REVIEW ON HEAT STORAGE MEDIA USED IN SOLAR AIR DRYERS FOR DRYING AGRICULTURAL PRODUCTS AND METHODS OF PERFORMANCE ENHANCEMENT OF SOLAR AIR DRYERS.

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Abstract: Generally farmers dry their agricultural products and food stuffs in open sun. In open sun drying the products were sprayed under sun and moisture evaporates from it. This open sun drying is having so many drawbacks such as dust contamination, insect contagion, microbial attack, Decadence due to rain etc. To overcome these drawbacks the new technology emerged in market is Solar Air Dryer. It is a device used for product drying and controlling product quality and taste with proper applications of solar energy. Solar dryer is operated during off sunshine period by using Thermal Energy Storage (TES) technology. Energy storage medium collects solar energy during sunshine period and supply it for product drying during off sunshine period. Developing efficient and cost effective energy storage in solar air dryer is as important as developing new energy sources. There are three kinds of TES technology namely sensible heat storage (SHS), Latent heat storage (LHS) and thermo chemical heat storage (TCHS). Out of these three technologies, due to high energy density and constant working temperature LHS technology is efficiently used in solar air dryer for drying agricultural products and foodstuffs in the temperature range of 45°C -90°C [10]. LHS technology uses Phase Change Material (PCM) as TES medium in solar air dryer which stores the thermal energy during sunshine period and supply the stored energy for drying products during off sunshine period. This paper presents the review on phase change materials, their corresponding performance in respective applications, related methods of performance enhancement of PCM and their applications and various designs of solar air dryers used to enhance its performance. Although a lot of research work on performance enhancement of LHS system has been performed and many valuable results have been obtained, there are still many works need to be performed. It is proposed that the novel phase change material will synthesized by Fischer's esterification Method. By Fischer's esterification of glycerin (i.e. Glycerol) with Acetamide in toluene with sulfuric acid as catalyst new PCM will be obtained. The comparative results of performance of glycerin, Acetamide and new PCM obtained by Fischer's esterification of glycerin (i.e. Glycerol) with Acetamide; can be presented in graph and table format.

Index Terms- **Solar Dryer, farm products, PCM, LHS, Glycerol, Acetamide.**

I.INTRODUCTION

In order to preserve agricultural products and foods stuffs, the farmers dry their products under open sun. Under open sun drying moisture evaporates from products and thus products can be preserved for long period of time. During drying products under open sun drying; due to addition of various factors the quality and taste of the product changes and it cannot remain eatable. The factors affecting quality and taste of products are addition of dust, dirt through flowing air, addition of water due to rain, attack of insects, birds and other microbes. Due to this low quality of products farmers do not get right price on selling product. To dry these agricultural products without destroying its quality and taste; the equipment available in the market is solar Air Dryer (SAD). Blower, flat plate or v-grooved plate collector, drying chamber, air exhaust fan, pyranometer (to measure solar intensity), temperature measurement instrument (i.e. temperature sensors, thermometer, etc), anemometer (to measure exhaust air flow rate) are the basic components of solar air dryer. In SAD the food grains or foods stuffs to be dry are kept in drying chamber. Atmospheric air is sucked by blower and it is forced to flow over heated plate collector. Air receives heat of plate collector by convection. The hot air is forced to flow around products kept in drying chamber. Convection type heat exchange takes place between products (at ambient temperature) and hot air which remove the moisture from the product. By proper selection of plate collector (flat plate-grooved or other of other types) and heat storage media inside collector; the temperature obtained at the outlet of plate collector can be controlled and thus the temperature of the air flowing around the products is controlled. Percentage of moisture to be removed from the products depends on the temperature of the air flowing around the products.

Due to unavailability of solar energy during night time, the products are dried only during day time by using available solar energy. It is the need to store the solar energy so that it can be used during off sunshine period and ultimately it will increase the performance and productivity of solar air dryer. To store solar energy when it is available and use it during unavailability of solar energy is the new technology incorporated in solar air dryer which accelerate the rate of drying by providing safety against attack of foreign things and increase the quality of product. New and newer heat storage Medias are being searched by the researchers day by day. There are three types of energy storage techniques namely sensible heat storage

(SHS) by heating a liquid or solid storage medium (e.g., water, mineral oil, molten salts, sand, rocks and concrete), latenet heat storage (LHS) and thermo chemical heat storage (TCHS). Due to high latent heat storage density, thermal energy stored as latent heat of fusion is more preferable than thermal energy stored as sensible heat [1],[10] . The market can be segmented by three major PCMs categories: Paraffin (45%), salt hydrates (33%) and biomass based PCM (22%)

Advantages of solar air dryer: Solar dryer provides various advantages like [24, 25]

- It saves fuel and electricity and drying time.
- Fruits and vegetables dried in solar dryer are better in quality, taste and hygienic.
- Flies, rain and dust does not affect products.
- Provides Better market price to the product.
- It Reduces Losses.
- Products dried under solar dryer provides; Low and uniform moisture content, Minimal proportion of broken and damaged grains, Low susceptibility to subsequent breakage, High viability, Low mould counts and High nutritive value.

II. REVIEW ON VARIOUS HEAT STORAGE MEDIA USED IN SOLAR AIR DRYERS.

This review presents use of various phase change materials, their corresponding performance in respective applications, Related methods of performance enhancement of PCM and their applications.

A.k. Bhardwaj, Ranchan chauhan,et all [2014] used indirect solar air dryers in forced convection mode with integrated PCM(Paraffin:RT-42) for drying Valeriana Jatmansi Rhizomes (A medicinal plant).They get the benefit of Paraffin: RT-42 (PCM) in maintaining constant and continuous hot air to rhizomes below optimum temperature of Valeriana (40°C).This indirect and isothermal drying below optimum temperature maintain quality of volatile product without any loss. This system takes 5days to remove moisture(from 89% to 9%) from rhizomes whereas heat pump drying and shade drying takes 8 days and 14days respectively to remove moisture from 89% to 9% from rhizome. As compare to heat pump drying and shade drying; solar air drying takes very less time for drying. In this solar air dryer using Paraffin RT-42, drying time reduced by 37.50% and 64.29% when compared to heat pump and shade drying respectively. Solar thermal collectors are more important element in solar air dryers system because it captured solar radiation and turned it into thermal energy and transmute to working fluid afterward.

Aiswarya M. S. and Divya. C. R (2015) depicts that; the thermal energy can be stored in three forms namely sensible heat storage, latent heat storage and chemical heat storage. The thermal energy storage material (TESM) are available in three forms namely solid state TESM, Liquid state TESM, gaseous state TESM. PCM`s are latent heat storage materials. The use of PCM in solar dryer to store the latent heat is the novel technology which required limited space availability, high initial cost and regular sunshine for charging. In order to use PCM in SAH it should have high specific heat and heat of fusion, high density, high thermal conductivity, stable composition, chemically inertness and non toxicity. Saman Rashidi, javad Abolfazli Esfahani (2017) states that the heat transfer rate in solar collector can be increased by using porous material at the inner surface of the collector. The porous absorber material such as metallic foam, porous metals and hybrid mixture of activated alumina and zeolite 13x can be used in solar chimneys due to more interface areas and higher heat transfer coefficients. These materials enhance natural ventilation and collects more solar radiations .A E kabeel, A khalil, et all(2016) , in their research paper ,'Experimental investigation of thermal performance of flat and v-corrugated plate solar air heater with and without PCM as thermal energy storage', investigate the thermal performance of flat and v-corrugated plate SAH integrated with PCM(Paraffin wax). Solar air heater with inbuilt PCM was designed and tested under local weather conditions of Tanta city, Egypt (30° 43`N, 31 ° E). Authors found parameters such as solar radiation, temperature difference of air across the heater, convective heat transfer coefficients between the absorber plate and flowing air, instantaneous thermal efficiency, daily average efficiency and freezing time of PCM affects thermal performance of flat and v-corrugated plated SAH with and without PCM,when the mass flow rate were 0.062,0.028 and 0.009 Kg/sec. The experiment on FPC with and without PCM and on v-corrugated plate collector with and without PCM was conducted when thickness of PCM beneath the absorber was 4cm and 2cm. The authors found that V-corrugated plate collector with PCM gives best results at mass flow rate 0.062 kg/sec in following manners

1. The daily efficiency of v-corrugated plate with PCM is –
   a) 12% higher than v-corrugated plate without PCM
   b) 15% higher than flat plate with PCM &
   c) 21.3% higher than flat plate without PCM

2. The outlet temperature of v-corrugated plate SAH with PCM was higher than ambient temperature by 1.5 to 7.2 °C during 3.5 hours after sunset compared with 1-5.5°C during 2.5 hours after sunset for flat plate SAH.

R.Balaji,K. Soundaranayaki,A.Mercy Vasan (2016) in their paper, Physibillity study of beeswax as phase change material examined heat storage efficiency of beeswax by comparing it with pebbles. A small model of storage system was fabricated. A cylinder of size 250 mm diameter and height 500mm was used to store thermal energy of medium in the form of bed using water as heat transfer fluid. Water is heated electrically in one cylinder and the hot water obtained imitate as solar energy. During charging, hot water is circulated over the bed of TES media and during discharging the cold water is circulated to receive the heat stored by TES media. Both during charging and discharging the temperature of storage bed was measured at different points using thermocouples (J type.0 to 300°C+_0.1°C accuracy) Both TES media (beeswax and pebbles) one by one during both charging and discharging. It was found that during charging at constant mass flow rate and heat input the beeswax has less heat storage efficiency (52%) than that of pebbles (63%). During discharging the heat storage efficiency of beeswax was 40% and that of pebbles was 48%. It was examined that heat storage efficiency was directly proportional to mass flow rate of heat transfer fluid for both TES media at constant heat input.

Yi Wang, Huan Shi, Tingzhang tiandong xia (2015) told that to increase the thermal conductivity and electrical conductivity some authors made the composite of PCM with material of PCM capsule but in this paper the author experimentally investigate the thermal properties and electrical conductivity of new microencapsulated PCM by entrapping SA (Stearic acid) in PANI (Polyaniline) shell through self assembly method. The two components are similar in temperature and have no chemical reaction occurred during fabrication and further used. But the hydrogen bonding between immune groups of SA and carboxyl group of PANI exists. The Authors has reached to the following conclusions:

1. The maximum mass fraction that can be loaded in SA/PANI composite is decided as high as 62.1.wt % without escape of melted SA from capsules.
2. The thermal conductivity of PCM embedded with SA was improved (0.07042s-cm-1). It is possible due to secondary doping with carboxyl group.
3. PCM temperature and latent heat of SA/PANI composite was found to be 55.6°C and 113.02 J/g for melting and 50.8°C and 112.58J/g for freezing respectively.
4. The thermal durability in working temperature range, thermal reliability and electrical conductivity and thermal conductivity of SA/PANI composite has found undetectable changes.

Saman Nimali,Gunasekara Joseph stalin,et all (2017) in their research paper,Erythritol,glycerol, their blends and olive oil as sustainable phase change materials, presents food grade materials of renewable origin namely eithritol,glycerol and olive oil as latent heat storage and phase change material. They found erythritol showing phase change characteristics on evaluation of its production process at melting point between 117-120 °C and enthalpy around 300kJ/kg. When glycerol-erythritol blending techniques assessed by using Temperature – history method, it did not reveal its phase change characteristics also the blend of glycerol and up to 30mol% erythritol did not shown phase change due to glass transition . The remainder froze but with large super cooling & system underwent thermally activated change. Thus he concluded that to recognize glycerol or glycerol and erythritol blends as PCM it is necessary to have an arrangement for fast crystallization. They tested the olive oil sample (containing fatty acid such as linoleum, Palmitic, marginic and Stearic acid) using T-History method. They found that olive oil melted between -4.5 to 10.4°C at enthalpy 105KJ/kg and froze between -8 to 119°C with enthalpy 97 KJ/kg and can be used as PCM in chilling applications with low thermal conductivity.

Saman Nimali, Gunasekara, Ruijun Pan, et all (2014) In this paper, thermal properties, temperature history graphs of pure erythritol, pure xylitol (for first heating cycle and for post first heating and melting cycle) pure PEG10000 during its heating and cooling was studied. By doing T-history characterization of some polyols material they concluded that different polyols have different phase and state change behaviors such as sub cooling and glass transition. Erythritol do not show glass transition while xylitol exhibits glass transition. Glass transition depends on hygroscopicity of materials. PEG 10000 exhibits proper phase change and negligible sub cooling. Through analysis of polyols by doing sub cooling, glass transition and similar behavior is important to evaluate suitability of polyols as PCM. To use polyols blends as PCM its miscibility, thermal properties characterization and phase equilibrium evaluation of blends must be evaluated and studied.

Murat M. Kenisarin (2010) says that according to Gasanaliеve barataeva (in their paper, Heat accumulating properties of melt: Russ chem. Rev2000:69(2):179:186), salt and metal melt can be used as high temperature PCM`s. For higher thermal energy storage, he has suggested the following essential properties in PCM-

1) Required melting temperature for providing desirable working temperature in storage unit.
2) High specific heat capacity, heat of fusion, heat density
3) PCM must maintain proper composition in solid and liquid phase appeared at fusion.
4) Reliable conversion ability at repeated phase change
5) High heat conductivity for charging and discharging
6) Minimum change in volume during phase change.
7) Must be overcooled during hardening
8) Chemically stable
9) Compatible and oxidation resistance with constructional material
10) Non-toxic
11) Readily available
12) Fire safety and non-flammable

He had also studied Inorganic salts as a high temperature phase change material. He put forward his views as ahead. Inorganic salts have suitably high melting temperature in the range 250°C to 1680°C and high heat of fusion (i.e. from 68 to 1041J/g). In case of pure salts such as (fluoride, chloride, bromide, etc), the less heat of fusion reduces area of its applications therefore expansion of temperature interval with simultaneous decrease in temperature of fusion of heat storage material (HSM) is required. To overcome this difficulty eutectic composition technique were discovered by scientist for example eutectic composition of fluoride and chloride is proposed by different researchers as phase change HSM`s, till 20th century ; salt composition on the basis of double and ternary eutectics are studied. In present century the scientists and researchers from Russia develops quaternary and quinary compositions on the basis of molybdates, vanadaters and sulphates.

The author also cited the review on metal alloys to use as high temperature PCM for heat storage. According to author as compared to salts and salts composition, metal alloys have better thermo physical properties such as high heat conductivity, more corrosion resistance, less change in volume at melting, negligible overcooling and less cost. Besides this authors also stated that poor attention is paid on thermal stability and chemical compatibility of PCM during operation.

Monica Delgado, AnaLAzaro.Javier Maxo, Et all (2015) determine thermo physical and rheological properties of PCM emulsion and has been compared to that of water. As compared to the water the PCM emulsion shows improved TES capacity (around 55% in a temperature range of 30-55 °C.).The TES systems with PCM emulsions are compared with other systems with PCM used in other literatures on the basis of global heat transfer coefficients and storage energy density. The comparison shows that PCM emulsion have the better results as a thermal energy storage medium. Karunesh Kant and et all (2016), analyse the performance of fatty acids namely capric acid, Lauric acid, Myristic acid, Palmitic acid and Stearic acid (when used with aluminum container) in terms of melt fraction, temperature variation, solid to liquid phase change, amount of thermal energy stored in different fatty acids with time during melting and solidification with same boundary conditions. By simulating the results authors suggest that among the studied fatty acids capric acid takes minimum time for melting and solidification.

Authors concluded that among the used fatty acids; Stearic acid stores maximum energy as compared to capric acid. Different thermo physical properties of different fatty acids and paraffin wax are tabulated as follows.

Table1. Thermo physical properties of PCM and PCM-container

Properties	Capric acid	Lauric acid	Myristic acid	Palmitic acid	Stearic acid	Paraffin	Aluminium
Melting temperature (°C)	32	44	58	64	69	53	N/A
Latent heat of fusion (kJ/kg)	152.7	177.4	186.6	185.4	202.5	243	N/A
Density (kg/m3) Solid Liquid	 1004 878	 1007 862	 990 861	 989 850	 965 848	 814 775	 2659(Solid) N/A
Specific heat (kJ/kg°C) Solid Liquid	1.9 2.1	1.7 2.3	1.7 2.4	1.9 2.8	1.6 2.2	2.160 2.4	0.867(Solid) N/A
Thermal conductivity (W/m°C)	0.153	0.147	0.15	0.162	0.172	0.15	137 (Solid)
Viscosity (m^2/s)	$4.93x10^{-6}$	$7.98x10^{-6}$	$8.38x10^{-6}$	$9.18x10^{-6}$	$9.19x10^{-6}$	$8.38x10^{-6}$	N/A
Thermal expansion coefficient (1°/C)	0.0001	0.000091	0.00089	0.0001	0.0001	0.000091	N/A

Aran Soléa, Hannah Neumannb, et all (2014) tested Sugar Alcohols (S.A.) for phase change characteristics. S.A. has higher melting enthalpy than other PCMs. Thermal stability tests are essential when developing new PCM as they will be melted and solidified at least once a day. Authors perform thermal cycling tests of D-mannitol, myo-inositol and dulcitol and studied their cycling stability. He used Differential scanning calorimeter for thermal cycling test of chosen sugar alcohols. Authors concluded that during heating process of D-mannitol, melting temperature and latent heat changes with increased number of cycles whereas thermal properties of Myo-inositol remains unchanged. During solidification process, D-mannitol`s enthalpy value was half of initial and freezing temperate changed to 63 from 114 whereas myo-inositol shows less cycling stability when cooling.[15] Authors perform the experiment s to recognize the exact concentration of Paraffin wax in paraffin wax – water nanoemulsion; to used as thermal energy storage media. By using probe ultrasonication and pluronics P-123 as the emulsifier different concentration of Paraffin wax (10wt%, 20wt%, 33wt%, and 50 wt %) were prepared. He found that paraffin wax – water emulsion containing 10wt% paraffin wax, 20wt% paraffin wax and 33wt% paraffin wax possessed 6.7%, 31% and 43% higher specific heat than that of water respectively and thermal conductivity of these emulsions was 95%,68% and 51% more than pure paraffin wax. As compare to pure Paraffin wax and water, paraffin wax – water emulsion posses high degree of energy storage per unit volume, good thermal conductivity and specific heat. Marc Escriba, Camilla Barreneche (2017) synthesized the bio-based PCMs (bisimidazol and monoimidazolechloride and hexafluorophosphate salts) from crude glycerol and carboxyl acid. Bisimidazol chloride salts found effective with regards to melting and solidification enthalpies.

III. METHODS OF PERFORMANCE ENHANCEMENT OF SOLAR AIR DRYERS

This review highlights the efforts made by different scholars, researchers and scientist in modification of configuration thermal energy storage collectors, methods of air passing in collector; single pass or double pass collectors, orientation of collectors, insulations used, used of packed bed material inside collector, or using different phase change material as latent heat storage material. Review highlights only latent heat storage media and thermo chemical heat storage media, as both provides high energy density and continuous supply of heat at constant temperature.

A.k. Bhardwaj,Ranchan chauhan,et all [1] used indirect solar air dryers in forced convection mode with integrated PCM(Paraffin:RT-42) for drying Valeriana Jatmansi Rhizomes (A medicinal plant).They studied the effect of temperature of air circulated in drying chamber, relative humidity, solar radiation intensity and thermal energy storage material on features of Valeriana Jatamansi rhizomes. The solar air dryer used in experiment maintained the constant temperature inside dryer and plant were dried from 89% moisture content to saturated level of 9% moisture content. Valeriana Jatamansi, rhizomes. They observed that Flat plate collector outlet temperature was 26.18°C higher than average atmospheric temperature of Solan (latitude-30.90°N, longitude-77.09°E) in the month October-November-2016. PCM (Paraffin: RT-42) maintain temperature till midnight; 8-10°C above ambient temperature and increase the drying time by about 7 hours (5.00PM-11:30 PM) per day.

Sagar kapadiya,et all (2014) depicts that near about 83 types of solar air dryers designs are available in the market. He classifies solar air dryers as shown in figure 1. Direct solar dryers used direct solar radiations to dry products whereas in indirect solar air dryer separate unit is provided for heating air. In passive type dryers air is flow naturally inside the collector i.e. by buoyancy forces where as in active dryers air is forced to move inside collector by electrically operated blowers. (M.A. Sahib, et all 2015).categories the collectors as stationary collectors and tracking collectors. Different collector configuration has different range of operating temperature. 20°C -80°C is the operating temperature range of Flat Plate Collector (FPC) & 50°C -200°C is the operating temperature range Evacuated tube solar Collector (ETSC).Though the FPC are more productive and mostly used, it has two major drawbacks:

13) Heat loss by convection through glass cover provided on collector plate.
14) No sun tracking.

ETSC have higher efficiency than FPC. It can collect both direct and diffuse radiations and has excellent thermal performance, convenient installation and transportable. ETSC are used for higher temperature applications

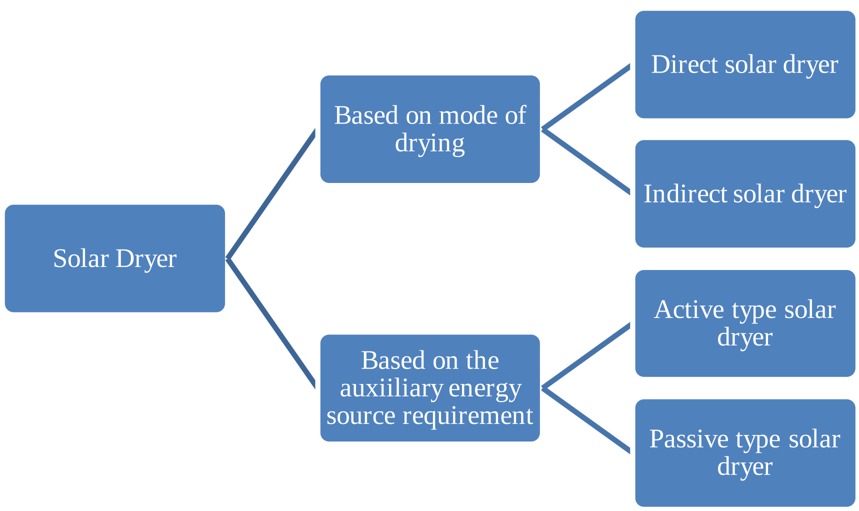

Figure 1 Classification of solar dryers [21]

E kabeel, A khalil, et all(2016) ,investigate the thermal performance of flat and v-corrugated plate SAH integrated with PCM(Paraffin wax).Authors found parameters such as solar radiation, temperature difference of air across the heater, convective heat transfer coefficients between the absorber plate and flowing air, instantaneous thermal efficiency, daily average efficiency and freezing time of PCM affects thermal performance of flat and v-corrugated plated SAH with and without PCM,when the mass flow rate were 0.062,0.028 and 0.009 Kg/sec. The experiment on FPC with and without PCM and on v-corrugated plate collector with and without PCM was conducted when thickness of PCM beneath the absorber was 4cm and 2cm. The authors found that V-corrugated plate collector with PCM gives best results at mass flow rate 0.062 kg/sec in following manners

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VI. 21.3% higher than flat plate without PCM

Ravi kant Ravi, et all (2016) review the different heat transfer enhancement techniques. He suggested using proper insulation to collector surface. According to authors, the convective heat transfer coefficient between heat collecting surface and working fluid can be increased by enhancing heat transfer area which can be increased by double pass design of solar air heater. Double Pass Solar Air Dryer (DPSAH) is having two types: counter flow type and parallel flow type. In counter flow type air flows above and below the absorber plate in opposite direction and in parallel flow type air flows both above and below the absorber plate in same direction. Thermal efficiency of conventional solar air heater can be increase either by increasing convective heat transfer coefficient (CHTC) between collecting plate and air (which is low due to low thermal conductivity of air) or by increasing the thickness of absorber plate. The thermal conductivity is increased by providing porous material inside the collector and thus thermal efficiency can be increased. Satyender Singh, Prashant Dhiman (2016) in their review paper reach to the conclusion that as compare to Double Passed Solar Air Heater (DPSAH) with Porous Packed Bed Material (PPBM) in the lower channel &

DPSAH without PPBM, the thermal performance of DPSAH with PPBM in upper channel; is higher Performance of double pass solar air heater is increased by adding reflectors to collector, increasing heat transfer from absorber plate by using extended surface on absorber plate, artificial roughness in collector, porous material in the air flow duct, by adding honeycomb structure in the space between absorber plate and glass cover. He told the Hottel-whiller-Bliss equations. These equations are used to calculate thermal performance of collector, to determine effect of changes in system and operating parameters on collector efficiency. The Hottel-whiller-Bliss equation is as follows-

$nth = [(\tau\alpha) - UL\,\frac{Tp-Ta}{I}]$ ------------ Eq. 1

$nth = F`[(\tau\alpha) - UL\,\frac{Tp-Ta}{I}]$ ------------ Eq. 2

$nth = \mathrm{Fr}[(\tau\alpha) - UL\,\frac{Tfi-Ta}{I}]$ ----------- Eq. 3

Where I is the intensity of solar radiation (W/m^2),
UL is overall loss coefficient (W/m^2) ,
Tp, Ta represents average plate temperature and ambient temperature respectively
$(\tau\alpha)$ Represent effective transmittance-absorptance product,
F` collector efficiency factor,
Fr is the collector heat removal factor,

$Fr = \frac{G`Cp}{UL}\left[1 - \exp\left(\frac{-F`UL}{GCp}\right)\right]$ ----Eq.4

T_{fi} is the average initial fluid temperature,
G` is the mass flow rate of air per unit area of collector (kg/s.m^2)
Cp is constant pressure specific heat of fluid (J/kg K).

Author also told that the solar collector should be tested by any one of the standard testing methods. He suggests two methods for testing solar collector namely National bureau of standard (NBS) & ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) Standard. The thermal performance of collector is greatly affected by meteorogical parameters (Such as incident solar radiations, ambient temperature, wind speed, shading and dust on top cover of collector, etc) ,System parameters (such as number of glass cover, glass cover emissivity, selective surface of absorber plate, glass plate placing, angle of collector tilt, etc), operational parameters (such as inlet fluid temperature, mass flow rate, etc).

V.V. Tyagi, N.L.Pawar (2012) Solar air heaters without thermal energy storage are used for low temperature (50°C -60°C) applications and it is achieved by Flat plate collectors. Hot air generated by collector can be supplied by either natural convection or by force convection mode. Solar air heaters using natural convections are most suitable in rural areas and in developing and developed countries where electricity is either available or having intermittent availability. Y.B. Tao and Ya – ling He (2018) collects the information regarding different thermal performance enhancement techniques. He told that to enhance the thermal performance; the uniformity of heat transfer between heat transfer fluid and PCM must be improved. As per the basic heat transfer equation, $\emptyset = KA\Delta T$; the performance of any thermal system with PCM can be increased:

1. By increasing PCM thermal conductivity (K)
2. By enhancing heat transfer area (A),
3. By extending uniformity of heat transfer process (ΔT) .

The author has collected numerous methods of increasing K, A & (ΔT) as follows-

a) Thermal conductivity of PCM (K) can be increased either by stuffing PCM into high thermal conductivity porous media such as metal foams (like foams of copper, nickel, aluminum , expanded graphite, expanded rocks such as perlite, vermiculate,etc) or by adding high thermal conductivity, chemically stable and chemically non-reactive nonmaterial. The carbon nonmaterial such as multiwall carbon nanotubes, single walled carbon nanotubes, graphite, graphene, metal oxides nanoparticles, metal particles are commonly used nano material additives.
b) Heat transfer surface area (A) can be enhanced either by using finned tubes (such as axially fins shell and tube LHS, radial fins, dimpled tubes, cone finned tube, helical finned tubes, heat pipes, finned heat pipes, etc.) or by arranging PCM capsule in latent heat storage container and heat transfer fluid allows to flow through gaps among different capsules; the heat transfer is efficiently increased by this method.
c) Uniformity of heat transfer process (ΔT) between heat transfer fluid and PCM is obtained by using cascade LHS with multiple PCMs (as shown in figure 2)

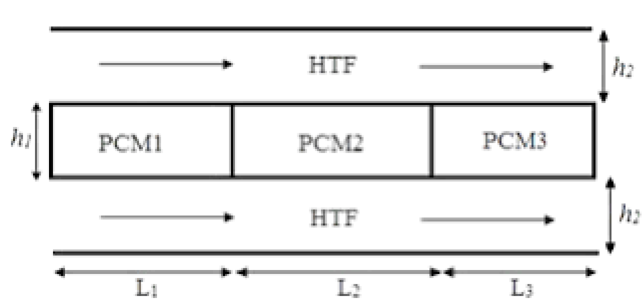

Figure 2. Cascade Latent heat system with Multiple PCM

Where, L_1, L_2, L_3 are lengths of PCM container 1, 2 and 3 respectively. h_1, h_2, h_l, are the widths of fluid pipe 1,2 and PCM container respectively. In this system during charging; when HTF flows from left to right, melting of PCM occurs from PCM1 to PCM3 and latent heat of fusion(LHF) will be in order $LHF_1 > LHF_2 > LHF_3$. In this way heat stored by all PCM is higher than the heat storing capacity of HTF and thus maximum temperature difference occurs which helps to maintain uniformity of heat transfer process.

IV. RESEARCH GAP

. Different agricultural products required different amount of heat to dry. Available solar air dryers are used to dry only one product at a time. If it is the need to dry multiple products at a time by same solar air dryer; then it's not practically possible. It is proposed that the solar air dryer should be flexible. It must supply variable heat for drying multiple crops or agricultural product at one time. It must use multiple PCMs to store and supply different amount of heat to different products.

V. CONCLUSION

Various heat storage media are used in solar air dryers for obtaining required output in required application. Sensible heat storage media are not providing high energy density and continuous supply of heat at constant temperature. Both thermo chemical heat storage media and latent heat storage media provides the facility of high energy density and continuous heat supply at constant temperature. It is seen that as compare to latent heat storage media more attention is given on thermo chemical heat storage media. Many researchers, scientist and scholars are searching new and newer thermo chemical heat storage media by using eutectic compositions of organic or inorganic salts, esterification of fatty acids, etc. Few scientists investigating the thermal performance of biobased PCMs. To use solar air dryer with efficient heat storage media to dry and preserve the medicinal plant is the new trend in the field of application of solar air dryer.

It is the need of today's era to make solar air dryer more flexible. Solar air dryers should be designed to supply heat at varying temperature and should facilitate to dry more than one type of product at one time.

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