DESIGN OF SOLAR DRYER

***Izhak Devid Paul[1] & Dr. Adwait Manoharrao Vaidya[2]**
**[1]Assistant Professor, S.S.G.B.COE Bhusawal, India.*
[2]Principal, Gangamai College of Engineering, Nagaon, India.
*[*1]izakpaul@gmail.com,[2]am_vaidya1@rediffmail.com*

Abstract

Drying of food item is important because excess of water lead to loss of food item. To maintain the proper amount of water with good amount of nutrients drying is used. Dryer is used in many industries but that dryer works on fossil fuels. Solar dryer saves the energy and the results obtain are good. Therefore, to design a dryer is a tedious thing, because the purpose of drying is different for different product and based on that the technique of design is different. There is no standard method for designing the dryer. By reviewing number of researches papers a design procedure is evaluated which is shown in this paper. The aim is to give the step by step procedure to design the solar dryer. This procedure can be used by any researcher which will help them to design any type of dryer.
Keywords: solar dryer, design of solar dryer, efficiency of dryer, performance analysis of dryer.

Nomenclature:

Isc – Solar Constant (1353 W/m^2)
I_{DN} – Direct Radiation
B- Atmospheric extinction (value is in range of 0.14 – 0.21)
β – Solar Altitude angle.
i - Latitude
Hr- Hour angle (The "Hour angle" is defined as the hour before or after the noontime multiplied by 15)
δ – Solar declination
n - the day of the year.
C – coefficient (0.058 for winter and 0.135 for the summer season)
Fss - ratio coefficient
S- Solar tilt angle from the horizon
$I_{r\theta}$ - Reflected radiation
$k_{r\theta}$- reflect coefficient of the environment its value is 0.2
F_{sg} – Collector angle
It = Total radiation
θ – incidence angle
Φ-Solar Azimuth
latφ - latitude of the collector location
U_L -Total heat loss coefficient
U_L - Top heat loss coefficient
U_b - *The bottom heat loss coefficient*
U_e - The Edge heat loss coefficient
M_1 - initial moisture content of grain
W_1 - initial weight and
M_2 - desired moisture content

W_2 - final grain weight
m_w = quantity or mass of water, kg
η is the collector efficiency, mostly in the range of 30 to 50%
Q_1 - sensible heat
Q_2 - heat required to evaporate the moisture from the surface of the material
ΔT - changes in temperature (°C)
Q = The amount of energy required for the drying process, kJ
h_{fg} = latent heat of evaporation, kJ/kg H2O
Tpr = product temperature
E = total heat energy, kJ
m` = mass flow rate of air, kg/hr
h_f and h_i = final and initial enthalpy of drying and ambient air, respectively, kJ/kg dry air.
t_d = drying time, hrs
h - enthalpy, h = 1006.9T +w[2512131.0 +1552.4T]
m_{dr} = average drying rate, kg/hr
$w_f - w_i$, final and initial humidity ratio, respectively, kg H_2O/kg dry air
A_v - area of the air vent, m^2,
V_w - wind speed, m/s.
L_v, - length of air vent, m,
B_v - the width of air vent, m
V_a = volumetric flow rate m^3/sec
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), m;
P - the air pressure, Pa;
g - the acceleration due gravity, 9.81m/s^2
Ta is the ambient temperature, C.
A_{ab} – Area of absorber
Lc – length of collector
W – width of the collector
I = rate of total radiation incident on the absorber ‘s surface (Wm^{-2});
Ac = collector area (m2); Qu = rate of useful energy collected by the air (W);
Q_{cond}= rate of conduction losses from the absorber (W);
Q_{conv}= rate of convective losses from the absorber (W);
Q_R= rate of long wave re-radiation from the absorber (W);
Q_ρ = rate of reflection losses from the absorber (W).
ρ - Reflection coefficient of the absorber
α - solar absorbance
UL = overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$);
Tc = temperature of the collector ‘s absorber (K);
q_u - energy per unit area of the collector
Q_g = heat gained by the air
m_a.= mass of air leaving the dryer per unit time (kgs^{-1});
Cp= specific heat capacity of air ($kJkg^{-1}K^{-1}$).
F_R- collector heat removal factor.
L_v = latent heat ($kJ\ kg^{-1}$)
m_a= mass of drying air (kg);
T_1 and T_2 = initial and final temperatures of the drying air respectively (K);

1. Introduction

Sun is the biggest source of energy and we don't need to pay while using this solar energy. It's a free and vital energy available on the earth. World is moving towards the green revolution where recycling of product is going on and even using of solar energy is increasing. Solar energy can be used in many ways here in this paper the design of solar dryer for drying the food item is discussed.

Thus, to get more use of this solar energy a proper design is needed which will help to get more output with less time. It is necessary to designed and developed an energy efficient solar dryer for continuous drying operations [1].

1.2. Characteristics of drying

The moisture content in the food element or any other material is not same it varies. It totally depends on its hygroscopic nature. zero moisture level can be attained in non-hygroscopic materials[3]. Fruits and vegetable are the Hygroscopic materials where it is required to keep a minimum amount of moisture [4, 5]. The moisture remains in hygroscopic material, may be bound or unbound moisture. This is due to surface tension of water as shown in Figure. 1. If the hygroscopic material is exposed to air, then it is possible that it will absorb or might desorb the moisture due the relative humidity of air.It is found that to reach the equilibrium moisture content (EMC) the vapour pressure of water in the material should be equal to the partial pressure of water in the surrounding air, [6, 7]. It is already known that theequilibrium moisture content is very important in the drying process. Because it is the moisture level up to which we can dried the product.

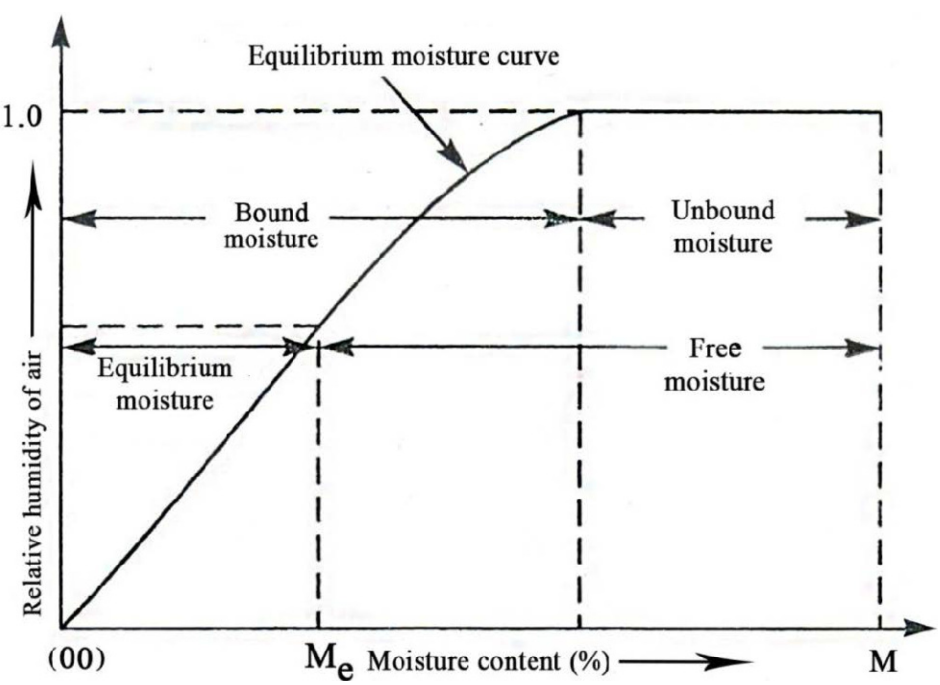

Figure. 1: Moisture in the drying material [2]

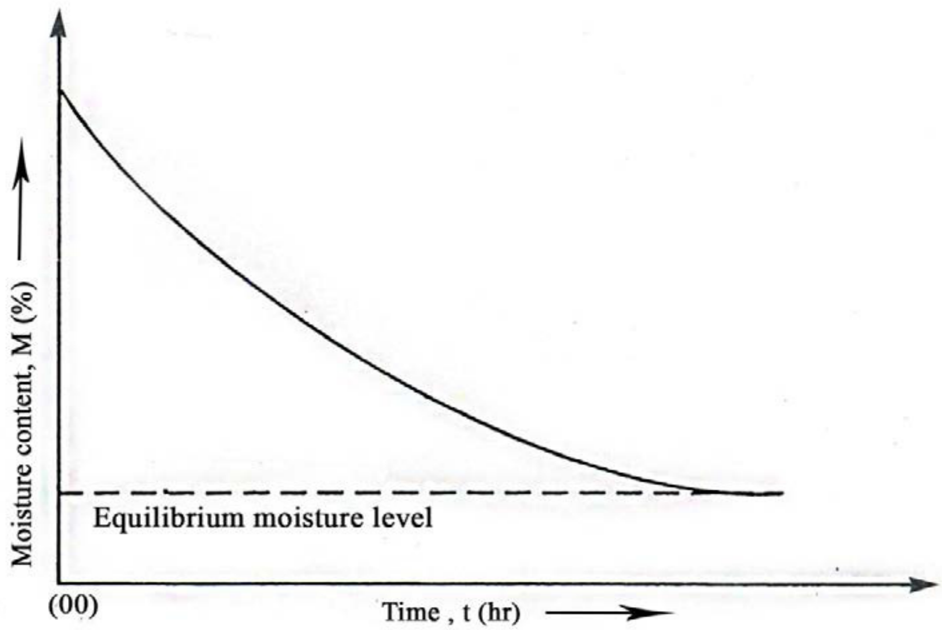

Figure. 2: Rate of moisture loss [2]

It is possible to plot a chain of drying curves. Figure.2 shows the plotted curve of moisture content M of the food material or any other material versus time.The curve explains the characteristic that with increases in time the moisture content in the product reduces drastically and this help to attain the equilibrium moisture content position. Furthermore, another curve plotted between drying rate i.e. dM/dt versus moisture content M shown in Figure.3.which explain more.The Figure explains the falling rate of moisture in the product. When the material it may be hygroscopic or non-hygroscopic dried at constant rate then the changes in its nature occurs at the critical point.From this point the falling rate started and this lead to achieve almost zero in the non-hygroscopic material. But in hygroscopic material the rate is different, here the falling rate is similar until the unbound moisture is removed. This goes on continuing until the vapour pressure of drying air not becomes equal to the vapour pressure of material [7,8]. It is seen that the zero drying rate is achieved at equilibrium stage.

The adiabatic drying means the heat content rate of air is constant. This adiabatic condition depends on many factors like air transport properties, flow rate of air and its aggregation state for material. Following Figure.4gives the information about constant falling rate. In drying the temperature of material will starts increasing and this gives the suitable drying. To attain it we must have an appropriate control over the humidity and temperature of air. Hence, it is difficult to predict the drying time in this falling rate period, therefore it is difficult to obtain an expression for it. There are number of theories for explaining the mechanisms of drying like vapour due to concentration gradients or liquid diffusion, liquid movement due to capillary forces are given to explain the moisture movement through the drying material. But no existing theory can properly explain the drying process [9-11].

Practically it is found that the constant drying period for most of the biological materials like timber, fruits and vegetables is small and mainly it is the falling rate period. It is found that the due to affected cells and jammed interstices in high moisture content materials the diffusion of moisture content is comparatively slow.

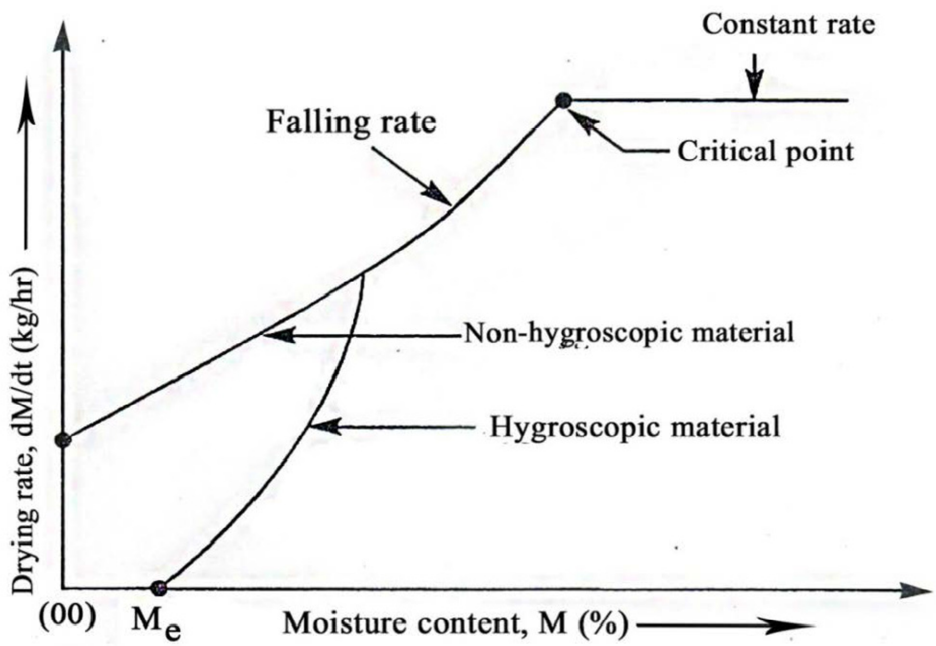

Figure. 3: Drying rate versus moisture content [2]

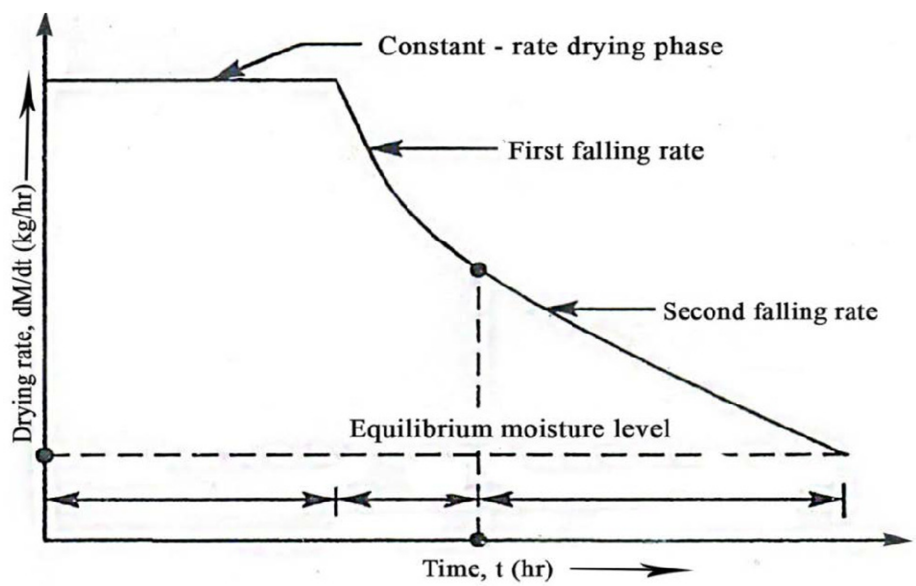

Figure.4: Drying rate versus moisture content [2]

The researchers [7, 12 and 13] have reported that.furthermost it is found that the fruits and vegetables content the starch and sugar in the liquid phase in it. This starch then migrates to surface while drying. This led to increases in the viscosity and result in reduction of the surface vapour pressure moisture evaporation. There two base method for agriculture product i.e. by thin layer drying or deep layer drying. Thin layer drying is done for fruits and vegetables. Where the product is spread in thin cutting layers on surface, so that the whole surface exposed to moving air.

Change in wall temperature, air velocity and downcomer height can lead to new result in drying with multi stage in drying [14]. Some designer did the design for drying the Areca leaf for

2. Designing of Solar Dryer

Dryers main functions is to dryer the product fast. To achieve this more effectively there is a need to control some parameters, the dryer can be used for many purposes. One of the examples for this is the dryer made to form a better quality of plates from shealth of the areca palm tree. They design an indirect type forced convection solar dryer to reduce the moisture content of the shealth and then they simply formed the plate using the press machine. The dryer helps them to control the cost drastically [15]. Parameter define the design values some uses drying efficiency, drying kinetics and energy efficiency as the criteria for evaluation [16].There is a need to find the amount of solar radiation receiving on the surface. If it is known then it will reduce the experiment time. The dynamic model with tilted surface radiation calculation was prepared and validated [17]. The parameter that are important in designing the dryer are air flow rate, collector area, and type of dryer.

Based on literature the following points are considered generally in designing of direct natural and forcedconvection solar dryer system [15-18]:
a) How much amount of moisture to be removed.
b) The daily sunshine hours for the selection of the total drying time.
c) The air quantity needed for drying for drying time.
d) Daily solar radiation according to the location.
e) Velocity of air for the calculation of air vent dimensions.

2.1 Design procedure

1. Determine the Design conditions and Assumptions needed before designing i.e. product characteristic, Climatic condition, capacity of dryer.
2. DetermineInitial and Final moisture (depends on product) content.
3. From gas laws equation determine amount of air to effect moisture loss.
4. Calculate the collector area, dimensions and select materials.
5. Calculate drying time.
6. Calculate the dryer chamber area, dimensions and select materials
7. Calculate the air vent dimensions and vent locations
8. Design a fan with capacity to deliver the required airflow and static pressure.
9. calculate collector efficiency.
10. Fabrication of the dryer for experimental drying tests.

There is no proper designing method for drying the solar dryer following are some design formulation which was taken from research paper.To design anything related to solar there is a need to know the solar radiation quantity in that location. It was not possible for everyone to purchase the pyranometer for the experimentation. Therefore, following mathematical calculation can give the data for solar radiation and now a days the data of solar radiation for the particular area can be get from google. Let’s see the mathematical formulation of solar radiation.

2.2. The solar radiation modelling

The total radiation on any tilt or horizontal surface is divided into three types of direct,
diffuse and reflected radiation [18,19]. Each type was calculated as follows:

Direct radiation [18]

$$I_{DN} = Ic e^{\frac{-B}{\sin(\beta)}} \quad (1)$$

Solar altitude angle *[18,19]*

$$Sin(\beta) = [\cos(i).\cos(Hr).\cos(\delta)] + [\sin(i).\sin(\delta)] \quad (2)$$

Solar Declination *[19, 20]*

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \quad (3)$$

Diffuse radiation [18-20]

$$I_{d\theta} = C.I_{DN}.F_{ss} \quad (4)$$

Fss is defined as the ratio of the diffusion radiation on the tilted surface of the collector to the horizontal onestilted surface of the collector to the horizontal ones [20]

$$Fss = \frac{[1+\cos(S)]}{2} \quad (5)$$

Reflected radiation

$$I_{r\theta} = (I_{DN} + I_{d\theta}).k_{r\theta}..F_{sg} \quad (6)$$

Collector angle [20]

$$F_{sg} = \frac{[1-\cos(S)]}{2} \quad (7)$$

Total radiation[18,19]

$$I_t = I_{DN}.\cos(\theta) + I_{d\theta} + I_{r\theta} \quad (8)$$

Incidence angle [18,19]

$$cos(q) = [cos(b).cos(j).sin(S)] + [sin(b).cos(S)] \quad (9)$$

Solar Azimuth [18,19]

$$\sin\Phi = \frac{\cos\delta.\sin Hr}{\cos\beta} \quad (10)$$

the capacity of the dryer can be selected as the need and product specifications. The types of dryer are selected as per the product and climatic conditions.

The angle of tilt for solar collector / Air heater

$$\beta = 100 + lat\varphi \quad (11)$$

From above equation (1) to (11) one can predict the radiance and even the tilt angle needed for collector as per the location.

2.3. The heat loss calculations for solar collector

The thermal efficiency mostly depends on thermal losses from outer surfaces of the collector. There are three main types of losses in solar collector [21].

Top heat loss coefficient

$$U_t = \left[\frac{N}{\frac{C}{T_P}\left[\frac{T_P - T_a}{N+f}\right]} + \frac{1}{h_w}\right]^{-1} + \frac{\delta\left(T_P{}^2 - T_a{}^2\right)\left(T_P + T_a\right)}{\frac{1}{d} + \frac{2N+f-1}{\epsilon_g} - N} \qquad (12)$$

and

$$C = \frac{204.429\,(\cos\beta)^{0.252}}{L^{0.24}} \qquad (13)$$

$$d = \varepsilon_p + 0.0425N\,(1 - \varepsilon_p) \qquad (14)$$

$$f = \left[\frac{9}{h_w} - \frac{9}{h_w{}^2}\right]\left[\frac{T_a}{316.9}\right]\,(1 + 0.091N) \qquad (15)$$

$$h_w = 5.7 + 3.8v$$

$$e = 0.252$$

The Bottom loss coefficient.[21]

$$U_b = \frac{1}{\frac{x_i}{k_i} + \frac{x_w}{k_w} + \frac{1}{h_w}} \qquad (16)$$

The Edge heat loss coefficient [21]

This loss can be ignored because it is very less as compared with the top and bottom loss.The edge loss coefficient is given as

$$U_e = 0.45\,(DxP)\,\frac{A_e}{A_c} \qquad (17)$$

Now the total heat loss coefficient is given by.

$$U_L = U_t + U_b + U_e \qquad (18)$$

The efficiency of solar collector is defined as the ratio of the useful energy gain to the incident
solar energy [21].

$$\eta_c = \frac{Q_u}{I_T\ x\ A_c} \qquad (19)$$

$$Qu = mc_p\,(T - Ta) \qquad (20)$$

2.3. Moisture content calculation

The moisture percent in the grain can be expressed as percentage moisture on dry matter and percentage moisture of wet grain.

$$M_{db} = \frac{Wt\ of\ Water\ x\ 100}{\text{Wt of dry matter}} \qquad (21)$$

Where,

$$M_{db} = \frac{[Wt\ of\ Water]\ x\ 100}{\text{Wt of water + Wt of dry matter}}$$

Or

$$M = \frac{Wt\ of\ Water\ x\ 100}{\text{inital grain Wt}}$$

In Grain dryer designing there is a need of calculation of moisture reduction or weight of water removed from grain. It helps to find how much air, fuel and power are needed to dry a grain.

Let us consider

$$W_2 = \frac{100 - M_1 \, x \, W_1}{100 - M_2} \quad (22)$$

2.4. Average drying rate [25-28]

following equation used to find the average drying rate

$$m_{dr} = \frac{m_w}{t_d} \quad (23)$$

The mass of air needed for drying was calculated using equation[28]

$$m` = \frac{m_{dr}}{w_f - w_i} \quad (24)$$

2.5. Quantity of heat needed to evaporate the H_2O:

The quantity of heat required to evaporate:[25-28]

$$Q = m_w \; x \; h_{fg} \quad (25)$$

The latent heat is calculated by equation[29]

$$h_{fg} = 4.186*103(597-0.56(Tpr)) \quad (26)$$

The total heat energy, E(kJ) required to evaporate water was calculated as follows:

$$E = m` \; (h_f - h_i)t_d \qquad [30] \quad (27)$$

2.4. Collector Design

The total heat required for drying consist of sensible heat and heat required to evaporate the moisture from the surface of the material. The useful heat to remove the moisture is given as:[21-25]

$$Q_u = Q_1 + Q_2$$

$$Q_1 = W_w C_p \Delta T \quad (28)$$

Where $\Delta T = (T_d - T_a)$

$$Q_2 = W_w l \quad (29)$$

Mass of moisture to be evaporated from the grain surface is calculated as follows

$$M_w = \frac{W_w \, (M_i - M_f)}{1 - M_f} \quad (30)$$

the area of the collector is given as follows [24,25].

$$Ac = \frac{Q_u}{\eta l_T t_d} \quad (31)$$

The suggested length to width ratio is 1:2 [24]. The another way is as follows:
The solar drying system collector area Ac, in m2 can be calculated from the

following equation:

AcIη = E = m` (hf -hi)td (32)

Therefore, area of the solar collector is:[28]

$Ac = \frac{E}{I\eta}$ (33)

2.5.1.Air vent dimensions:

The air vent dimension and area can be calculated from below equation [25,27]

Vent Area = width of collector × air gap (35)

or

The air vent was calculated by dividing the volumetric airflow rate by wind speed:

$A_v = \frac{V_a}{V_w}$ (36)

The width of the air vent can be given by:

$Bv = \frac{A_V}{L_V}$ (37)

2.5.2.Absorber Surface Area

The surface area of the absorber $A_{ab}$is approximately equal to the area of the collectorsurface area, Ac; this is related to the length, Lc and width, W of the solar collector asfollows: [28]

Aab = Ac = Lc x W. (38)

Volume flow rate (Va)= vent area × air velocity (39)

2.6.Required pressure:

The velocity of air can be determined from following equation: [25]

$Velocity = \frac{V_a}{Area\ of\ vent}$ (40)

Air pressure can be determined by equation given by [32]:

$P = 0.00308\ g(T_i - T_a)H$ (41)

2.7. Energy balance equation

The energy balance on the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the solar collector[33-41]. Therefore,

$I^*A_c = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_P$ (42)

$Q_L = Q_{cond} + Q_{conv} + Q_R$ *(combine the three heat loss)* (43)

$IA_c = \tau I_T A_c$ --- (44)

The reflected Energy from the absorber

$Q_P = \rho\tau I_T A_c$ (45)

By putting 43, 44, & 45 equation in 41

$\tau I_T A_c = Q_u + Q_L + \rho\tau I_T A_c$, *or*
$Q_u = \tau I_T A_c\ (1\text{-}\rho) - Q_L$ (46)
For an absorber (1 – ρ) = α and hence,
$Q_u = (\alpha\tau)\ I_T A_c - Q_L$ -- (47)
QL composed of different convection and radiation parts. It is presented in the following form [29]:
$Q_L = U_L A_c (T_c\text{-}T_a)$ --- (48)
From Equations (5) and (6) the useful energy gained by the collector is expressed as:
$Q_u = (\alpha\tau)\ I_T A_c - U_L A_c (T_c\text{-}T_a)$ --- (49)
Therefore, the energy per unit area (q_u) of the collector is
$q_u = (\alpha\tau)\ I_T - U_L (T_c\text{-}T_a)$ -- (50)
If the heated air leaving the collector is at collector temperature, the heat gained by the air *Qg*is:
$Q_g = \boldsymbol{m_a}.C_{pa}(T_c - T_a)$ --- (51)

The collector heat removal factor, *FR*, is the quantity that relates the actual useful energy gained of a collector, Eq. (49), to the useful gained by the air, Eq. (51). Therefore,

$$F_R = \frac{m_a C_p\ (T_c - T_a)}{A_c\ [\propto\tau I_T - U_L(T_c - T_a)]} \quad (52)$$

Or

$Q_g = A_c\ F_R\ [(\alpha\tau)\ I_T - U_L A_c(T_c\text{-}T_a)]$

The thermal efficiency of the collector [35]

$$\eta_c = \frac{Q_g}{A_c I_T} \quad (53)$$

Energy Balance Equation for the Drying Process The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water [34 & 36]

$$m_w L_v = m_a C_p (T_1 - T_2) \quad (54)$$

2.8.Exergy Performance of dryer

According to law of thermodynamics no machine can convert the 100% energy in work. Therefore the energy here which can be converted is exergy and rest is waste energy[43]. Following equation (55) to (56) gives the exergy values at the inlet and outlet of the drying cabin by the following equation. In this equation the inlet and outlet temperatures, the specific heatcapacity and the mass flow rate of the air from the collector is considered. [44]

$$EX_{in} = m_a C_p\ [(T_{in} - T_a) - T_a \ln\frac{T_{in}}{T_a}] \quad (55)$$

$$EX_{out} = m_a C_p\ [(T_{out} - T_a) - T_a \ln\frac{T_{out}}{T_a}] \quad (56)$$

The exergy loss (E_{xloss}) was determined as follows;

$$Ex_{loss} = Ex_{in} - Ex_{out} \quad (57)$$

The exergy efficiency (Exeff) was calculated with Eq.

$$Exeff = 1 - \frac{EX_{loss}}{EX_{in}} \quad (58)$$

The design of solar dryer is totally dependent on the heat transfer coefficient of material. It is design on the basis of heat transfer equation. To understand the solar dryer, one should understand the heat transfer subject. The design can be done by using software's now there is no need to calculate all the details. The paper gives the formula's for designing the dryer.

3. Conclusion

The major aim of the paper is to review design paper related to solar dryer and to reveal the design procedure used by the research on one paper. There are various techniques used by researcher to design the dryer. The equation used is truly on the heat transfer basis. The dryer deals with the heat and mass flow of air. Therefore, use of Nusselt number and Reynolds number is also applicable in designing the dryer. This was not shown in this paper. As in designing the dryer the important key is the collector. The collector converts the radiation energy in the thermal energy and then it is used to dryer the food item by means of air. Many research papers were reviewed and the equation based on that is written in the paper. The paper gives the idea of how to design a solar dryer more effectively and how to get the radiation data mathematically. The equation helps to find the collector area, vent area, mass flow rate and even more. Overall, this paper is the key to design the solar dryer with all parameters. During literature it is found that the collector efficiency is affected by temperature, type of material, absorberplate,airflow rate, and solar insolation. One can use this paper for finding all the formula related to design of solar collector in one place. It is more reliable to prepare the software for designing the solar dryer instead of this calculation. The new scope of this paper is to prepare a software for designing the solar dryer. Very limited software is available in market for solar design that also not perform well. Therefore, this can lead to new beginning for designing the solar dryer.

References

[1]. S. Murali, P.R. Amulya, P.V. Alfiya, D.S AniesraniDelfiya, Manoj P. Samuel, Design and Performance Evaluation of Solar - LPG Hybrid Dryer for Drying of Shrimps, Renewable Energy (2019), pp.2417-2428. https://doi.org/10.1016/j.renene.2019.10.002.
[2]. Tripathy, P. P. and Kumar, S., Influence of sample geometry and rehydration temperature on quality attributes of potato dried under open sun and mixed mode solar drying, *International journal of green energy*, vol.6, issue 2, (2009) pp.143-156.
[3]. Lof, G. O. G., Solar energy for drying solids, *solar energy*, vol.6, issue.4, (1962),pp. 122-128.
[4]. Ting, K. C and Shore, G. C., Daily efficiency of flat plate solar air collectors for grain drying, *Journal of solar energy*, vol.36, issue 6, (1983), pp.605-607.
[5]. Khalil, E. J. Al-Juamily, Khalifa, A. J and Yassen, T. A., Testing of the performance of a fruit and vegetable solar drying system in Iraq, *Journal of desalination*, vol. 209, (2007) pp.163-170.
[6]. Sharma, V. K, Colangelo, A and Spagna, G., Experimental investigation of different solar dryers suitable for fruit and vegetable drying, *Renewable energy*, vol.6, issue.4, (1995) 413-424.
[7]. Garg, H. P. Solar energy, 1st Reprint, Tata McGraw hill publications, New Delhi, (2002),pp. 191-200.
[8]. Roa, G and Macedo, I. C., Grain drying in stationary bins with solar heated air, solar energy, vol.18, (1976),pp. 445-449.
[9]. Togrul, I. T. and Pehlivan, D., Mathematical modeling of solar drying of apricots in thin layers, *Journal of food engineering*, vol.55, (2002),pp.209-216.
[10]. Abdullah, K., Wulandani, D., Nelwan, L. O., Manalu, L. P., Recent development of GHE solar drying in Indonesia, *Drying technology*, vol. 9, (2011), pp.245-255.
[11]. Johnson, H. K and Dale, A. C., Heat required to vaporised moisture, *Agricultural engineering*, vol.33, (1974),pp.709-714.
[12]. Johnson, H. K and Dale, A. C., Heat required to vaporised moisture, *Agricultural engineering*, vol.33, (1974),pp.709-714.

[13]. Igbeka, J. C., Simulation of moisture movement during drying of a starchy food product cassava, *Journal of food technology*, vol.17, (1982),pp.27-36.
[14]. D. Yogendrasasidhar, Y. PydiSetty, Experimental studies and thin layer modeling of pearl millet using continuous multistage fluidized bed dryer staged externally, Engineering Science and Technology, an International Journal, vol. 22, (2019),pp.428–438,https://doi.org/10.1016/j.jestch.2018.10.010.
[15]. Nikhil R, Raahul N, Sateesh N, Shivpriyan M, Tiffany Clein, Anita Tang, Pramod R, Design and Development of Solar/LPG powered Areca-nut leaf Plate Press Machine and Areca Leaf Sheath-Solar dryer, Materials Today: Proceedings 5, (2018)pp.24541–24547.
[16]. L_opez-Vida~na Erick C_esar , C_esar-Munguía Ana Lilia, García-Valladares Octavio, Pilatowsky Figueroa Isaac, Brito Orosco Rogelio, Thermal performance of a passive, mixed-type solar dryer for tomato slices (Solanum lycopersicum),Renewable Energy, vol.147, (2020),pp.845-855, DOI:- https://doi.org/10.1016/j.renene.2019.09.018.
[17]. Hatami S, Payehaneh G, Mehrpanahi A, Energy and exergy analysis of an indirect solar dryer based on a dynamic model, *Journal of Cleaner Production, vol.244,* (2020), pp. 118809 doi: https://doi.org/10.1016/j.jclepro.2019.118809.
[18]. Jamil, B., Khan, M.M., 2014. Estimation of clear-sky solar radiation using ASHRAE model for Aligarh, India. International Journal of Engineering Research and Technology, pp.227-236.
[19]. S.P.Sukatme, Solar energy- Principles of thermal collection and storage, second edition, Tata McGraw Hill Publishing,2004, pp.61-97.
[20]. Gunerhan, H., Hepbasli, A., 2007. Determination of the optimum tilt angle of solar collectors for building applications. Building and Environment vol.42, issue (2),pp.779-783.
[21]. J. A. Duffie and W. A. Beckman, Solar engineering of thermal process, John Wiley & sons, New York, 1980.
[22]. Khalil E.J. Al-Juamily, Abdul Jabbar N. Khalifa, Testing of the performance of a fruit and vegetable solar drying system in Iraq, Desalination, vol.209, (2007),pp.163–170. doi:10.1016/j.desal.2007.04.026.
[23]. M.C. Ndukwu, D. Onyenwigwe, F.I. Abam, A.B. Eke, Dirioha C, Development of a low-cost wind-powered active solar dryer integrated with glycerol as thermal storage, Renewable Energy (2020), https://doi.org/10.1016/j.renene.2020.03.016
[24]. Forson, F. K., Nazha, M. A. A., Akuffo, F. O. and Rajakaruna, H. (2007). Design of Mixed-Mode Natural Convection Solar Crop Dryers: Application of Principles and Rules of Thumb. Journal of Renewable Energy, vol.32, issue (14), pp.2306–2319.
[25]. ElAminOmda Mohamed Akoy, Mohamed Ayoub Ismail, El-Fadil Adam Ahmed and W. Luecke, Design and Construction of a Solar Dryer for Mango Slices, Conference: Tropentag 2006 Prosperity & poverty in a globalized world: Challenges for Agricultural Research. Bonn, Germany, October 11-13, 2006.
[26]. Maundu Nicholas Musembi, Kosgei Sam Kiptoo, Nakajo Yuichi, Design and Analysis of Solar Dryer for Mid-Latitude Region, Energy Procedia, vol.100, (2016),pp.98–110.
[27]. KhinOhnmarMyo, Aye ThawiThawi Tun, Dr. Cho ChoKhaing, KhinSwe Win, Design Calculation of Solar Fish Dryer, International journal of scientific engineering nad technology research, Vol 08, 2019, pp-213-216.
[28]. Prakash Kolhe, Pradip Kolhe, ICT Tool: Development of calculator for Design of solar dryer, Oriental journal of computer science and technology, vol.9.no.(1) pp. 30-35, 2016.
[29]. Sodha, M. S.; Bansal, N. K.; Kumar, A.; Bansal, P. K and Malik, M. A. Solar crop drying. Vol. I and II. CPR press, Boca Raton, Florida, USA. (1987).
[30]. Youcef-Ali, S.; Messaoudi, H.; desmons, J. Y.; Abene, A. and Le Ray, M. (2001). Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices. Journal of food engineering, vol.48, issue(2),pp.95-101.
[31]. Brooker, D. B.; Bakker-Arkema, F. W. and Hall, C. W. Drying and storage of grains and oilseeds. Avi, Van Nostrand Reinhold. USA. (1992).
[32]. Jindal, V. K. and Gunasekaran, S. Estimating air flow and drying rate due to natural convection in solar rice dryers. Renewable energy review, vol.4, issue(2), (1982), pp.1-9. (1982).
[33]. Youcef-Ali, S., Desmons, J.Y., 2004. The turbulence effect of the airflow on the calorific losses in food stuff dryers. Renewable Energy, Vol.29, pp.661-674.
[34]. Bolaji, B.O. 2005. Performance evaluation of a simple solar dryer for food preservation. Proc. 6th Ann. Engin. Conf. of School of Engineering and Engineering Technology, Minna, Nigeria, pp. 8-13.
[35]. Itodo, I.N.; Obetta, S.E.; and Satimehin, A.A. Evaluation of a solar crop dryer for rural applications in Nigeria. Botswana J. Technol. Vol.11,issue (2),(2002).pp.58-62.
[36]. Youcef-Ali, S.; Messaoudi, H.; Desmons, J.Y.; Abene, A.; and Le Ray, M. Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices. J. Food Engin. Vol.48,issue (2), (2001), pp.95-101.

[37]. Sodha, M.S., Dang, A., Bansal, P.K., Sharma, S.B., An analytical and experimental study of open sun drying and a cabinet type drier. Energy Conversion & Management, Vol.25, issue (3), (1985) pp. 263–271.
[38]. Tchaya, G.B., Kamta, M. and Kapseu, C., "Improvement of an indirect solar dryer with forced convection by variation of airflow mode", International Journal of Emerging Technology and Advance Engineering, Vol. 4, No. 1, (2014), pp.518-522.
[39]. PangavhaneDilip, Sawhney R.L. " Design, development and performance testing of a new natural convection solar dryer", Journal of Energy,vol 27, (2000), pp.579-590.
[40]. Babagana, G.; Silas, K.; and Mustafa, B. G.; "Design and construction of forced natural convection solar vegetable dryer with heat storage", APRN journal of engineering and applied sciences, vol.7, issue (10), (2012) ,pp.1213-1217.
[41]. Amedorme, S.K.; Apodi, J.; and Agbezudor, K; "Design and construction of forced convection indirect solar dryer for drying Moringa leaves", Scholar journal of engineering and technology, vol.1, issue (3), (2013),pp.91-97.
[42]. HalilAtalay , Comparative assessment of solar and heat pump dryers with regards to exergy and exergo economic performance, Energy, vol.189, (2019),pp.116180.
[43]. Akbulut A, Durmus¸ A. Energy and exergy analysis of thin layer drying of mulberry in a forced solar dryer. Energy vol. 35, (2010), pp.1754-1763.