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Design and Analysis of Solar Dryer for Mid-Latitude Region

Maundu Nicholas Musembi[a] *, Kosgei Sam Kiptoo[b], Nakajo Yuichi[c*]

[a,b] *Graduate School of Engineering, Ashikaga Institute of Technology, Ashikaga-shi,326-0845, Japan*

[c] *Renewable Energy and Environmental Engineering, Ashikaga Institute of Technology, Ashikaga-shi,326-0845, Japan*
**Corresponding authors: nickmaundu2014@gmail.com, ymnakajo@yahoo.co.jp*

Abstract

In this study, an indirect natural convection updraft solar dryer was designed and fabricated with objectives to; suit mid-latitude applications, determine its performance efficiency, analyze air properties by use of psychrometric chart and assess the quality of dried product. The dryer was fabricated using low cost and locally available materials. For mid-latitude regions, zenith angle is dependent on latitude, solar declination angle, time of the year and of the day. Based on these changing parameters, the solar dryer was designed to suit the conditions. The main parts of the dryer are; hinged flexible angled solar collector, drying chamber consisting of three drying trays, updraft chimney with metallic absorber plate. The experiments were carried out to dry sliced apples of 2.5mm thickness spread over the drying trays. Temperature and relative humidity of airflow were taken at the collector inlet, drying chamber inlet and drying chamber outlet to chimney using data loggers. Airflow inlet to solar collector and from drying chamber was determined using hot wire anemometers, irradiation in W/m^2 was measured by radiation meter. Drying characteristics such as the collected solar energy to evaporated moisture, average drying rate, moisture content, etc., were determined. Natural convectional flow was adopted with an advantage of utilizing updraft air chimney to induce thermo-siphoning effect hence improving efficiency. In our current study, fresh apples of 886.64 grams with moisture content of 86% were dried to moisture content of 8.12 % (wet basis) within 9 hours 20 minutes at an average irradiance of $534.45 W/m^2$. The overall dryer efficiency was estimated to be 17.89%. The possibility of formation of water droplets within the drying chamber, which is a challenge to most direct solar dryers was considered to be minimal. This was based on analysis of the dew-point of drying chamber inlet air in comparison to outlet air properties. This design is simple; it can easily be replicated elsewhere in the world, products can be dried in one day and has capability to dry products at commercial scale while retaining the color, flavor and nutrients.

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* Corresponding author. Tel.: +818066059423
E-mail address: nickmaundu2014@gmail.com, ymnakajo@yahoo.co.jp

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1. Introduction

With the current trend towards renewable energy resource utilization as concerns over the impacts of using fossil fuels to climate change, cost of energy and the need to minimize post harvesting damages increases, solar energy in food processing is expected to play a major role in food systems.

One of the major challenges for farmer in Africa and most of the developing countries is post-harvest losses which is estimated at 30-40% of the farm produce [1,2]. Under very adverse conditions, the losses can be as high as 80% [3] especially during bumper harvest for seasonal and highly perishable farm output such apples, mangoes, tomatoes, and other citrus fruits. This deprives farmers of the potential income from their output and thus jeopardize chances of highly anticipated economic contribution of agriculture in general. Agricultural products are dried to increase shelf-life, reduce packaging cost, increase shipping capacity, enhance appearance while maintaining flavor and nutritional value. By drying, moisture is removed from food and thus bacteria, yeast and mold cannot grow leading to food spoilage [4].

Solar Dryers can play a major role in minimizing post harvesting damages in both developed and developing countries as well as for value addition [4]. Understanding of the basic principles of operations of solar dryers and expected performance will go a long way in promoting utilization of solar energy for drying purposes.

For the purpose of this research work, a study on performance of solar dryer was carried out, it involved; design, fabrication and testing of a solar dryer intended for use in mid-latitude regions such as Japan. Various parameters affecting the drying process and the dried product were analyzed. Indirect updraft convectional flow dryer was used for drying apples with the intention of maintaining the color, improving the flavor and increasing the shelf-life without the use of chemical related preservatives.

This experiment was carried out within the compound of Ashikaga Institute of Technology, Tochigi Prefecture-Japan. The GPS of the location of experiment (Ashikaga-Tochigi) is 36◦21'8"N139◦23'54"E and elevation is 60 meters above sea level.

2. Design Methodology and Construction

In this section, Design analysis shows some equations considered for sizing of solar collector for the prototype solar dryer based on the estimations of drying 600 grams of apples. Other considerations specific to location as well as design procedure have been highlighted.

2.1. Design analysis and basic theory

The amount of moisture to be removed from the product, $m_{w,}$ can be determined by the following equation [5,6];

$$m_o = m_w \frac{(M_i - M_f)}{(100 - M_f)} \tag{1}$$

Where; m_o= is the amount of moisture to be removed from the product, m_w is initial mass of product to be dried, M_i = the initial moisture content in % wet basis and M_f =the final moisture content % wet basis.

The quantity of heat required to evaporate water was determined based on eqn. (2) [7];

$$\mathbb{Q} = m_o x h_{fg} \tag{2}$$

where Q is the amount of energy required for the drying process, kJ, h_{fg} is latent heat of vaporization, kJ/kg of water.

The latent heat of vaporization was calculated using equation given by *Youcef-Ali et al (2002)* [5,7];

$$h_{fg} = 4.186x10^3(597 - 0.56xT_P) \tag{3}$$

Where T_p is the temperature of the product in °C. The total collected solar energy (E_T) falling on the collector can be obtained as shown in eqn. (4) while the total heat energy (E) in kJ required to evaporate water can be determined from eqn. (5) [7];

$$E_T = A_c I \quad (4)$$

$$E = m_a (h_f - h_i) t_d = \frac{A_C I \eta}{1000} \quad (5)$$

where m_a is the mass flow rate of air in kg/hr, h_f and h_i are final and initial enthalpy of drying air in kJ/kg of air and I is the global radiation on the horizontal surface during the drying period (kJ/m^2) and t_d is the drying period (s).

The enthalpy of moist air in J/kg at temperature T(°C) can be approximated using the eqn. (6) [7];

$$h = 1006.9T + m_w(2512131.0 + 1552.4T) \quad (6)$$

The performance of a solar collector, represented by its outlet air temperature and its efficiency depends on parameters such as: the region where the collector is installed, collector internal parameters such as its surface and external conditions such as the temperature and the velocity of ambient air.

The efficiency of solar collector as transformed by Hottel-Whiller-Bliss for the steady state case can be expressed as [8];

$$\eta = \frac{\mathbb{Q}_u}{A_c I} = F_R(\tau\alpha) - F_R U_L (\frac{T_i - T_\alpha}{I_T}) \quad (7)$$

F_R is the heat removal factor of solar collector calculated which can be determines as;

$$F_R = \frac{mC_p}{A_c U_L}(1 - \exp(\frac{A_C U_L F'}{mC_P})) \quad (8)$$

Where m is the mass flow rate, F' collector efficiency factor, C_p specific heat(J/kg.K) ,A_C is the area of collector(m^2)and Q_u is useful energy of collector(W/m^2).

The energy balance on the absorber is obtained by equating the total heat gained to the total heat lost by the heat absorber of the solar collector. Therefore [3];

$$IA_C = \mathbb{Q}_{UC} + \mathbb{Q}_{cond} + \mathbb{Q}_{conv} + \mathbb{Q}_R + \mathbb{Q}_\rho \quad (9)$$

Where I is the rate of total radiation incidence on the absorber surface(W/m^2) and thus the total radiation incident to the total area of the collector, IA_C can be written as;

$$IA_c = \tau I_T A_C \quad (10)$$

$\mathbb{Q}_{cond}$ and $\mathbb{Q}_{conv}$ are rates of absorber conduction losses(W) and convective losses(W) respectively. $\mathbb{Q}_R$ is the rate of long wave re-radiation from the absorber in J/s. These three loss terms are usually combined into one term ($\mathbb{Q}_L$) which is useful in estimation of heat loss of the collector as;

$$\mathbb{Q}_L = \mathbb{Q}_{cond} + \mathbb{Q}_{conv} + \mathbb{Q}_R = U_L A_C (T_C - T_a) \quad (11)$$

Where; U_L is the overall heat transfer coefficient of the absorber (Wm^{-2}K^{-1}) , T_C temperature of the collector's absorber and T_a ambient air temperature. $\mathbb{Q}_\rho$ is the reflected energy from the absorber and is given as shown below;

$$\mathbb{Q}_\rho = \rho\tau IA_c \quad (12)$$

Where ρ is reflection coefficient of the absorber and τ transmittance of the cover. $\mathbb{Q}_{UC}$ is the rate of useful energy collected by the air (W) which can be determined by use of eqn. (13) derived from eqns. (9,10,11 and 12) as;

$$\mathbb{Q}_{UC} = (\alpha\tau)I_T A_c - \mathbb{Q}_L \quad (13)$$

Substituting the value of $\mathbb{Q}_L$ given by the last part of eqn. (11) into eqn. (13) gives;

$$\mathbb{Q}_{UC} = (\alpha\tau)I_T A_c - U_L A_C (T_C - T_a) \quad (14)$$

Where;

$$U_L = \sum \frac{k}{L} \quad (15)$$

Eqn. (14) therefore is applicable in determining the rate of useful energy collected by air.

2.2. Design Consideration

The following points were of great essence in this design; The location where the solar dryer shall be used, changing incident angle of sun rays in the region, solar collection efficiency, Updraft thermo-siphoning effect, the cost of solar dryer, moisture to be removed from material and the quality of the dried products. Mobility of the dryer was key in this case for ease of relocation.

2.3. Design Procedure

The size of the dryer was made suitable enough for laboratory experiment considering portability, flexibility, local materials, efficient and effective data collection. An average irradiance of 500W/m^2 for 8 hours was considered suitable for the design at useful efficiency of 15%. From these assumptions, a collector area of 0.56265m^2 was chosen so as to dry 600 grams of apples from moisture content of 86% to 15% in a day.

2.4. Dryer Construction and Material

A natural convection solar dryer was constructed consisting of variable elevation solar collector, drying chamber and draught chimney. Fabrication of the dryer can be described as follows;

i) Solar Collector

The collector was fabricated as follows: - the base of collector was constructed from 1 cm thickness plywood of dimensions 51cm by 96cm with an extra extension of 51 cm by 27 cm to the drying chamber, the sides of the collector were constructed from two pieces of trapezoidal timber of measurements 9.3cm by 96cm length by 15cm and thickness of 0.5cm. A 1mm thick matte black painted iron sheet was used to cover the base of the collector, a 2 mm thick transparent polycarbonate sheet was used to cover the top side of the collector. All the joinery work was done by the use of 3/4" nails and sealed by use of silicone caulk. The collector area was 0.56265m^2 derived from eqn. (2) and eqn. (5) and has an inlet of 0.00925m^2. The solar collector was hinged to the drying chamber and provided with flexible angle support to facilitate tilting to the changing elevation of the sun. The air inlet opening was located on the front-end side of the solar collector.

ii) Drying chamber construction

The drying chamber sides were constructed from three pieces of 1 cm thick timber resulting to drying chamber of dimensions 50 cm by 50 cm by 69 cm. The bottom and the top of the chamber were fabricated from 1 cm thick plywood of dimensions 50 cm x 39 cm and 50 cm x 43 cm respectively providing for the air inlet at the bottom-front side of collector and outlet to chimney at the top-backside. Three removable trays were constructed using wire mesh of dimensions 47cm by 47cm.The four edges of trays were reinforced using thin timber pieces. The slide bars for holding the trays were fixed at 20cm, 36cm and 53cm from the bottom of the dying chamber. An air-tight wooden door was made with rubber seals at the edges and hinges as well as wooden locks. The chamber was raised using timber frames of measurements (L x W x H) 4cm x 4cm x 101cm.The base of the stand was fitted with lockable caster wheels.

iii) Construction of Draught Chimney

The chimney was constructed to a wedge-shape with a base and top cross-section of 44cm x 20cm and of 44cm x 5cm respectively with overall chimney height of 43cm. The back side of the sun-facing side was covered by use of a 1mm thick matte black painted iron sheet. It was then covered with 1mm thick clear polythene paper

The materials used to construct this prototype solar dryer can be summarized as shown in table1.

Table 1. Summary of Materials used for Construction

Item No.	Material	Description
1	Plywood (Thermal conductivity 0.13W/m.K,)	Construction of the collector body, drying chamber, Chimney and supporting structures.
2	1 mm thick iron-sheet painted Matte- Black on one side. (Thermal conductivity 16.2W/m.K , Specific heat Capacity 500J/kg.K , Thermal diffusivity $4.2*10^6$m/s, absorptivity 0.92, Emissivity 0.95)	Collector Absorber surface
3	Clear polycarbonate sheet (Transmissivity 0.88, thermal conductivity 0.19 W/m.K),thickness 0.15cm.	Cover sheet for collector.
4	Thick transparent polythene paper	Chimney cover, flexible termination of collector sheet to the drying chamber
5	Silicon-Caulk	Sealant for intersections
6	Caster Wheels	Dryer foot for mobility
7	Nails and Screws	Joinery work and mounting
8	Matte-Black grade paint	Painting absorber surfaces
9	Door Hinges	Angular deflection point connection for collector to drying chamber, door hinges
10	Perpendicular angle brackets	Reinforcement of stands
11	Stainless steel Wire Mesh	Construction of product holding trays

3. Solar Dryer Operation and Equations for Analysis

The solar radiation strikes the earth's atmosphere in the form of visible light, ultraviolet (UV), infrared (IR) and other types of light that are invisible to the human eye.

UV radiation has a shorter wavelength and higher energy level than Visible Light, IR radiation has longer wavelength and thus weaker energy level. About 30% of solar radiation striking earth's atmosphere is immediately reflected back to space by clouds, ice, snow, dust and other reflective surfaces. About 70% reaches the earth's surface and thus can be utilized as solar energy [9].

3.1. Operation of solar dryer

In general, a non-concentrating solar collector consists of four main components: the transparent cover, solar thermal absorber, collector base and heat transfer media. The transparent cover allows solar radiation to pass through and reach absorber while reducing the convective and radiation losses. The material used must be transparent to shortwave solar radiation and opaque to long-wave solar radiation [10]. When solar rays strike the surface of the solar thermal absorber, it absorbs and converts the energy received into heat and transfers it to air (heat transfer medium) by mean of convection within the collector chamber, this heats up the air within the collector, rising its temperature and increasing vapour pressure thus reducing its relative humidity. The capacity for the air to contain more water vapour is increased, the warm/ heated air can then be directed through a drying chamber by passive convective system to dry the material.

3.2. Analysis of dryer performance

Analysis of solar dryers is key to understanding its performance parameters. Depending on existing conditions, a moist product in a stream of air may lose or gain moisture, this depends on the partial pressure vapors in the air and the gradient of vapor pressure of water that is present in the product. Assuming partial pressure of vapor in the air remains constant in a sample, if we pass a stream of air for a sufficiently long time, we will reach an equilibrium condition referred to as equilibrium moisture content (EMC).

EMC depends on temperature, relative humidity and the nature of the product.

Water Activity; the more water there is in the product the better it is for the growth of micro-organism, this determines the shelf stability and safety, the water activity of apple is considered to be 0.95. Equation of water activity [7].

$$a_w = \frac{EMC}{100} \tag{16}$$

Usually, the drying rate is proportional to the difference in the moisture content between materials to be dried and the equilibrium moisture content. Average drying rate A_{dr} can be determined from the mass of moisture removed by solar heat and drying time(t_d) by the eqn. (17) [11];

$$A_{dr} = \frac{m_o}{t_d} \tag{17}$$

For a controlled drying rate, the mass of air needed for drying can be calculated from the eqn. (18) given as;

$$m_a = \frac{A_{dr}}{W_f - W_i} \tag{18}$$

Where A_{dr} is the average drying rate, kg/hr; W_f, W_i are final and initial humidity ratio, kgH_2O/kg (dry air).

The percentage moisture removed from the product $\gamma\%$ and the percentage final moisture content of the dried material can be determined from equations 19 and 20 respectively [11,12,13];

$$\gamma\% = \frac{m_w - m_d}{m_w}100 \tag{19}$$

$$m_f = \frac{100-\gamma}{100} m_w \tag{20}$$

Efficiency of solar dryer in relation to total heat energy of evaporation and irradiation relates as [14];

$$\eta = \frac{E}{A_c I} \tag{21}$$

Where E is the total useful energy received by the drying air in kJ as obtained from eqn. (5). The energy falling on the collector from the sun can be converted to units of energy (kWh) (E_u) as;

$$E_u = \frac{A_C I}{3.6x10^6} \tag{22}$$

The pressure difference across the drying product bed is solely due to the density difference between the hot air inside the drying chamber and the ambient air. Air pressure can be determined by the equation given by *Jindal and Gunasekaran (1982)* [7]*;*

$$P = 0.00308g(T_i - T_{am})H \tag{23}$$

Where H is the pressure head (height of the hot air column from the base of the dryer to the point of air discharge from the dryer), P is the air pressure in Pascals, g is acceleration due to gravity and Tam is the ambient temperature(°C)

Dew-point: This is the temperature to which the air must be cooled before dew condenses from it. The actual water vapor content of the air is equal to the saturation water vapor pressure. The dew point is usually calculated from the RH.

The saturation vapor pressure (P_s) at ambient temperature is determined first then the actual water vapor pressure(P_a) is determined as follows;

$$P_a = \frac{P_S xRH\%}{100} \tag{24}$$

Next, determination of temperature at which P_a would be saturation vapor pressure from temperature, by running the equation backward this can be achieved as follows;

Let w = ln (P_a/610.78)

$$w = \ln(\frac{P_a}{610.78})$$

Thus dew point can be given as follows;

$$D.P = \frac{Wx238.3}{(17.294 - w)} \tag{25}$$

In this analysis, psychometric chart was used to determine dew-point at various temperatures and humidity.

4. Experiment Set-up

Red Apples were purchased from a nearby supermarket a day before the experiment and kept in fridge at a temperature of 10 degrees.

In the morning of experiment, three temperature and humidity data loggers were programmed to record temperature and humidity at intervals of 20 minutes and were set at collector inlet, drying chamber inlet and drying chamber outlet. The collector absorber surface was set at an angle of 30 degrees to the horizontal by use of the angle slide-support bar. Apples were washed, chopped using slicer into slices of 2.5mm, weighed using digital weighing scale with accuracy of 0.01 g, they were then evenly spread on the trays and placed inside the drying chamber.

Fig. 1. Weighing a portion of product (left) and drying product inside the drying chamber (right).

Fig.1 shows a portion of sliced apples on a weighing scale (left) and on the drying trays in the drying chamber (right), hot wire anemometers were placed at the inlet to the collector and outlet of the chimney to measure air flow velocities and temperatures. The solar irradiance (W/m^2) was measured using digital irradiance meter and recorded at intervals of 20 minutes.

The experiment set-up showing side view and front view during the experiment is shown on Fig.2.

Fig. 2. Experimental Set-Up during drying, side view (left) front view (right).

5. Results and discussion

At the end of the experiment, 886.64 grams of sliced apples were dried to a final mass of 135.1 grams. Fig.3 shows dried apples on electronic weighing scale, the mass of the empty bowl was 85.84 grams.

Fig.3. Dried apples on electronic weighing scale.

The final moisture content was obtained as 8.12%.eqn (20). The total solar energy radiation on the surface of collector during drying was obtained as 10103.77 kJ, eqn. (4), and to standard units of energy to be 2.81 kWh, eqn. (22). The useful efficiency of solar collector was found to be 17.89 %.eqn. (21) and the average irradiance was 534.4 W/m^2. Other useful values in performance evaluation where determined as shown in table 2.

Table 2. Calculated values for performance analysis

Description	Value	Egn.no.
Quantity of heat required for evaporated water in joules (0.75151 kg of water)	1807.66	2
Latent heat of vaporisation (h_{fg}) at T_P=40 degrees Celsius in kilojoules	2405.28	3
Rate of radiation incident on the overall absorber area, IA_C (Irradiance 534.45 W/m^2, W)	264.76	10
Reflected Energy from the absorber, Qp, W	21.18	12
Pressure difference across the drying bed (Pascal)	0.346	23
Drying rate(grams/second)	0.02237 g/sec	17
Air mass flow rate needed for drying (use of humidity ratios)	0.012929 kg/s	18

Irradiance, Relative humidity and temperature at collector inlet and drying chamber air inlet as well as drying chamber air outlet were graphically represented as shown in Fig.4 and Fig.5.

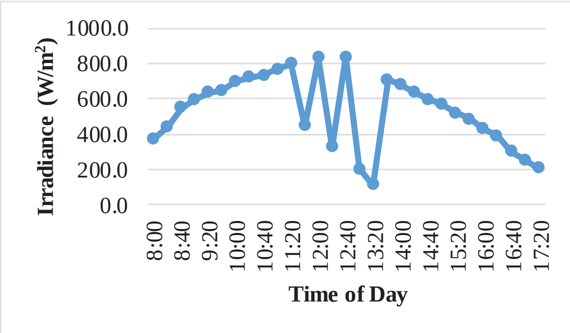


Fig. 4. Irradiance (W/m^2) against time of the day.

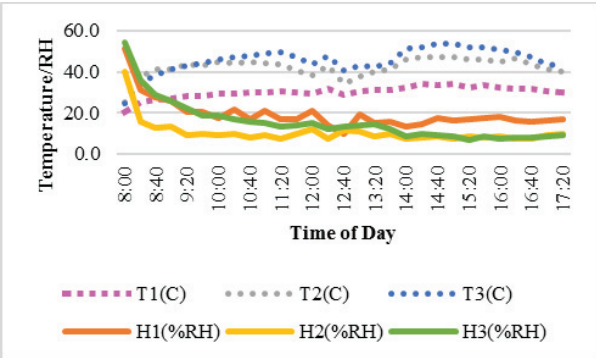


Fig.5. Temperatures and relative humidity against time of the day.

The relative humidity of the air entering the drying chamber (H2) seems more stable within the first 40 minutes of the experiment while that of the air from the drying chamber (H3) continuously decrease until around 15:20 hrs (Fig.5), this might be an indication that most of the moisture from the product had already evaporated by that time though the irradiance seems to have gone low at the same time. At lower moisture content, heat duty required to evaporate moisture is very high so at this stage temperature may not have significant effect [15]. The temperature of the air leaving the drying chamber (T3) was found to be higher in comparison to the air entering the chamber (T2), this is contrary to the expectations, the authors realised that it was occasioned by the chimney- absorber-plate which was design to be placed at the start of the exit point of air from the drying chamber and thus high proximity to the data logger. Relative humidity was found to decrease with increase in temperature as reflected by the air inlet to the collector and as it leaves to the drying chamber.

To investigate air moisture content, Psychrometric chart was used to determine the humidity ratios for the drying chamber air inlet and drying chamber air outlet, HR2 and HR3 respectively as shown in Fig.6. The results indicate a high humidity ratio difference between the inlet and outlet of the drying chamber at the beginning of the experiment, almost double at the start of the experiment and the gap nearly closing towards the end.

The dew point (D.P) of the drying chamber inlet in relationship to its temperature and relative humidity (D.P, T2, H2) as well as the dew point of air in relation to input air temperature and outlet relative humidity (D.P, T2, H3) were determined.

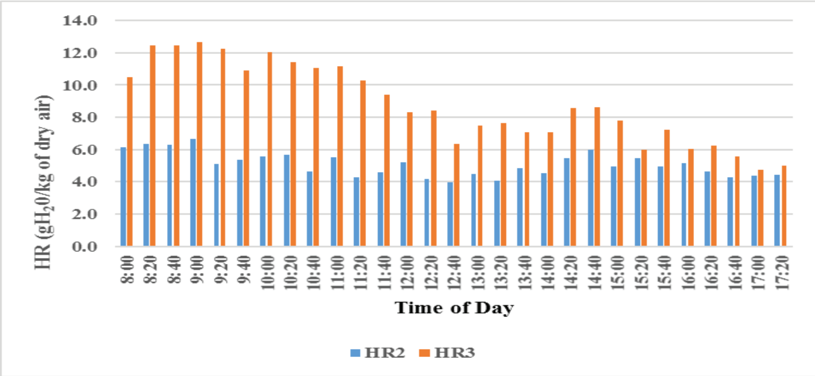


Fig.6. Humidity ratio at the drying chamber inlet (HR2) and outlet (HR3) against time.

The results are as shown in Fig.7. From the graph, the authors feel that the probability of vapour condensation within the drying chamber is very low, this is one of the challenges of direct solar dryers.

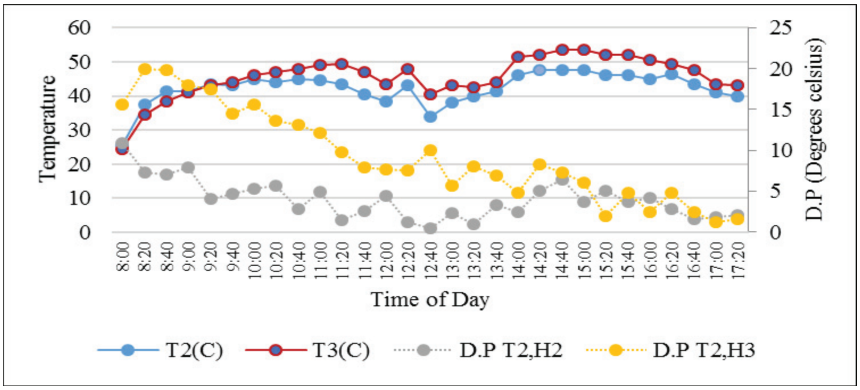


Fig. 7. Temperature of drying chamber inlet, outlet and dew points against the time of the day.

The standard deviation of relative humidity was found to be high at the drying chamber outlet compared to drying chamber inlet, this may be attributed to variation in the rate of drying of the material as the moisture content decreases. Table 3.is a summary of the air properties in relation to temperature and relative humidity at collector inlet, drying chamber inlet and drying chamber outlet.

Table 3. Summary of drying air properties related to temperature and relative humidity.

Description	Collector inlet	Chamber Inlet	Chamber Outlet
Sample interval	20 min	20 min	20 min
Average Temperature(C):	30.0	41.7	44.9
Maximum Temperature(C):	34.0	47.5	53.5
Minimum Temperature(C)	20.5	25.5	24.5
Standard Deviation(C):	2.8	5.1	6.6
Average RH(%RH):	20.3	11.3	16.1
Maximum RH(%RH):	51.3	40.0	54.3
Minimum RH(%RH):	13.6	7.2	7.0
Standard Deviation(%RH):	7.9	7.1	10.2

The dried apples were found to have good taste, good texture and bright colour, they are easy to handle during consumption and have no immense water associated with fresh apples which may drop on clothes or water your body. Fig.8 is a photo of the dried and packed apples dried at different times in our laboratory.

Fig. 8. Portions of dried packed apples.

6. Conclusion and recommendations

The results indicated a higher overall efficiency even with a higher quantity of drying batch as compared to initially designed drying batch size. This can be attributed to the tray design layer type of drying chamber, good air flow distribution, high efficacy of the chimney as well as a higher average irradiance (534.45 W/m^2) compared to designed average irradiance (500 W/m^2).

Psychrometry is important as it refers to the properties of air-vapor mixture that control the rate of drying. It was found useful in determining humidity ratios and thus giving an idea on changes in humidity ratio between the drying chamber inlet and outlet.

Based on relative humidity and the dew points obtained at the inlet and outlet of the drying chamber and the temperatures, the chamber can accommodate one additional drying tray column by expanding vertically thus improving on its performance efficiency.

From this research, the solar dryer of the same design requires a collector area of 0.658 m^2 to dry one kilogram of sliced apples from moisture content of 86% to moisture content of 8.12 % within 9 hours at an average irradiance of 534.4 W/m^2.This implies a collector area of approximately 32m^2 to dry a batch of 50 kilograms to the same moisture content within 9 hours and a collector area of approximately 30 m^2 to dry 50 kg from M.C of 86% to the minimum required M.C of 15% with potential benefits of economy of scale.

Duplication of this design in large scale within mid-latitude regions can mitigate the impact of post harvesting loses especially to the developing countries thus improving the state of food insecurity and providing higher returns to the farmers.

This design may present some challenge for a large scale system design, the dryer may require special design for elevation angle variation mechanism of the collector due to increased size and weight. The airflow for natural convection solar dryer cannot be kept constant since the flow and temperature are determined by irradiance and hence it may not be possible to predetermine when the material will be completely dried especially in areas with hourly variable weather conditions.

Further study is recommended for this type of solar dryer especially coming up with a mechanism to trace the moisture content of the product while still in the drying chamber. This will ensure the dried product is removed from the dryer just at the required moisture content.

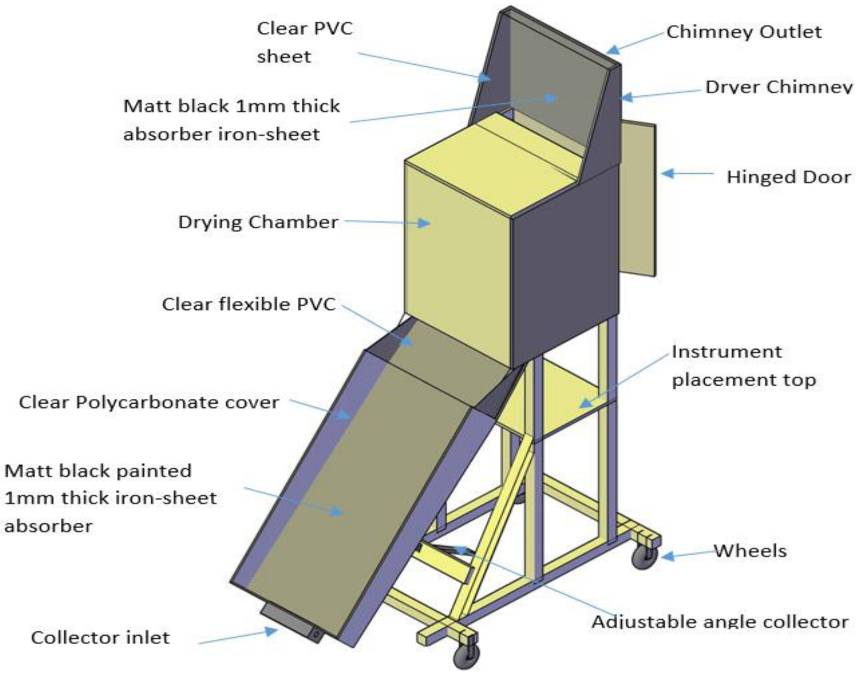
Indirect natural convection flow solar drying was found to be a suitable method for drying apples since the results gave good color, texture and taste.

Acknowledgement

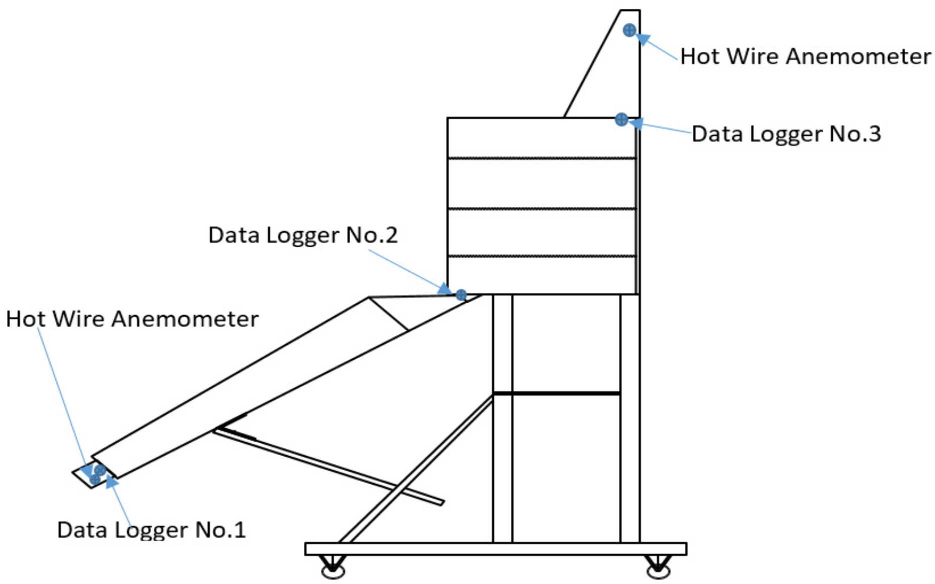
We acknowledge with gratitude for the support given by the management team of Ashikaga Institute of Technology more so the technical assistant and moral support from the staff in Renewable Energy and Environmental Engineering Division.

Appendices

Appendix A: Design and labelled parts of the fabricated natural convection solar dryer.



Appendix B: Experiment set-up drawing showing placement positions of data loggers.



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