PERFORMANCE EVALUATION OF FLAT PLATE SOLAR DRYER

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***Abstract*— Flat plate collector are simple devices to heat air by utilize solar energy and employed in many application requiring low to moderate temperature below 80oC, such as food drying and agriculture crop . Drying processes play an important role in the protection of agricultural products. Solar energy is very great, vast source of energy and it is one of the widely used renewable energy sources. Drying undeveloped products increases their storage life, minimizes losses during storage, and saves shipping and transportation costs. Drying means removal of moisture from there center of material to the surface.The Solar drying tools would give up clean dust free and good quality of agriculture produce. An attempt is made to review a variety of aspects of solar driers functional to drying of food products at small scale. Popular types of driers in Asia-Pacific region, and new types of driers with enhanced technologies are discussed. Open sun drying and some alternating solutions are accessible. A natural convection solar dryer is used as per the weather condition of the installation site. There is an experimental study is carried out to study the drying process with the help of exhaust fan in the solar dryer. The exhaust fan is installed at the upper most part of the drying chamber which helps to overcome the pressure drops in drying chamber.**

Ginger is selected for drying since it has the high moisture content.And the performance of the flat plate solar dryer is evaluated based on the observation and record data.

I. INTRODUCTION

On the subject of the current era aiming higher cost of fossil fuels and lack of confidence on the subject of future cost and ease of use, when we are using solar energy in food processing will most likely increase and become more inexpensively possible in the near future [1,2]. Solar dryers having reward over sun drying when the design are rather correct. It gives earlier drying rates by heating the air to 10-31o C above ambient, which having the air to shift faster into the dryer, reduce its humidity and stop insects. The mean earlier drying rate reduce the risk of spoilage, increases quality of the product and give a advanced output, so plummeting the drying area that is needed [3]. On the other hand care is needed when drying fruits to put off too rapid drying, which will put off complete drying and would result in case harden and successive mould growth [4,5]. Solar dryers also defend foods form dust, insects, birds and animals. Solar dryer can be constructing from locally obtainable materials at a relatively low capital cost and there is no fuel cost [6]. Thus, they can be helpful in areas where fuel are costly, land for sun drying is in comfortable, sunshine is plenty but the air humidity is high [7,8]. What is more, they may be useful as a means of heating air for non-natural dryers to decrease fuel costs [9,10]. Solar food drying can be used in the majority areas but how rapidly the food dries is exaggerated by many variables, particularly the amount of sunlight and relative humidity. Drying time is taken 2 to 3 days depending upon sun radiation, air velocity, humidity, moisture content of the material, and kind of food to be dried.

II. PHYSICS OF DRYING

Drying can be accelerated by [11,12]:

Increasing flow rate of air Increasing temperature of drying air

Initial Drying - Surface drying, later on drying depends on type of materials.

Non hygroscopic- drying possible up to zero moisture content.

Hygroscopic - grains, fruit, food stuff have residual moisture.

III. PARAMETERS OF SOLAR DRYING

The drying of product depends on external variables like temperature, humidity and velocity of air stream and interior variables which is a purpose of drying material and depends on limitation like surface characteristics (rough and smooth), chemical compositions (sugar, starch etc.), physical structure (porosity, density, etc.) and size and shape of the product. The rate of moisture movement from the product inside to the air outside differ from one product to another and very much depends weather the material is hygroscopic or non-hygroscopic [13,14,15]. Non-hygroscopic materials can be dried to zero moisture level while the hygroscopic materials like most of the food products will always have residual moisture content [16,17].

The design of a solar dryer depends on: solar radiation, temperature of air, relative humidity : of air, moisture content of the product, amount of product to be dried, time required for drying, ease of use of auxiliary energy, material of creation of dryer and the resource accessibility [18,19].

IV. METHODOLOGY-DESIGN ANALYSIS

Sun is a large sphere of very hot gases, the heat being generated by various kind of fusion reaction.Its diameter is 1.39×104 km.The mean distance between the two is 1.496×108 km.Although the sun is large,it subtends an angle of only 32 minutes (.53o) at the earth's surface. This is also because very large distance. Thus, the beam radiation received from the sun on earth is almost parallel.

Declination: Declination is the made by the line joining the centre of the sun and the earth with the projection of this line on the equatorial plane.

It arises by the fact that the earth rotates about an axis which makes an angle of approximately 66.5o with the plane of its rotation around the sun.The declination angle varies from maximum value of +23.45o on june 21 to minimum value -23.45o on December 21.

Cooper has given following relation for calculating the declination.

δ(in degree)= 23.45 sin [(360/365)*(284+n)]

Where,

n= day of the year

δ= -15.03 on 31st October.

Latitude: is a geographic coordinate that specifies the north south position of a point on the earth surface. Lines of constant latitude or parallel run east-west as circle parallel to the equator. Latitude is an angle which ranges from 0o at the equator to 90o (north or south) poles.

Φ = 30.264o

Hour Angle: is an angular measure of time and is equivalent to 15o per hour.It is also varies from -1800 to +180o.

Generally it is adopted the convention of measuring it from soon based on local apparent time(LAT) being positive in the morning and negative in the afternoon.

- If hour angle is positive then it is sun rise angle.
- If hour angle is negative then it is sunset angle.

A) *Horizontal Surface*

the hour angle corresponding to sun rise or sunset (ωs) on a horizontal surface can be found from the following equation,if one substitute the value of 90o for the zenith angle.

Cos ω s= -tanΦ tanδ

ωs = Cos-1(-tanΦ tanδ)

ωs = 80.98o

If above equation yields a positive and negative value for ωs the positive value corresponding to sunrise and negative value to sunset.Since 15o hour angle is equivalent to 1 hour, the corresponding day lenth (in hours).

Smax = (2/15) ωs

Smax = 10.90 hours

S = 6.5 hours

B) *Inclined Surface Facing Due South*

the hour angle at sunrise and sunset as seen by an observer on an inclined surface facing south will also be given by the same equation as for horizontal surface if the day under consideration lies between September 22 and march 21, and the location is in northern hemisphere .this is because during this period, the declination is negative and the apparent plane of motion of the sun intersects thr horizontal plane.However, if the day under consideration lies between march 21 the hour angle at sunrise or sunset (ωst) would be smaller in magnitude than the value given by the equation of horizontal surface an would be obtained by substituting θ=900 in the following equation.

Cos θ = sinδ sin(Φ-β)+cosδ cosω cos(Φ-β)

ωst = cos-1[-tan(Φ-β) tanδ]; ωst=89.81

Monthly Average Daily Global Radiation:

Ho= (24/Л)Isc [1+0.033 cos(360n/365)(ωs sinΦ sinδ+cosΦ cosδ sin ωs)

Where,

Ho= monthly average of the daily extraterrestrial radiation which would fall on a horizontal surface at the location under consideration.(kj/m2-day)

Isc= solar constant is the rate at which energy is received from the sun, at the mean distance from the earth from sun. based on subsequent measurement, as standard value of 1366 W/m2.

Ho= (24/Л×1.366×3600)[1+.033cos(360× 304/365)][(1.413 sin 30.264o sin(15.03o)+cos30.264o cos(-15.03o) sin 80.98o]

Ho= 24424.2912kj/m2-day

Hg= Ho[a+b(S/Smax)

Where,

Hg= monthly avg of the global radiation on a horizontal surface at a location kj/m2-day.

Lets assume constant a= 0.25, b=0.56 (of delhi).

Hg= 24424[0.25+0.56(6.5/10.69)

Hg= 14492.5542 kj/m2-day

When available India data is analysed, the following linear equation was obtained by modi and sukhatme for estimated diffused to global radiation ratio. One of the fact is that the diffuse component is much larger in India.

Hd/Hg = 1.41-1.69[Hg/Ho]

Hd = Hg[1.41-1.69(14492/ 24424)]

Hd = 14492×(0.2426) 28

Hd = 5864.5696 kj/m2-day

Beam Radiation: The ratio of the beam radiation flux falling on tilted surface to that falling on a horizontal surface is called the tilt factor of beam radiation.It is denoted by the symbol rb, for the case of tilted surface facing south(i.e γ=0).

Rb= [ωst sinδ sin(Φ-β)+cosδ sin ωst cos(Φ-β)]/ωs sinΦ sinδ+cosΦ cosδ sinωs]

Where,

β = 0.9,Φ=26.24o

Rb= 1.46

Diffuse Radiation: The tilt factor Rd for diffuse radiation is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on the horizontal surface.The value this tilt factor depends on the distribution of the difuuse radiation over the sky and on the portion of the sky dome saeen by the tilted surface.Assuming that sky is isotropic source of diffuse radiation, we have for tilted surface with a slope β,

Rd= (1+cosβ)/2;Rd=0.94

Reflected Radiation: Since (1+cosβ)/2 is the radiation shape factor for atilted surface with respect to the sky, it follows that (1-cosβ)/2 is the radiation shape factor for the surface with respect to the surrounding ground.Assuming that the reflection of the beam and diffuse radiation falling on the ground is diffuse and isotropic and that the reflectivity is ρ, the tilt factor of reflected radiation is given by.

Rr= ρ (1-cosβ)/2

Ground reflectivity is general taken as 0.2 so Rr=0.01

4.10 Average daily beam radiation on a tilted surface: The daily radiation falling on tilted surface (Ht) to the daily global radiation on a horizontal surface(Hg) is given by Liu and Jordon.

Ht/Hg= [1-(Hd/Hg) Rb+ (Hd/Hg) Rd+Rr]

Ht = 18339.626 kj/m2-day

Drying Chamber /Cabinet Area Calculation: To obtain the area Ad required to dry a given mass of water to be evaporated from the given quantity, the latent heat of vaporization and efficiency of the drying unit should be known as prior.

1) Mass of water to be evaporated (Mv)

Mv= W(Mi-Mf)/(100-Mf)

Where,

W= weight of the product to be dried,

Mv= Mass of water required to vapourise,

Mi and Mf = initial and final moisture content og the product to be dried

Mv= 5kg×(81-2)/(100-2)

Mv= 4.03 kg

2) Latent heat or heat of vaporization(Lv)

From the steam table the value of Lv for 40o temperature i.e 106o F is

= 2.41043 MJ/kg

Conversion factor for Lv from steam table:

= 1036.3 BTU/lb

And 1 BTU/lb= 0.002326MJ/kg

3) Energy required to vapourise 4.03kg of water (Q)

Q= Mv×Lv

Where,

Q= 9.61403 MJ

4)Drying chamber area(Ad)

η= Q/(Ad×Ht)

where,

η= drying efficiency(lets assume 35%)

Ht = average daily beam radiation on tilted surface (1833.626 kj/m2-day)

Hence,Ad = 1.51 m2

Since, area of drying chamber is (Ad) = 1.51 m2.So according to thumb rule lenth of dryer should be three times to its widhth to avoid shading effect.

Lets length (L) = 3x

Width(w) = x

So area (Ad) = L×w

3x2 = 1.51

x = 0. 705 m i.e width and

3x= 2.10 m i.e lenth of drying chamber.

Solar Flat Collector:

Specifications:

Glass plate thickness = 4 mm

Absorber plate thickness = 1mm

Material of absorber plate = Aluminium

Paint used for painting absorber plate = Black board plate

Inulation used below the absorber plate; glass wool

Plywood casing thickness, outer = 17 mm

Inner = 20 mm

1) Length of collector = 2m

2) Width of collector inside = 70.5 cm

Outside =77.9 cm

3) Depth/height of collector = 0.122m

Hence,

Volume of flat plate collector = length× height× width

= 2× 0. 779× 0.122

= 0.194 m3

The instantaneous efficiency of collector

ηi = Qu/Ac.It

where,

Ac=collector area = 1.41 m2

It=incident radius of the collector = 18.339 MJ/m2-day=212.25W/m2

Because 1W/m2 = 0.0864MJ/m2-day

ηi = 66% assume

Qu = 201.64

Useful energy of collector is given by

Qu = mo Cf (Tfo-Tfi)

Where,

mo= mass flow rate of heat transfer fluid through collector(kg/s)

Cf =specific heat of fluid (J/kg-K) = 1.006×103 J/kg-K

Tfo =outlet fluid temperature(oK) = 40o C = 313 oK

Tfi =inlet fluid temperature(oK) = 12oC= 285 oK

mo= 0.008 kg/s

V. RESULT ANALYSIS AND DISCUSSION

After the experiment conducted on solar dryer I have found the effective result and enhance the performance of solar dryer

Initial moisture content = 96 %

Final moisture content = Initial moisture content- moisture removed in drying

= 96-87.83

= 8.17 %

IMC= 96 %, EMC= 7-13 %

Since equivalent moisture content for ginger 7 to 13 % and computed moisture content is 8.17 % i.e accepted and desirable.

Drying Rate:

The drying rate of ginger is determined as follows:

Drying rate (D.R) = ΔW/ΔT,

Where,

ΔW=Weight loss in hour interval

ΔT=Difference in time reading (h)

Drying was carried out by taking the ginger in morning 10 am to evening 5 pm. final moisture content of ginger is 10% (w.b) .The drying time is critically observe through IMC to FMC.

Drying Rate Computation:

Weight loss per 1030 gram= 1030-954= 76 g

So weight loss in 1040 gram= 76 g

1 gram= 76/1030

Thus weight loss in 100 gram= 76×100/1030

= 7.37 g.

ΔW = 7.37 gm, ΔT= 7 hour,

Hence Drying Rate (D.R)= 7.37/7= 1.05 g/hr.

VI. EXPERIMENTAL OBSERVATION

A. *Effect Of Mass Product*

At different solar radiation there is little change in mass of the product i.e taken of 4 kg of ginger in the very first day, and when it is taken up to 10 days it has changed w.r.t moisture content.

B. *Rate Of Moisture Removal*

When the experiment is conducted the moisture removal rate increases with the help of time and temperature.

C. *Drying Temperature*

When we observed all the data, that I want to know that the temperature inside the drying chamber is not exceeded the maximum allowable temperature i.e 35^{o}C.

D. *Discussion Based On The Result*

Our experiment is performed in the month of May,2013 in IIT Roorkee , Haridwar state INDIA. This month is mostly the dry season. The radiation of solar is varied in between 4 mV to 13 mV.

We have performed our test on ginger, during the test the ginger is taken from the dryer and weighted twice in one particular day that is morning and evening. The product is reassembled three to four times in a day for uniform drying and air flow velocity is uniform through the dryer product.

From the table we can see that the drying product is decreased on the first 3 to 5 days and then after it is rapidly decreased in next days. The product surface is constantly fed out of interstitial water by capillary forces. This phase is also called isenthalpic phase since the energy received by the product is entirely used by the vaporization of surface water. During this phase all the product remain in the drying chamber and the product is reached upto its threshold level. At the beginning of this phase the drying rate decreases, and the air is circulated through the drying chamber rapidly. The evaporation zone is now inside the product, From each side of evaporation zone, there are two methods of transport.

There is capillary is capillary is formed in the ginger from where the water comes out in the form of vapors when the drying product were put in the drying chamber. When the temperature is increases in the zone of drying product the vaporization is increases in the drying product. The rate decreases very slowly and tends towards zero. These values are reached when the moisture content balance of the surface in contact with air which are circulated through the drying chamber. And after that our drying process is finished.

VII. CONCLUSION AND FUTURE SCOPE

The solar dryer have been developed as per the requirement of herb which is to be dried. The experiment is performed at the installation site of Roorkee, Uttarakhand state, of India. The test was performed on the ginger which is taken of 4 kg. We have observed the data from loading to unloading from very first day upto tenth day. When our experiment is going on, the inside temperature should not exceed from the allowable temperature. The data is observed for evaluation the performance of the solar dryer, the following conclusion are as follows:

1 This solar technology that is natural circulation solar dryer is used for rural areas as this work belongs to the organization "Rural Technology Action Group" that is RUTAG, managed by IIT Roorkee.

2 Natural circulation of the solar dryer is used for domestic drying of the product up to 20 to 25 kg capacity. With the help of Natural circulation of the solar dryer the domestic product does not change its properties.

3 The moisture present in the ginger decreases as the drying process is going on. And after 10 days the final moisture content removed from the ginger that is of 8.17 %.

4 The allowable temperature should not exceed 35 oC through the drying chamber. Because when the temperature is go beyond the 35 oC, the drying product changes its medical property which is not desirable.

5 Exhaust fan is installed for maintaining the pressure drop in the drying chamber. And air velocity through the drying chamber is uniformly circulated for maintaining the mass flow rate of the product.

Future Scope

Further investigations can be done on this work by providing dessiccant so that when air becomes humid inside the dryer , dessicant will dehumidify it and circulation will be proper.

Adevice can be developed by using thermistor connected to fan so that inside temperature goes beyond maximum allowable temperature it senses and automatically shuts the heated air supply to the drying chamber from flat plate collector.

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