SOLAR DRYER WITH PHASE CHANGE MATERIAL – A WAY FORWARD

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Abstract: Solar dryer is a device which is used to dry agricultural product by using sun as a source of energy. Solar drying is superior method for drying agricultural product to maintain its quality for longer period of time. Solar energy is intermittent source of energy and hence dryer is available only for sun-shine hours. Further, the drying process in solar dryer consumes longer time compared to artificial drying process. This negative effect can be minimized using thermal energy storage along with solar dryer. Latent heat energy storage is the one attractive method compared to sensible thermal energy storage due to high energy storage density. In present work, recent investigation in the area of solar dryer and phase change material as solar dryer is reviewed. This review summarises the previous research works based on the types of dryer, types of TES and method of work. A mind map and charts etc. are developed for solar drying technologies and different TES. Types of dryers are first introduced and followed by the types of TES and use of PCM as a TES. The most of the recent work of different dryers and TES are discussed. In the subsequent part of paper, the methodology of using PCM as a TES in dryer are also reviewed as a way forward to increase performance by means of working hours to fulfil the requirement of preservation of food.

Key Words: Solar dryer, TES, PCM.

1. INTRODUCTION

A preservation of eatable products is challenging task for most developing countries due to poor processing techniques and shortage in storage facilities. To solve above problem different methods are available like: canning, freezing, drying etc. drying has become one of the main techniques used to preserve food products. [24]

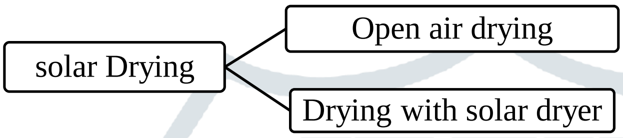
Drying or dehydration may be defined as a process of removing excessive moisture from a product to its safe or desired level of moisture content to store it for a longer time period without spoilage. [39]

Drying with fossil fuel it causes of pollution and it is expensive also it requires more appliance. Sun is a source of light and heat energy for the residents of the planet earth. Solar energy is free of cost, readily available and pollution free. For drying, solar energy can be used as it available free of cost from sun.

There are two type of drying processes as open air drying or un-improved drying and drying with solar dryer the block diagram of classification is shown in Figure 1. In open air drying product is exposed in open environment for drying in sunlight. Major advantage of this method is that it does not need fuel and appliance. However, in this method product loose its quality and nutrients, contamination of product by leaves dust etc. and product may get infected by fungal and other micro-organism. [23] Drying with solar dryer is required initial cost, but the product is maintained its quality.

Solar energy can be stored by thermal energy storage, electrical ES, chemical ES, and mechanical ES methods. The energy store by TES is economical option to use with solar drying system in order to increase the heat cycle time. During bright sunshine hours TES absorb solar energy in the form of heat and after that during cloudy weather and during night it supplies energy in the form of heat for drying.

Figure: 1 Types of solar drying



2. Solar dryer as an instrument for drying (Preservation of food product for longer period of time)

Solar dryer is a device which absorb solar radiation in the form of heat and heated up the atmospheric air for drying of product in drying chamber for preservation of product, reach to the global demand.

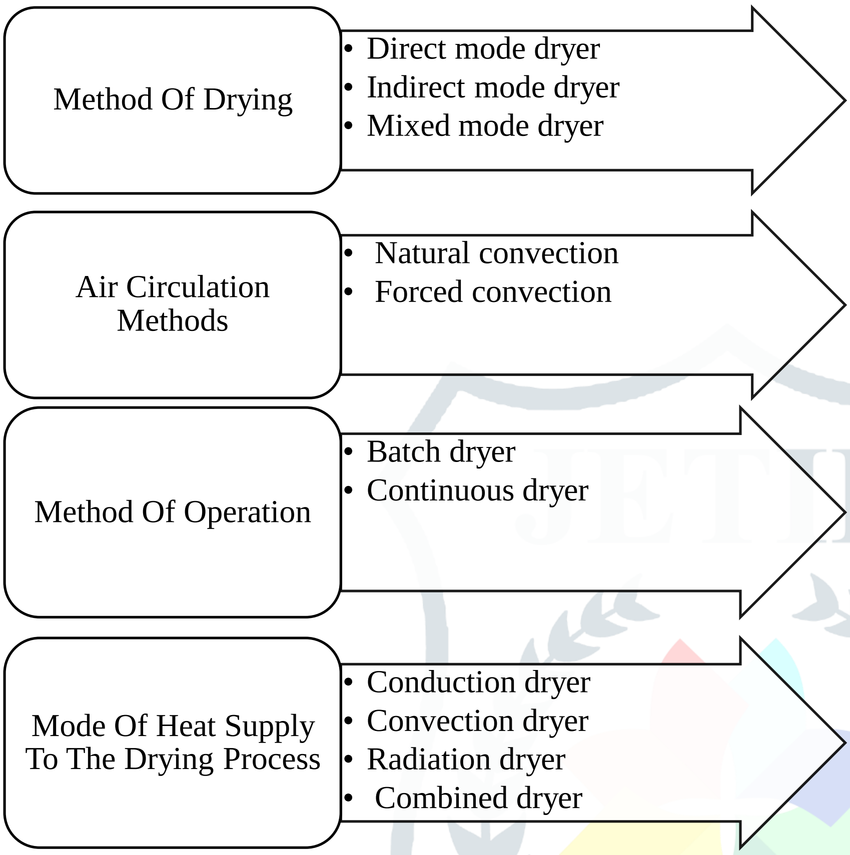
The solar dryer can be classified as: based on the method of operation: Batch dryer, continuous dryer. based on mode of heat supply to the drying process: Conduction dryer, convection dryer, radiation dryer, combined dryer. based on the method of drying: Direct type dryer, indirect type dryer, mixed mode dryer. based on air circulation methods: Natural convection dryer, forced convection dryer. The classification also presented in form of block diagram as shown in Figure 2. [1] The mind map for various drying technology is prepared as shown in Figure 3.

Mahesh Kumar et. al. (2016) [2] compare various solar dryer with same capacity of 100 kg, and for different product. They compare solar dryers such as natural convection and forced convection dryers, cabinet dryers, mixed mode dryers, tunnel dryers, direct and indirect type dryers, hybrid and integral dryers, from that they conclude that indirect mode forced convection dryer is superior in drying speed and quality drying for large capacity of batch. Due to high drying rates and energy effectiveness, that type of dryer is suitable for low solar insolation and high humidity climate zones. They added that dryer integrated with PCM is helps to accelerate drying performance.

Mukul Sharma et. al. [3] suggested general parameters regarding performance evaluation of solar dryers which are as follows. Physical parameters like: type, size, shape, capacity, loading density, area and no. of trays. Thermal performance parameters like: Drying rate, drying air temperature, air flow rate and drying efficiency. quality of dried product parameters like: Sensory quality (taste, colour, aroma, etc.), Nutritional attributes, Rehydration capacity. Payback period and cost of dryer. They also give the calculation of performance parameters such as dryer efficiency, collector efficiency, drying period. Also they said that Solar drying technologies are economic as well as efficient for food drying and they are useful at any climate condition after the minor modification in structure and orientation of dryer.

N. S. Rathore et. al. (2011) [14] they conclude that for fruits and vegetables proved that solar drying can be attractive method for food preservation and also for a commercial proposition. The system is saving about 25.37 USD per day. There is need to integrate solar tunnel dryer for drying agriculture, horticulture and industrial products on large scale at different agro-industrial levels. S.K. Dhiman et. al. [15] they suggest certain improvements can be made in the model insulation may be replaced by Teflon which is a better insulator than wood.

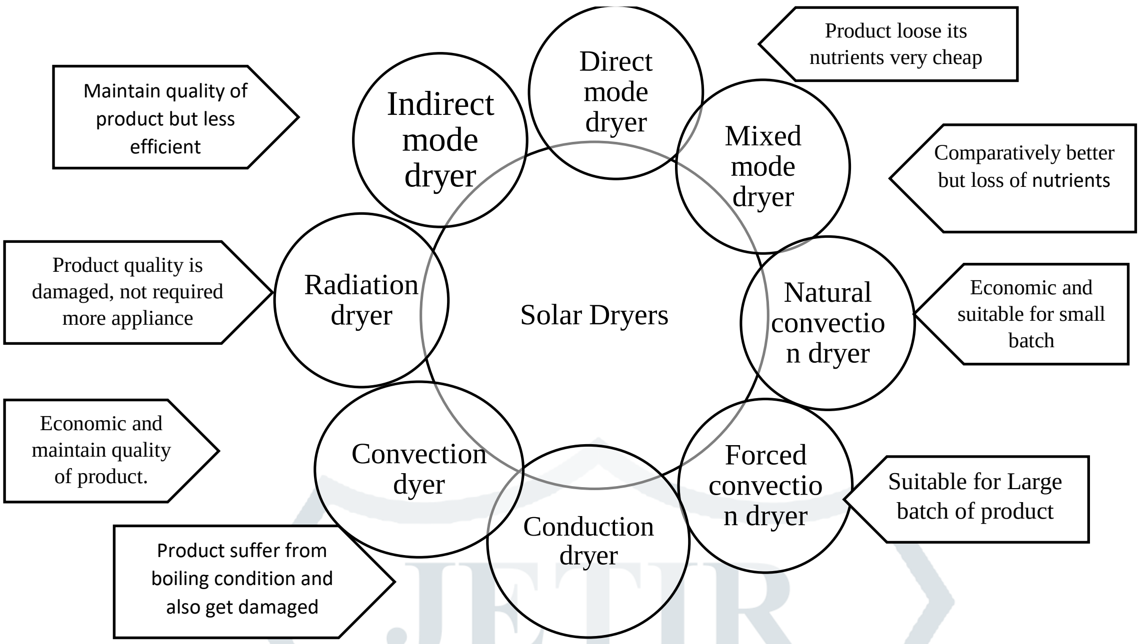
Figure: 2 Classification of dryer



A.G.M.B. Mustayen et. al. (2014). [4] Direct solar drying is mainly used in farming. It is also preferable where electrical power is not available. This type of dryer is more efficient in dryings large amounts of crops, fruits, and vegetables. A locally made indirect-type natural convection dryer is useful for drying fruits and vegetables in rural region. A solar tunnel dryer can be used for drying jack fruit and leather. The mixed-mode dryer is cheap, readily available, and can be easily construct by local farmers. Tomatoes, mango slices, and grains can be dried using mixed mode dryer, which is driven by a fan. Therefore, agricultural products are dried within a short time at ambient temperature. The natural convection dryer is more advantageous and applicable than other dryers. The forced convection solar dryer is used in small firms. They are also adding some environmental impacts and how that impacts can be mitigate.

S. Sivasundar et. al. [6] They were checked performance of an indirect natural convection solar drier integrated with booster mirror for cashew drying. They found that inclusion of reflector mirror helps in decreases the drying time also increase effectiveness of solar dryer. maximum value of thermal efficiency and drying chamber efficiency with reflector are found as 62 % and 21% and they include research gap that further performance enhanced by using PCMs for TES.

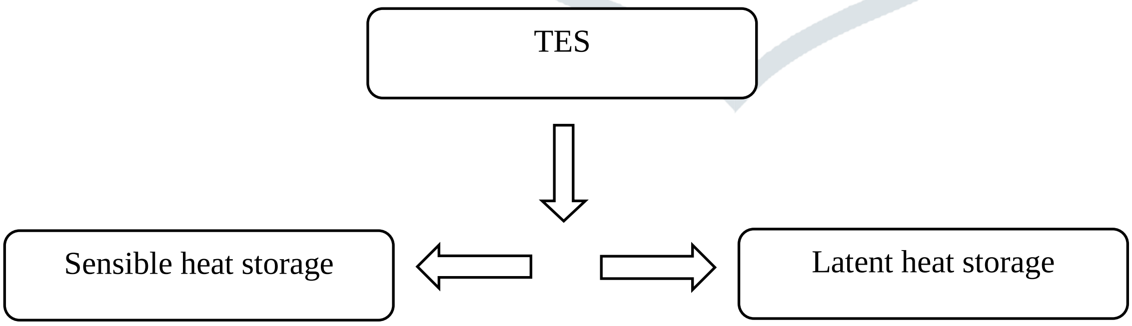
Figure: 3 Mind map of solar dryer



3. TES materials

TES is helps to absorb heat energy during day time at sunny weather and supply heat energy at cloudy weather, during night or after bright sun-shine hours. There two type of TES as follow: Sensible heat storage and Latent heat storage, as shown in Figure 3. [25,34]

Figure: 4 Types of TES



3.1 Sensible Heat Storage

In sensible heat storage TES material during absorption of heat only its temperature is increases, there is no changing od phase during the heat absorption.

Halil Atalay (2018) [10] he was used rock bed as TES and design a dryer. He noted that the quantity of the thermal energy stored is sufficiently for the drying of orange slices even at times when solar radiation is absent.

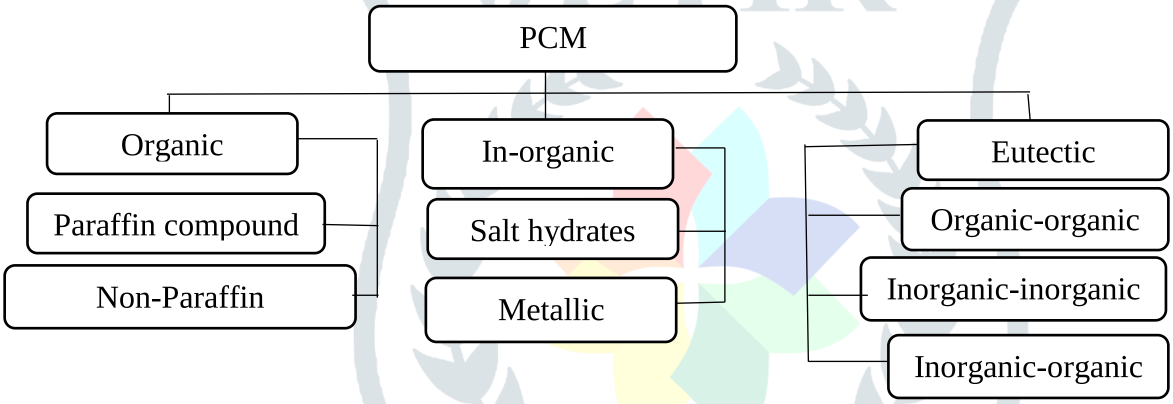
He found that using the energy storage systems in drying processes will significantly increase the energy and exergy efficiency.

Messaoud Sandali et. al. (2018) [11], they used geothermal water for TES and supply it to heat exchanger then by using blower they supply hot air to drying chamber. They found that the drying air temperature remains important and almost steady with an average value of 46°C and exceeds that in case of solar dryer without heat exchanger by 30°C. The integration of the heat exchanger inside solar dryer ensures the continuity of drying process at the night and even during cloudy days. But in every region on earth there is no geothermal water is available.

3.2 Latent Heat Storage

PCM is use as a latent heat storage material. PCM absorbs and stores heat for further use. PCM absorb latent at constant temperature during of itself and as soon as melting process complete it absorb sensible heat during which its temperature increases. PCM are categorised by melting temperature range. The classification of PCM is represented with the tree as per the Figure 4. [5]

Figure 5: General classification of PCM



Arif Kayapunar el. Al. (2019) [12] they said that PCM as a TES easily used into existing thermal system. Also it does not need any other energy input and additional complex mechanism to handle it.

A.K. Bhardwaj et. al. (2017) [21] they are using sensible heat storage material as mixture of gravel and iron scrap in the collector along with engine oil in the copper tube, also they are simultaneously using PCM also. Their analyses show that using TES, drying time reduced by 37.50%.

Enrico [33] spoletini found that by using PCM as ES system required less system volume as compared to Latent heat storage system. Murat M. Kenisarin [35] seen from the review some developers of novel PCMs undergone to thermal cycling test only 3 times whereas other researchers 5000 times. Thermal cycling less than one hundred times is not reasonable. At the same time, it is improbable that the PCM product can be undergone 5000 times to thermal cycling in real condition of operation. It is expected that PCM product in solar applications will be undergo to thermal cycling about 1000 times. Therefore, when developing commercial latent heat storage products at acceptable prices, stability of thermal properties of these substances we recommend to carry out at least 1000
thermal cycles.

PCM become good candidate for the energy storage if they satisfy the following conditions: [8,22]

a. The melting point of the PCMs must be match with working temperature of the device (application condition),
b. The material used as PCM should have enough phase change latent heat to absorb a large amount of thermal energy,
c. The coefficient of thermal expansion of PCM should be relatively small to ensure the system work safely,
d. The PCM should have excellent reversibility of phase transition,
e. The PCM should be non-toxic, non-corrosive and produce no chemical reaction to the container and devices,
f. The PCM raw material should be easily available at economical rate.

3.2.1 Paraffin wax

Paraffin wax as a PCM is an attractive option for heat storage applications. It has high latent heat storage capacities over a narrow temperature range.

Akgun et al., (2007) [13] The main limitation of paraffin as PCM is the low thermal conductivity. It causes a long time for the melting and solidification process. Also, it requires large surface area.

Onkar A. Babar el. Al. they compared six PCMs were investigated to determine their suitability as a thermal energy reservoir in solar drying applications. Five paraffin waxes and wood resin were considered. The thermo-physical properties like melting point, solidification point latent heat of melting and latent heat of solidification, effective thermal conductivity and specific heats in solid and liquid phases and bulk density were determined. It is concluded that the PCM PW1 possesses maximum density of 932.9 kg/m3 in liquid state, and maximum latent heat of fusion and solidification were383.87 kJ/kg and 320.26 kJ/kg K, respectively. Also thermal conductivity of PW1was found to be maximum, i.e., 0.11 W/m K, whereas specific heat in liquid phase was 2.1 W/m2K.Thus, the PW1was selected as PCM for a flat plate collector solar dryer.

3.2.2 Fatty acids

Fatty acids have good characteristics of PCM with long-term stability. They have many similar characteristics of organic paraffin, specifically low thermal conductivity and significant expansion on melting. However, they typically have lower latent heats than paraffin in similar melting ranges and higher costs. Some fatty acids are gentle corrosive with critical container design. The blends of fatty acid with paraffin may be utilised to change the melting temperatures. The study found that fatty acids have good thermal reliability but poor thermal conductivity as in the case of paraffin wax.

Jankowski et. al. [26] said that fatty acids provides shifted melting temperatures with the cost of significant latent heat reduction.

3.2.3 Salt hydrates

Zalba et al. [28] and Sharma et. al. [27] said that salt hydrates have good characteristics of PCM such as higher latent heats, densities, and thermal conductivities than paraffin and fatty acids. They are also relatively economical than other PCMs. Hence, they are one of the more commonly studied classes of PCMs.

3.2.4 Compound or eutectic PCM

A eutectic PCM is an engineered material as combination of two or more compounds of either organic, inorganic or both. There are a number of eutectics that may be produced to almost any desired melting point for TES systems. A eutectic is a minimum melting composition of two or more components. Tyagi el. al. [29] During crystallisation, each component of eutectic melts and freezes identically forming a mixture of the component crystals and they act as a single component. Sharma et al. [30] Eutectics are freeze to close mixture of crystals and melt simultaneously without separation. As the use of eutectic materials is very new to TES application; only limited data is available on thermo-physical properties.

Jotshi et al. [31] experimentally found that thermo-physical properties of ammonium alum and ammonium nitrate eutectic and eutectic has good thermo-physical properties (enthalpy 287 kJ/kg in the temperature range of 25–67°C) for energy storage in solar space heating applications.

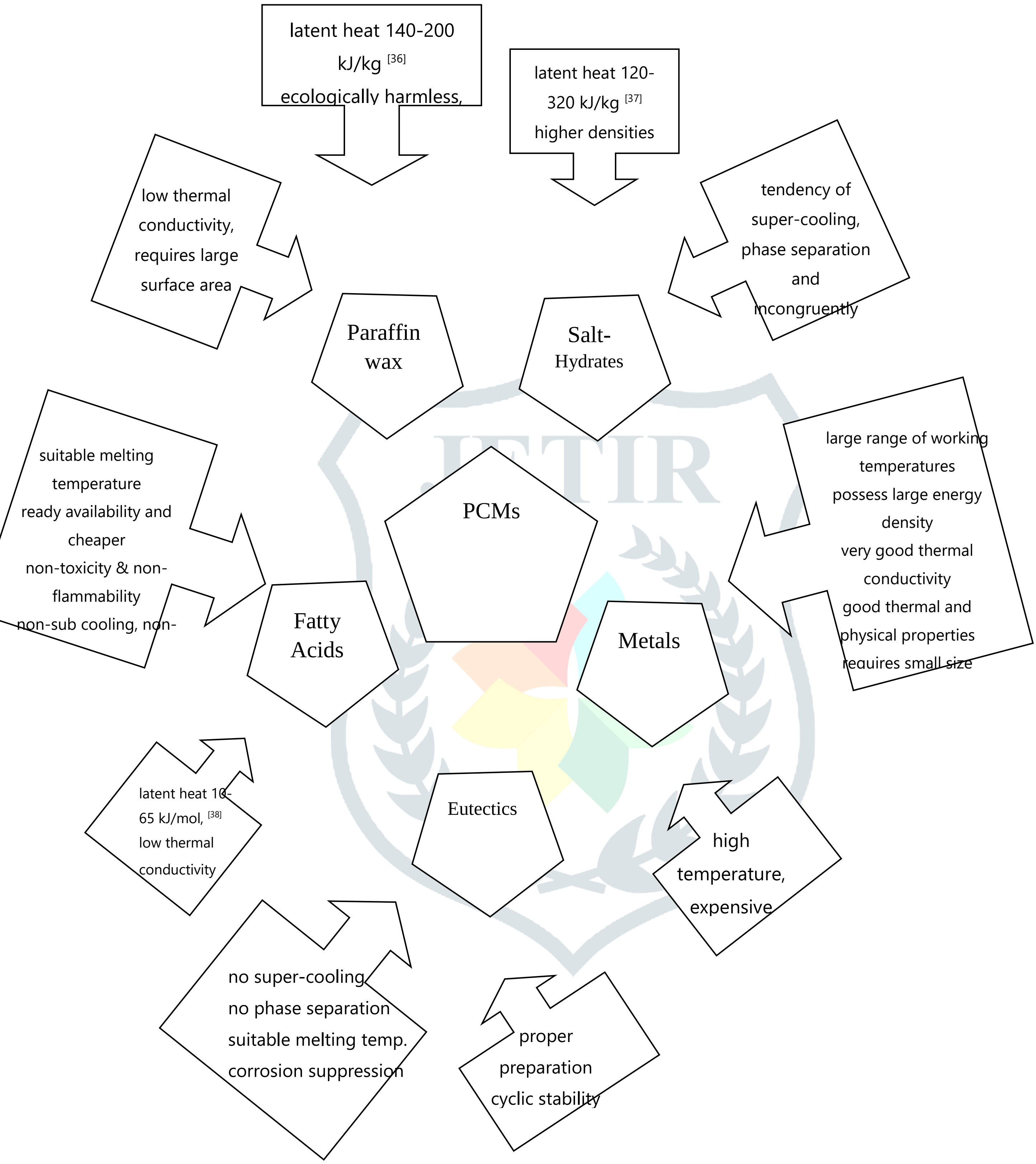
3.2.5 Metallic

Metallic alloys have a high heat of fusion, a wide range of working temperatures, low vapour pressure, better thermal and physical properties, less corrosive and toxic. During solid–liquid transformation, they produce large enthalpy changes without large density changes; hence they are good candidates for PCMs. Metallic as PCM requires small size ES equipment compared to other PCMs since it possess large energy density.

Metallic PCMs may be categorised as low, medium and high melting point metals or alloys. Low melting point metallic PCMs may be utilised as ES for solar water heating while high melting point metallic PCMs for that of concentrator solar power plant.

Ge et al. [32] summarised various low melting point metals or alloys with respect to their application, merits, and properties. They concluded that metals and alloys with a melting point between at 0°C and 100°C are displaying increasing potentials in various thermal and energy management fields.

Figure 6: Mind map of different PCMs



4. METHOD OF WORK

José Vásquez et. al. (2018) [16] they were used absorber as well as accumulator. Absorber having zinc fin which is working during day time and heated up the air for drying product. Accumulator is containing cans filled with PCM which is only absorb heat during day time. After the bright sunshine or during night accumulator heated up the air for drying of product. Also here arrangement is available for recirculating the exit air from drying chamber. Aymen El Khadraoui et. al. (2017) [17] they are work with same concept like José Vásquez but here recirculation arrangement of exit air is not available.

Himangshu Bhowmik et. al. (2017) [18] they were developed prototype of a flat plate collector with or without reflector and tested in different atmospheric condition, reflector is used to concentrate the solar heat on the collector surface, thus maximize the collector efficiency. The collector efficiency is obtained without reflector as 51%, and with reflector as 61% and the overall efficiency of the flat plate solar collector is increased approximately 10% by using the reflector with the collector.

Zoran T. Pavlovic et. al. (2015) [19] they were concluding that If the top and bottom reflectors were about the same size as the collector and optimally tilted, total solar radiation intensity on the collector in the summer period was about 50% higher in comparison to the structure without reflectors. Also they found optimal angle for reflectors according to tilt angle of collector also for different seasonal conditions.

S. Nabnean et. al. (2016) [20] they were used solar water heart to heated up the water and stored into the insulated tank. Hot water from tank to heat exchange via pump. And air heated up via heat exchange and circulate by blower and supplied to drying chamber.

5. CONCLUSION

Indirect type natural convection solar dryer is relatively economic and effective. Drying rate of indirect solar dryer is less compared to forced convection solar dryer. But as per the literature survey blower required external electrical energy supply which can be provided by fossil fuel or PV cell. Using of fossil fuel and PV cell causes pollution and extra initial cost respectively. Forced convected solar dryer is suitable for large batch size and natural convected solar dryer is suitable for small batch size.

PCM is effective for TES because it absorbs heat in the form of latent heat. So, it can absorb more heat that sensible heat storage system. Paraffin wax is most applicable as PCM.

If we put PCM behind the absorber of indirect natural convection solar dryer, which is user friendly and inexpensive method.

It is concluding that there is a need to find the inexpensive and user friendly dryer. There is an experimental work needed to realize the actual performance of dryer with PCM and TES. This review work in form of mind map, block diagram and charts may provide a guideline for future work.

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Nomenclature

PCM PCM
TES TES
ES Energy Storage