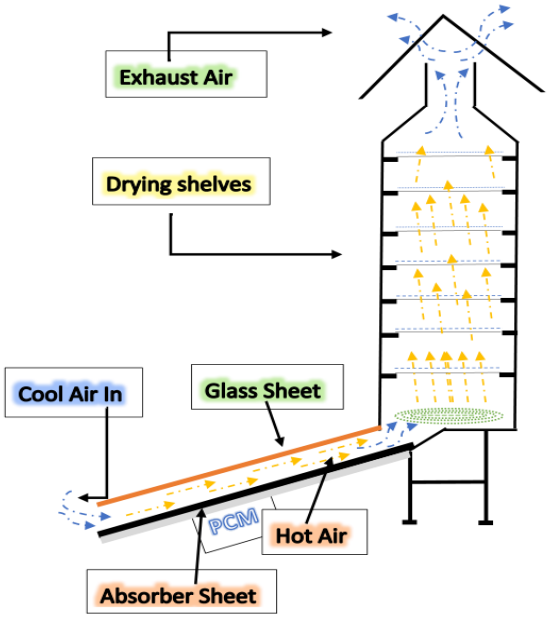


Fig. 1: -Sketch diagram of a solar dryer using PCM

As we see in above fig [1]. the sun radiation is absorbed by the pcm which is stored in collector area. This phase change material will change its state from phase solid state to liquid state this results in melting of phase changing material. At that point a large amount of thermal energy is stored in it. And during evening time this energy is released and the pcm will convert into solid this released energy will come in contact with collector air and that air will go in dryer chamber and it will remove moisture even in absence of solar radiation.

Aiswarya.M.S, Divya.C.R[18] in 2015, has published paper on in which study of solar dryer was carried out using latent heat storage device as well as sensible heat storage device also using with and without pcm was done. The solar dryer was developed with a thermal storage system as paraffin.

Research was carried out on Potato chips and other Vegetables. It was seen that quality of the food was maintained even color was maintained as direct sunlight was not falling on sample.

Result also says that inclusion of conductivity materials like aluminum improve the thermal conductive of the paraffin wax. The trays are made of aluminum mesh to avoid rusting. The area has a temperature of 33-36ºC.

The day-time thermal efficiency of the heaters with PCM is high for 0.032, 0.04, and 0.048 kg/s while it is low for 0.008, 0.016 and 0.024 kg/s regarding the heater without PCM. Thus, the use of the PCM in Solar dryer at a **flow rate of 0.032 kg/s** and more is energy-efficient and usable.

Based on the experiment carried out by [19] few conclusions were derived. Author used **honeycomb** structure for improving thermal conductivity of the heat storage device.

The daytime temperature of PCM material in the heater with honeycomb increased between by **8.8 and 2.0 °C**, respectively in reverse proportion to the increasing the air mass flowing rate.

Besides the PCM heaters, the highest peak lasts about 6 h, and the lowest peak is close to 10 h.

In the PCM heaters, equalizing the outlet air temperature with the inlet air temperature is shorter than 1 h to 16 min in favour of the honeycomb heater according to the increase in air mass flow rate.

As the air mass flow rate increases, the equalization times of the inlet and outlet air temperature of the heaters with heat storage were shortened.

The use of honeycomb has significantly shortened charge–discharge times.

The PCM were more efficient when the mass flow rate was higher between 2.6 to 22.3 %.

The use of honeycomb is suitable for applications where charge discharge times are essential, as well as for applications with high panel thicknesses.

[33] Shows the design of the solar dryer with nocturne which was great for increasing the drying rate. [34]The need to use a nocturnal-shutter to reduce the air temperature drop at night-time with an adverse night effect has emerged.

Different parameters of drying were taken into consideration like drying rate, moisture content from [22]. For banana internal moisture absorbing coefficient was 0.6.

3.3 Selection of PCM material:

Table 1: Physical Properties of PCMs. [20]

Properties	Organic		Inorganic	
	PCM	Non PCM	H_2S	Metallic material
Fusion enthalpy	More	More	More	Medium
Conductivity of material	Less	Less	More	Most
Temperature of fusion	-19 to 104+	6 to 120+	0 to 200	156 to 850+
Latent Heat of material(KJ/Kg)	199 to 281	91 to 251	61 to 301	26 to 301
Melting and solidifying cycle	Cycle is uniform	Non uniform during melting	Non Uniform of offend	Uniform
Density of PCM	Medium	Medium	Less	More
Effect of environment	Non corrosive	Mildly corrosive	Corrosive	Varies

Author [20] many more application of PCM was seen in paper in which solar air drying was used. The drying process for each food items is different. Like the temperature of drying can change from 45 to 90 degree. This drying can be done using solar dryer of same kind by varying phase changing material amount.

The different aspects considered for **selection** of PCM,

- Mainly economically feasible and viable
- The melting point of the material
- The high latent heat of fusion

By doing Literature review it seems that paraffin was due to its specific functions is proofed as the most useable latent heat storage materials. Paraffin comes in different type they can be melting at 40 to Paraffin has a large melting point selection options. Degree hence gives a wide range for customer to choose temperature.
Study is ongoing on increasing the quality of the PCM and also increasing the efficiency of the solar dryer.

- To increase the heat transfer capacity
- To increase the air mass flow rate in dryer

More over recent research also carried on increasing the thermal conductivity of paraffin wax by inclusion of nano particles. The temperature and heat transfer rate depends upon air flow also. Hence overall efficiency of solar dryer is increased.

By the paper review can be done that using phase changing material as best option for enhancing the efficiency. Using PCM can also make 24 hours working solar dryer. Some of the paper also uses active type of solar dryer by installation of induction fans used by solar panels. Phase changing material can bring a revolution in drying industry if used properly. Study also says that using phase changing material for initial drying increases efficiency of drying product.

3.4 Measurement of PCM Parameters:

For recording melting point of any type of PCM thermal analysis techniques are used. Differential scanning calorimetric abbreviated as (DSC) is a device which can measure latent heat of fusion and melting point of PCM. DSC was developed by Watson in 1962. According to **Error! Reference source not found.** the qualitative measured are based on exothermic as well as endothermic process. According to **Error! Reference source not found.** differential scanning calorimeter are used to measure amount of heat absorbed or released with the change in temperature, different samples measurement is taken out at same time and thermal action with a linear temperature ramp.
Before designing any solar thermal appliance the proper study of different Latent heat storage materials are very important. [10].

3.3 *Paraffin Wax*

Paraffin wax is an organic compound. It is mainly coming under natural alkane series. Paraffin wax are of many variety, the melting point of paraffin wax ranges from 41 to 100 ºC. Paraffin wax are very cheap, more reliable, when it is melted the change in volume when it is melting is very less. Paraffin wax also have low vapor pressure. In drying process specially items which are eatables like vegetables, fruit etc. the drying temperature is ranged between 40 to 60 º C Normally.**Error! Reference source not found.**.
For calculation of water content present in different type of fruits [24] was refereed. According to [24] raw banana has moisture content of 70 %.
Paraffin wax has received considerable attention in thermal energy storage because of its good thermal physical properties, including a suitable melting temperature, high latent heat energy, negligible super cooling, and stable chemical and thermal performance [20]. Paraffin wax (C_nH_{2n+2}) generally has a linear, cyclic, or branched structure. The melting point of paraffin wax is between **30 and 90 ◦C** [20], and its specific melting enthalpies are **180–270 kJ/kg**, which is determined by the chain length of the alkane. In general, the melting point of these types of materials increases with increasing average molecular weight, as shown

Table 2. Thermal physical properties of some paraffin materials [21].

Materials	Melting Point (◦C)	Latent Heat (kJ/kg)
Tetradecane	5.9	258
Pentadecane	9.9	193.9
Hexadecane	18.1	236
Heptadecane	20.8	171
Icosane	36.7	246
Tricosane	47.5	232
Hexacosane	56.3	256
Nonacosane	63.4	240
Dotriacontane	69.5	170
Tetratriacontane	75.9	269

4. CONCLUSION:

From the literature review commercial paraffin wax is found to be most appropriate PCM for solar dryer applications. Usually paraffin is used as thermal storage material but it is not so effective as the thermal conductivity of wax is very less. Tain has suggested to enhance this thermal property by adding metal powder, metal beads or metallic fins in collector. Graphite composite or metal foams are used to enhance thermal conductivity [39]. Overall the paper provides an idea about the methodology of why paraffin wax is considered as suitable PCM for solar drying.

After undergoing research review experiments were performed on solar dryer. The solar drying of banana chips was done with the use of Phase change material.

A natural convective drying system is developed along with thermal storage material as paraffin wax. The system is able to generate hot air at constant temperature throughout the drying period almost. [38]

Dimension of the solar dryer was selected based on the models presented by [35] [36] [37].

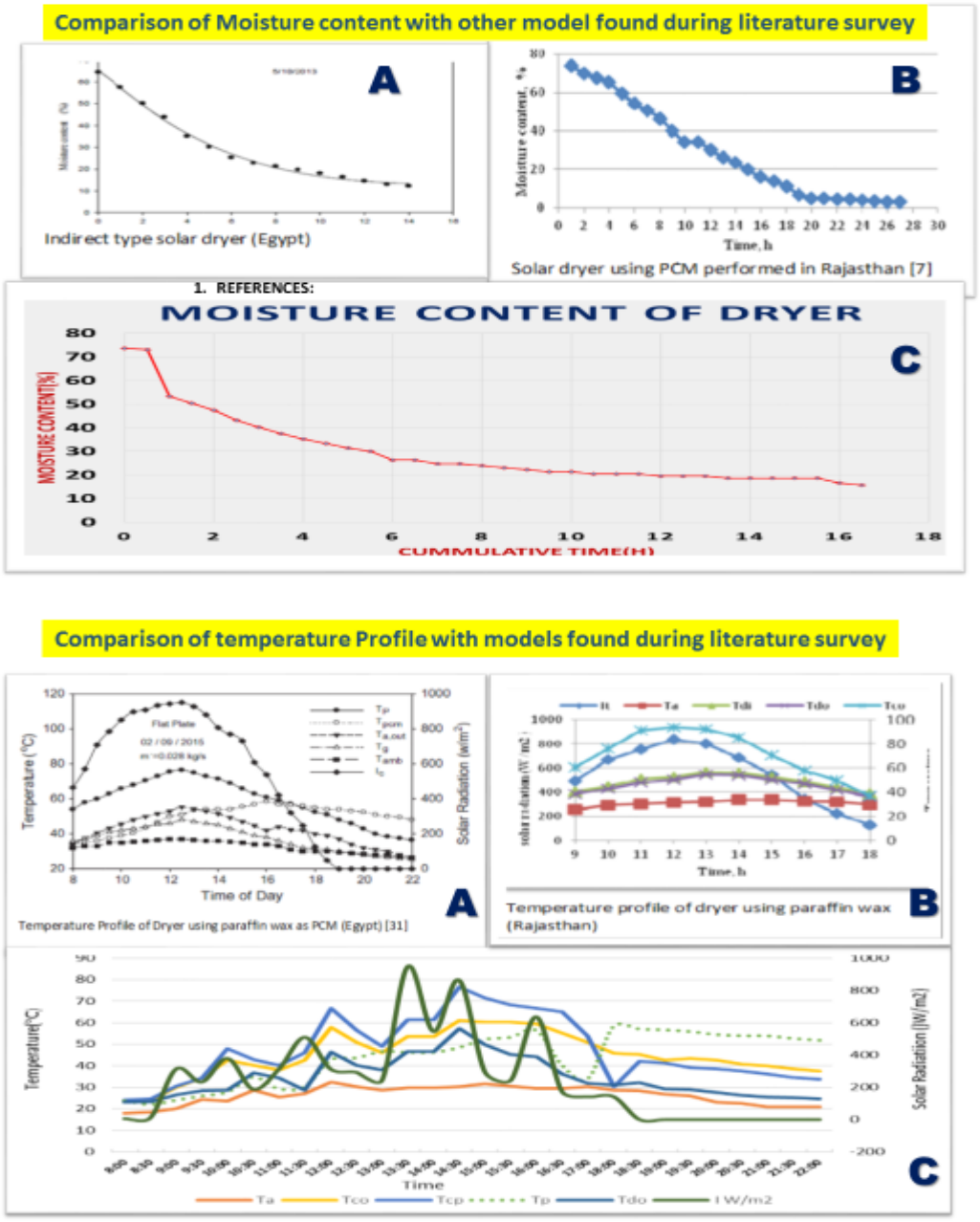
Banana Chips were dried within 16 hrs. from the moisture content of **72% to 15 %.**

The Heat utilization factor varied in the range of 0.12 to 0.91. The average heat utilization factor average was calculated **0.49.**

For drying process, the exergy efficiency varied in range of 28.5% to 100 % and the average exergy efficiency was calculated **67.61**%.

So at the end of the paper it is reviewed that if proper inclusion is carried on then paraffin is a good material for thermal storage.

5. COMPARISION OF THE WORK DONE WITH EXISTING WORK:



Here A refers to be the reading of [27] and B refers to [29]. C refers to experiment done by me.

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