"Experimental investigation of solar dryer with thermal storage material for crop drying application"

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Abstract: The unpredictable rise and frequent scarcity of fossil fuel accelerated the continuous search for an alternative power source. Solar is one of the renewable and sustainable sources of power that attracted a large community of researchers from all over the world. This is largely due to its abundant in both direct and indirect form. So, here we are used ETC type collector for solar drying application which performance is tested at the meteorological condition of Patan, Gujarat. The performance is to be evaluated with and without thermal storage material. Investigated results are compared with OSD (Open sun drying). The good quality of products was gained when using ITSD (Indirect type solar dryer).

Key word: Solar Energy, Solar dryer, ETC, Crop drying, ITSD, Thermal Storage Materials

1. Introduction:

India is developing country but it might grow like developed country. In developed countries, up to 25% of energy is used for industrial drying applications such as food drying, bio-oil-industries, building materials, chemical industries, paper industries, textile industries, nuclear waste disposal, pharmaceutical industries etc.

India is among the fastest growing dairy nation in the world. With increase in population, and enhancement in lifestyle of people, demand for food products is increasing day by day. With increase in product demand, energy demand as well as well commercial energy consumption rate is increased 6% during last two decades, India ranking 5th in the world in total energy consumption. Energy consumption in industry is about 49% of total energy. Import dependency at present, is 9% for coal, 77% for crude oil and petroleum product and 31% for natural gas. [1, 26, 27]

Therefore, innovative ideas are needed more than ever before on reliability and performance enhancement of all renewable energy systems. Solar drying of material is far from being simple as the general perception of the onlookers if the dried product must possess the high qualities and meet the international market standard. Dryers with the high rate of drying are gaining the attention of users, but they are largely powered by fossil fuels. Drying of edible products such as medicinal herb is difficult because of various conditions attached to its drying process such as drying temperature range, moisture content after drying, color retention, hygienic condition etc. [2, 26, 27]

Drying is one of the important preservation techniques for fruits and vegetables. Removing water molecular is the oldest method used in many applications like wood pulp drying for marketing paper, drying for food preservation and drying building material. As per early mentioned fossil fuels and all other types of thermal drying process are pollute the environment and these are limited source available on earth therefore solar drying is must require for preventing that.

Drying is actually nothing but the removing moisture content from the product which is to be dried. It is the process of preventing bacterial growth so this food preservation technique is termed as drying. Drying is complicated process with unsteady heat and mass transfer or physical or may be chemical transformation which is majorly affected by product quality. [3, 24, 25, 26, 27] This involves simultaneously heat and mass transfer processes as the product is heated and then moisture is removed.

There are different types of drying methods are available now-a-days. Detailed classification is given in next subsequent portion of this report. But majorly it will classify such conventional drying, non-conventional drying also there may be sub classified as solar drying, microwave drying (di-electric drying), freeze drying etc. The food dried in open air call open sun drying

(OSD). It is very popular and one of the oldest method or traditional method to dry the product domestically this method is very used in our societies. Generally, industries are used method call indirect type solar drying (ITSD).

Types of ITSD include [4] (A) Natural convection solar type dryer or natural circulation type solar dryer: Here food product is heated by the thermo-syphon principle. Hot air which is heated by collector (SAC) and that is used to dry the product hence this method is also known as "passive solar drying method". Natural convection drying method also includes following type: 1 Conventional ITSD.2 ITSD with chimney.3 ITSD with chimney and heat storage system. (B) Forced convection type solar dryer: Here as blower or electric fan is used to increase the drying rate because with use of them hot air rapidly moves toward the drying cabinet where food is supposed to dry. As natural convection method is known as passive solar drying method similarly, forced convection method is known as "active solar drying method". Forced convection drying methods include: 1. Greenhouse collector. 2. Tunnel type collector. [4] Etc.

Thermal storage system is also important factor which may further divide into three types which may be includes: [5] (1) Sensible type of heat storage. (2) Latent type of heat storage. (3) Thermo chemical type of heat storage. In sensible type of heat storage system, thermal energy is stored by increasing the temperature of liquid or solid.

$\therefore$Where $Q \alpha C_p, \Delta T$.

Hence sensible energy storage is depended on specific heat of medium at constant pressure (C_p), temperature difference (ΔT), and amount of storage material. Latent heat storage stores thermal energy at the time of phase transition from solid to liquid or liquid to vapour by means of latent heat of fusion and vapourization respectively. Solid → liquid (Fusion) Liquid → vapour (Vapourization) for phase transition different types of material is used which is known as phase change materials (PCMs). [1]

2. Literature survey:

Several attempts are taken to improve the performance of solar dryer and its drying efficiency [7, 9, 10, 15] etc. Many researchers worked on the flat plate collector and analysis the drying time, moisture content level [8, 13. 14, 16, 17]. Many of researcher worked on greenhouse type solar dryer and several types of data may be analyzed [18-20]. Several attempts are taken with hybrid drying system which includes mirror arrangements [11, 12].

From all the literature it is observed that with solar collector solar drying is the best option along all types of dryer but there are multiple advantages of ETC comparing with FPC because it gives us a higher temperature compare to FPC as well as good thermal efficiency even if bad weathering condition in atmosphere. Hence this is most suitable collector. [23-26]

3. Materials and Methodology:

Experimental Set-up:

The design of solar dryer consists of drying cabinet, primary storage material, evacuated tube collector, motor which is shown in Fig.1 The evacuated solar tube having 3 layer (SS-Al N/Cu) borosilicate vacuum tubes. The inner and outer diameter is found to be 37mm & 47mm respectively. The length of the tube is 1500mm.

Solar dryer consists of 10nos. of ETC tube collector. The collector is tilt at optimum angle 34º Patan district (Gujarat) latitude 23.86 in N-S direction. Plywood box with dimensions 99*35.5*22cm^{3}is used as a primary heat storage material because of its lower thermal conductivity, the entire body is covered by aluminum foil inside the box. C-PVC arrangement is used inside the box for better guidance of air from atmosphere.

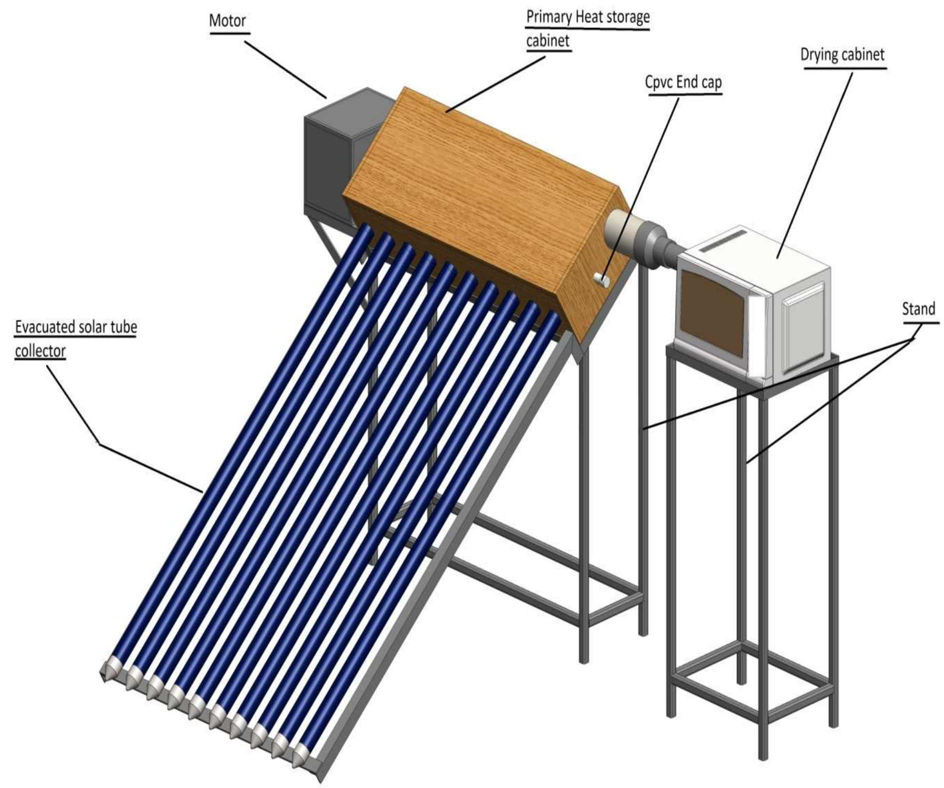

Fig. 1 Experimental set-up of solar dryer

Blower motor is attached with 0.335Kw with 1300 rpm and speed control mechanisms such that desired velocity of wind is obtained. C-PVC end cap is provided to at another end such that no air flow is leaked from primary storage cabinet. Primary storage cabinet is air tight by using silicon and chemical bonding materials.

Heat storage material and its selection:

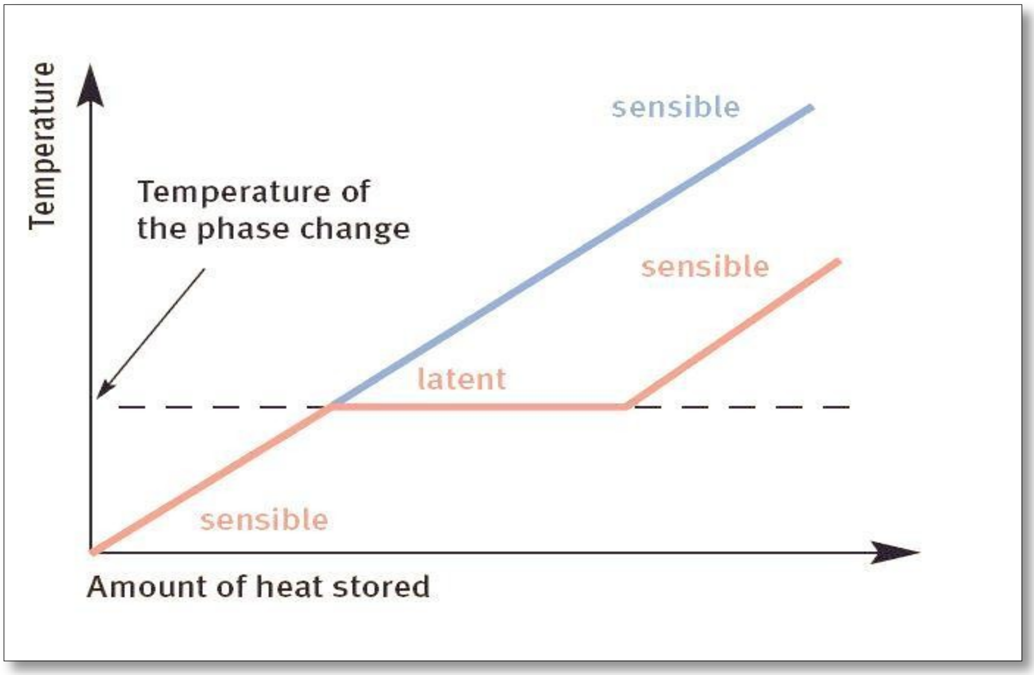

Fig. 2 Basic diagram of sensible heat and latent heat

We know that when temperature is constant amount of heat energy is known as latent heat while at a variable temperature amount of heat energy is termed as a sensible heat. Following table 1 & 2 indicates the different materials and its property.

Table 1 A list of selected solid–liquid materials for sensible heat storage. [27] (A. Sharma, Tyagi,Chen, & Buddhi, 2009).

Medium	Fluid type	Temperature range (°C)	Density (kg/m^3)	Specific heat (J/kg K)
Rock		20	2560	879
Brick		20	1600	840
Concrete		20	1900-2300	880
Water		0–100	1000	4190
Caloriea HT43	Oil	12–260	867	2200
Engine oil	Oil	Up to 160	888	1880
Ethanol	Organic liquid	Up to 78	790	2400
Proponal	Organic liquid	Up to 97	800	2500

Butanol	Organic liquid	Up to 118	809	2400
Isotunaol	Organic liquid	Up to 100	808	3000
Isopentanol	Organic liquid	Up to 148	831	2200
Octane	Organic liquid	Up to 126	704	2400

Table 2. Comparison of various heat storage media (stored energy=10^6 kJ=300 kWh;ΔT=15 K) (www.eolss.net/ebooks)

	Heat Storage Material			
	Sensible heat storage		Phase Change Materials	
Property	Rock	Water	Organic	Inorganic
Latent heat of fusion (kJ/kg)	*	*	190	230
Specific heat (kJ/kg)	1.0	4.2	2.0	2.0
Density (kg/m^3)	2240	1000	800	1600
Storage mass for storing 10^6 kJ (kg)	67000	16000	5300	4350
Relative mass**	15	4	1.25	1.0
Storage volume for storing 10^6 kJ (m^3)	30	16	6.6	2.7
Relative volume**	11	6	2.5	1.0

*The latent heat of fusion is not of interest for sensible heat storage.

**Relative mass and volume are based on latent heat storage in inorganic phase change materials.

Instrumentations and Devices:

Temperature of different location is measured by PID temperature controller (HEATCON) (inlet and outlet temperature of collector, temperature inside the trays) which having an accuracy up to ±1%. Velocity of inlet wind and outlet wind is measured by anemometer with range 0.01 to 45 m/s. A digital electronic balance is used for weighting the sample with ±0.1g accuracy.

Experimental Procedure:

Solar dryer with and without heat storage material is tested for Potatoes and Tulsi along with open sun drying and ITSD. First of all, small potatoes slice is cut into number of small pieces up

2-3 mm thickness and put it into hot boiled water such that output product is well crispy for eating. Now it dries in different modes and get different results from that.

100grm of potatoes are used for samples. The experimental results are shown in table from 8:00 am to 6:00pm. During the experiment's solar radiation, moisture content level and velocity of flow as well as temperature of all locations is measured between 8:00am to 6:00pm. Same can be applied to Tulsi.

Determination of Moisture content:

Moisture content on wet basis (M_{wb}) is determined by following equations:

$$\therefore M_{wb} = M_i - M_f / M_i$$

Where, M_i initial mass,

M_f is final mass of samples.

Determination of Moisture Ratio:

The moisture ratio MR is given by

$$\therefore MR = M_t - M_e / M_o - M_e$$

Where, M_t moisture content at any time,

M_o initial moisture content,

M_e equilibrium moisture content

Determination of Moisture losses:

Moisture losses of sample simply given by following expression:

$$\therefore ML = M_i - M_f$$

Where, M_i initial mass before drying

M_f is final mass of samples after drying.

Determination of Dryer Efficiency:

Dryer efficiency is measured by following expression:

$$\therefore \eta_d = M_d / P_d$$

Where, M_d = Final mass of the sample at any time

P_d = Blower power (KWh).

Determination of Specific Moisture Extraction Ration:

$$\therefore SMER = M_d / P_d$$

4. Result and Discussion:

The initial moisture content of Basil is found 90% and after 6 hr it was reduced to 14-14.5% of moisture content, at 65°C. Total sample is collected of 100grm of Basil and after drying it is about to 12grm. This experiment is taken with heat storage material and ITSD type solar drying. Without heat storage material this result is about to 9hr. While done this same experiment with heat storage material it was taken approximately 8 to 9 hr. With open sun drying Basil takes approximately 13 hr and with 20 % of moisture content on % wb.

During the experiments it was estimated that total radiation is about to 500W/m^2 to 1250 W/m^2 on the month of mid-March. The average temperature of drying cabinet was found out 61°C without heat storage and 64°C with heat storage material.

Another experiment is carried with Potatoes and similar pattern was derived from that results. Some graphs are given below.

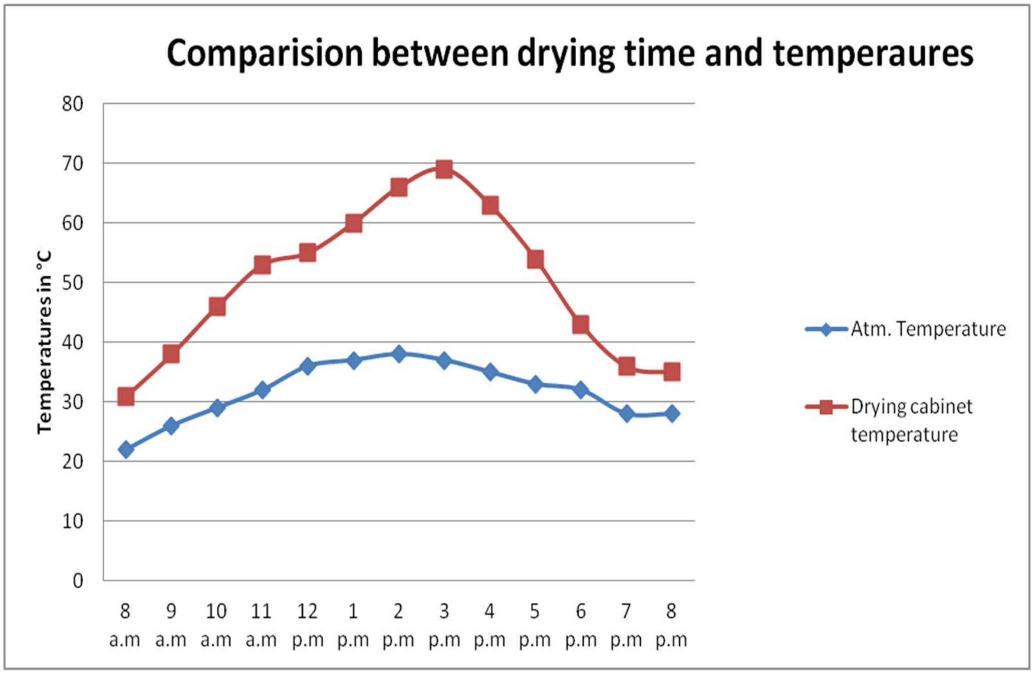

Fig. 3 Comparison diagram between drying time and temperatures

Above diagram shows the two-temperature atmospheric temperature shown by blue line and drying Cabinet temperature shown by red line, the reading is taken from 8:00 am to 8:00 pm. The maximum temperature was achieved at around three o'clock.

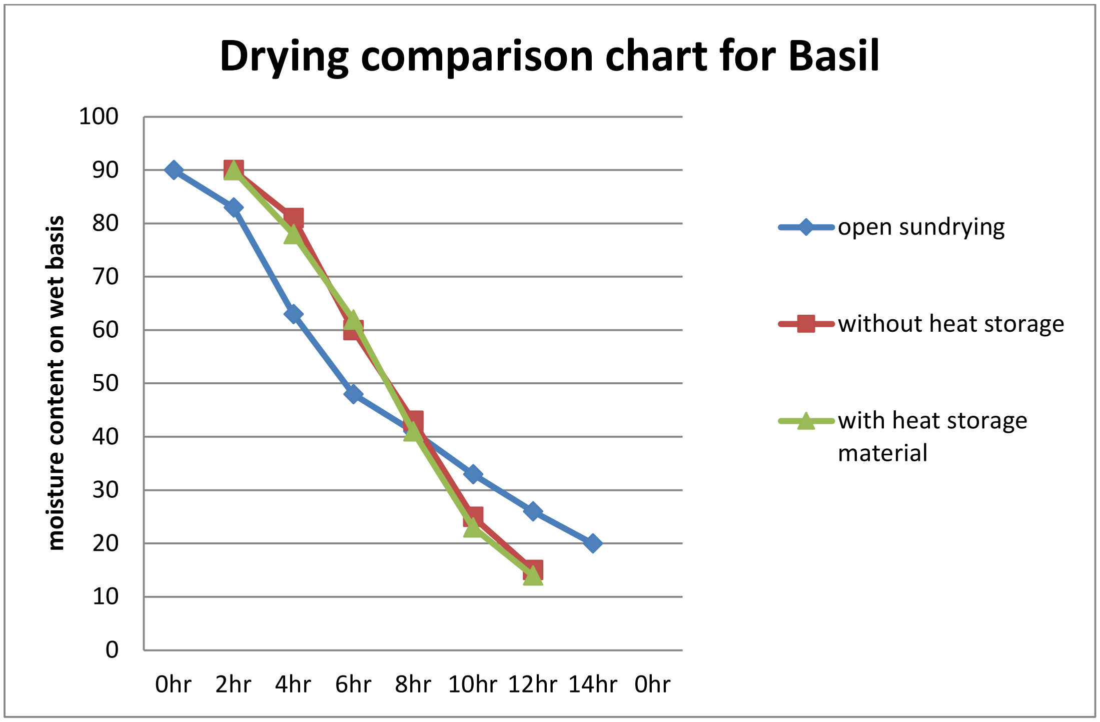

Fig. 4 Comparison diagram between drying time and moisture content with three different modes

The experiment was carried out with 3 different modes as per shown in fig. 3. In which open sun drying takes maximum drying time to remove moisture content while with and without heat storage material it creates marginal gap of drying time for drying a Basil with atmospheric condition of may and march 2021 Patan, Gujarat.

5. Conclusion:

New ITSD evacuated type solar collector is suitable for drying herb like Basil. It also found that it required less time compare to conventional solar drying techniques also the quality of product is good. There were three systems in which drying with heat storage material take approximately 8.5 hr without heat storage material dryer takes 9 hr while with open sun drying this value is increased to 13 hr. Moisture removal rate after drying is 20 % (on wet basis) for open sun drying while these values are reduced to 14-15% (on wet basis) in case of ITSD type.

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