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Development and feasibility study of a mixed-mode solar dryer for Bankariya, Hetauda, Province-3, Nepal

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Abstract

Solar drying is one of the practical and efficient ways to preserve vegetables, fruits and other crops from spoilage and periodic degradation. Bankariya VDC Hetauda, Province-3, Nepal where the study was conducted has been facing the problem of spoilage mainly due to lack of transportation and prevalent effective drying practices. To address the existing situation, basing upon the geographic and economic factors, a mixed mode solar dryer was fabricated for the locality and the performance of the solar dryer against 2.5 mm slice of fresh ginger was evaluated. The mixed mode solar drier showed good results with percentage time saved of 77.77%.and with the cumulative drying rate of 0.0368 kg/h for 1 kg sample and 0.085 kg/h for 2 kg sample, respectively. The mixed mode solar dried showed promising results for varying sample sizes and could be further up scaled for larger quantity of varying crops.

Keywords: Solar dryer; Temperature; Drying rates; Natural convection

1. Introduction

One of the most common challenges imputed with food, especially meats and vegetables is in their storage. The former consisting mostly of protein while the latter is dominant in carbohydrates, are both prone to an array of bacteria, yeast, molds and other microbes which instigates change in the physical and chemical composition of the food item, deeming them unsuitable for consumption. Vegetables have a high pH which creates a favorable environment for the growth of such unwanted organisms. Popular food preservation techniques are commonly used which help in the restriction of microbial action which causes spoilage. Despite being an agriculture-based economy, Nepalese agriculture has suffered from low production and productivity for years. Studies have estimated about 20 to 30% post-harvest losses occur for fruits and vegetables which in adverse case could exceed 50%. Similarly, there is also Transportation losses which are about 15-36% depending upon the commodity, while transporting different vegetables and fruits from of Nepalese border to different Indian markets [1]. Development in the field of agriculture is of paramount importance if Nepal is to head towards economic and social prosperity. For the task, various agro-products have been identified by Nepal Trade Integration Strategy (NTIS), amongst them ginger is one in which Nepal has a comparative advantage. The advantage is more due to low-labor cost, well-adapted local varieties and established marketing network. In fact, Nepal is the third largest exporter of ginger in terms of total export volume [2].Nepal also happens to be geographically connected to two of the largest consumers of ginger; namely China and India. Despite being a global leader in ginger exports, Nepali ginger commands some of the lowest prices in the global markets, only $195 per metric ton (ITC) which is generally caused by the low quality of Nepali ginger when compared to the competition due to lack of proper post-harvest processing and preserving practices. Nepalese ginger is superior in quality for the production of dried ginger, oleoresins or essential oils. But due to the lack of ginger processing facilities within the country, farmers have to sell their products in fresh form or traditionally dried form [3]. Contemporary food preservation techniques (both conventional and sophisticated) include *Freezing, Drying, Heat processing, pressure processing,* and the use of natural or synthetic preservatives, which tend to be anti-fungal, anti-bacterial in nature [4]. Chemical preservation also includes the use of edible coatings in food items.

Out of all the preservation methods, *Drying* is a better alternative as it not only impedes microbial, fungal and bacterial degradation but also lacks the adulteration of food by chemicals, such as using preservatives. A contemporary method of Drying involves mechanical drying: using convective air flow, Vacuum Drying: moisture removal by the use of low pressure environment, Lyophilization: Drying by using low temperatures and so on[5]. A conventional method would be open techno-dependent desiccation techniques are efficient in a modern household or at the industrial level, these are unsuitable for the traditional households and communities like the village of Bankariya, Hetauda in Nepal. Open drying is not sustainable as contamination becomes an issue. The best method of food preservation for rural communities would be the use of single or communal solar dryers. Solar dryers would act as an enclosed environment for food items to desiccate under the freely available solar energy, severing ties to other forms of limited and costly energy.

Food preservation is a major problem in Bankariya, Hetauda. A field survey led by the research team of this paper in 2016, concluded that due to the lack of market and ease of transportation, the prominent produce of Bankariya, viz. Ginger and Banana were subjected to post harvest losses. Rural Hetauda is known for its ginger produce and has a high benefit-cost ratio for production [6]. However, at the time of the survey, ginger was sold as low

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as NRs. 30/Kg along the neighboring lines of Sannanitar, Hetauda. Bankariya posits a produce of nearly 5 tonnes of ginger and about 3 tonnes of bananas annually. Accounting for the low selling price and the post-harvest losses, farmers are at a serious economic disadvantage.

Solar drying can be an alternative to reduce post-harvest losses by spoilage and also add value to the product. Ginger *sutho,* or dried Ginger powder go as high as NRs. 300/kg in the market, and has become a trend among ginger farmers [7]. Banana chips can be sold as high as Nrs. 40/200g, or 1 *pau*. Further, Desiccation opens the possibility of more value added products like Ginger candy or Banana flour. Solar drying is a cheap, accessible and minimally techno-invasive to employ at the rural community of *Bankariya*, to expedite the process of value addition to local produce, and help the farmers gain the edge in market.

Mixed-mode solar dryers which employ both the passive heating conventionally used in open-air drying systems and convective hot air flow like in contemporary Mechanical Dryers are best suited for use in Bankariya. Convection air flow can be expedited by the use of fans which permits forced convection, leading to faster drying rates. Drying rates can reach upto 10% moisture removal per hour, depending upon the food item and the ambient temperatures [8]. The key parameters in designing a suitable dryer depends on the Relative Humidity (RH), Ambient Temperatures and wind speeds. Drying rates are proportional to Temperature, and therefore exhibit a higher drying rate during peak solar exposures (midday)[8]. Relative humidity decreases convection rates [9]. Also, wind speeds are conducive to higher convection rates.

Hetauda lies in the Terai region of Nepal, at an elevation of 464m from sea level. Temperatures in the winter can drop as low as 2°C on average and in the summer can rise up to 35°C, on average [10]. In the months of April to October, Hetuda experiences high relative humidity while peaking at August. In terms of wind speed, Hetauda experiences an average speed of 6.5 mph during April (highest) and 4.5 mph in October (lowest). During the months of April to September, Hetauda experiences a solar exposure from 8 AM to 6 PM while during the rest of the year the exposure window is smaller (except during high precipitation)[11]. These factors are conducive to employ a mixed mode solar dryer. The scope of this research is to design a suitable mixed-mode solar dryer capable of desiccating a variety of food items, cardinally ginger and banana for the climactic condition of Bankariya, Hetauda.

The application of solar drying technology in agricultural area to preserve vegetables, fruits, and other crops has proved to be practical, economical, and eco-friendly There are various trends in solar dying technology mostly depending upon the geographic and economic factors. The type and nature of solar drying can be passive or active drying, direct, indirect, mixed mode or hybrid drying. For the scope of our research mixed mode solar dryer was designed and installed and its performances were analyzed.

2. Method

2.1. Design considerations

Raw ginger is very susceptible to environmental conditions and therefore must be processed as quickly as possible before it can be stored for future usage. The hot and humid climatic conditions of the region can make it difficult for the ginger to be stored for longer periods right after harvest. In addition, drying processed ginger would increase the overhead cost and the product wouldn't be able to compete in the market. Therefore, for initial stages only 20% of the local production was selected for drying purposes. Based on rotating harvest method, two-month period was idealized for the drying 2000kg ginger. .

A mixed mode drier with trays was considered due to remote location of the installation site and the ability of the selected drier to perform in conditions where technical assistance weren't available. The drying period for 3-5 mm slices for a tray-type drier has been identified at approximately 3-4 days [12]. At 3 days per batch and 1000 kg in a month to dry we take a loading density of 10 kg/sq.m. in coherence with [13]. To dry, 1000 kg in 30 days, and with 3 days per batch, we need to dry at least 100 kg per batch. This sets the required tray area to be 10 sq. m which is impractical for a single unit. The area was therefore distributed over 3 machines of 40kg capacity each. The approximated thickness of the ginger slices was set between 3 and 5 mm [14]. The approximate mass removal required in the time frame is 12-16 kg. The Solar Dryer was modeled to be able to dry up to 40 kg of ginger per batch, with an approximate 60% - 80% moisture removal in the predetermined period.

No heating element was used, and flat plate collector was used due to its simplicity in construction and economic nature. MS wire mesh was used in collector and was painted black to increase absorption of heat. The system was insulated with common Styrofoam sheets 25 mm available locally. The external surfaces were covered with shiny GI sheets to reflect any inbound or outbound radiation that affect the drying chamber conditions.

2.2. Design and 3D modeling

The Solar Dryer was modeled using the 3-D Computer Aided Designing (CAD) software by Dassault System, SolidWorks 2016. The 3D modeling was carried out separately for the absorber plate, the collector and the drying chamber separately and was assembled using the CAD tool. Additional elements like the drying trays, the blower unit, etc. were added later on. The structural frame holding the main parts were designed with a factor of safety of 2 for a mild loading and environmental conditions [15].

2.3. Materials fabrication and assembly

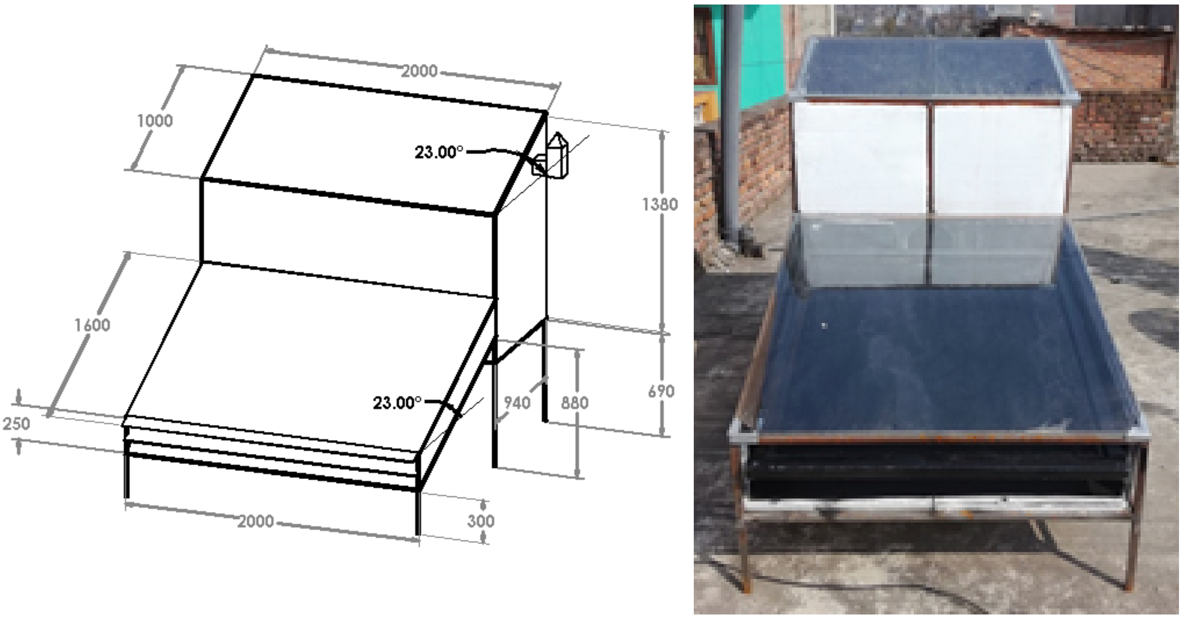
The frame consisted of a standard Mild steel (MS) square section ISO 20×20×3. The absorber plate was fabricated from a 3mm aluminum plate, which was coated with generic black enamel. The collector plate was covered with the ASTM D778, 0.06" acrylic sheet, to transmit the incident sunrays inside the collector chamber. The same type of sheet was used on the top surface of the drying chamber. The body of the unit composed of 30 gauge corrugated Galvanized Iron (GI) sheets and was varnished with black enamel to increase radiation absorptivity [16]. The inside of the chamber, least exposed to the sun rays, was insulated using double layer of 25 mm polystyrene sheets. The drying trays and miscellaneous article like the hinges, door knob and so on were made up of MS.

2.4. Experiment design

Testing was conducted using a sample of peeled and sliced ginger. The sample size was taken as 1 and 2 kg of ginger respectively and was measured for the high temperature months i.e. Apr, May. June. The moisture desiccation was estimated by measuring the mass of ginger, before and after drying. The following parameters were conducive to determining the dryer's effectiveness.

2.4.1. Temperatures

Temperatures inside the collector chamber (T_{cc}) and the drying tower (T_{dc}) was calculated by using a TL-IR350 Non-contact infrared thermometer ranged: -50°C to 750°C. The ambient temperature was estimated by using a lab-grade alcohol thermometer and cross-referenced against the meteorological data available at AccuWeather [17]. The temperature was tracked for 10AM to 4PM NST.



(a) 3D model of the design. **(b)** Fabricated model.

Figure 1: Mixed mode solar dryer.

2.4.2. Mass of the specimen

The mass was measured on an AC beam balance, capacity: 5 kg, initially and after each drying period. The moisture dissipated was calculated by using equation 1.

$$\%\text{mass removal} = \frac{M_i - M_d}{M_i} \times 100\% \quad (1)$$

Where M_i is the initial mass of the chips, and M_d is the desiccated mass after trial period.

2.4.3. Drying rate

The rate of drying was calculated using equation 2 [8], represented in terms of kilogram per hour. The drying rate was computed for each hour during the drying period and compared.

$$\frac{dM}{dt} = \frac{M_i - M_d}{t} \quad (2)$$

Where, M_i and M_d are taken from equation 1 and t is the drying period. Since, the rate is taken on a hourly basis, the rate simply becomes the hourly mass desiccated of the ginger chips.

2.4.4. Efficiency

Efficiency was calculated by considering the standard desiccated mass of ginger *Sutho,* commercially and the mass obtained from the Solar Dryer for the same amount of drying time. The standard moisture content of ginger is 85% [18], and that of *Sutho* is 3.75 for solar dried ginger [18]. Commercial ginger dryers i.e. electric powdered desiccators claim that a 2.5 mm thickness ginger size, i.e sample of 1 kg can dry within 2.5 hours under a temperature of 63°C and a RH of 10% [19]. If M_{ds} is taken as standard mass after 2.5 hour period, drying efficiency can be calculated using equation 3.

$$\eta = \frac{M_{ds} - M_d}{M_{ds}} \quad (3)$$

Further, the chips were subjected to open-air passive drying which required t_{od} hours, while the solar dryer required t hours to obtain a moisture of about 3.5% in the final product. The percentage time saved is given as

$$\%\text{time saved} = \frac{t_{od} - t}{t_{od}} \times 100\% \quad (4)$$

3. Design

3.1. Working of the dryer

The collector is a rectangular chamber with an inlet vent as shown as in Fig. 1a and 1b. The incident sun ray falls upon the collector chamber and gets absorbed by the perforated absorber plate as well as the inside walls of the collector chamber. The heat trapped by the chamber using the greenhouse effect, energizes the air molecules which rise up to the drying chamber. If the outlet vent in the drying chamber is kept open, hot air moves through the drying chamber and escapes out the vents. This causes fresh air to enter from the inlet vent of collector there by setting up an air current. The outgoing temperature is greater than the incoming temperature, and when the drying chambers are empty, relative humidity is greater in the ambient which enables moisture absorption in the drying chamber. This is how solar dryer abstracts moisture from the food item [8]. This dryer is a passive solar dryer, as it is deprived of moving parts however a fan can be installed in the drying chamber to set up forced convection if the ambient condition renders natural airflow stagnant. Forced convection can increase this process of moisture abstraction [17].

3.2. Orientation of the collector

Solar collector is designed and oriented in such a way that it absorbs the shorter wavelengths of light and prevents the longer wavelengths from escaping, thus trapping the solar energy and transferring it to the ambient air (working fluid).The solar drier works most efficiently when it is oriented in a way to receive the maximum solar radiation and it varies significantly depending upon the month of the year and the geographical location of dryer [20]. Depending upon these factors the orientation of collector was set at north-south direction with the tilt angle is 23° [10,11,17].

3.3. Design of the collector chamber and absorber plate

A cuboid frame of dimensions 2000×1600×250 mm was created for the chamber with a 23° to the horizontal. The cuboid frame was supported to the ground on four MS supports. A GI sheet was wrapped around the cuboid frame and the insulation of 25 mm polystyrene was placed over it. Another 30 gauge GI sheet was placed over the polystyrene such that the polystyrene is sandwiched between two GI sheets. The inside surface of the arrangement is colored black for the absorption of sun rays. The absorber plate was fabricated from a perforated aluminum sheet. The sheet was painted black to enhance absorption and the perforation was needed to facilitate air flow within the collector chamber (Fig. 2).

3.4. Design of the drying chamber

A drying chamber (Fig. 3) of dimensions 2000×1380×1000mm was designed and fabricated using the MS square tube ISO 20×20×3 with the top inclined 23° to the horizontal. GI sheet was used to wrap around the drying chamber frame and 25mm polystyrene is placed over it. GI sheet was also placed on the top of polystyrene and was painted black to enhance absorption. Racks were designed and fabricated to be placed inside the drying chamber and the top of the drying chamber is housed with acrylic sheet.

4. Results

The solar dryer was tested in the month of June and July 2018 at Bankariya, Hetauda, Province-3, Nepal. The testing was carried out for 1 kg, 2 kg of 2.5 mm sliced ginger and four sets of data were recorded. The set of data recorded is plotted and presented in Fig. 4, 5, 6 and 7.

4.1. Temperature and relative efficiency

Temperature variation in the ambient, drying chamber and collector chamber was recorded separately for 1 kg and 2 kg samples of 2.5 mm slice ginger for the month of June and July. The results are shown in Fig. 4a, 5a, 6a and 7a. As seen in above graphs, the highest temperatures are recorded in the collector unit in June at 67°C followed by the drying chamber and then the ambient. The temperature peaks around mid- day (noon) which is common as per weather variation of Hetauda in summer [11]. Similarly, relative humidity of the ambient is also recorded in the Fig. 4b, 5b, 6b and 7b. The relative humidity of inlet air is corresponding to the ambient RH which drops around the peak temperature hours as higher temperatures increase the water bearing capacity of the ambient air. As for the outlet RH, it should remain more or less steady as moisture abstracted from the ginger gets incorporated in the drying chamber air, and this neutralizes, more or less, the effect of increasing temperatures. However, the graphs represent a similar trend of the drying chamber RH with the ambient air.

4.2. Drying rates

Drying rates were calculated using equation 2 and was computed on an hourly basis until the rate stabilized for the month of July. The two graphs for 1 kg and 2 kg were augmented on each other and represented in Fig. 8. It is to be noted that hours 1 to 8 was estimated in day 1 while the rest was estimated in day 2. It can be seen that drying rates significantly improved over the 4^{th} hour with drying rate of 0.22 kg/hr for 2 kg and 0.11 kg/hr for 1 kg. Similarly next peak was recorded on 12^{th} hour with the drying rate of 0.8kg/hr for 2 kg and 0.35 kg/hr for 1 kg. High temperatures were evident from Fig. 4a and 5a Further from Fig. 4b and 5b,it can be seen that the increased drying rate is conducive to drop in RH in the ambient. The drop of RH inside the chamber can be attributed to the fact that the drying rates weren't enough to saturate the air. If a larger quantity was taken then the RH would remain steady inside the drying chamber [6,8]. The drying rate is low for lower mass i.e. 1 kg and almost twice for the 2 kg samples. It can be also seen that the rate has dropped in the later half i.e 2^{nd} day compared to day 1.

Table 1: Sampling mass before and after the period of 16 hours.

Parameters		
Initial Mass	1 kg	2 kg
Final mass after drying	0.41 kg	0.64 kg
Mass of water evaporated	0.59 kg	1.36 kg
Time elapsed in the drier	16 hr	16 hr
Time elapsed in open air	9 days	9 days

5. Discussion

For Equation 1, the percent of moisture removed is calculated to be 59% for 1 kg and 68% for 2 kg sample.

The drying rate can be inferred from Fig. 8 but using equation 2, the cumulative drying rate can be determined i.e for the period of 16 hours. The rate comes out as 0.0368 kg/h for 1 kg sample and 0.085 kg/h for 2 kg sample. The higher the sample size, more the value of drying rate was observed, however, this increase can also be attributed to the temperature and RH conditions as shown in Fig. 4a and 4b.

In 2.5 hours, a commercial dryer (electric) can abstract moisture of up to 0.815kg for a 1 kg sample and 1.63 kg for a 2 kg sample. Using equation 3, the efficiency can be attributed in terms of a standard electric dryer. In 2.5 hours from Fig. 8, the mixed mode solar dryer absorbs about 0.1145 kg and 0.2185 kg from the 1 and 2 kg samples respectively. Using equation 3, it was inferred that the solar drier is 20.89% and 21.78% as effective as the electric dryer for the 1 and 2 kg respectively.

In terms of time saved as compared to manual drying, using equation 4, the percentage saved was 77.77%.

6. Conclusion

From our study of the Variegated Food Desiccating Mixed-Mode Solar Drier for the Locality of Bankariya, it was concluded that the solar drying can be an effective way to dry the ginger and can help reduce the spoilage thus increasing efficiency of the whole drying process The 1 kg and 2 kg of 2.5 mm slice ginger was dried to 0.41 kg, 0.64 kg respectively in 16 hours with the 77.77% of time saved, thus greatly reducing the drying time from 9 days using open drying (Table 1) [21]. The drying rate was highest during the mid-day (noon) for both samples and the maximum collector temperature recorded was 67°C. Furthermore, to bolster drying process, a fan can be incorporated in the system to create forced convection and increase drying rate. However, various factors such as wind, dryer location and nature of drying element played the role during the drying process, the improved drying time and the quality of the thus dried product was evident of the feasibility of such drier in locality of Bankariya, Hetauda, Province-3, Nepal.

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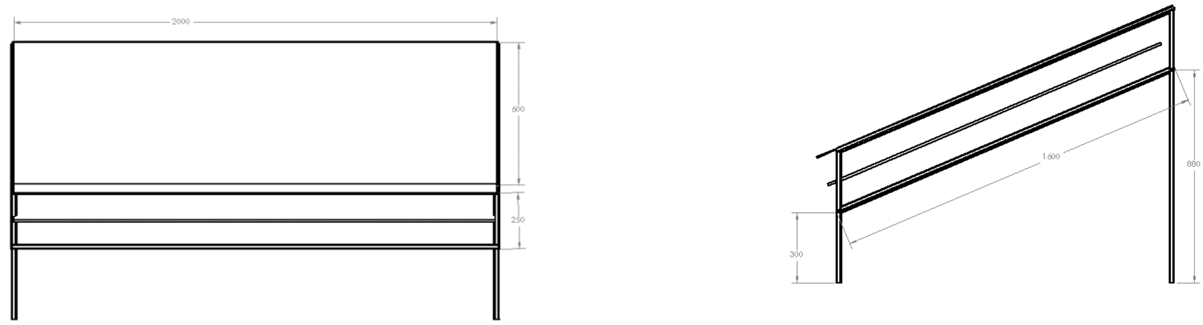
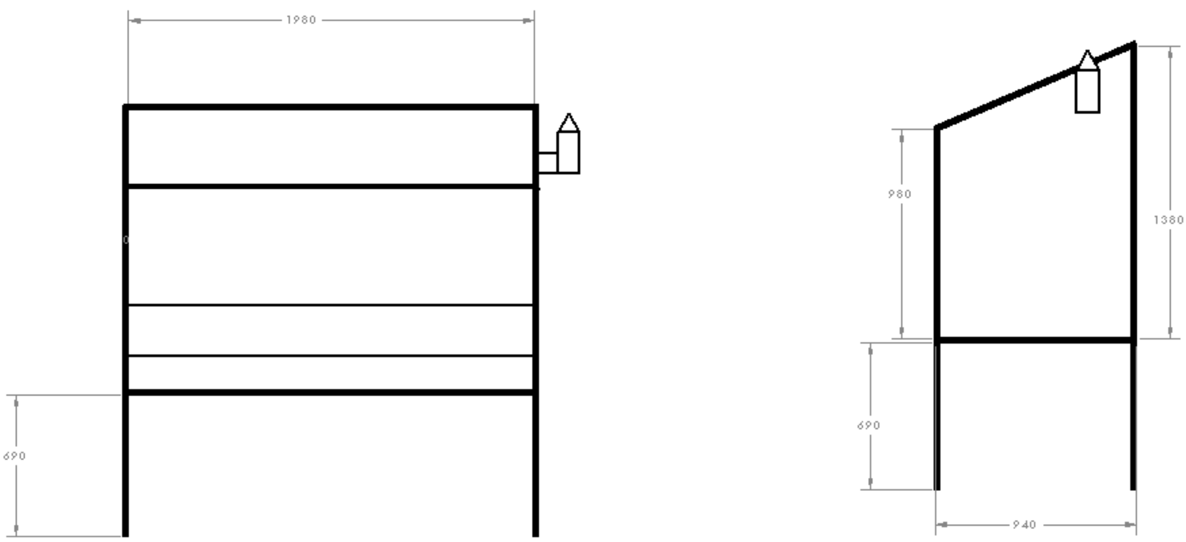


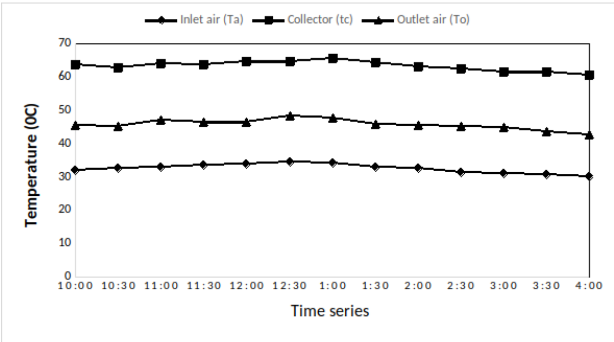
(a) Front view. **(b)** Side view.

Figure 2: The collector.

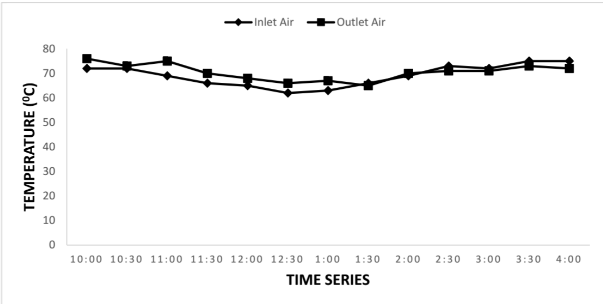


(a) Front view. **(b)** Side view.

Figure 3: The drying chamber.

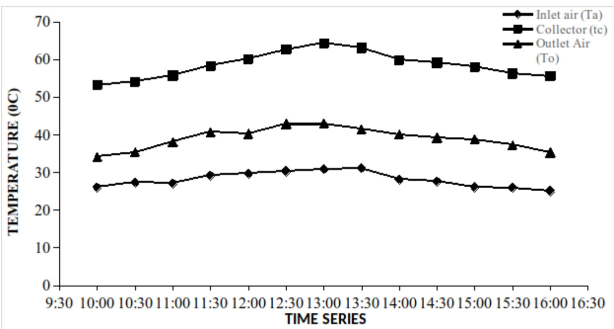


(a) Temperature vs. time of day (hr).

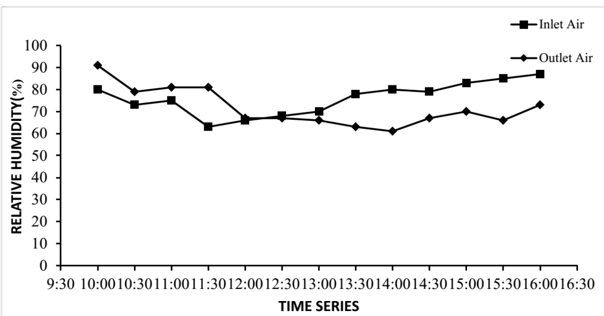


(b) Relative humidity (%) vs. Time of day (hr).

Figure 4: Graphs for sample of 1 kg in June.

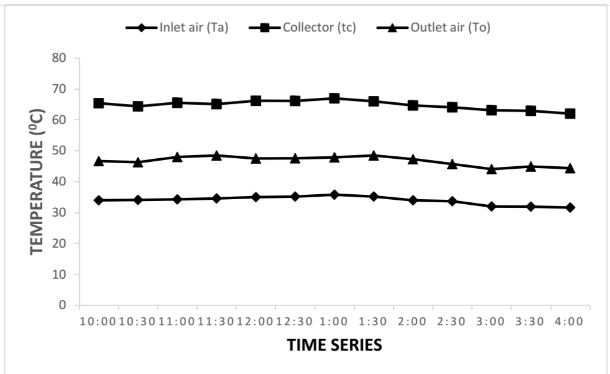


(a) Temperature vs. time of day (hr).

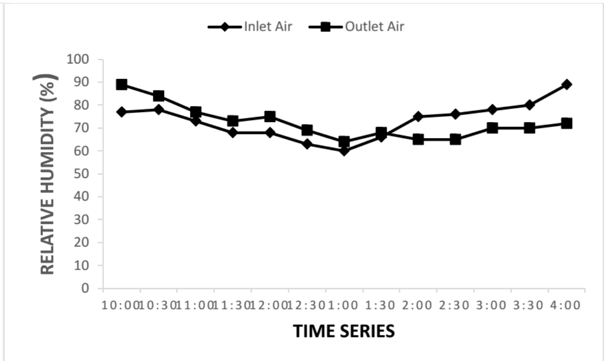


(b) Relative humidity (%) vs. Time of day (hr).

Figure 5: Graph for the sample of 1kg in July.

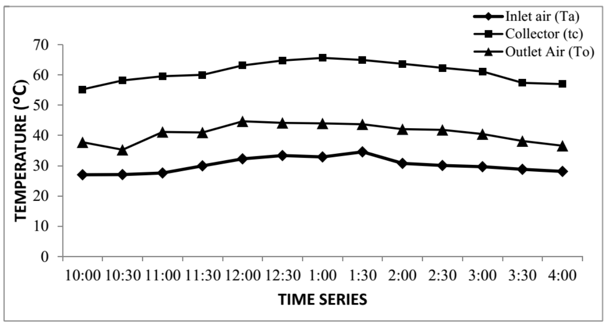


(a) Temperature vs. time of day (hr).

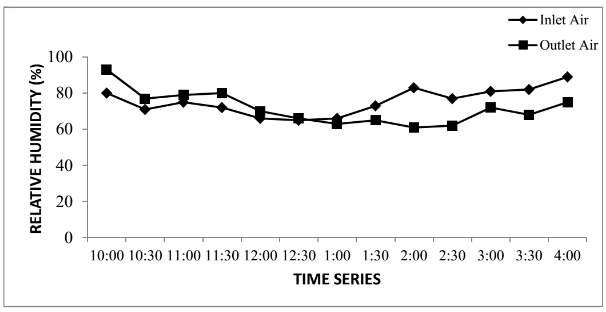


(b) Relative humidity (%) vs. Time of day (hr).

Figure 6: Graph for the sample of 2 kg in June.



(a) Temperature vs. time of day (hr).



(b) Relative humidity (%) vs. Time of day (hr).

Figure 7: Graph for sample of 2 kg in July.

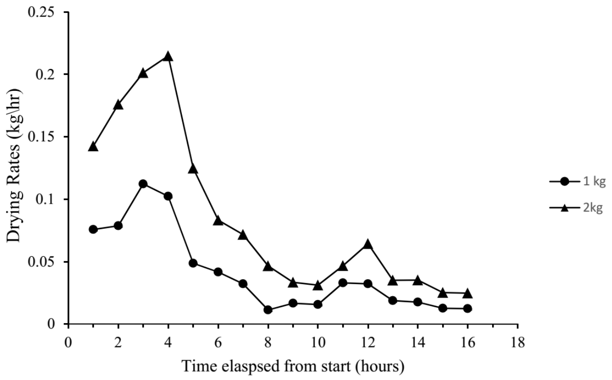


Figure 8: Drying rates in kg/h vs. time elapsed from start.

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