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DESIGN AND DEVELOPMENT OF SOLAR DRYER FOR FOOD & VEGETABLE DEHYDRATION

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Abstract: To dry a variety of agricultural goods, an indirect, active-type, affordable hybrid solar dryer was created. This dryer functions solar energy through solar panels and without solar panels through sun rays. The dryer was constructed using inexpensive, locally accessible materials. The dryer is made up of a solar panel, a thermostat, a drying chamber, and a fan with a regulator to create the necessary air flow in the system for the stated item that has to be dried or dehydrated. Because of their enormous output and significant loss in India, grapes were chosen as the experimental fruit. Additionally, raisins, which have significant nutritional content and are a staple food, are dried grapes. We have achieved in determining drying efficiency of grapes ,bananas etc food items, drying rate and quality of drying. drying time & temperature for the grapes and other food itmes available around Pune. We have made sustainable solar dryer with ambient heat under humidity. The dryer efficiency at the end of 8 h of drying is 5.05 and 6.96 % for 1 m/s, with reducing moisture content form 80% to 15 % with max range of temperature of 54-64 degree Celsius .

Keywords: Solar radiation , Atmospheric disturbances **,**Energy transformation, Environmentally friendly, Economically beneficial, Drying Renewable energy **,**Fossil fuels, Solar dryer, Pollution **,**Greenhouse effect ,Efficient method **,**Population growth,, Food demands **,**Preservation **,**Conventional fuels **,**Post-harvest activity, Herbal practitioner.

Introduction - Solar radiation is an abundant and readily available energy source that holds immense potential for various applications, including drying processes. In recent years, the escalating concerns over atmospheric disturbances caused by the utilization of fossil fuels have compelled researchers to explore alternative energy transformation methods that are both environmentally friendly and economically beneficial. Among these alternatives, solar drying has emerged as a promising solution to meet the escalating demands of drying in a sustainable manner. Drying, as a post-harvest activity, plays a crucial role in preserving agricultural produce, medicinal herbs, and other perishable commodities. The conventional use of fuels such as firewood, electricity, or fossil fuels for drying not only contributes to pollution but also exacerbates the greenhouse effect, leading to adverse environmental impacts. Additionally, the ever-increasing global population and its subsequent food demands necessitate efficient methods of preserving food while minimizing resource consumption and environmental damage. Solar dryers harness the power of solar radiation to dry various products efficiently, making them a compelling alternative to conventional fuel-dependent drying methods. By utilizing renewable energy, solar dryers significantly reduce the reliance on fossil fuels and mitigate the associated environmental pollution and greenhouse gas emissions. This transition towards a greener and more sustainable approach holds the promise of fostering a healthier and more balanced ecosystem. In this research article, we aim to explore the effectiveness and feasibility of solar dryers as an environmentally friendly and economically viable solution for drying applications. We will examine the various design configurations and operational parameters that optimize the drying process, ensuring high-quality dried products while maximizing energy efficiency. Additionally, we will analyse the potential benefits of solar drying in addressing the challenges posed by population growth, food demands, and the need for sustainable post-harvest activities. By investigating the advantages and limitations of solar dryers, we can develop a comprehensive understanding of their potential applications, efficiency, and economic viability. This research will contribute to the existing body of knowledge, empowering policymakers, agricultural practitioners, and herbal experts to make informed decisions regarding the adoption and implementation of solar drying technologies. Ultimately, the integration of solar dryers into various industries can revolutionize drying practices, offering an environmentally conscious solution that aligns with the principles of sustainability. By reducing the reliance on conventional fuels and promoting renewable energy sources, solar dryers have the potential to transform the drying landscape, enabling a greener and more efficient future.

Objectives -

1.To determine drying efficiency of grapes ,bananas etc food items

2.To determine drying rate and quality of drying.

3.To determine drying time & temperature for the grapes and other food itmes available around Pune

4.To determine provide ample amount of heat that is more than ambient heat under given Humidity.

5.To provide an sustainable futuristic solar dryer with cost efficiency.

Literature Review - This device dries agricultural items using solar radiation. It is a strategy for reducing postharvest losses and poor quality associated with traditional solar drying Following numerous (attempts) tests, a successful design of solar dryer with natural convection was established, which can be used in active- and passive-type solar dryer applications. Several experiments have been carried out over the years . In this system, the drying rate is entirely determined by mass transfer and heat transfer. In indirect drying, heat is first applied to the absorber plate from the glass to cover it and then it is transferred to the absorber tray to evaporate any remaining moisture. We have figured out that solar drying of agricultural goods using natural convection in a solar food drier is more efficient than open-air sun drying. Compared with traditional or open-air drying methods, it takes less time and achieves better drying results. It is dependent on two mechanisms: first, it removes moisture from the surface and prevents moisture from migrating from the interior of surface particles. By , research on the testing procedures of box-type solar collectors for evaluating their energy performance had been published. the solar radiation intensity ratio between the absorber and the ambient air at the stagnation state has been determined as a test parameter based on outdoor experiments conducted underno-load or overload conditions. Following a thorough review of the literature, it was discovered that the thermal test process on a solar dryer with no-load condition and with load condition had two parameters that were superior in both cases. This method calculates the overall heat transfer coefficient (U.L.) and the drying efficiency (d). The maximum temperature of several solar dryer components, including the glass cover and absorber plates, and the air velocity present inside the dryer, determines the U.L. value. [1]

Drying is a method of dehydration of food products which means reducing the moisture content from the food to improve its shelf life by preventing bacterial growth . It is still used in domestic up to small commercial size drying of crops, agricultural products and foodstuff such as fruits, vegetables, aromatic herbs, wood etc. contributing thus significantly to the economy of small agricultural communities and farms Hii et al. have shown that sun drying (laying the crops under direct sunlight) is economical, but the product obtained by it is of lower quality due to contamination by dust, insects, birds, pets and rain. Also, loss of vitamins, nutrients and unacceptable colour changes due to direct exposure to ultraviolet rays, and it takes long time to dry. Solar dryers are specialized devices that control the drying process and protect agricultural products from damage by insect pests, dust and rain. made a comparison between sun drying and solar drying and obtained that solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process than sun drying. Rajeshwari and Ramalingam have demonstrated that the drying time in case of solar dryers compared to open air drying reduced by about 20 % and produces better quality dried products. Solar dryers are available in a range of size and design such as tunnel dryers, hybrid dryers, horizontal- and vertical-type dryers, multi-pass dryers and active and passive dryers . Hii et al. classified solar dryer according to their heating modes and the manner in which the solar heat is utilized, namely forced air circulation or active solar dryers and natural air circulation or passive solar dryers. Three distinct sub-classes of either the active or passive solar drying system can be identified depending upon the design or working principle of the dryer, mode of drying and type of product to be dried, namely integral or direct mode, distributed or indirect mode and mixed mode solar dryers. It should be noted that sunlight may affect certain essential components in the product, e.g. chlorophyll is quickly decomposed. If available places are scarce, indirect mode types of dryers are preferred for drying larger quantities. In such case of indirect mode, nutritive value of the food product and colour is retained. Mohanraj and Chandrasekar and Ban out and concluded that forced convection solar dryer is more efficient than natural convection dryers. Also, products can be dried faster in the case of forced convection solar dryer than in the case of natural convection solar dryer, and end products obtained from forced convection drying have a superior quality [3]. Diemuodeke E. OGHENERUONA*, Momoh O.L. YUSUF:- Designed and fabricated direct natural convection solar dryer to dry tapioca in rural areas. A minimum of 7.56 m2 solar collector area is required to dry a batch of 100 kg tapioca in 20 hours (two days drying period). The initial and final moisture content considered were 79 % and 10 % wet basis, respectively. The average ambient conditions are 32ºC air temperatures and 74 % relative humidity with daily global solar radiation incident on horizontal surface of 13 MJ/m2/day. The weather conditions considered are of Warri (lat. 5°30’, long. 5°41’), Nigeria. A prototype of dryer was fabricated with minimum collector area of 1.08 m 2 . [4].Umesh Toshniwal, S.R Karale :- Classification of Solar Dryer Solar dryers are available in a range of size and design and are used for drying of various agricultural products. Various types of Dryers are available in the market as per requirement of farmers. Primarily all the drying systems are classified on the basis of their operating temperature ranges that is High Temperature solar dryer and Low Temperature Solar dryer. Following criteria's are required for the classification of solar dryer:- 1) Air movement mode 2) Insulation exposure 3) Air flow direction 4) Dryer arrangement 5) Solar contribution 6) Type of fruit to be dried [5].

M. MOHANRAJ, P. CHANDRASEKAR:- The performance of an indirect forced convection solar drier integrated with heat storage material was designed, fabricated and investigated for chili drying. The drier with heat storage material enables to maintain consistent air temperature inside the drier. The inclusion of heat storage material also increases the drying time by about 4 h per day. The chili was dried from initial moisture content 72.8% to the final moisture content about 9.2% and 9.7% (wet basis) in the bottom and top trays respectively. They concluded that, forced convection solar drier is more suitable for producing high quality dried chilli for small holders. Thermal efficiency of the solar drier was estimated to be about 21% with specific moisture extraction rate of about 0.87 kg/kW h. [6] Bukola O. Bolaji and Ayoola P. Olalusi: Built a simple and inexpensive mixed mode solar dry locally source materials. The temperature rise inside the drying cabinet was up to 24o C (74%) for a hours immediately after 12.00h(noon). The drying rate, collector efficiency and percentage of moistre removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4% respectively. The dryer sufficient ability to dry food

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items reasonably rapidly to a safe moisture level and simultaneously it superior quality of the dried product [7] Bukola O. Bolaji.et.al:- Designed, constructed and tested the solar wind ventilated cabinet dryer in Nigeria on latitude N.Comparatively, drying with the solar cabinet dryer showed better results than open air-drying. During the period of test, the average air velocity through the solar dryer was 1.62 m/s and the average daylight efficiency of the system was 46.7%. The maximum drying air temperatures was found to be 64oC inside the dryer. The average drying air temperature in the drying cabinet was higher than the ambient temperature in the range of 5oC in the early hours of the day to 31oC at midday.80% and 55% weight losses were obtained in the drying of pepper and yam chips, respectively, in the dryer . [8] Ahmed Abed Gatea Designed and developed solar drying system for maize with V-groove collector of 2.04 m² area, drying chamber and blower. The thermal energy and heat losses from solar collector were calculated for each three tilt angles (30º,45º, 60º). The results obtained during the test period denoted that the maximum gained energy occurred at 11 o'clock hour and then gradually declined since the maximum solar radiation occurred at this time. Other many important results found are The theoretical thermal energy, the experimentally actual heats gain increase by increasing radiation intensity, the maximum values occurred at the 11 am and then gradually declined. The energy gained obtained at the angle tilt 45º is higher than the corresponding values obtained at 60º, 30º tilt. [9] F.K. Forson.et.al Designed A mixed-mode natural convection solar crop dryer (MNCSCD) for drying cassava and other crops. A batch of cassava 160 kg by mass, having an initial moisture content of 67% wet basis from which 100 kg of water is required to be removed to have it dried to a desired moisture content of 17% wet basis, is used as the drying load in designing the dryer. A drying time of 30–36 h is assumed for the anticipated test location (Kumasi; 6.71N,1.61W) with an expected average solar irradiance of 400W/m2 and ambient conditions of 25 1C and 77.8% relative humidity. They concluded that A minimum of 42.4m2 of solar collection area, according to the design, is required for an expected drying efficiency of 12.5%. Under average ambient conditions of 28.2 1C and 72.1% relative humidity with solar irradiance of 340.4W/m2 a drying time of 35.5 h was realised and the drying efficiency was evaluated as 12.3% when tested under full designed load signifying that the design procedure proposed is sufficiently. [10] EL- Amin Omda Mohamed Akoy.et.al A natural convection solar dryer(Cabinet Type) was designed and constructed to dry mango slices. They concluded that the designed dryer with a collector area of 16.8m2 is expected to dry 195.2kg fresh mango (100kg of sliced mango) from 81.4% to 10% wet basis in two days under ambient conditions during harvesting period from April to June. A prototype of the dryer is designed and constructed that has a maximum collector area of 1.03m2 . [11]. M.A. Hossaina and B.K. Bala Designed and developed A Mixed mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh as shown in figure .The dryer consists of (1.air inlet 2.fan;3.solar module;4.solar collector;5.side metal frame;6.outlet of the Collector7.wooden support; 8.plastic net; 9.roof structure for supporting the plastic cover; 10.base structure for supporting The dryer;11.rolling bar; 12,outlet of the drying tunnel.)Moisture content of red chilli was reduced from 2.85to 0.05 kg/kg(db) in 20 h in solar tunnel drier and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg/kg (db) in improved and conventional sun drying methods, respectively[12] J. Banout et.al Doubled Pass Solar Dryer (DPSD) was designed for drying red chilli in central Vietnam and DPSD is compared with cabinet dryer (CD) and traditional open sun drying. They found that average drying temperatures were 60ºC, 52ºC and 35.8ºC and corresponding relative humidity 34%, 45% and 62% for DPSD, CD and open air sun drying, respectively. The overall drying efficiency of DPSD is 20% which is typical for forced convection solar dryer. The moisture content of fresh red chilli was almost similar during all drying tests where as the initial values were 9.18kg/kg,9.17kg/kg and 9.30kg/kg (db) for DPSD, CD and open-air sun drying, respectively. Where the final moisture content in case of DPSD

0.05kg/kg was reached after 23 h, 0.09kg/kg after 29h for CD and 0.18kg/kg after 36 h in case of open sun drying (excluding nights).The performances of a new designed DPSD have been compared with those of a typical CD and a traditional open-air sun drying for drying of red chilli. The DPSD resulted in the shortest drying time to meet desired moisture content of chilli (10% w.b.), which corresponds to the highest drying rate comparing to other methods. Although the construction cost of DPSD was higher than CD the overall drying efficiency was more than two times higher in case of DPSD compared to CD. Hence, Double pass solar drier was found to be technically and economically suitable for drying of red chillies under the specific conditions in central Vietnam. [13]

Materials and Methods -

Equipments –

1. Thermometer
2. Weighing machine (For light weight measuring purpose).
3. Measuring tape
4. Stop Watch

Method and formulas to calculate and meet the objective - Relative humidity: - The ratio of the partial pressure of water vapour in an air-water combination to the saturated vapour pressure of water at a specific temperature is known as relative humidity. The temperature and pressure of the system of interest affect the relative humidity of the air.

$$RH = (P_w/P_{ws}) * 100$$

P_{ws} = Saturation vapour pressure (hpa) , P_w = Vapour pressure

MOISTURE CONTENT: The amount of water that is present in a substance, such as soil (also known as soil moisture), rock, pottery, fruit, or wood, is referred to as its water content or moisture content. Bacteria, yeasts, and mould develop more readily when food products are moist. To investigate the behaviour in terms of the pattern of moisture removal from Banana slices at various temperatures, the solar drier was put to the test. A proportion of moisture based on wet weight (wet basis) or dry matter (dry basis) is used to represent moisture content. Most often, wet basis moisture content is employed.

$$M_W \text{ (wetbasis)} = (w - d / w) * 100$$

W = Weight of sample product, d = Dry weight of sample product , M = Moisture content on a percent basis.

The goal of the experiment was to establish the moisture content on a wet basis. After 8 hours, the dried banana slice sample was weighed to determine the moisture content in relation to temperature.

Results and discussion

The maximum temperatures achieved with 1 and 2 m/s are 54 and 51 °C, respectively, with almost similar ambient air temperature for all the velocities. At the end of 8 hrs of drying, the moisture content in the bananas is 28.39 and 38.84 % for 1 and 2 m/s, respectively. If the absolute moisture removal rate is considered then the moisture removal rate is fastest with the velocity of 1 m/s, followed by 2 m/s as seen in Figures 1 & 2. The dryer efficiency at the end of 8 h of drying is 5.05 and 6.96 % for 1 and 2 m/s, respectively. The reason for slight increase in dryer efficiency for 2 m/s over 1 m/s is that the bananas dried at 1 m/s have reached the falling rate stage of drying for the given time which has impacted the dryer efficiency for the time frame considered.

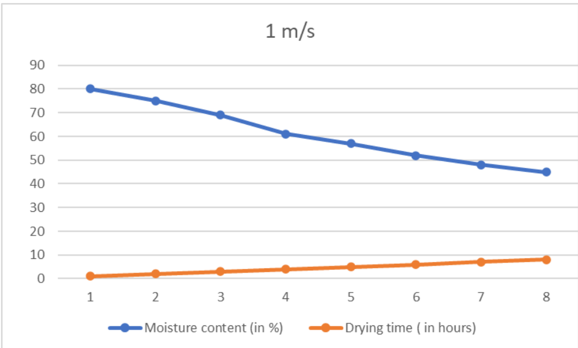

Fig. 1

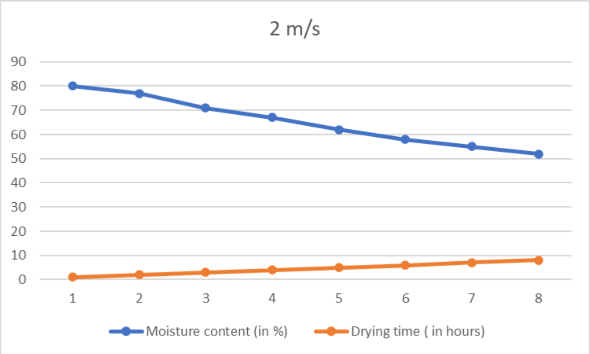

Fig. 2

Fig 1 & 2 shows the comparison of moisture content for different flow rates (1m/s and 2 m/s) over drying time.

The drying efficiency is clearly higher with air inlet velocity of 1 m/s, followed by 2.This indicates that higher air temperatures are much more effective in increasing the drying rate with the air velocity playing a minor role. But it is also to be noted that it is just not the drying rate that is important, the quality of the products obtained is more important. It is noted that with velocity of 2 m/s, the dried banana obtained has cardboard-like structure, hard outer surface, too light and looks like not ripened which is unacceptable. Because of the faster rate of moisture removal with 2 m/s, the rate of evaporation increased which resulted in hardening of the surface. On the other hand, the rapid cooling of the surface of banana slices due to faster air velocity with the air inlet velocity of 2 m/s resulted in dark colour with blackening of the surface, and the surface became hard. Due which the banana obtained is of unacceptable quality. This also impacted the rate of drying But the banana samples obtained by drying at a velocity of 1 m/s at the collector inlet are having more consistent quality of dried banana with good colour, texture, no dusty appearance, chewy and natural aroma. So with 1 m/s, good quality of banana can be obtained with quite high drying rates. These also confirm that the dried banana samples obtained by a velocity of 1 m/s are acceptable.

Product	**Moisture Content**		**Drying time(h)**
	Initial %	**Final %**	
Grapes	80	15-20	8
Bananas	80	15	7.5
Potato chips	75	13	48
Onions	85	6	16
Tomatoes	95	7	24
Green peas	80	5	4
Apples	82	11	16
Figs	70	20	24
Chillies	80	5	34
Pepper	71	13	48

Drying rate

Drying rate- To calculate the moisture lost by the sample in a specified time period, the moisture content data from each experiment were analysed. The drying rate was calculated using the formula g water/g dry matter- h. Calculating the drying rate is possible by –

DR = WML / Time interval X DM

Where, WML = Weight of moisture loss DM = Drying matter

Hourly drying efficiency- The drying efficiency were calculated by the following formula

$$\eta di = [(mw \times \lambda) / (I \times A)] * 100$$

Where,

mw=Mass of water evaporated per hour, kg

λ = Latent heat of vaporization, kcal / kg K

I = Solar insolation, W/m2

A = Total collector area, m2

Table 1. Drying rate of Solar Drying for various items.

Table 2. Max allowed temperature for various items

Fig. 3 Solar Dryer used for drying banana

Product	Max. Allowable Temp.(0C)
Grapes	54
Bananas	65
Potato chips	70
Onions	54
Tomatoes	55
Green peas	60
Apples	65 - 70
Figs	65
Chillies	45
Pepper	45

Conclusion – In this research paper we can state that, it is more beneficial and sustainable approach toward solar drying. We have successfully achieved all our objectives for the project. We have determined the flow of air in the solar dryer to be 1m/s is most suitable for achieving good efficiency. determine drying rate and quality of drying. Primarily Grapes and Bananas were studied for experiments and we were able to produce good quality dried raisins and bananas within 8 hrs with reducing moisture content form 80% to 15 % with max range of temperature of 54-64 degree Celsius . We have determined drying time & temperature for the grapes and other food items available around Pune. For all the data related to objective fulfilment please refer to the result and discussion section. We have successfully achieved the providing ample amount of heat that is more than ambient heat under given Humidity. provide an sustainable futuristic solar dryer with cost efficient budget.

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