SOLAR DRYING OF AGRICULTURAL PRODUCE

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

HYDROELECTRIC SYSTEM ENGINEERING AND MANAGEMENT (HSEM)

By

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CANDIDATE'S DECLARATION

Certified that the work which is being presented in the dissertation entitled "**Solar Drying Of Agricultural Produce**", in partial fulfillment of the requirements for the award of the degree of **"Master of Technology"** in Hydroelectric System Engineering & Management (HSEM) at Water Resources Development & Management (WRDM), Indian Institute of Technology Roorkee, India under the supervision of **Dr. S.C. Solanki**, Professor in Department of Mechanical and Industrial Engineering and **Mr. Devadutta Das,** Professor WRDM, Indian Institute of Technology Roorkee.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Date: 20. June, 2005

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then to remove this moisture from the surface of the drying material. Solar drying equipment would yield clean, dust free and good quality of agriculture produce. A dryer would make the drying process much faster as compared to that in open field drying normally adopted by the farmers. Moreover, the damage caused by birds, pests, rats and insects and by weather is reduced giving about 20 – 30 % higher output of crops.

Attempts have been made to increase the efficiency of cabinet dryer. Through one such attempt, a "Reverse Absorber Cabinet Dryer" (RACD) is developed. In a RACD, the solar energy is directed and concentrated by a parabolic reflector on to the bottom of the absorber plate and gets absorbed. The crop is kept above the top of absorber plate (not in contact with the absorber plate) in trays. Atmospheric air drawn in by natural convection effect flows over the top of the absorber plate. The hot air then flows through the crop, removing moisture from the crop.

In the present work, an experiment investigation has been carried out to study the drying process in a Reverse Absorber Cabinet Dryer. Three different crops namely Wheat, Peas and Paddy are tested. The mass of the crops to be dried is varied. Also dryer system parameters viz vent width (V) and duct depth (D) are varied to study their effect on the drying process and on the performance of the system.

The hourly variation of temperatures of the crop, plate and fluid and moisture removed are observed and recorded. The variation of solar radiation is also recorded.

The instantaneous efficiency, total efficiency and daily efficiency were evaluated. Typical trends observed are critically examined. Some of the typical characteristic revealed are presented and discussed.

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(Irffan Effendy)

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NOMENCLATURE

A_d	Area of the dryer, m^2
B	Width of the drying chamber, m
D	Duct depth, m
H_{bt}	Beam radiation intensity on a tilted surface, MJ/m^2
H_{bz}	Beam radiation intensity on a horizontal surface, MJ/m^2
H_{dz}	Diffuse radiation intensity on a horizontal surface, MJ/m^2
h_{cc}	Convective heat transfer coefficient from crop surface to chamber, $W\ m^{-2}\ {}^oC$
h_{pf}	Convective heat transfer coefficient from crop plate to fluid, $W\ m^{-2}\ {}^oC$
h_{rpc}	Radiative heat transfer coefficient from absorber plate to crop, $W\ m^{-2}\ {}^oC$
L	Length of the drying chamber, m
Lv	Latent heat of vaporization of moisture, MJ/kg
Mc	Moisture content of the crop, %
M_{db}	Moisture content on dry basis, %
M_f	Final moisture content, %
M_i	Initial moisture content, %
M_t	Moisture content at any time t, %
Mv	Mass of moisture vaporized, %
n	Number of the day in a year
Q	Energy required to vaporize moisture, MJ
T_c	Crop Temperature, ^oC
T_f	Fluid Temperature, ^oC
T_p	Plate Temperature, ^oC
V	Vent width, m

W	Mass of crop, kg
W_d	Mass of dried material, kg
W_o	Mass of undried material, kg
η_d	Daily drying efficiency, %
η_i	Instantaneous drying efficiency, %
η_n	Normalised drying efficiency, %
β	Tilt angle of the surface with the horizontal, degree
δ	Declination angle, degree
ω	Hour angle, degree
ϕ	Latitude of a place, degree

CHAPTER I

INTRODUCTION

1.1. ENERGY & RESOURCE UTILIZATION

Solar energy power from the sun is clean and unlimited. Capturing the freely available sun's energy for light, heat, hot water, and electricity would, not only help in saving the conventional energy resources but also in maintaining environment pollution free. Whether drying crops, heating buildings, or powering a water pump, using the solar energy can make the farm more efficient and achieve self-reliance [1].

For their drying, Exposing of crops and grains in an open field to the sun directly is one of the oldest applications of solar energy. Traditionally, crops, even after having got matured, are left in the open field in the sun to get dried. Not only it takes longer time (1 to 1.5 months just to get dried), but are spoiled to the entrant of 20 to 30 % by birds, pest and weather. It gets mixed with dust, dirt and insects/pests. Solar drying equipment can dry crops faster and more evenly than leaving them in the field after harvest, with the added advantage of avoiding damage by birds, pests, and weather. Thus solar drying equipment would yield clean, dust free and good quality of wheat, rice and other agricultural produce.

Commercial greenhouses often rely on the sun for lighting, but on gas or oil heaters to maintain constant temperatures. A solar greenhouse uses building materials to collect and store solar energy as heat. Insulation retains the heat for use during the night and on cloudy days. To capture the most sunlight, a solar greenhouse generally faces south, while its northern side is well insulated, with few or no windows. A gas or oil heater may be used only as a backup.

Sunlight can also generate electricity. Photovoltaic (PV) panels are often a cheaper option than new electric lines for providing power to remote locations. And because they require no fuel and have no moving parts, they are more convenient to operate and maintain than diesel or gasoline generators. In some areas, the distance from a power source at which PV becomes more economical than new transformers and electric lines is surprisingly short often as little as 50 feet (15 m). PV systems are a highly reliable and low-maintenance option for electric lights, and water pumps. Although current prices for solar panels make them too expensive for most crop irrigation systems, photovoltaic systems are economical for remote livestock water supply, pond aeration, and small irrigation systems. In addition, the cost of PV is projected to decline significantly over time, which will make more applications cost-effective.

1.2. SOLAR ENERGY

Solär energy systems from Radiantec (Fig. 1.1) use a water based antifreeze solution to put solar energy [2] to work . In stead of water, the antifreeze solution (e.g. ethylene glycone in water) is used necessarily in places where water in the collectors and pipe-line gets freezed due to cold weather condition. The freezing of water causes cracks in the collector and pipe-lines, therefore antifreeze solutions are used in the collector system. The only drawback of antifreeze solution is that the hot fluid from the collector system cannot be used for drinking or cooking directly. The sun shines upon a solar collector and the solar energy heats the antifreeze solution within the collector. Then the heated fluid is circulated to one or more heat exchangers and the solar generated heat is put to use. The fluid then returns to the solar collectors to be reheated.

Low intensity thermal needs, such as the need for domestic hot water and the need for space heat, make up most of a typical building's energy consumption.

To the extent that we meet these needs with solar energy, we can save money and help the environment. Then we can save our conventional energy supplies for other, more difficult tasks. Solar energy systems work best when they are simple. They operate most efficiently when they run at low to moderate temperatures. They are also most economical when they have something to do year around. Thermodynamically also, solar heating systems, whether hot water supply, space heating or process heat supply, are the most efficient compared to electric heating or gas or oil burner.

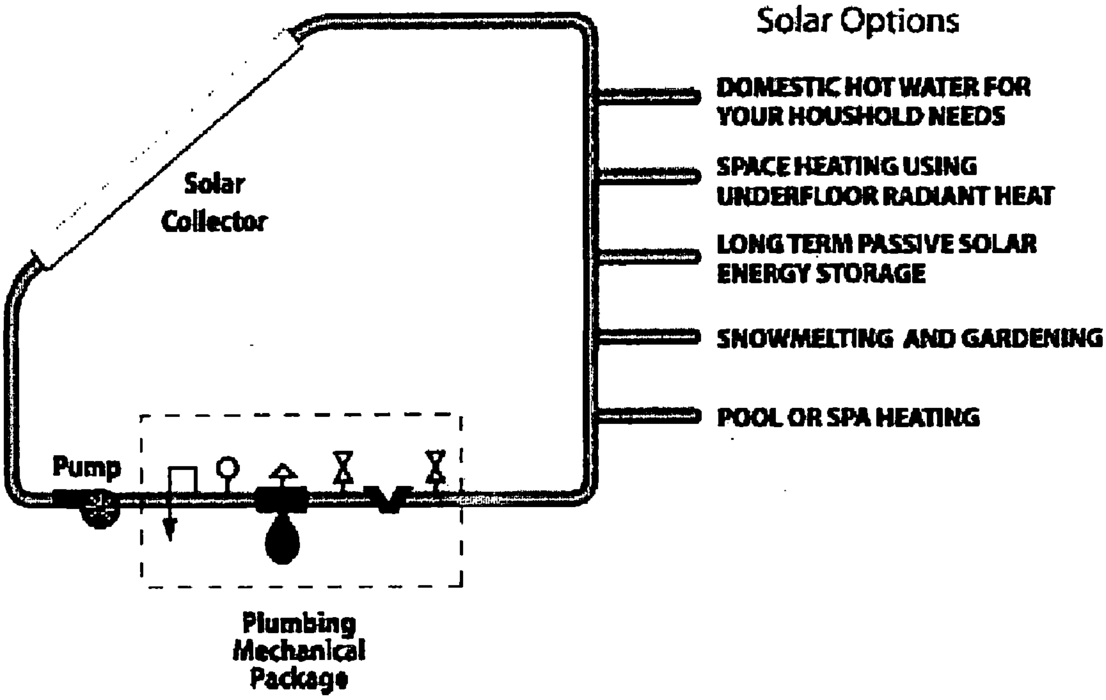


Figure 1.1. Solar Energy System [2]

1.3. BIOMASS ENERGY

Biomass is a general term for all organic matter [1], which includes not only crops, wood, and marine products, but also organic wastes such as sewage sludge. Biomass is the only renewable organic resource that fixes atmospheric CO_2 by photosynthesis and does not break the CO_2 balance on a global scale. As one of the most abundant resources, biomass is an attractive and environmentally compatible energy source.

<u>Recovery of Hydrocarbons from Microalgae.</u>

The green algae, Botryococcus braunii, fix CO_2 using solar energy and produce abundant hydrocarbons. One can obtain liquid fuel from algae cells of the microalga of inorganic nutrients such as phosphorus and nitrogen from secondarily treated sewage by the process of thermochemical liquefaction. This process can also be applied to other forms of organic wastes, such as sewage sludge, which is liquefied at high pressure and temperature without a catalyst into oil that is nearly equivalent to "C-grade" heavy oil. This process can help environmental preservation.

Biological Production of Electricity,

Photosynthesis by living plants and some bacteria can be considered clean solar-energy conversion systems. The first step of biological photosynthesis is absorption of this light energy by an organism, with subsequent photolysis of water, which generates high-energy electrons and releases oxygen. These electrons are used to reduce carbon dioxide and produce carbohydrates.

This technology can convert the excited electrons generated by an algal photosystem into electricity. This technology also allows conversion of electrons generated by oxidative degradation of carbohydrates accumulated within algal cells into electrical energy.

The efficiency of this technology is higher than that of biomass incineration, since electrical energy is generated directly by conversion from plant cells with no intermittent steps and resultant loss of energy along the way.

1.4. WIND ENERGY

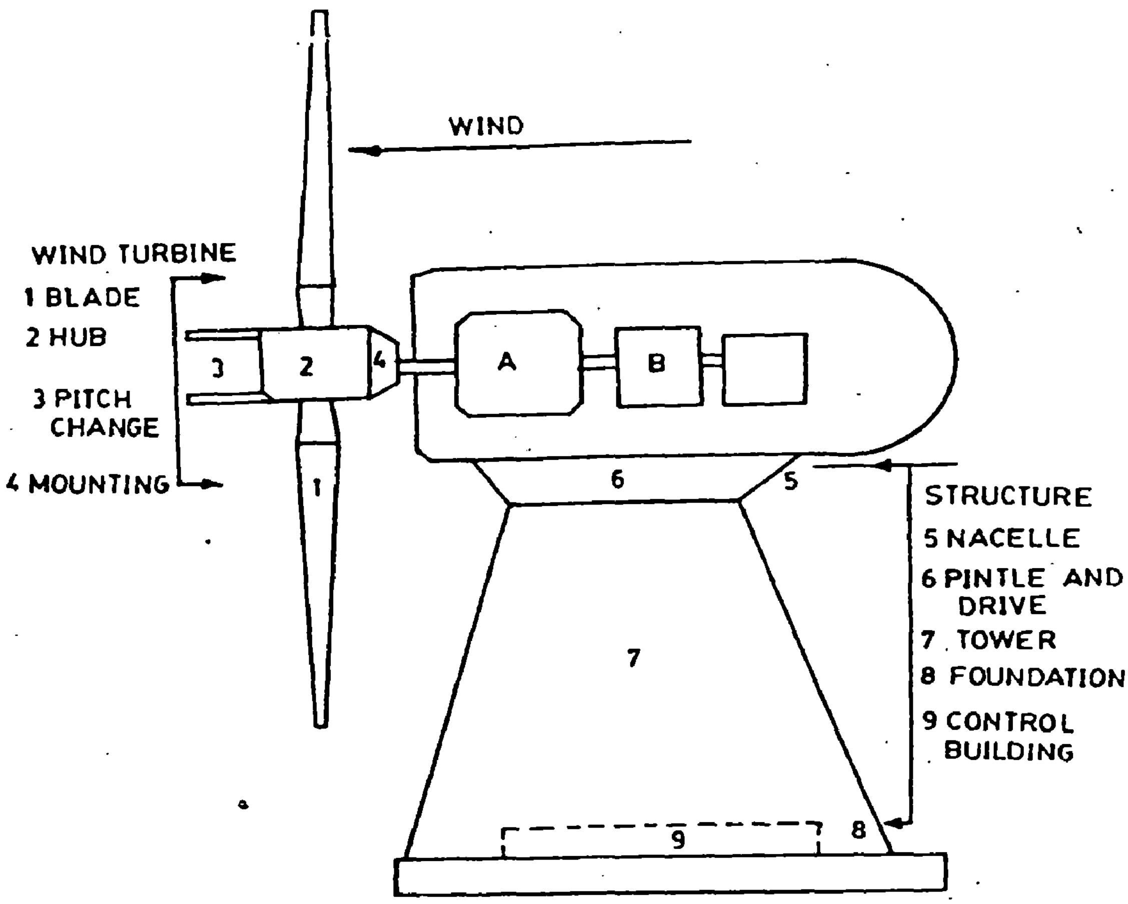
Wind turbines convert the energy of moving air into useful mechanical or electrical energy.

Wind turbines need more maintenance than a PV array, but with moderate winds, 4.5 meters per second (m/s) or greater, they typically produce more energy than a similarly priced array of PV modules. Like PV modules, multiple wind turbines can be used together to produce more energy. Because wind turbine energy production tends to be highly variable, wind turbines are often best combined with PV modules or a generator to ensure energy production during times of low wind speeds. This section focuses on small wind turbines with ratings of 10 kW or less.

Wind Turbine Components,

The components common to most wind turbines are shown in figure 1.2. The blades capture

the energy from the wind, transferring it via the shaft to the generator. In small wind turbines, the shaft usually drives the generator directly. Most small wind turbines use permanent magnet alternators as generators. These produce variable- frequency "wild" AC that the power electronics convert into DC electricity. The yaw bearing allows a wind turbine to rotate to accommodate the changes in wind direction. The tower supports the wind turbine and places it above any obstructions.



A -*Transmission*
Speed Increaser
Driver Shaft add Bearing Brake
Clutch and Coulping.
B—*Electrical*
Generator
Control and indicators (at ground level)

Figure 1.2. Diagram of Wind Energy [3]

1.5. SOLAR RADIATION

1.5.1. Solar Radiation Outside the Earth's Atmosphere [4, 5]

The characteristics of the sun's energy available outside the earth's atmosphere are first, considered . The sun [4] is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions. Its diameter is 1.39 x 10^6 km, while that of the earth is 1.27 x 10^4 km. The distance between the two is 1.496 x 10^8 km. Although the sun is large, it subtends an angle of only 32 minutes at the earth's surface. This is because it is also at a very large distance. Thus, the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its center to its edge. However, for engineering calculations, it is customary to assume that the brightness all over the solar disc is uniform.

The solar constant I_{Sc}, is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun. The value of the solar constant is 1367 W/m^2.

The radiation coming from the sun is essentially equivalent to blackbody radiation.

Using the Stefan-Boltzmann law, the equivalent backbody temperature can be shown to be 5762 K for a solar constant of 1353 W/m^2 and 5779 K for a solar constant of 1367 W/m^2 [4, 5].

1.5.2. Solar Radiation At The Earth's Surface [4, 5]

Solar radiation is received at the earth's surface in an attenuated form because it is subjected to the mechanisms of absorption and scattering as it passes through the earth's atmosphere (Fig. 1.3).

Solar radiation received at the earth's surface without change of direction, i.e. in line with the sun, is called **'beam'** or **'direct radiation'**. The radiation received at the earth's surface from all parts of the sky's hemisphere (after being subjected to scattering in the atmosphere) is called **'diffuse radiation'**. The sum of the beam and diffuse radiation is referred to as **'total or global radiation'**.

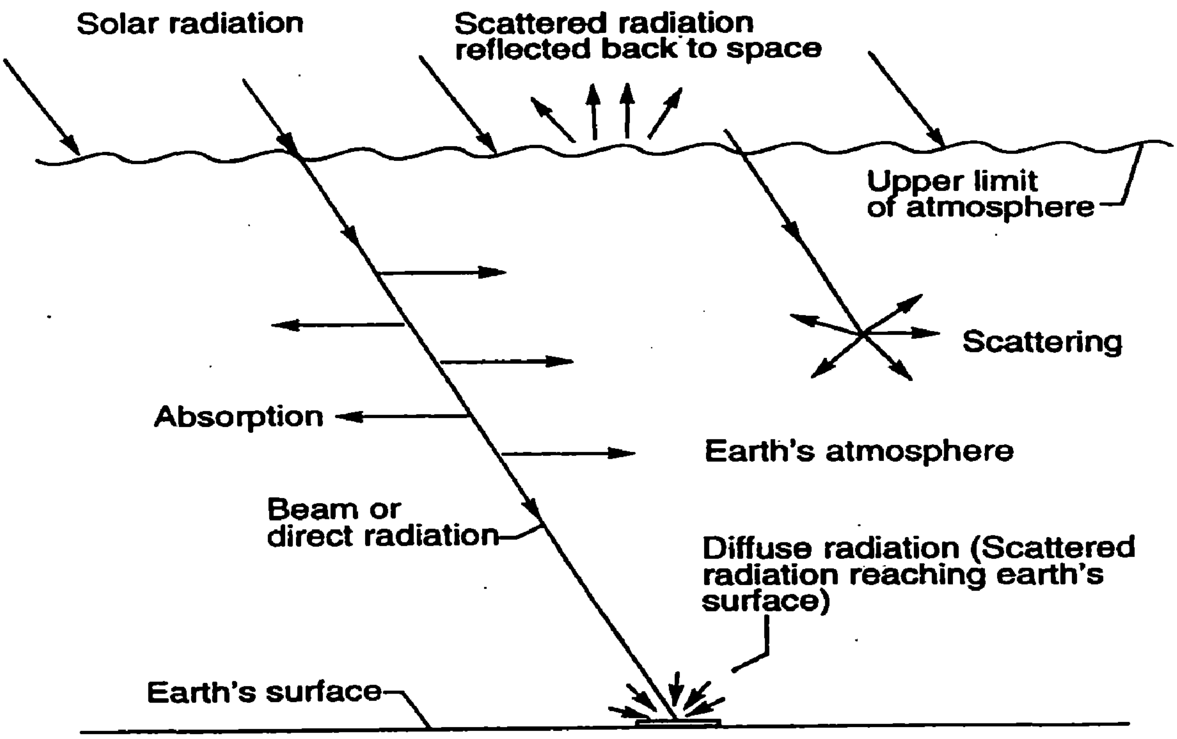


Figure 1.3. Schematic Representation of (i) the Mechanisms of Absorption and Scattering, and (ii) Beam and Diffuse Radiation Received at the Earth's Surface [4]

1.5.3. Instruments For Measuring Solar Radiation And Sunshine [4,5]

The instruments used for measurement of Solar radiation is usually are pyranometer , pyrheliometer and sunshine recorder.

1. A **'pyranometer'** (also called **'Solarimeter'**) is an instrument which measures either global or diffuse radiation over a hemispherical field of view. Basically the pyranometer consists of a `black' surface which heats up when exposed to solar radiation. Its temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction and reradiation. The hot junctions of a thermopile are attached to the black surface, while the

cold junctions are located in such a way that they do not receive the radiation.

2. A **'pyrheliometer'** (also called **'Actinometer'** [5]) is an instrument which measures beam radiation. In contrast to a pyranometer, the black absorber plate (with the hot junctions of a thermopile attached to it) is located at the base of tube. The tube is aligned with the direction of the sun's rays with the help of a two-axis tracking mechanism and an alignment indicator. Thus the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument.

3. Sunshine **Recorder**

The duration of bright sunshine in a day is measured by means of a sunshine recorder. The sun's rays are focused by a glass sphere to a point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere.

Whenever there is bright sunshine, the image formed is intense enough to burn a spot on the card strip. Through the day as the sun moves across the sky, the image moves along the strip. Thus, a burnt trace whose length is proportional to the duration of sunshine is obtained on the Strip.

1.5.4. Solar Radiation Geometry [4, 5]

In order to find the beam energy falling on a surface having any orientation, it is necessary to convert the value of the beam flux coming from the direction of the sun to an equivalent value corresponding to the normal direction to the surface. Relationships for making this conversion will now be given.

The latitude ϕ of a location is the angle made by the radial line joining the location to the center of the earth with the projection of the line on the equatorial plane. By convention, the latitude is measured as positive for the northern hemisphere. It can vary from $-90° + 90°$.

The declination δ is the angle made by the line joining the centers of the sun and the earth with its projection on the equatorial plane. It arises by virtue of the fact that the earth rotates about an axis which makes an angle of approximately 66.5° with the plane of its rotation around the sun. The declination angle varies from a maximum value of +23.45° on June 21 to a minimum value of –23.45° on December 21. It is zero on the two equinox days of March 21 and September 22. Cooper has given the following simple relation for calculating the declination,

$$\delta \text{ (in degrees)} = 23.45 \sin \left[360 \times \frac{284 + n}{365}\right] \tag{1.1}$$

where n is the day of the year. Equation (1.1) is plotted and its accuracy of prediction is adequate for engineering purposes.

The surface azimuth angle γ is the angle made in the horizontal plane between the line due south and the projection of the normal to the surface on the horizontal plane. It can vary from –180° to +180°. We adopt the convention that the angle is positive if the normal is east of south and negative if west of south.

The hour angle ω is an angular measure of time and is equivalent to 15° per hour. It also varies from –180° to +180°. We adopt the convention of measuring it from noon based on local apparent time (LAT), being positive in the morning and negative in the afternoon. (The term `local apparent time' will be defined later.)

The slope β is the angle made by the plane surface with the horizontal are shown in Fig. 1.4.

It can be shown that [4],

$$\cos\theta = \sin\phi\,(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) \tag{1.2}$$

$$+ \cos\phi\,(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta$$

Simpler versions of Eq. (1.2) are normally required. Some of these are as follows,

Vertical surface, $\beta = 90^0$,

$$\cos\theta = \sin\phi\cos\delta\cos\gamma\cos\omega - \cos\phi\sin\delta\cos\gamma + \cos\delta\sin\gamma\sin\omega \tag{1.3}$$

Horizontal surface $\beta = 0^0$,

$$\cos\theta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \tag{1.4}$$

Surface facing due south $\gamma = 0^0$,

$$\cos\theta = \sin\phi\,(\sin\delta\cos\beta + \cos\delta\cos\omega\sin\beta) + \cos\phi\,(\cos\delta\cos\omega\cos\beta - \sin\delta\sin\beta)$$

$$\cos\theta = \sin\delta\sin(\phi - \beta) + \cos\delta\cos\omega\cos(\phi - \beta) \tag{1.5}$$

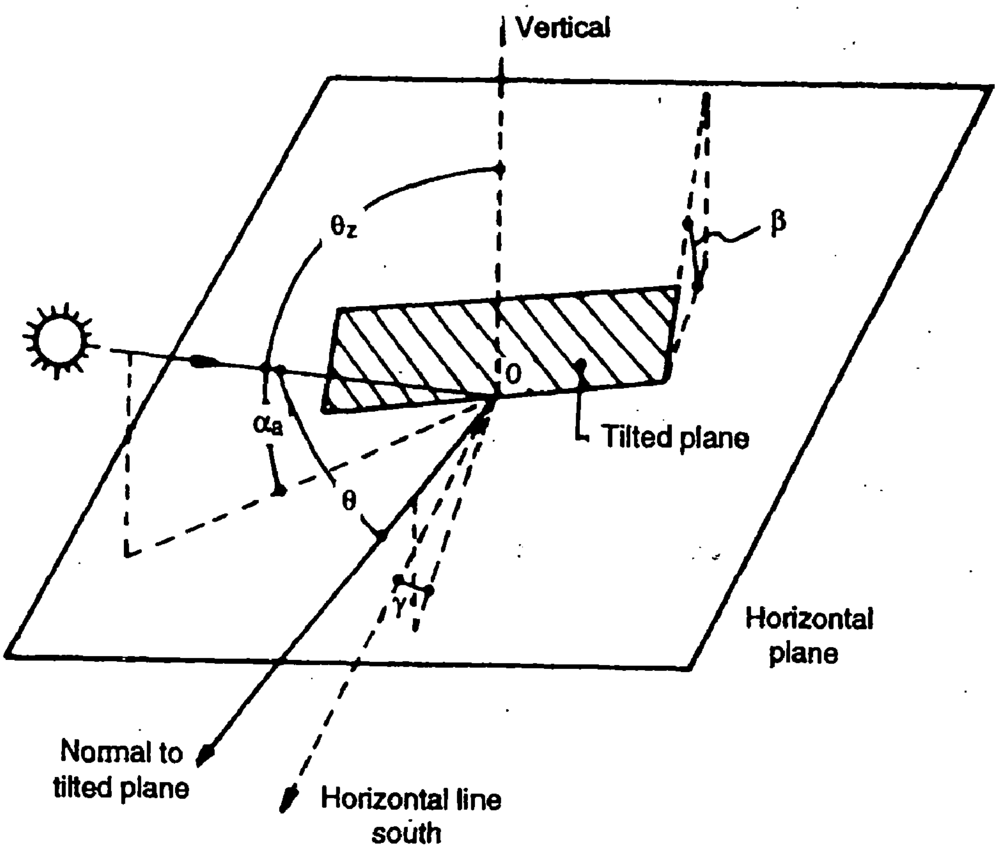


Figure 1.4. Diagram Illustrting the Angle of Incidence θ , The Zenith Angle θz , The Solar Altitute Angle α_a , The Slope β , and The Surface Azimuth Angle γ [4]

Vertical surface facing due south $\beta = 90^0$, $\gamma = 0^0$,

$$\cos\theta = \sin\phi\cos\delta\cos\omega - \cos\phi\sin\delta, \quad (1.6)$$

The angle of incidence θ can also be expressed in terms of **θz the zenith angle,** β the slope, γ the surface azimuth angle and γ_s the solar azimuth angle. Braun and Mitchell* have shown that,

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma), \quad (1.7)$$

The solar azimuth angle γ_s is the angle made in the horizontal plane between the line due south and the projection of the line of sight of the sun on the horizontal plane. Thus it gives the direction of the shadow cast in the horizontal plane by a vertical rod. By convention, the solar azimuth angle is taken to be positive if the projection of the line of sight is east of south and negative if west of south. In order to use Eq. (1.7), it is necessary to first calculate θz and γ_s.

θz is obtained from Eq. (1.4), while γ_s is obtained from the expression

$$\cos \gamma_s = (\cos \theta z \sin \phi - \sin \delta) / (\sin \theta z \cos \phi), \quad (1.8)$$

Sunrise, Sunset and Day Length :

The hour angle corresponding to sunrise or sunset (ω_s) on a horizontal surface can be found from Eq. (1.4) if one substitutes the value of 90° for the zenith angle. We obtain

$$\cos \omega_s = - \tan \phi \tan \delta$$

$$\omega_s = \cos^{-1} (-\tan \phi \tan \delta) \quad (1.9)$$

Equation (1.9) yields a positive and a negative value for ω_s , the positive value corresponding to sunrise and the negative to sunset. Since 15° of the hour angle is equivalent to 1 hour, the corresponding day length (in hours)

$$S_{max} = 2/15 \cos^{-1} (-\tan \phi \tan \delta) \quad (1.10)$$

Local Apparent Time :

The time used for calculating the hour angle ω is the local apparent time, this can be obtained from the standard time observed on a clock by making two corrections. The first correction arises because of the difference between the longitude of a location and the meridian on which the standard time is based. The correction has a magnitude of 4 minutes for every degree difference in longitude. The second correction called "the equation of time correction" is due to the fact that the earth's orbit and rate of rotation are subject to small fluctuations and equation of time for each day of a year[5] is given by Eq.(1.11). It can be taken from the Figure 1.5.

$$\begin{aligned}\text{Local apparent time} = {} & \text{Standard time} \\ & \pm 4\,(\text{Standard time longitude} - \text{longitude of location}) \\ & + (\text{Equation of time correction}) \qquad (1.11)\end{aligned}$$

The negative sign in the first correction is applicable for the eastern hemisphere, while the positive sign is applicable for the western hemisphere.

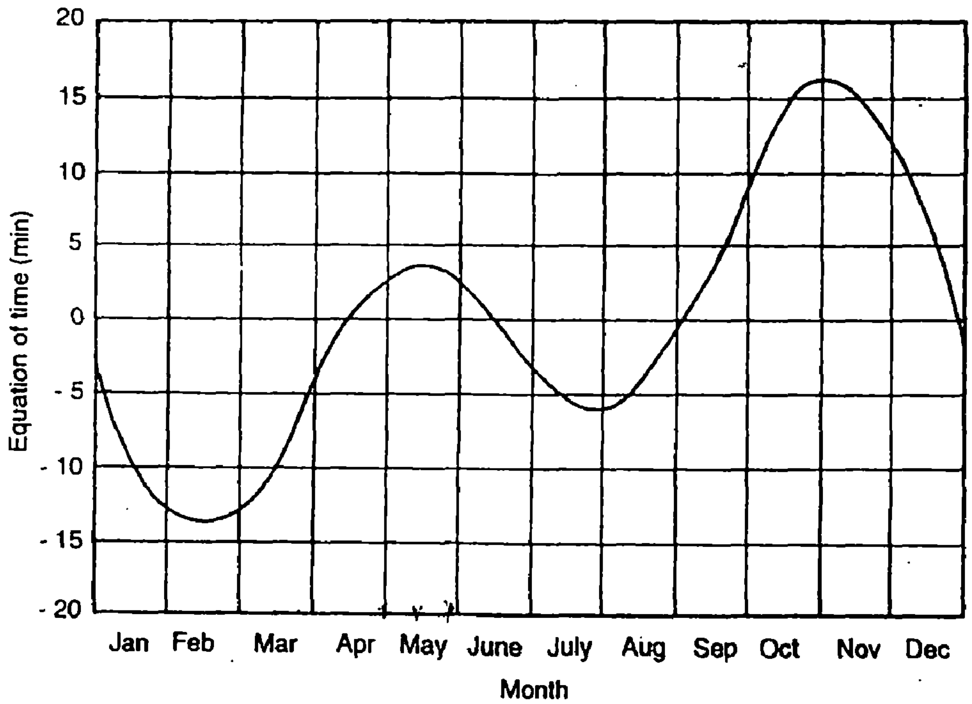


Figure 1.5. Equation Of Time Correction

1.5.5. Empirical Equations for Predicting The Availability of Solar Radiation [4, 6]

Since measurement of solar radiation is often not available, attempts have been made by many investigators to establish relationships linking the value of radiation (global or diffuse) with meteorological parameters like number of sunshine hours, cloud cover, and precipitation.

1. Monthly Average Daily Global Radiation

The first attempt at estimating solar radiation was due to Angstrom who suggested that it could be related to the amount of sunshine by a simple linear relation of the form,

$$\frac{\overline{H}_g}{\overline{H}_c} = a + b\left(\frac{\overline{S}}{\overline{S}_{max}}\right) \qquad (1.12)$$

where,

$\overline{H}_g$ = monthly average of the daily global radiation on a horizontal surface at a location (kJ/m^2- day),

$\overline{H}_c$ = monthly average of the daily global radiation on a horizontal surface at the same location on a clear day (kJ/m^2 -day),

$\overline{S}$ = monthly average of the sunshine hours per day at the location (h),

$\overline{S}_{max}$ = monthly average of the maximum possible sunshine hours per day at the location, i.e. the day length on a horizontal surface (h),

a, b = constants obtained by fitting data.

2. Monthly Average Daily Diffuse Radiation

Based on a study of data for a few countries, Liu and Jordan* showed that the daily diffuse-to-global radiation ratio could be correlated against the daily global to extra-terrestrial radiation ratio. The correlation was expressed by the equation ,

$$\frac{\overline{H}_d}{H_g} = 1.411 - 1.696\left(\frac{\overline{H}_g}{\overline{H}_o}\right) \tag{1.13}$$

3. Monthly Average Hourly Global Radiation

A number of studies have also been conducted with the objective of obtaining relations for predicting the diurnal variation of the monthly average hourly global radiation at a location. Collares-Pereira and Rabl have developed the following relation ,

$$\frac{\overline{I}_g}{\overline{H}_g} = \frac{\overline{I}_o}{\overline{H}_o}(a + b\cos\omega) \tag{1.14}$$

Where,

a = 0.409 + 0.5016 sin (ω_s - 60°),

b = 0.6609 - 0.4767 sin (ω_s - 60°),

I_g =monthly average of the hourly global radiation on a horizontal surface (kJ/m^2 - h),

I_o = monthly average of the hourly extra-terrestrial radiation on a horizontal surface (kJ/m^2-h).

4. Monthly Average Hourly Diffuse Radiation

In a manner similar to that adopted for developing Eq. (1.14), the following relation for estimating the monthly average hourly diffuse radiation ,

$$\frac{\bar{I}_d}{\bar{H}_d} = \frac{\bar{I}_o}{\bar{H}_o} \qquad (1.15)$$

1.5.6. Solar Radiation On Tilted Surfaces [4, 5]

From the preceding sections, it is seen that very often measuring instruments give the values of solar radiation falling on a horizontal surface. The same is also true of the empirical equations. But most solar equipments (e.g. flat-plate collectors), for absorbing radiation, are tilted at an angle to the horizontal. It therefore becomes necessary to calculate the flux which falls on a tilted surface.

Tilt Factor for Beam Radiation, 'r_b':

The ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the tilt factor for beam radiation. It is denoted by the symbol r_b. For the case of a tilted surface facing south (ie. $\gamma = 0^0$),

$$\cos\theta = \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)$$

While for a horizontal surface

$$\cos\theta_z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega$$

Hence, $r_b = \dfrac{\cos\theta}{\cos\theta_z}$ (1.16)

Tilt Factor for Diffuse Radiation 'r_d':

The tilt factor 'r_d' for diffuse radiation is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on a horizontal surface. The value of this tilt factor depends upon the distribution of diffuse radiation over the sky and on the portion of the sky dome seen by the tilted surface. Assuming that sky and on the portion of the sky dome seen by the tilted surface. Assuming that the sky is an isotropic source of diffuse radiation, we have for a tilted surface with a slope β,

$$r_d = (1 + \cos\beta) / 2 \tag{1.17}$$

since ,

$(1 + \cos\beta) / 2$ is the radiation shape factor for a tilted surface with respect to the sky.

Reflected Radiation 'r_r' :

since $(1 + \cos\beta) / 2$ is the radiation shape factor for a tilted surface with respect to the sky, it follows that $(1 - \cos\beta)/2$ is the radiation shape factor for the surface with respect to the surrounding ground. Assuming that the reflection of the beam and diffuse radiations falling on the ground is diffuse and isotropic, and that the reflectivity is ρ, the tilt factor for reflected radiation is given by

$$r_r = \rho\left(\frac{1 - \cos\beta}{2}\right) \tag{1.18}$$

where, ρ = reflectivity ($\rho = 0.2$ for ground).

Flux on Tilted Surface, 'I_T' :

The flux I_T falling on a tilted surface at any instant is thus given by

$$I_T = I_b\, r_b + I_d\, r_d + (I_b + I_d)\, r_r \tag{1.19}$$

where the values of r_b, r_d and r_r, are as given in Eqs (1.16), (1.17) and (1.18). It should be noted that Eq. (1.16) is valid only for a tilted surface with $\gamma = 0°$, whereas Eqs (1.17) and (1.18) are valid for any tilted surface with a slope β. Dividing both sides of Eq. (1.19) by I_g, we obtain the ratio of the flux falling on a tilted surface at any instant to that on a horizontal surface.

$$\frac{I_T}{I_g} = \left(1 - \frac{I_d}{I_g}\right) r_b + \frac{I_d}{I_g} r_d + r_r \tag{1.20}$$

Where ,

$r_b = (1 + \cos \beta) / 2$

$r_r = \rho \ (1 - \cos \beta \ ) / 2$

The daily radiation falling on such a surface (H_T) to the daily global on horizontal surface (H_g) is given by an equation having a form similar to Eq. (1.20). Thus

$$\frac{\overline{H}_T}{\overline{H}_g} = \left(1 - \frac{\overline{H}_d}{\overline{H}_g} \right) \overline{R}_b + \frac{\overline{H}_d}{\overline{H}_g} \overline{R}_d + \overline{R}_r \qquad (1.21)$$

Where ,

$r_b = (1 + \cos \beta) / 2$

$r_r = \rho \ (1 - \cos \beta \ ) / 2$

CHAPTER II

SOLAR DRYING BASIC & LITERATURE REVIEW

Drying of agricultural products [7] to optimum moisture content results in safe storage of the product over a long period. India has been blessed with good sunshine. Hence as an alternative to the existing energy sources such as mechanical and electrical powdered systems for drying of agricultural commodities, Natural convection portable solar dryer has been introduced in the post harvest technology. From the farmers' economy point of view, recent emphasis is on development of natural convection solar dryers of low initial cost and also of low running cost.

Solar energy is all the more effective for food drying because of following reasons [8]:

(a) Solar energy is diffuse in nature and provides low grade heat. This characteristic of solar energy is good for the drying at low temperature, high flow rates with low temperature rise.

(b) The intermittent nature of solar radiation will not effect the drying performance at low temperature. Even the energy stored in the product itself will help in removing excess moisture during this period.

(c) Solar energy is available at the site of use and saves transportion cost.

(d) The high capital cost of solar dryiers can be compensated if the dryer is used for drying other products also or at least is put to other multiple uses such as space heating, etc.

2.1. BASICS OF SOLAR DRYING

Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then to remove this moisture from the surface of the drying material. In natural sun drying where the product is directly exposed to the sun in the open air, the necessary heat required for moisture removal is supplied from the sun and a little from the ambient air and the wind and the natural convection disperse water vapour.

The drying of product is a complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream and internal variables which is a function of drying material and depends on parameters like surface characteristics (rough or smooth surface), chemical composition (sugars, starches, 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 differs from one product to another and very much depends weather the material is hygroscopic or non-hygroscopic. Non-hygroscopic materials can be dried to zero moisture level while the hygroscopic materials like most of the food products will always have a residual moisture content. This moisture in hygroscopic material may be a bound moisture (remained in the material due to closed capillaries or due to surface forces) and unbound moisture which remained in the material due to surface tension of water (Fig.2.1).

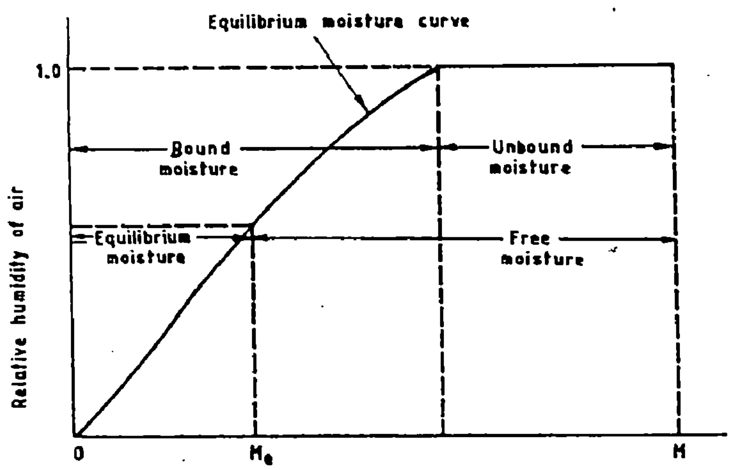


Figure 2.1. Moisture in the Drying Material [8]

The equilibrium moisture content (EMC) will soon reach when the vapour pressure of water in the material becomes equal to the partial pressure of water in the surrounding air. The equilibrium moisture content in the drying is therefore important since this is the minimum moisture to which the material can be dried under a given set of drying conditions.

A series of drying characteristic curves can be plotted. The best is if the average moisture content M of the material is plotted versus time as shown in Fig.2.2.

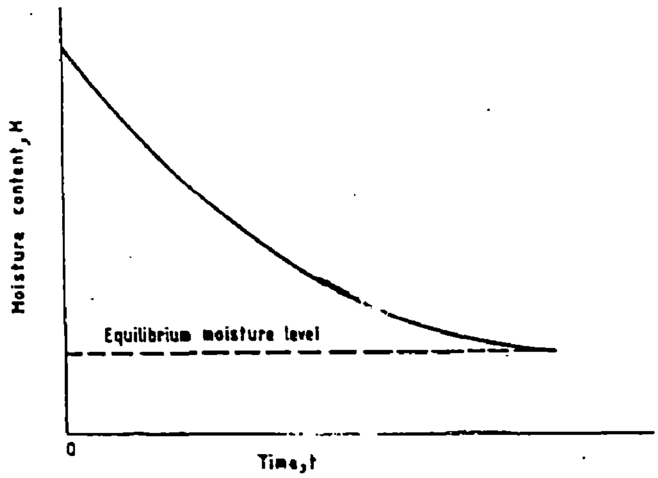


Figure 2.2. Rate of Moisture Loss [8]

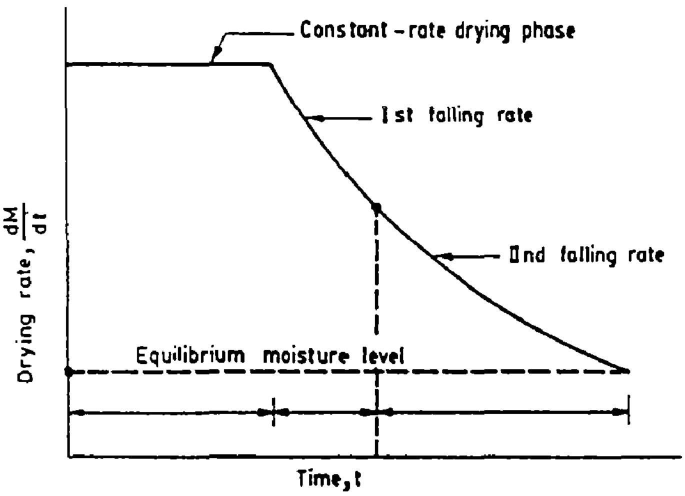


Figure 2.3. Drying Rate with Time Curve [8]

Another curve can be plotted between drying rate i.e. dM/dt versus time t as shown in Fig.2.3. But more information can be obtained if a curve is plated between drying rate dM/dt versus moisture content M as shown in Fig.2.4. As is seen from Fig.2.4 for both non-hygroscopic and hygroscopic materials, there is a constant drying rate terminating at the critical moisture content followed by falling drying rate. The constant drying rate for both non-hygroscopic and hygroscopic materials is the same while the period of falling rate is little different.

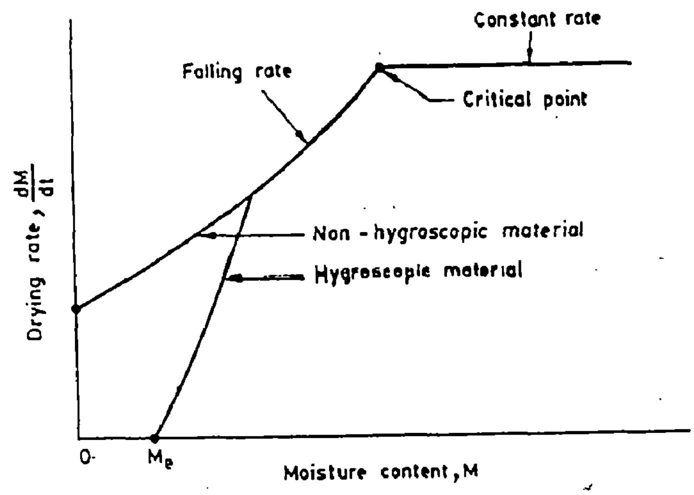


Figure 2.4. Typical Drying Rate Curve [8]

2.2. TYPES OF SOLAR DRYERS [9]

The three modes of drying are: (i) open sun, (ii) direct and (iii) indirect in the presence of solar energy. The working principle of these modes mainly depends upon the method of solar energy collection and its conversion to useful thermal energy.

1. Open Sun Drying (OSD)

Figure 2.5. shows the working principle of open sun drying (OSD) by using solar energy. The short wavelength solar energy [I(t)] falls on the uneven crop surface having an area of A_t. A part of this energy is reflected back and the remaining part is absorbed by the surface depending upon the colour of crops. The absorbed radiation is converted into thermal energy and the temperature of crop [T_c] starts increasing. This results in long wavelength radiation loss from the surface of crop to ambient air through moist air. In addition to long wavelength radiation loss there is convective heat loss too due the blowing

wind through moist air over the crop surface. Evaporation of moisture takes place in the form of evaporation losses and so the crop is dried.

In open sun drying, there is a considerable loss due to various reasons such as rodents, birds, insects and micro-organisms. The unexpected rain or storm further worsens the situation. Further, over drying, insufficient drying, contamination by foreign materials like dust, dirt, insects, and micro-organisms as well as discolouring by UV radiation are characteristic for open sun drying, In general, open sun drying do not fulfill the international quality standards and therefore it can not be sold in the international market.

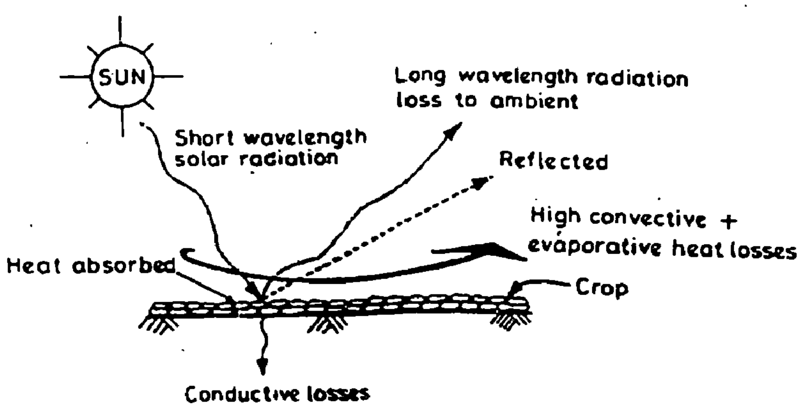


Figure 2.5. Working Principle of Open Sun Drying [9]

2. Direct Solar Drying (DSD)

The principle of direct solar crop drying is shown in Figure 2.6. This is also called cabinet dryer. A part of incidence solar radiation on the glass cover is reflected back to atmosphere and remaining is transmitted inside cabinet dryer. Further. A part of transmitted radiation is reflected back from the surface of the crop.

The remaining part is absorbed by the surface of the crop. Due to the absorption of solar radiation, crop temperature increases and the crop starts emitting long wavelength radiation which is not allowed to escape to atmosphere due to presence of glass cover unlike open sun drying. Thus the temperature above the crop inside chamber becomes higher.

The glass cover serves one more purpose of reducing direct convective losses to the ambient which further becomes beneficial for rise in crop and chamber temperature respectively. However, convective and evaporative losses occur inside the chamber from heated crop. The moisture (the vapor formed due to evaporation) is taken away by the air entering into the chamber from below and escaping through another opening provided at the top as shown in Figure 2.6.

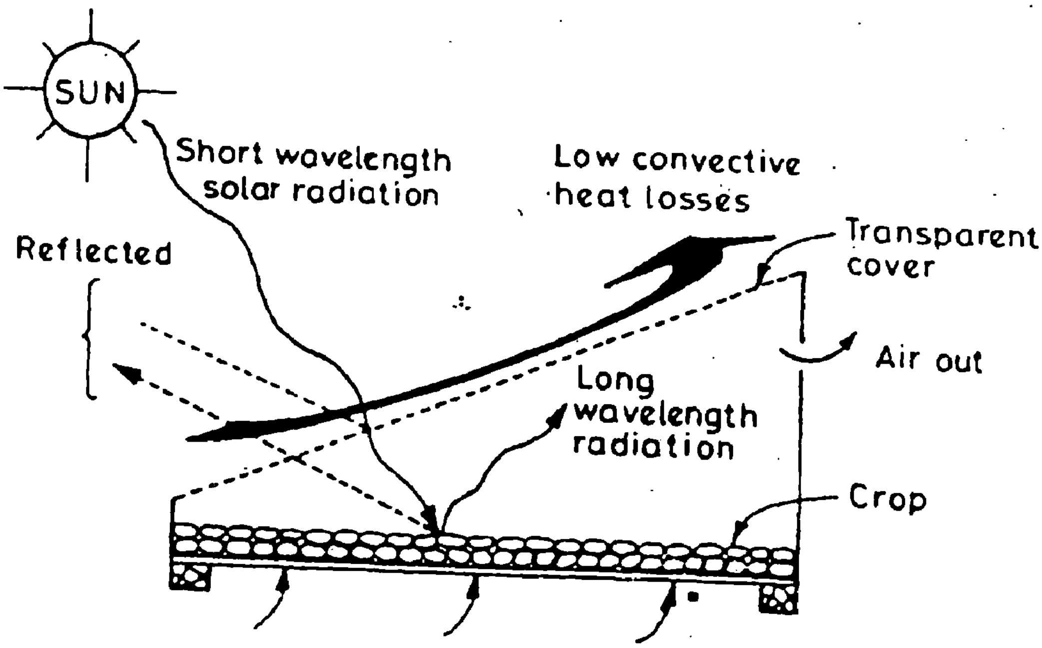


Figure 2.6. Working Principle of Direct Solar Drying [9]

3. Indirect Solar Drying (ISD)

In this case, the crop is not directly exposed to solar radiation to minimize discolouration and cracking on the surface of the crop. Goyal and Tiwari (1990) have proposed and analysed reverse absorber cabinet dryer (RACD) as shown in Figure 2.7.

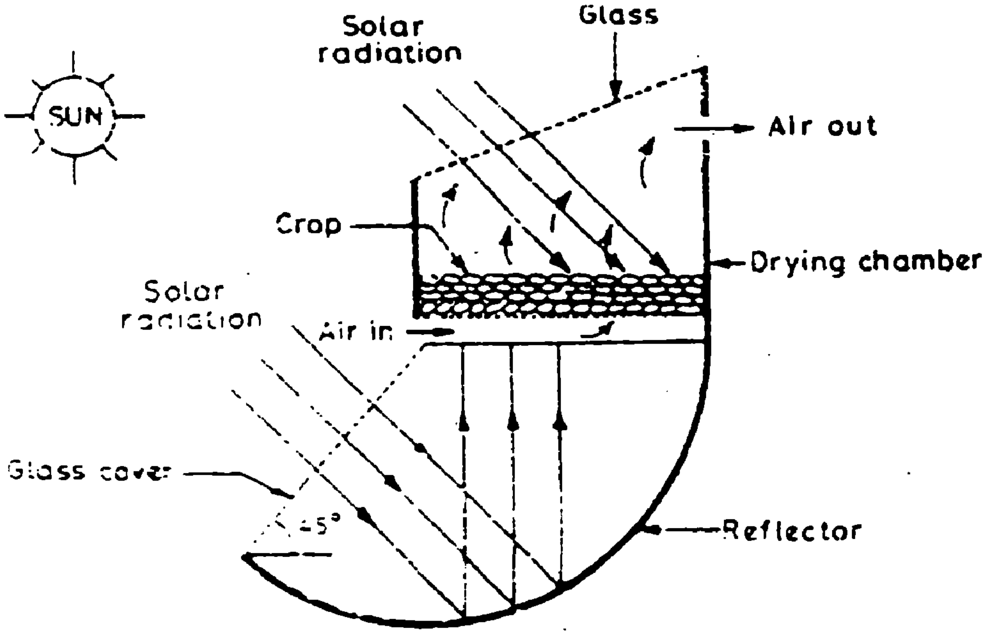


Figure 2.7. Reverse Absorber Cabinet Dryer (RACD) [9]

2.3. PARAMETER OF SOLAR DRYER [10]

The parameters influencing dryer performance are:

1. Physical features of the dryer

These refer to the type, weight, dimensions and construction materials of the dryer. Wood and metals are the common construction materials. Solar collectors are usually constructed as bare-plate absorbers made of aluminium, galvanized iron or steel, and painted with a non-reflecting (matt finish) black paint. Selectively coated absorber sheets are used when the required temperature rise exceeds 40'C.

2. Drying Time

The duration of the drying process is the most important parameter to be considered in evaluating a dryer. It is estimated from the time when the dryer is loaded with fresh product until when the product dries to the required moisture level, usually given as hours or days.

3. Drying air temperature and relative humidity

Increasing the temperature of the drying air will increase the drying rate in two ways. First, this increases the ability of drying air to hold moisture. Secondly, the heated air will heat the product, increasing its vapor pressure. This will drive the moisture to the surface faster.

4. Airflow rate

Alt˜flow is another important parameter that influences the drying process. As the airflow rate is increased, the conduction and radiation losses may be small due to the smaller temperature rise. Drying efficiency may suffer at high airflow rates since air may not have adequate contact time with the food to increase its moisture content.

5. Dryer efficiency

Drying (or system) efficiency indicates the overall thermal performance of the drying system. The system efficiency of a solar dryer is a measure of how effectively the input energy (solar radiation) to the drying system is used in drying the product.

Drying efficiency is commonly used to represent dryer performance. Major factors affecting drying system efficiency include air temperature rise in the drying chamber, airflow rate, wind speed and collector/dryer design, which directly or indirectly relate to overall thermal losses in the system.

6. Quality of dried products

Drying usually affects the physical properties of the product and results in changes in size, shale, colour and texture. Many chemical and enzymatic conversions also take place during dehydration. Although these conversions are not always undesirable, some may make the product unpalatable. Quality comparison between solar dryers is necessary as it could vary widely, depending on the drying temperature, dryer design, airflow rate and other parameters.

2.4. LITERATURE SURVEY

R.K. Goyal and G.N. Tiwari [11] in their work presented the concept of a reverse absorber plate collector has been used as a heating of air for drying agricultural products in a cabinet dryer. The result concluded that: (i) The crop temperature decreases with an increase of the number of air changes, as expected. The crop temperature is higher in the RACD than in the normal cabinet dryer due to maximum utilization of solar energy in the RACD. (ii) The crop temperature decreases with an increase of crop capacity during sunshine hours, whereas the trend reverses during off sunshine hours due to the storage effect. (iii) The RACD can be operated for more time in comparison to the normal cabinet dryer. (iv) The drying of crop in the RACD will be more uniform compared to the normal cabinet dryer because the crop is not directly exposed to solar radiation.

A. Hachemi, B. Abed and A. Asnoun [12] in their work brought out the necessity of drying the certain agricultural products (fruits, fodder, cereals, etc.) in order to avoid deterioration when they are exposed to the elements. Solar air collectors have been optimized in previous studies resulting in a clear enhancement of their thermal performances in relation to the flat plate. The result concluded that the solar dryer presents a greater advantage, from the point of view of time of drying and quality of product, than natural drying where crops is directly laid out to the ambient air and solar radiation. It avoids the deterioration of the product when it is exposed to the elements. The flat-plate collector is used as a heat source to dry the wet crops.

R.K. Goyal and G.N. Tiwari [13] presented the thermal performance of the RACD. The proposed dryer is analyzed by solving the various energy balance equations. An attempt has been made to optimize the vent area of the dryer for speedy flow of humid air from the drying chamber to the atmosphere. The result concluded that (a) The crop and chamber temperatures are less than the plate and fluid temperatures during sunshine hours as shown in figure 2.8, and the crop temperature remains a little higher than the other temperatures during periods of no sun. This is because of the thermal storage effect of the crop. (b) The crop temperature in the reverse absorber cabinet dryers is more than for normal cabinet dryers because of the maximum utilization of the available solar energy and minimum heat loss. (c) There is significant variation in crop temperature with heat capacity of the crop, as temperature decreases with an increase of crop capacity as shown in figure 2.9. Further, it is higher in the case of RACD and remains almost the same in the late hours because of the storage effect. And the effect of mass of crop on the overall system efficiency is significant in both cases, it decreases with increase of crop capacity as shown in figure 2.10. Therefore, these systems can be used for small crop capacity.

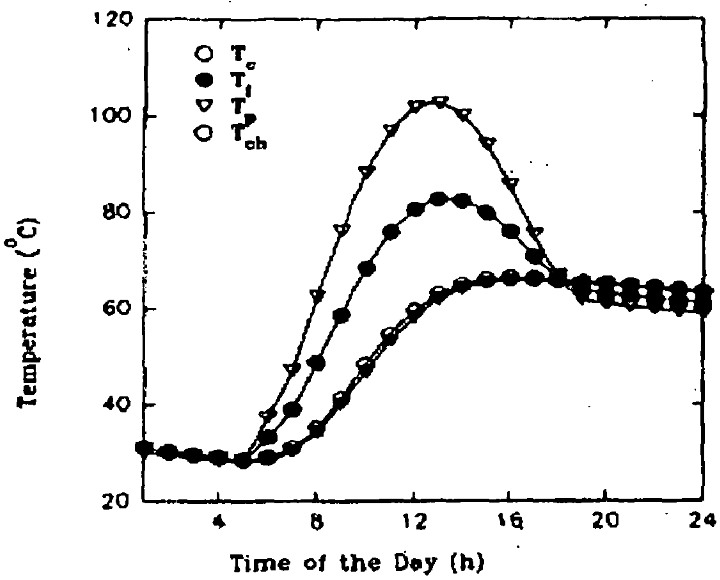


Fig. 2.8. Hourly Variation of Different Temperatures (Crop, Fluid, &Plate) [13].

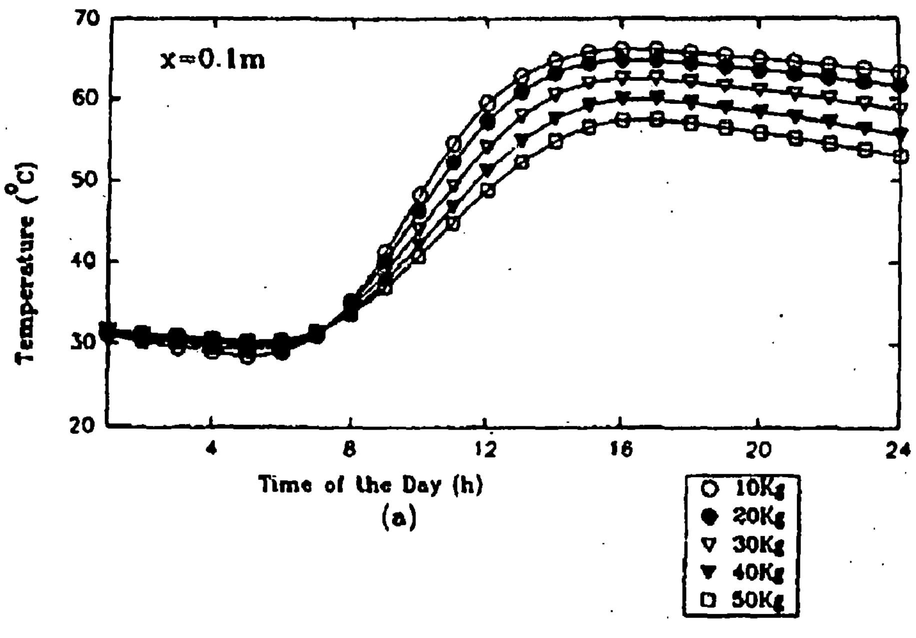


Figure. 2.9. Effect of Crop Capacity on Hourly Temperature [13]

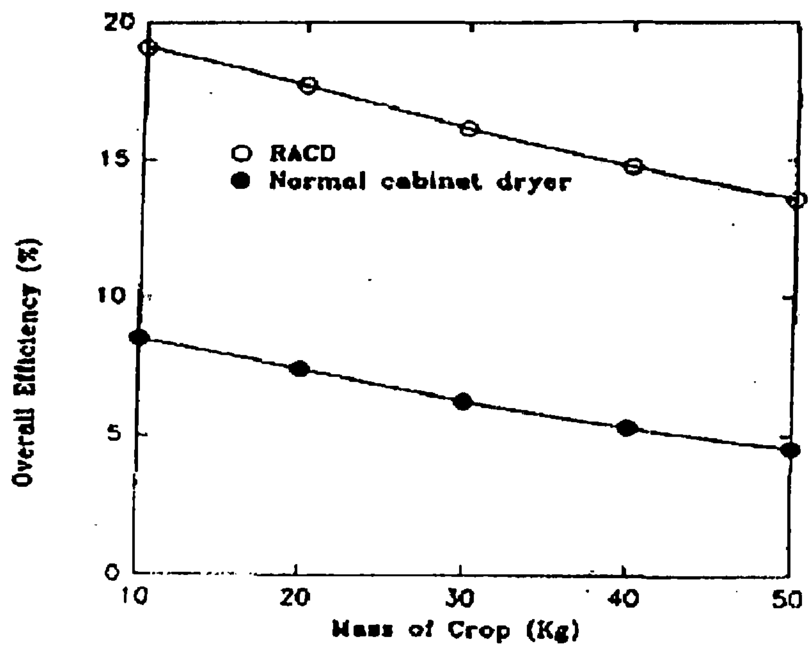


Figure. 2.10. Effect of Mass of Crop Capacity on Overall Efficiency [13]

D.R. Pangavhane, R.L. Sawhney & P.N. Sarsavadia [14] presented a multipurpose natural convection (indirect mode) dryer which was developed for drying of agricultural produce mainly horticulture and vegetable crops using solar energy. It consisted of flat plate collector and a drying chamber with five drying trays. The result concluded that the developed dryer is capable of producing average temperature between 50 to 55 ^{0}C, which is optimum for dehydration of the grapes as well as for most of the fruits and vegetables. The drying time in natural convection indirect type dryer for the grapes is also reduced by nearly half that of the open sun drying. It produces better quality raisins.

Pradip Vishnu Bhosale, Ghanasham B. Vidhale and Bhushan G. Malandkar [7] in their work studied the drying the agricultural commodities such as Chilli and Potato flakes in a natural convection Natural convection portable solar dryer. During the first drying day of Chilli and Potato flakes, the maximum temperature attained in Natural convection portable solar dryer were 40°C and 39°C respectively.

M. Augustus Leon, S. Kumar and S.C. Bhattacharya [10] presented a detailed review of parameters generally used in testing and evaluation of different types of solar food dryers. The parameters significantly influencing dryer performance are: 1. drying air characteristics (drying air temperature, humidity and airflow rate); 2. product variables (initial and final moisture contents, product size and size distribution); and 3. dimensional variables (width, length, height or diameter of the dryer, number of passes and dryer configuration).

Saber Chemkhi, Fethi Zagrouba and Ahmed Bellagi [15] presented the main application for solar energy in southern Mediterranean countries in agriculture is the drying of agricultural crops. The optimisation of dryers necessitates complete knowledge of the whole drying process, thus leading to energy savings and avoiding environmental pollution by using renewable sources of energy. In this study we present an analysis of a drying convective pilot using solar energy. This solar dryer is essentially composed of three parts: a solar plan collector, a drying box and a chimney. The experimentation by using 1. Experimental device to take the climatic data (ambient temperature, solar radiation and wind speed), the distribution of the temperature on the collector (under the cover, on the internal face of the insulator, on its external face and along the absorber) and the two input and output air temperatures. 2. Test of the collector in free out-flow to make several measurements for different days in order to be able to get an idea on the behaviour of our collector, its outlet temperature and its efficiency for different climatic conditions. For the first regime of out-flow, studied different climatic agent effects on the efficiency of our collector. 3. Test in forced out-flow worked in forced outflow to put in evidence the effect of the mass flow of the circulating air in the heater. For a climatic factor effect such as in free out-flow, noted the existence of a direct relationship between the outlet temperature of the collector and the climatic factors, especially solar radiation.

Dilip R. Pangavhane, R.L. Sawhney and P.N. Sarsavadia [16] presented Mechanical drying is an energy consuming operation in the post-harvesting technology of agricultural products, so more emphasis is given on using solar energy sources due to the high prices and shortages of fossil fuels. Solar dryers are now being increasingly used since they are a better and more energy efficient option. Sun shines in India over an average 3000–3200 h per year, delivering about 2000 kWh/m2-year of solar radiation on the horizontal surface. This abundantly available solar energy can be used for the drying of agricultural products. During the five days of the experiment, the diurnal variation of the ambient air temperature, solar irradiance, collector outlet air temperature and dryer outlet air temperature for the solar dryer were plotted and are shown for April 1998 in Fig. 2.11. From these figures it is observed that the rise in air temperature due to the generated air flow rate in the collector were sufficient for the purpose of grapes drying. For the inlet air temperature of 38°C, the maximum air temperature at the dryer inlet at no load conditions was recorded as 69.5°C at the solar irradiance level of 909 W/m2. The maximum temperature gain in the collector during the peak afternoon hours on all the days was around 30°C (varying between 25.9 and 33.5°C). During the 5 days, the daily mean values of air temperature at the dryer inlet vary from 51.9°C to 64.6°C and for solar radiations it varies from 605 to 673 W/m2.

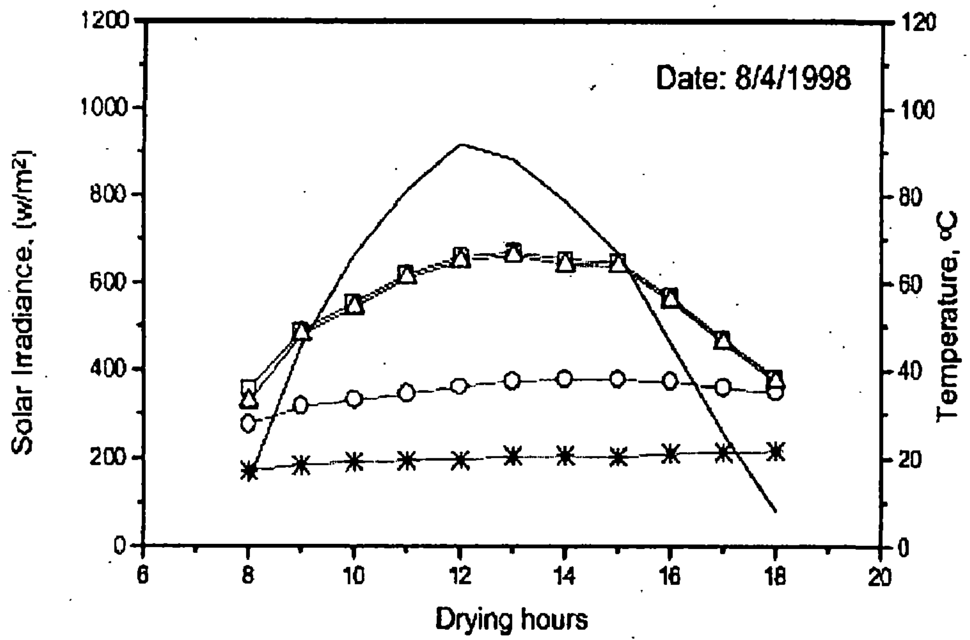


Fig. 2.11. Variation of the solar irradiance —, Collector outlet air temperature □, Dryer outlet air temperature Δ, ambient air temperature (dry) O and ambient air temperature (wet) -*-

2.5. PROBLEM FORMULATION

It is observed that the conventional drying method by natural convection in solar cabinet dryers has certain drawbacks: 1) Direct exposure of material to the solar radiations resulting in poor quality of the dried product. 2) The transmissivity of the glass cover is reduced because of moisture condensation on it. 3) The absorptivity of the absorber plate is reduced as part of the solar radiation is reflected from the uneven crop surface and part of it absorbed by the crop before it reaches the absorber. The above problem have been solved by the indirect natural convection solar drying systems, which generally consists of a flat plate solar air heater connected with the drying chamber. The drying chamber is used for keeping the crop in wire mesh tray. A downward facing absorber (reverse absorber) is fixed below the drying chamber at a sufficient distance (0.05m) from the bottom of the drying chamber. A cylindrical reflector is placed under the absorber to reflect the solar radiation on to the bottom of the absorber plate. The crop is placed above the absorber plate in wire mesh trays. Studies on the performance of reverse absorber cabinet dryer have been reported in the literature survey. But none of studies has considered the effect of variation of the crops such as : wheat (3kg), peas (2kg, 3kg, 4kg) and paddy (3kg, 4kg, 5kg), and at various values of the parameters vent width (V) and duct depth (D) on the performance of the system. There is a need for thorough investigation on these parameters. In the present work an attempt has been made to fabricate a test facility for Reverse flat plate absorber cabinet dryer and investigation on effect of the variation of the parameters on the performance of the system. It is expected that this study will generate data for the efficient of reverse flat plate absorber cabinet dryer.

2.6. OBJECTIVES OF THE PRESENT STUDIES

The objective of the present work is (1) to review and compile the literature and work on solar drying and (2) to conduct experiments to evaluate performance of a solar dryer reverse flat plate absorber cabinet dryer for drying some agricultural produce like paddy, wheat, and peas. It is expected that this study will generate data for drying some agricultural produce.

CHAPTER III

EXPERIMENT TO EVALUATE PERFORMANCE OF SOLAR DRYER

3.1. INTRODUCTION

The conventional method of crop drying, in most of the developing countries [13], is to spread the agricultural produce on the ground and allow it to dry in the open sun. Such studies have been conducted by many workers, and it has been reported that open sun drying has the following disadvantages: (i) it requires both a large amount of space and long drying times; (ii) the crop becomes damaged because of hostile weather conditions; (iii) contamination of crop from foreign materials; (iv) the crop is subject to insect infestation and (v) the crop is susceptible to reabsorption of moisture if it is left on the ground during periods of no sun which reduces its quality.

In order to overcome some of these problems, the reverse flat plate absorber as the air heating medium could be introduced. In the present study, an attempt has been made to develop a model using both a reverse flat plate absorber as the heating medium and a cabinet dryer as the drying chamber. The whole unit is termed a reverse absorber cabinet dryer (RACD).

3.2. EXPERIMENT SET UP

3.2.1. Design of The Set up

The drying experiment with a reverse absorber cabinet dryers with the variation of the crops is placed inside the dryer (as shown in Figure 2.7). The drying has been carried out for a period of five hours from 10:00 AM to 3:00 PM, with various values of the parameters vent width (V) and duct depth (D) and the variation of the crops such as : wheat (3kg), peas (2kg, 3kg, 4kg) and paddy (3kg, 4kg, 5kg). At every one hour interval of time, four samples of 60 gram for Wheat, 55 gram for Peas and 60 gram for Paddy are taken and decrease in moisture is measured with the help of a digital weighing machine. The ambient temperature is measured with help of digital thermometer. The temperatures of fluid air T_f, crop T_c and absorber plate T_p are measured with the help of thermocouples. The global and diffuse radiations are measured on a horizontal surface using a pyranometer and shading ring. The hourly and daily efficiency are calculated using the suitable formulae. Thus drying is carried out with variation of the crops and various values of the parameters vent width (V) and duct depth (D) and their effect on the performance of the drying unit is studied.

3.2.2. Drying area calculation

To obtain the area A_d required to dry a given mass of crop, we should know in prior the mass of water to be evaporated from the given quantity, the latent heat of vaporation and efficiency of the drying unit.

The area required for drying is evaluated as follows [9]:

Total weight of crop in dryer, for paddy w= 4 kg

Initial moisture content, $M_i = 30$ %

Final moisture content, $M_f = 13$ %

Maximum crop temperature while drying = 50^0 C

Therefore, at the crop temperature 50^0 C from the steam table [17] is obtained the latent heat of vaporation $L_v = 2.3829$ MJ/kg.

And mass of water to be evaporated from paddy w= 4 kg is given by [18],

$$M_v = \frac{W\left(M_i - M_f\right)}{\left(100 - M_f\right)} \qquad (3.1)$$

$$M_v = \frac{4\,kg\,(30 - 13)}{(100 - 13)}$$

$M_v = 0.7816$ kg ,

hence the energy required to vaporize 0.7816 kg of water is given by,

$$Q = M_v \times L_v \qquad (3.2)$$

$Q = 0.7816$ kg x 2.3829 MJ/kg

$Q = 1.8625$ MJ

From solar radiation data handbook [19], the daily average beam radiation on a horizontal surface at Roorkee is $h_{bz} = 12.24\ MJ / m^2$,

So, the beam radiation on a tilted surfaced at an angle β with horizontal [4],

$$H_{bt} = h_{bz} \times r_b , \qquad (3.3)$$

where, r_b = ratio of beam radiation on tilted surface to that on horizontal surface.

$$r_b = \frac{\sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)}{\sin\delta \sin\phi + \cos\delta \cos\omega \cos\phi} \qquad (3.4)$$

the latitude (ϕ) at Roorkee = 29.85 °

the solar radiation is calculated for a tilted surface, β = 45 °

let the be March 21, 2005 and the number of the day in this year, n = 31+28+21 = 80,

time = 12 noon,

the hour angle (ϖ) is an angular measure of time and is equivalent to 15 ⁰ per hour

$$\varpi = 15^0 \times (12 - t) \qquad (3.5)$$

t = time = 12 : 00 $\varpi = 15^0 \times (12 - 12) = 0^0$

therefore, the declination, $\delta = 23.45 \sin [360 \times \frac{284 + n}{365}]$ (3.6)

$$\delta = 23.45 \sin [360 \times \frac{284 + 80}{365}] = - 0.40.3^0$$

$$r_b = \frac{\sin -0.4036 \sin(29.85 - 45) + \cos -0.4036 \cos 0 \cos(29.85 - 45)}{\sin -0.4036 \sin 29.85 + \cos -0.4036 \cos 0 \cos 29.85}$$

r_b = 1.1195

$H_{bt} = 12.24\ MJ / m^2 \times 1.1195$

$H_{bt} = 13.7027\ MJ / m^2$,

Assuming the efficiency of drying unit η = 31.5 %

Drying efficiency, $\eta = \dfrac{Q}{A_d\, H_{bt}}$ (3.7)

The area of the dryer, $A_d = \dfrac{Q}{\eta\, H_{bt}}$

$A_d =$ 1.8625 MJ / (0.315 x 13.7027 MJ / m^2)

$A_d =$ 0.4314 m^2 $\approx$ 0.43 m^2

3.2.3. Details of Set up

3.2.3.1. Drying Chamber

Since the drying area, A_d = 0.43m^2 , the dimensions of the chamber according to standard guidelines [11] recommended for construction of solar drying chamber, the length of the chamber chosen to be three times the width to avoid shading effect are as follows:

Width of the chamber, B = 0.38m

Length of chamber, L = 1.14m

Drying chamber is shown in figure 3.1.

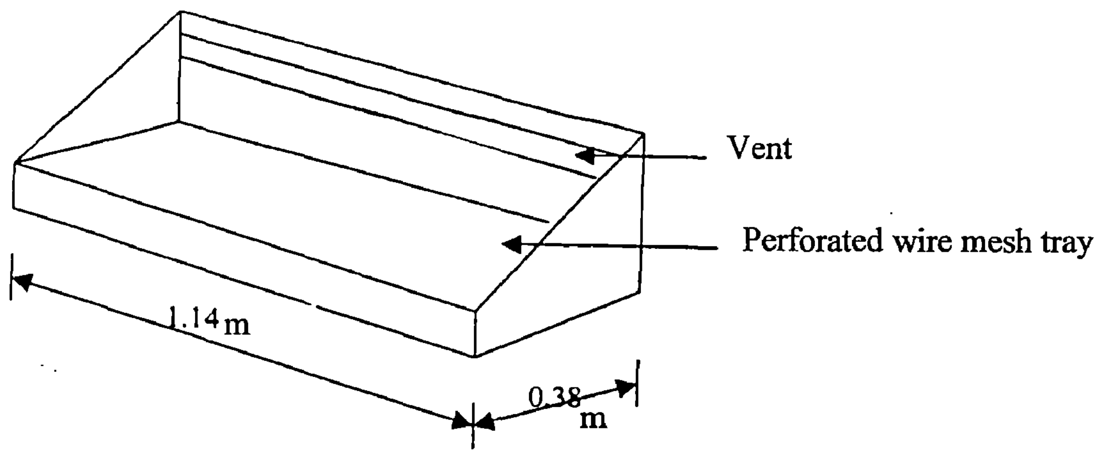


Figure 3.1. Drying Chamber

From the economy point of view, the material of the chamber is selected to be light plywood of thickness 12 mm. For holding the product to be dried, a wire mesh tray is fixed at the bottom of the chamber. A vent is provided along lengthwise at the top of the chamber such that its width can be varied for moist air to escape.

3.2.3.2. Absorber Plate

The absorber plate is painted with lamp black for maximum absorptions. It is made of mild steel with dimensions as follows:

Width of the absorber plate, B = 0.38m

Length of absorber plate, L = 1.14m

A glazed cover is fixed on the absorber plate maintaining a gap of 0.04m with the help of wooden frame as shown in figure 3.2.

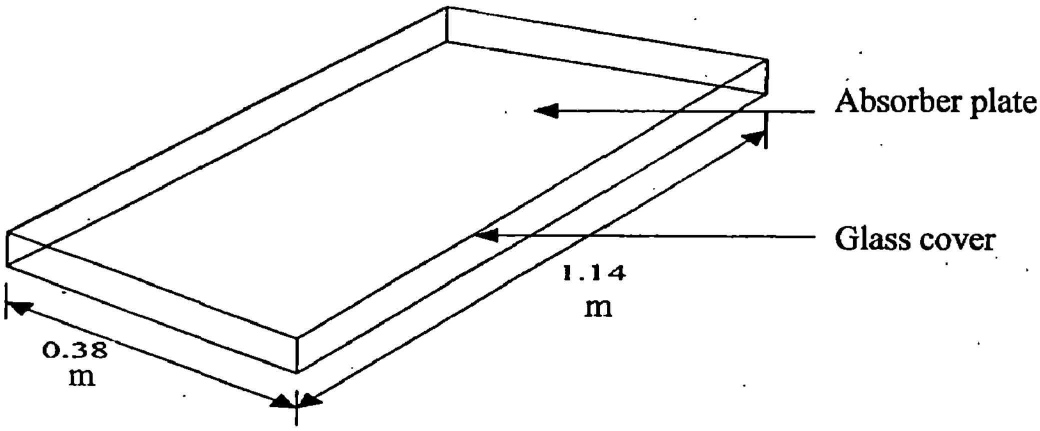


Figure 3.2. Absorber Plate

3.2.3.3. Cylindrical Reflector

The cylindrical Reflector is placed under the glazed absorber plate to introduce solar radiation from below. It is shown in figure 3.3.

An aluminium sheet with dimensions 1.14m x 0.9m of thickness 1.5×10^{-3} m is bent into cylindrical shape such that its radius of curvature is 0.38m and the included angle is 135^0. The sheet is supported with plywood on rear side in order to have rigidity. The reflecting mirrors with size 0.02m x 0.02m are fixed on the sheet, so that they reflect the incoming beam radiation on the absorber plate and the aperature area of reflector is 0.43 m^2.

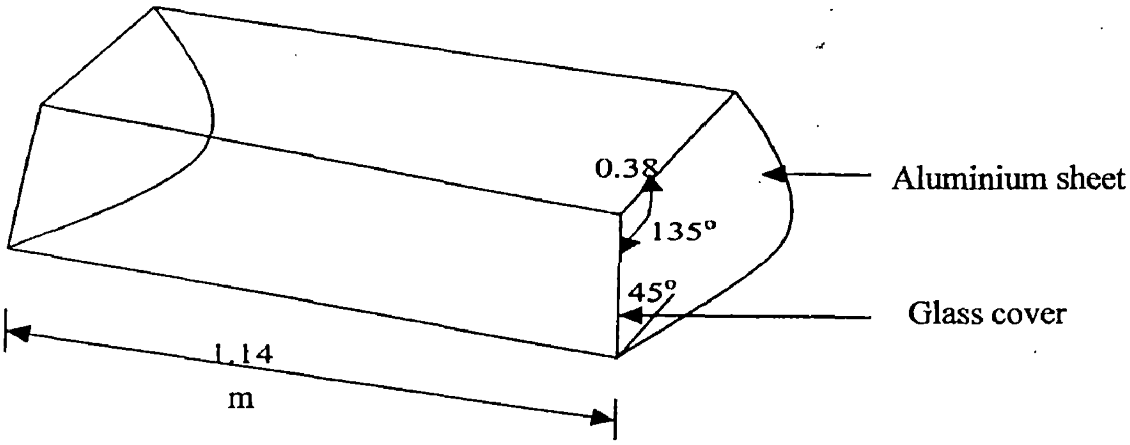


Figure 3.3. Cylidrical Reflector

3.2.4. Principle of Working of a Reverse Flat Plate Absorber Cabinet Dryer

The principle of a reverse flat plate absorber cabinet dryer [11] is shown in Fig. 3.1. The absorber plate is horizontal and downward facing. A cylindrical reflector is placed under it to introduce solar radiation from below. The area of the aperture is the same as that of the absorber plate. The cabinet dryer is mounted on top of the absorber plate, maintaining a gap of 0.03 m for air to flow above the absorber plate, where it gets heated, and enter the dryer from the bottom. Unlike a conventional dryer it is not insulated from the bottom, but it does not allow insolation from the top. The bottom area of the dryer is equal to the absorber plate area. The length to width ratio of the dryer is taken as 3:1 to avoid the shading effect.

Firstly, hot air heats the crop spread over the wire mesh, and then moisture starts moving from the interior of the crop kernel to its surface due to diffusion. Then, the heat transfer takes place from the crop surface to the chamber air by convection and evaporation. The convective heat loss is controlled by the buoyancy force. These convective and evaporative heat losses are, generally, governed by Lewis' relation in the process of mass transfer from the crop surface to the chamber air. Further, the moisture laden air leaves the chamber through the vent due to the vapour pressure difference between the chamber and outside in a natural convective mode of operation. The advantage of this assembly is that a selective coating can be used for the absorbing surface, which is not possible in the case of a conventional cabinet dryer. As the crop is subjected to much direct contact with solar radiation, its quality is better then the conventional natural convection dryer.

CHAPTER IV

DATA COLLECTION AND REDUCTION

4.1. INTRODUCTION

The drying experiment was carried out in the RACD (Reverse Absorber Cabinet Dryer) as shown in figure 4.1. The solar beam radiations are first transmitted by the glass cover on the reflector and then the cylindrical surface reflects these radiations towards the glazed absorber plate. After absorption, the absorber emits long wavelength radiation, which is trapped between the absorber and glazed cover. In this case, the convection and radiation heat losses is suppressed due to hot plate facing downward. Ambient air enters the duct and flows over the absorber plate and gets heated due to convection heat transfer from the absorber and air exits the chamber trough the vent.

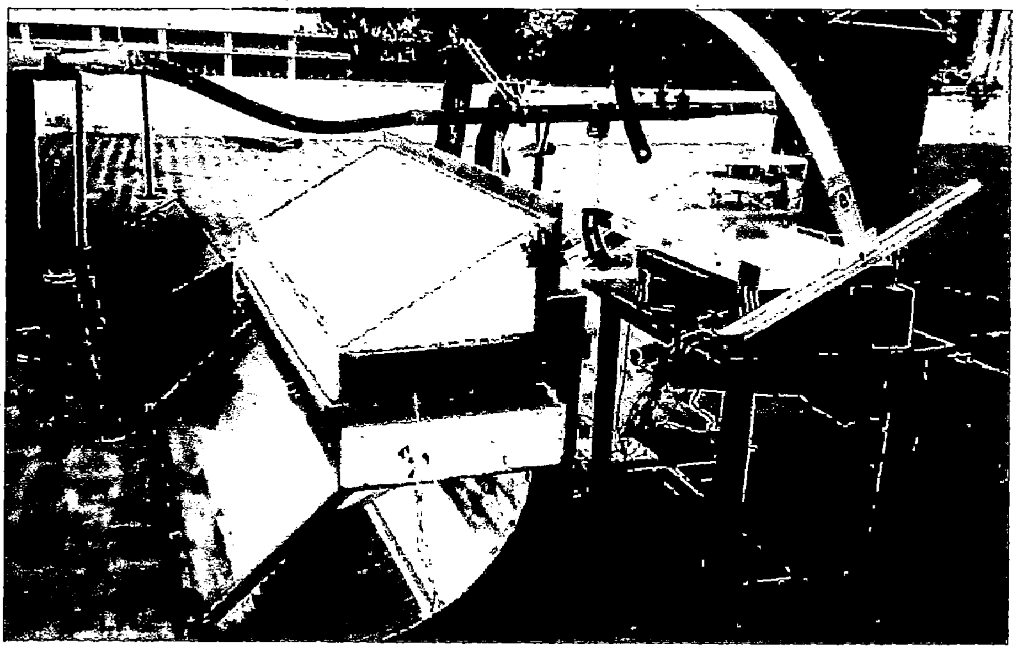


Figure 4.1. RACD (Reverse Absorber Cabinet Dryer) for Experiment

4.2. DATA COLLECTION

The drying was carried out in the Reverse Absorber Cabinet Dryer and the instruments used in recording the data are shown in figure 4.2, with the variation of the crops such as : wheat (3kg), Peas (2kg, 3kg, 4kg) and paddy (3kg, 4kg, 5kg). At various values of the parameters vent width (V) and duct depth (D), the experiment of data is collected and shown in the tables 4.1 to 4.26.

Figure 4.2. Instruments used in recording the data

4.2.1. The Instruments Used in Recording the Data

1. Digital Temperature Meter

   Model : 155-6 SNO. 151

   Range : 0 to 199.9 °C

   Power supply : 230 V ± 10 %, AC, 50 Hz

   Trademark : India – National Instrument Limited.

2. Digital Micro-Volt Meter

   Model : DMV – 02 (AERO – 93)

   Accuracy : ± 0.1 °C

Trademark : India – Electromek.

3. Solari Meter (Pyranometer)

   Model : DD -048-7B (0582)

   Calibration Factor : 13.52 $\mu V / W / m^2$

   Trademark : India – National Instrument Limited.

4. Shading Ring

   Model : SL-NO-26 (1981)

   Trademark : India – National Instrument Limited.

5. Selector Switch

   Range : 24 points (double poles)

   Trademark : Roorkee – Electrotech.

6. Digital Temperature

   Accuracy : $\pm 0.1\ ^oC$

   Trademark : Flake

7. Thermocouple (copper-constantan)

8. Digital Weighing Machine

   Accuracy : ± 1 gram

   Trademark : India – National Instrument Limited.

4.3. DATA PROCESSING

The processing of the measured data is carried out with the parameters vent width V, duct depth D and the variation of the crops, in the following steps :

1. In order to find the beam radiation & the diffuse radiation falling on a tilted surface :

   the latitude (ϕ) at Roorkee [4] = 29.85 °

   the solar radiation is calculated for a tilted surface, $\beta = 45\ ^o$.

the declination δ [4] is calculated from equation , $\delta = 23.45 \sin\left[360 \times \frac{284+n}{365}\right]$

where n = the number of the day in the year.

the hour angle (ϖ) is an angular measure of time and is equivalent to 15^0 per hour

$\varpi = 15^0 \times (12 - t)$, t = time.

2. Average Crop Temperature Tc (avg) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$,

   From the steam table [17] is obtained the latent heat of vaporation Lv at Tc (avg).

3. Using the solari meter (pyranometer) and shading ring one can measure the total radiation (H_{tz}) and the diffused radiation (H_{dz}) in millivolts converted into MJ / m^2 using the calibration factor of the solari meter constant which is equal to :

   $1\ W / m^2 = 13.52\ \mu V$

   So, the beam radiation (H_{bz}) can be calculated [4]:

   $H_{bz} = H_{tz} - H_{dz}$

4. The beam radiation on a tilted surfaced at an angle β with horizontal at place [4] with the latitude (ϕ) is given by: $H_{bt} = h_{bz} \times r_b$,

   where, r_b = ratio of beam radiation on tilted surface to that on horizontal surface,

$$r_b = \frac{\sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)}{\sin\delta \sin\phi + \cos\delta \cos\omega \cos\phi}$$

The diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} \times r_d$,

r_d, for diffuse radiation is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on the horizontal surface,

$$r_d = \frac{1 + \cos\beta}{2}$$.

Neglecting the inclination of the top glass cover and considering the top surface (which is horizontal) which receives the radiation,

H_{tz} = the total or global radiation on a horizontal surface

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

where: $\cos\theta = \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)$.

5. The hourly efficiency or instantaneous efficiency is calculated from equation,

$$\eta = \frac{Mv \ x \ Lv}{H \ x \ A}$$

where, Mv = moisture evaporated (removal)

Lv = latent heat of vaporation of moisture

H = solar radiation intensity

A = area of the dryer.

6. Finally, the Daily Efficiency is obtained from the equation,

$$\eta = \frac{Mv \ x \ Lv_{(avg)}}{A \times \Sigma \overline{H}}$$

where, $Lv_{(avg)}$ = average of latent heat of vaporation of moisture

$\Sigma \overline{H}$ = total solar radiation intensity

4.4. SAMPLE CALCULATION

A calculation for one set of data is given for the solar drying carried out with the parameters as follows:

Dated : 21-03-2005, at 10 : 00 AM (Table: 4.15)

a. Average Crop Temperature (Tc) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$

Tc (avg) = (24.3+23.8+24.2+24) / 4 = 24.0 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.4449 MJ / kg

b. Mv = Moisture removed from the crop by drying process

Mo = Initial weight of sample

Wi = Final weight of sample

W = Total weight of crop in the dryer

$$Mv = \frac{Wo - Wi}{W} \times W$$

At 10 : 00 AM , W = 4.2 kg, Wo = 60 gram, Wi = Wo = 60 gram

$$\text{Moisture removal} = \frac{60\ gram - 60\ gram}{60\ gram} = 0\ \frac{gram}{gram}$$

Total mass of crop in the dryer = 4.2 kg (in the morning at 10 : 00 AM)

So, Total moisture evaporated (removal),

Mv = 0 x 4.2 kg = 0 kg

c. Using the solari meter (pyranometer) and shading ring one can measure the total radiation (H_{tz}) and the diffused radiation (H_{dz}) in millivolt converted into MJ / m^2 using the calibration factor of the solari meter constant which is equal to

1 W / m^2 = 13.52 μ V

So, the beam radiation (H_{bz}) can be calculated :

$H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 9.81 mV – 4.85 mV = 4.96 mV (clouds were present)

the solari meter constant, 1 W / m^2 = 13.52 μ V

$$H_{bz} = \frac{1\ W/m^2}{13.52\ \mu V} \times 4.96 \times 10^3\ \mu V = 366.86\ W/m^2$$

Gain of energy in 0 hour = 366.86 W / m^2 x 0 second = 0 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °

the solar radiation is calculated for a tilted surface, β = 45 °

let the be March 21, 2005 and the number of the day in this year, n= 31+28+21= 80,

therefore, the declination, $\delta = 23.45 \sin [360 \ x \frac{284 + n}{365}]$, n= 80

$$\delta = 23.45 \sin [360 \ x \frac{284+80}{365}] = -0.40.3^{0}$$

at 10 : 00 AM,

the hour angle (ϖ) is an angular measure of time and is equivalent to 15^{0} per hour

$\varpi = 15^{0} \mathrm{x} (12 - \mathrm{t})$, t = time = 10 : 00 AM

$\varpi = 15^{0} \mathrm{x} (12 - 10) = +30^{0}$

So, the beam radiation on a tilted surfaced at an angle β with horizontal,

<u>On the below area of the reverse flat plate absorber cabinet dryer :</u>

$H_{bt} = h_{bz} \ x \ r_b$,

where, r_b = ratio of beam radiation on tilted surface to that on horizontal surface.

$$r_b = \frac{\sin\delta \ \sin(\phi-\beta) + \cos\delta \cos\omega \cos(\phi-\beta)}{\sin\delta \sin\phi + \cos\delta \cos\omega \cos\phi}$$

$$r_b = \frac{\sin -0.4036 \ \sin(29.85-45) + \cos -0.4036 \cos 30 \cos(29.85-45)}{\sin -0.4036 \sin 29.85 + \cos -0.4036 \cos 30 \cos 29.85}$$

r_b = 1.121

$H_{bt} = 0 \ MJ / m^2 \ x \ 1.121 = 0 \ MJ / m^2$

and the tilted factor, r_d, for diffuse radiation is the ratio of the diffuse radiation flux falling on the tilted surface to that falling on the horizontal surface,

$$r_d = \frac{1 + \cos\beta}{2} \quad , \beta = 45^{0}$$

$$r_d = \frac{1 + \cos 45}{2}$$

r_d = 0.8536

the diffuse radiation on tilted surfaced at angle $\beta = 45^{0}$ with horizontal ,

$H_{dt} = H_{dz} \ x \ r_d$,

where: $H_{dz} = 4.85\ mV = \dfrac{1\ W/m^2}{13.52\ \mu V} \times 4.85 \times 10^3\ \mu V = 358.73\ W/m^2$

Gain of energy in 0 hour = $358.73\ W/m^2 \times 0$ second = $0\ MJ/m^2$

$H_{dt} = 0\ MJ/m^2 \times 0.8536 = 0\ MJ/m^2$.

On the top area of the reverse flat plate absorber cabinet dryer:

Neglecting the inclination of the top glass cover and considering the top surface (which is horizontal) which receives the radiation,

H_{tz} = the total or global radiation on a horizontal surface

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

where: $\cos\theta = \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)$

$\cos\theta = \sin -0.4036 \sin(29.85 - 45) + \cos -0.4036 \cos 30 \cos(29.85 - 45) = 0.8378$

$H_{bz} = 366.86\ W/m^2$, $H_{dz} = 358.73\ W/m^2$

So, $H_{tz} = (366.86\ W/m^2 \times 0.8378) + 358.73\ W/m^2 = 666.08\ W/m^2$

Gain of energy in 0 hour = $666.08\ W/m^2 \times 0$ second = $0\ MJ/m^2$

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

$$\eta = \frac{Mv \times Lv}{H \times A}$$

where, Mv = moisture evaporated (removal)

Lv = latent heat of vaporation of moisture

H = solar radiation intensity

A = area of the dryer

On the top area of dryer, $A_1 = L_1 \times W_1$

Where, L_1 = length of the drying chamber = 1.14 m

W_1 = width of the drying chamber = 0.38 m

$A_1 = 1.14\ m \times .38\ m = 0.43\ m^2$

On the bottom area of dryer, $A_2 = L_2 \times W_2$

Where, L_2 = length of the cylindrical reflector = 1.14 m

W_2 = width of the cylindrical reflector = 0.38 m

A_2 = 1.14 m x .38 m = 0.43 m^2

So, at 10 : 00 AM , Mv = 0 kg , Lv = 2.4449 MJ/kg

$$\eta = \frac{0\ Kg\ x\ 2.4449\ MJ/kg}{(A_1\ x\ H_{tz}) + (A_2\ x\ H_{bz}) + (A_2\ x\ H_{dz})} x\ 100\%$$

$$\eta = \frac{0\ Kg\ x\ 2.4449\ MJ/kg}{(0.43\ m^2 x0\ MJ/m^2) + (0.43 m^2 x0\ MJ/m^2) + (0.43 m^2 x0\ MJ/m^2)} x\ 100\%$$

$\eta = 0\ \%$

At 11 : 00 AM

a. Average Crop Temperature (Tc) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$ = 24.7 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.443 MJ / kg

b. $Mv = \frac{Wo - Wi}{W} x\ W$, W = 4.2 kg, W_{10} = 60 gram, W_{11} = 55 gram

$Mv_{10\text{-}11}$ = 0.3500 kg

c. $H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 10.24 mV – 5.01 mV = 5.23 mV (clouds were present)

H_{bz} = 386.83 W / m^2

Average H_{bz} = (386.83 + 366.86) / 2 = 376.85 W / m^2

Gain of energy in 1 hour = 376.85 W / m^2 x 3600 second = 1.3567 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °, β = 45 °, δ = - 0.40.3 ^{0},

$\varpi = 15^0 \times (12 - 11) = +15^0$

So, the beam radiation on a tilted surfaced at an angle β with horizontal,

<u>On the below area of the reverse flat plate absorber cabinet dryer :</u>

$H_{bt} = h_{bz} \times r_b$, r_b = 1.1097

H_{bt} = 1.1097 x 1.3567 MJ / m^2 = 1.5190 MJ / m^2

and the tilted factor, r_d, = 0.8536

the diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} \times r_d$,

where: H_{dz} = 5.01 mV = 370.56 W / m^2

Average H_{dz} = (370.56 + 358.73) / 2 = 364.64 W / m^2

Gain of energy in 1 hour = 364.64 W / m^2 x 3600 second = 1.3127 MJ / m^2

H_{dt} = 1.3127 MJ / m^2 x 0.8536 = 1.1205 MJ / m^2 .

<u>On the top area of the reverse flat plate absorber cabinet dryer:</u>

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

<u>At 10.00 AM</u> , $\cos\theta_{10} = 0.8378$

H_{tz} = (366.86 W / m^2 x 0.8378) + 358.73 W / m^2 = 666.08 W / m^2

<u>At 11.00 AM</u> , $\cos\theta_{11} = 0.9342$

H_{tz} = (376.85 W / m^2 x 0.9342) + 364.64 W / m^2 = 716.70 W / m^2

Average H_{tz} = 691.39 W / m^2

Gain of energy in 1 hour = 691.39 W / m^2 x 3600 second = 2.4890 MJ / m^2

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

$$\eta = \frac{0.3500\ Kg \times 2.443\ MJ/kg}{\left(0.43\ m^2 x (2.4890 + 1.1205 + 1.5190)\ MJ/m^2\right)} x\ 100\,\% = 38.49\,\%$$

At 12 : 00 AM

a. Average Crop Temperature (Tc) = $\dfrac{Tc1 + Tc2 + Tc3 + Tc4}{4}$ = 31.0 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.4283 MJ/kg

b. $Mv = \dfrac{Wo - Wi}{W} x\, W$, W = 4.2 kg, W_{10} = 60 gr, W_{11} = 55 gr, W_{12} = 51.3 gr

Moisture removal after 1 hour = $Mv_{11\text{-}12}$ = 0.2864 kg

Moisture removal after 2 hours = $Mv_{10\text{-}12}$ = 0.6125 kg

c. $H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 9.74 mV – 4.42 mV = 5.32 mV (clouds were present)

H_{bz} = 393.49 W / m^2

Average H_{bz} = (386.83 + 393.49) / 2 = 390.16 W / m^2

Gain of energy in 2 hours = 390.16 W / m^2 x 7200 second = 2.8092 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °, β = 45 °, δ = - 0.40.3 ^{0},

$\varpi = 15^0 \text{ x } (12 - 12) = 0^0$

So, the beam radiation on a tilted surfaced at an angle β with horizontal,

<u>On the below area of the reverse flat plate absorber cabinet dryer :</u>

$H_{bt} = h_{bz} \text{ x } r_b$, r_b = 1.1195

H_{bt} = 1.1195 x 2.8092 MJ / m^2 = 3.1449 MJ / m^2

and the tilted factor, r_d, = 0.8536

the diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} \text{ x } r_d$,

where: H_{dz} = 4.42 mV = 326.92 W / m^2

Average H_{dz} = (370.56 + 326.92) / 2 = 348.74 W / m^2

Gain of energy in 2 hours = 348.74 W/m^2 x 7200 second = 2.5109 MJ/m^2

H_{dt} = 2.5109 MJ/m^2 x 0.8536 = 2.1433 MJ/m^2 .

On the top area of the reverse flat plate absorber cabinet dryer:

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

At 11.00 AM , $\cos\theta_{11} = 0.9342$

H_{tz} = (376.85 W/m^2 x 0.9342) + 364.64 W/m^2 = 716.70 W/m^2

At 12.00 AM , $\cos\theta_{12} = 0.9671$

H_{tz} = (390.16 W/m^2 x 0.9671) + 348.74 W/m^2 = 726.07 W/m^2

Average H_{tz} = 721.38 W/m^2

Gain of energy in 2 hours = 721.38 W/m^2 x 7200 second = 5.1940 MJ/m^2

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

For : $M_{v(11-12)}$

$$\eta = \frac{0.2864\ Kg\ x\ 2.4283\ MJ/kg}{\left(0.43\ m^2 x (5.1940 + 2.1433 + 3.1449)\ MJ/m^2\right)} x\ 100\% \quad = 15.31\ \%$$

For : $M_{v(10-12)}$

$$\eta = \frac{0.6125\ Kg\ x\ 2.4283\ MJ/kg}{\left(0.43\ m^2 x (5.1940 + 2.1433 + 3.1449)\ MJ/m^2\right)} x\ 100\% \quad = 32.75\ \%$$

At 13 : 00 AM

a. Average Crop Temperature (Tc) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$ = 34.7 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.4190 MJ/kg

b. $Mv = \frac{Wo - Wi}{W} x\ W$, W = 4.2 kg, W_{10} = 60 gr, W_{12} = 51.3 gr, W_{13} = 47.5 gr

Moisture removal after 1 hour = Mv_{12-13} = 0.3073 kg

Moisture removal after 3 hours = Mv_{10-13} = 0.8750 kg

c. $H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 10.48 mV – 4.71 mV = 5.77 mV (clouds were present)

H_{bz} = 426.78 W / m^2

Average H_{bz} = (426.78 + 393.49) / 2 = 410.13 W / m^2

Gain of energy in 3 hours = 410.13 W / m^2 x 10800 second = 4.4294 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °, β = 45 °, δ = - 0.40.3 ^{0},

ϖ = 15 ^{0} x (12 – 13) = - 15 ^{0}

So, the beam radiation on a tilted surfaced at an angle β with horizontal,

<u>On the below area of the reverse flat plate absorber cabinet dryer :</u>

$H_{bt} = h_{bz} \times r_b$, r_b = 1.1197

H_{bt} = 1.1197 x 4.4294 MJ / m^2 = 4.9596 MJ / m^2

and the tilted factor, r_d, = 0.8536

the diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} \times r_d$,

where: H_{dz} = 4.71 mV = 348.37 W / m^2

Average H_{dz} = (348.37 + 326.92) / 2 = 337.65 W / m^2

Gain of energy in 3 hours = 337.65 W / m^2 x 10800 second = 3.6466 MJ / m^2

H_{dt} = 3.6466 MJ / m^2 x 0.8536 = 3.1127 MJ / m^2 .

<u>On the top area of the reverse flat plate absorber cabinet dryer:</u>

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

<u>At 12.00 AM</u> , $\cos\theta_{12}$ = 0.9671

H_{tz} = (390.16 W / m^2 x 0.9671) + 348.74 W / m^2 = 726.07 W / m^2

<u>At 13.00 AM</u> , $\cos\theta_{13}$ = 0.9342

H_{tz} = (410.13 W / m^2 x 0.9342) + 337.65 W / m^2 = 720.79 W / m^2

Average H_{tz} = 723.43 W / m^2

Gain of energy in 3 hours = 723.43 W / m^2 x 10800 second = 7.8131 MJ / m^2

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

For : $M_{v\,(12\text{-}13)}$

$$\eta = \frac{0.3073\ Kg\ x\ 2.4190\ MJ / kg}{\left(0.43\ m^2 x (7.8131 + 3.1127 + 4.9596)\ MJ / m^2\right)} x\ 100\% \quad = 10.80\ \%$$

For : $M_{v\,(10\text{-}13)}$

$$\eta = \frac{0.8750\ Kg\ x\ 2.4190\ MJ / kg}{\left(0.43\ m^2 x (7.8131 + 3.1127 + 4.9596)\ MJ / m^2\right)} x\ 100\% \quad = 30.76\ \%$$

At 14 : 00 AM

a. Average Crop Temperature (Tc) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$ = 32.7 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.4240 MJ/kg

b. $Mv = \frac{Wo - Wi}{W} x\ W$, W = 4.2 kg, W_{10} = 60 gr, W_{13} = 47.50 gr, W_{14} = 45 gr

Moisture removal after 1 hour = $Mv_{13\text{-}14}$ = 0.2211 kg

Moisture removal after 4 hours = $Mv_{10\text{-}14}$ = 1.0500 kg

c. $H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 10.51 mV – 4.32 mV = 6.19 mV (clouds were present)

H_{bz} = 457.84 W / m^2

Average H_{bz} = (426.78 + 457.84) / 2 = 442.31 W / m^2

Gain of energy in 4 hours = = 442.31 W / m^2 x 14400 second ≐ 6.3692 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °, β = 45 °, δ = - 0.40.3 ^{0},

$\varpi = 15^0 x (12 - 14) = -30^0$

So. the beam radiation on a tilted surfaced at an angle β with horizontal,

On the below area of the reverse flat plate absorber cabinet dryer :

$H_{bt} = h_{bz} \times r_b$, $r_b = 1.121$

$H_{bt} = 1.121 \times 6.3692\ MJ / m^2 = 7.1399\ MJ / m^2$

and the tilted factor, r_d, $= 0.8536$

the diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} \times r_d$,

where: $H_{dz} = 4.32\ mV = 319.53\ W / m^2$

Average $H_{dz} = (348.37 + 319.53) / 2 = 333.95\ W / m^2$

Gain of energy in 4 hours $= 333.95\ W / m^2 \times 14400$ second $= 4.8089\ MJ / m^2$

$H_{dt} = 4.8089\ MJ / m^2 \times 0.8536 = 4.1049\ MJ / m^2$.

On the top area of the reverse flat plate absorber cabinet dryer:

$H_{tz} = H_{bz} \cos\theta + H_{dz}$,

At 13.00 AM , $\cos\theta_{13} = 0.9342$

$H_{tz} = (410.13\ W / m^2 \times 0.9342) + 337.65\ W / m^2 = 720.79\ W / m^2$

At 14.00 AM , $\cos\theta_{14} = 0.8378$

$H_{tz} = (442.31\ W / m^2 \times 0.8378) + 337.65\ W / m^2 = 704.52\ W / m^2$

Average $H_{tz} = 712.65\ W / m^2$

Gain of energy in 4 hours $= 712.65\ W / m^2 \times 14400$ second $= 10.2622\ MJ / m^2$

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

For : $M_{v\,(13\text{-}14)}$

$$\eta = \frac{0.2211\ Kg \times 2.4240\ MJ / kg}{\left(0.43\ m^2 x (10.2622 + 4.1049 + 7.1399)\ MJ / m^2\right)} \times 100\,\% = 5.75\,\%$$

For : $M_{v\,(10\text{-}14)}$

$$\eta = \frac{1.0500\ Kg \times 2.4240\ MJ / kg}{\left(0.43\ m^2 x (10.2622 + 4.1049 + 7.1399)\ MJ / m^2\right)} \times 100\,\% = 27.32\,\%$$

At 15 : 00 AM

a. Average Crop Temperature (Tc) = $\frac{Tc1 + Tc2 + Tc3 + Tc4}{4}$ = 31.9 °C

From the steam table is obtained the latent heat of vaporation Lv

at Tc (avg) = 2.4260 MJ/kg

b. $Mv = \frac{Wo - Wi}{W} x W$, W = 4.2 kg, W_{10} = 60 gr, W_{14} = 45 gr, W_{15} = 44 gr

Moisture removal after 1 hour = Mv_{14-15} = 0.0933 kg

Moisture removal after 5 hours = Mv_{10-15} = 1.1200 kg

c. $H_{bz} = H_{tz} - H_{dz}$

H_{bz} = 9.92 mV – 4.86 mV = 5.06 mV (clouds were present)

H_{bz} = 374.26 W / m^2

Average H_{bz} = (374.26 + 457.84) / 2 = 416.05 W / m^2

Gain of energy in 5 hours = = 416.05 W / m^2 x 18000 second = 7.4889 MJ / m^2.

d. In order to find the beam energy and the diffuse energy falling on a tilted surface:

the latitude (ϕ) at Roorkee = 29.85 °, β = 45 °, δ = - 0.40.3 ^{0},

$\varpi = 15^0 x (12 – 15) = - 45^0$

So, the beam radiation on a tilted surfaced at an angle β with horizontal,

<u>On the below area of the reverse flat plate absorber cabinet dryer :</u>

$H_{bt} = h_{bz} x r_b$, r_b = 1.1223

H_{bt} = 1.1223 x 7.4889 MJ / m^2 = 8.4048 MJ / m^2

and the tilted factor, r_d, = 0.8536

the diffuse radiation on tilted surfaced at angle $\beta = 45^0$ with horizontal ,

$H_{dt} = H_{dz} x r_d$,

where: H_{dz} = 4.86 mV = 359.47 W / m^2

Average H_{dz} = (359.47 + 319.53) / 2 = 339.50 W / m^2

Gain of energy in 5 hours = 339.50 W / m^2 x 18000 second = 6.1109 MJ / m^2

H_{dt} = 6.1109 MJ / m^2 x 0.8536 = 5.2163 MJ / m^2 .

<u>On the top area of the reverse flat plate absorber cabinet dryer:</u>

$H_{tz} = H_{bz} \cos \theta + H_{dz}$,

<u>At 14.00 AM</u> , $\cos \theta_{14} = 0.8378$

H_{tz} = (442.31 W / m^2 x 0.8378) + 337.65 W / m^2 = 704.52 W / m^2

<u>At 15.00 AM</u> , $\cos \theta_{15} = 0.6844$

H_{tz} = (416.05 W / m^2 x 0.6844) + 339.50 W / m^2 = 624.24 W / m^2

Average H_{tz} = 664.39 W / m^2

Gain of energy in 5 hours = 664.39 W / m^2 x 18000 second = 11.9588 MJ / m^2

e. The hourly efficiency or instantaneous efficiency is calculated from equation,

<u>For : $M_{v\,(14\text{-}15)}$</u>

$$\eta = \frac{0.0933\ Kg\ x\ 2.4260\ MJ / kg}{\left(0.43\ m^2 x(11.9588 + 5.2163 + 8.4048) MJ / m^2\right)} x\ 100\,\% \quad = 2.04\ \%$$

<u>For : $M_{v\,(10\text{-}15)}$</u>

$$\eta = \frac{1.1200\ Kg\ x\ 2.4260\ MJ / kg}{\left(0.43\ m^2 x(11.9588 + 5.2163 + 8.4048) MJ / m^2\right)} x\ 100\,\% \quad = 24.52\ \%$$

f. Finally, the Daily Efficiency is obtained from the equation,

$$\eta_d = \frac{Mv\ x\ Lv_{(avg)}}{A \times \Sigma \overline{H}}$$

$$L_{v\,(average)} = \frac{2.4449 + 2.443 + 2.4283 + 2.419 + 2.424 + 2.426}{6} = 2.4\ \text{MJ/kg}$$

$$\Sigma \overline{H} = \frac{\frac{1}{2}\left[H_{10} + 2H_{11} + 2H_{12} + 2H_{13} + 2H_{14} + H_{15}\right]}{5}$$

Table 4.1 Measured Data: 21-2-05(D=0.06m,V=0.03m), wheat: 3kg & on wet 4.05kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 5.2 Nauts & Instantaneous: 0 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		20.9	24.5	25.3	25.8	26.9	24.8
T_F (°C)	T_{F1}	21.6	25.3	26.6	26.6	24.8	25.3
	T_{F2}	21.6	25.3	26.6	26.6	24.8	25.2
	T_{F3}	22.4	26.1	27.4	27.4	25.6	26.0
	T_{F4}	21.7	25.4	26.7	26.7	24.9	25.3
	$T_{F(avg)}$	21.8	25.5	26.8	26.8	25.0	25.5
T_C (°C)	T_{C1}	17.1	19.3	22.6	22.9	21.3	23.4
	T_{C2}	16.6	18.8	22.1	23.4	21.8	22.9
	T_{C3}	17.0	19.2	22.5	23.0	21.4	23.3
	T_{C4}	16.8	19.0	22.3	23.2	21.6	23.1
	$T_{C(avg)}$	16.9	19.1	22.3	23.2	21.5	23.2
T_P (°C)	T_{P1}	21.5	30.1	31.6	31.9	29.6	29.4
	T_{P2}	22.3	30.9	32.3	32.7	30.4	30.2
	T_{P3}	21.7	30.2	31.7	32.1	29.8	29.6
	T_{P4}	21.6	30.1	31.6	31.9	29.6	29.5
	$T_{P(avg)}$	21.8	30.3	31.8	32.2	29.8	29.7
H_{Tz} (mV)		9.37	9.25	8.31	8.91	8.12	8.96
H_{dz} (mV)		4.56	5.01	4.82	4.76	4.13	5.23
H_{bz} (mV)		4.81	4.24	3.49	4.15	3.99	3.73
Sample (grams)	S_1	60	56	52	50	47	46
	S_2	60	56	52	50	46	46
	S_3	60	56	52	50	47	46
	S_4	60	56	52	50	47	47
	$S_{(avg)}$	60.0	56.0	52.0	50.0	46.8	46.3
$\eta\%_{(1\ hour)}$		0.00	30.16	16.81	6.19	7.96	1.60
$\eta\%$		0.00	30.16	31.37	26.81	27.04	23.32
$\eta_d\%$		22.47					
$M_{v-1\_hour\ (kg)}$		0.00	0.2700	0.2893	0.1558	0.2633	0.0650
$M_{v\ (kg)}$		0.00	0.2700	0.5400	0.6750	0.8944	0.9450

Table 4.2 Measured Data: 22-2-05(D=0.06m,V=0.03m), wheat: 3kg & on wet 3.17kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 3.9 Nauts & Instantaneous: 0 kmph) & Direction: WN

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		18.9	23.5	26.2	25.7	24.2	22.5
T_F (°C)	T_{F1}	19.4	20.0	27.4	23.2	24.6	22.8
	T_{F2}	19.4	20.0	27.4	23.2	24.5	22.8
	T_{F3}	20.2	20.8	28.2	24.0	25.4	23.6
	T_{F4}	19.6	20.2	27.6	23.4	24.8	23.0
	$T_{F (avg)}$	19.7	20.3	27.7	23.5	24.8	23.0
T_C (°C)	T_{C1}	14.7	14.7	22.4	20.9	22.1	20.4
	T_{C2}	14.9	14.8	22.6	20.7	21.9	20.6
	T_{C3}	14.9	14.9	22.7	20.7	21.9	20.6
	T_{C4}	15.1	15.1	22.9	20.4	21.7	20.8
	$T_{C (avg)}$	14.9	14.9	22.6	20.7	21.9	20.6
T_P (°C)	T_{P1}	20.3	24.8	33.5	28.8	30.3	27.5
	T_{P2}	19.9	24.4	33.1	28.4	29.9	27.1
	T_{P3}	20.3	24.7	33.5	28.8	30.2	27.5
	T_{P4}	20.1	24.5	33.3	28.6	30.0	27.3
	$T_{P (avg)}$	20.1	24.6	33.3	28.6	30.1	27.4
H_{Tz} (mV)		8.62	8.34	7.45	7.76	8.46	8.78
H_{dz} (mV)		4.23	4.62	3.22	5.56	3.83	4.31
H_{bz} (mV)		4.39	3.72	4.23	2.20	4.63	4.47
Sample (grams)	S_1	47	45	44	43	42	42
	S_2	47	45	43	43	42	42
	S_3	47	44	43	42	42	42
	S_4	47	44	43	42	42	42
	$S_{(avg)}$	47.0	44.5	43.3	42.5	42.0	42.0
η % (1 hour)		0.00	20.72	5.66	2.48	1.22	0.00
η %		0.00	20.72	16.08	13.72	11.06	8.23
η_d %		8.63					
M_{v-1_hour} (kg)		0.00	0.1686	0.0890	0.0550	0.0373	0.0000
$M_{v (kg)}$		0.00	0.1686	0.2529	0.3035	0.3372	0.3372

Table 4.3 Measured Data: 24-2-05(D=0.05m,V=0.03m), wheat: 3kg & on wet 4.05kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 2.8 Nauts & Instantaneous: 0 kmph) & Direction: WS

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		20.0	22.1	25.9	26.3	24.5	23.4
T_F (°C)	T_{F1}	23.1	27.7	28.1	27.9	27.5	27.7
	T_{F2}	22.3	26.9	27.2	27.1	26.6	26.8
	T_{F3}	22.8	27.4	27.7	27.6	27.1	27.3
	T_{F4}	22.5	27.1	27.4	27.3	26.8	27.0
	$T_{F (avg)}$	22.7	27.3	27.6	27.5	27.0	27.2
T_C (°C)	T_{C1}	16.9	19.7	22.3	24.2	23.8	24.0
	T_{C2}	17.0	19.8	22.4	24.1	23.6	24.1
	T_{C3}	17.5	20.4	22.9	23.5	23.1	24.7
	T_{C4}	17.6	20.4	23.0	23.5	23.0	24.7
	$T_{C (avg)}$	17.2	20.1	22.6	23.8	23.4	24.4
T_P (°C)	T_{P1}	22.5	32.3	32.5	32.8	32.0	31.6
	T_{P2}	22.9	32.6	32.9	33.1	32.4	31.9
	T_{P3}	23.1	32.9	33.1	33.4	32.6	32.2
	T_{P4}	22.5	32.2	32.5	32.8	32.0	31.6
	$T_{P (avg)}$	22.7	32.5	32.8	33.0	32.2	31.8
H_{Tz} (mV)		9.89	9.75	8.24	8.14	8.85	8.81
H_{dz} (mV)		4.88	5.13	4.72	4.12	4.52	4.71
H_{bz} (mV)		5.01	4.62	3.52	4.02	4.33	4.10
Sample (grams)	S_1	60	56	53	50	47	46
	S_2	60	56	52	50	47	46
	S_3	60	56	52	50	47	46
	S_4	60	56	52	50	47	46
	$S_{(avg)}$	60.0	56.0	52.3	50.0	47.0	46.0
$\eta\%_{(1\ hour)}$		0.00	29.65	14.82	7.98	7.21	1.83
η %		0.00	29.65	29.50	28.49	27.28	22.83
η_d %		22.28					
$M_{v-1\_hour (kg)}$		0.00	0.2784	0.2628	0.1938	0.2340	0.0756
$M_{v (kg)}$		0.00	0.2784	0.5231	0.6919	0.8859	0.9450

Table 4.4 Measured Data: 25-2-05(D=0.05m,V=0.03m), wheat: 3kg & on wet 3.17kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 4.2 Nauts & Instantaneous: 0 kmph) & Direction: WS

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		19.8	23.4	26.5	24.5	24.9	23.4
T_F (°C)	T_{F1}	21.2	27.3	27.9	29.0	28.4	27.9
	T_{F2}	21.6	27.7	28.3	29.4	28.8	28.3
	T_{F3}	20.8	26.8	27.4	28.6	28.0	27.5
	T_{F4}	21.0	27.0	27.6	28.7	28.1	27.7
	$T_{F(avg)}$	21.2	27.2	27.8	28.9	28.3	27.8
T_C (°C)	T_{C1}	16.5	20.4	23.2	24.9	24.3	25.4
	T_{C2}	16.3	20.2	23.0	25.1	24.5	25.1
	T_{C3}	15.8	19.7	22.6	25.6	25.0	24.7
	T_{C4}	15.7	19.6	22.4	25.7	25.1	24.5
	$T_{C(avg)}$	16.1	20.0	22.8	25.3	24.8	24.9
T_P (°C)	T_{P1}	21.2	32.4	33.1	34.8	33.9	32.6
	T_{P2}	20.9	32.1	32.7	34.4	33.5	32.2
	T_{P3}	20.9	32.1	32.8	34.5	33.6	32.3
	T_{P4}	21.6	32.8	33.4	35.1	34.2	32.9
	$T_{P(avg)}$	21.1	32.4	33.0	34.7	33.8	32.5
H_{Tz} (mV)		10.95	9.87	8.12	7.81	8.75	8.92
H_{dz} (mV)		4.85	5.12	4.65	4.35	4.37	4.68
H_{bz} (mV)		6.10	4.75	3.47	3.46	4.38	4.24
Sample (grams)	S_1	47	44	43	42	42	42
	S_2	47	44	43	42	42	42
	S_3	47	45	43	43	42	42
	S_4	47	44	43	42	42	42
	$S_{(avg)}$	47.0	44.3	43.0	42.3	42.0	42.0
η % (1 hour)		0.00	18.37	4.98	2.33	0.59	0.00
η %		0.00	18.37	15.01	13.49	10.68	8.09
η_d %		7.92					
M_{v-1_hour} (kg)		0.00	0.1855	0.0895	0.0553	0.0188	0.0000
M_v (kg)		0.00	0.1855	0.2698	0.3204	0.3372	0.3372

Table 4.5 Measured Data: 28-2-05(D=0.06m,V=0.03m), peas: 2kg & on wet 2.47kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 4.2 Nauts & Instantaneous: 0 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		25.00	28.50	29.40	29.80	27.50	27.10
T_F (°C)	T_{F1}	26.84	30.94	32.06	31.96	28.58	27.49
	T_{F2}	26.80	30.90	32.03	31.93	28.55	27.45
	T_{F3}	27.59	31.69	32.81	32.71	29.33	28.24
	T_{F4}	26.91	31.01	32.13	32.03	28.65	27.55
	$T_{F (avg)}$	27.03	31.13	32.26	32.16	28.78	27.68
T_C (°C)	T_{C1}	21.07	23.42	27.00	27.75	24.70	25.36
	T_{C2}	20.59	22.94	26.51	28.24	25.18	24.87
	T_{C3}	21.00	23.35	26.93	27.83	24.77	25.28
	T_{C4}	20.79	23.14	26.71	28.04	24.98	25.07
	$T_{C (avg)}$	20.86	23.21	26.79	27.96	24.91	25.15
T_P (°C)	T_{P1}	26.78	36.80	38.03	38.34	34.07	32.05
	T_{P2}	27.57	37.59	38.81	39.12	34.86	32.83
	T_{P3}	26.96	36.98	38.20	38.52	34.25	32.23
	T_{P4}	26.81	36.83	38.05	38.37	34.10	32.08
	$T_{P (avg)}$	27.03	37.05	38.27	38.59	34.32	32.30
H_{Tz} (mV)		5.52	9.56	10.94	10.53	9.58	9.51
H_{dz} (mV)		2.80	3.12	2.45	2.42	2.21	2.32
H_{bz} (mV)		2.72	6.44	8.49	8.11	7.37	7.19
Sample (grams)	S_1	55.00	50.00	45.95	44.00	41.00	40.00
	S_2	55.00	50.00	46.00	44.00	41.00	40.00
	S_3	55.00	50.00	46.02	44.00	41.00	40.00
	S_4	55.00	51.00	47.00	44.00	42.00	40.00
	$S_{(avg)}$	55.00	50.25	46.24	44.00	41.25	40.00
$\eta \%_{(1\ hour)}$		0.00	30.93	10.09	3.67	3.76	1.59
η %		0.00	30.93	20.14	15.13	15.04	14.29
η_d %		14.03					
$M_{v-1\_hour\ (kg)}$		0.00	0.2133	0.1969	0.1198	0.1544	0.0748
$M_{v\ (kg)}$		0.00	0.2133	0.3933	0.4940	0.6175	0.6736

Table 4.6 Measured Data: 1-3-05(D=0.06m,V=0.03m), peas: 2kg & on wet 1.86kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 3 Nauts & Instantaneous: 2 kmph) & Direction: W

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		25.5	29.5	29.8	30.5	28.0	27.4
T_F (°C)	T_{F1}	26.8	31.5	32.6	33.0	30.1	29.2
	T_{F2}	26.8	31.4	32.5	33.0	30.1	29.2
	T_{F3}	27.6	32.2	33.3	33.7	30.9	30.0
	T_{F4}	26.9	31.5	32.7	33.1	30.2	29.3
	$T_{F(avg)}$	27.0	31.6	32.8	33.2	30.3	29.4
T_C (°C)	T_{C1}	21.1	23.8	27.4	28.7	26.1	26.9
	T_{C2}	21.6	24.5	26.9	29.2	26.6	26.4
	T_{C3}	21.0	23.7	27.4	28.8	26.1	26.8
	T_{C4}	21.8	24.9	27.1	29.0	26.4	26.6
	$T_{C(avg)}$	21.4	24.2	27.2	28.9	26.3	26.7
T_P (°C)	T_{P1}	26.8	37.4	38.6	39.6	35.9	34.1
	T_{P2}	27.6	38.2	39.4	40.4	36.7	34.8
	T_{P3}	27.0	37.6	38.8	39.8	36.1	34.2
	T_{P4}	26.8	37.4	38.7	39.6	35.9	34.1
	$T_{P(avg)}$	27.0	37.7	38.9	39.8	36.1	34.3
H_{Tz} (mV)		7.41	8.79	10.32	10.83	5.59	5.42
H_{dz} (mV)		3.44	2.61	2.56	3.42	3.88	3.91
H_{bz} (mV)		3.97	6.18	7.76	7.41	1.71	1.51
Sample (grams)	S_1	42	39	37	35	34	33
	S_2	41	39	37	36	35	34
	S_3	41	38	37	36	35	34
	S_4	42	39	37	35	34	34
	$S_{(avg)}$	41.5	38.7	37.0	35.5	34.5	33.8
η % (1 hour)		0.00	15.97	4.51	2.41	1.55	1.45
η %		0.00	15.97	10.84	8.59	9.27	12.47
η_d %		8.45					
M_{v-1_hour} (kg)		0.00	0.1233	0.0839	0.0754	0.0524	0.0404
M_{v} (kg)		0.00	0.1233	0.2017	0.2689	0.3137	0.3473

Table 4.7 Measured Data: 3-3-05(D=0.06m,V=0.03m), peas: 3kg & on wet 3.7kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 4.3 Nauts & Instantaneous: 0 kmph) & Direction: WE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		25.2	28.1	29.2	30.1	28.4	27.3
T_F (°C)	T_{F1}	25.3	29.9	30.5	30.9	27.1	26.0
	T_{F2}	25.3	29.9	30.5	30.9	27.0	25.9
	T_{F3}	26.1	30.7	31.2	31.7	27.8	26.7
	T_{F4}	25.4	30.0	30.6	31.0	27.1	26.0
	$T_{F(avg)}$	25.5	30.1	30.7	31.1	27.3	26.2
T_C (°C)	T_{C1}	19.9	22.7	25.7	26.8	23.3	24.0
	T_{C2}	19.4	22.2	25.2	27.3	23.8	23.5
	T_{C3}	19.8	22.6	25.6	26.9	23.4	23.9
	T_{C4}	19.6	22.4	25.4	27.1	23.6	23.7
	$T_{C(avg)}$	19.7	22.5	25.5	27.0	23.5	23.8
T_P (°C)	T_{P1}	25.2	35.6	36.2	37.1	32.3	30.3
	T_{P2}	26.0	36.4	36.9	37.9	33.0	31.1
	T_{P3}	25.4	35.8	36.3	37.3	32.4	30.4
	T_{P4}	25.3	35.6	36.2	37.1	32.3	30.3
	$T_{P(avg)}$	25.5	35.8	36.4	37.4	32.5	30.5
H_{Tz} (mV)		8.25	8.74	10.21	10.67	8.82	8.25
H_{dz} (mV)		3.16	2.65	2.14	2.82	2.53	2.67
H_{bz} (mV)		5.09	6.09	8.07	7.85	6.29	5.58
Sample (grams)	S_1	55	52	48	45	42	41
	S_2	55	51	47	45	42	40
	S_3	55	52	47	45	42	40
	S_4	55	51	47	44	42	41
	$S_{(avg)}$	55.0	51.5	47.3	44.8	42.0	40.5
η % (1 hour)		0.00	28.74	16.39	6.31	5.82	3.15
η %		0.00	28.74	27.98	22.23	22.39	23.24
η_d %		21.19					
$M_{v\text{-}1\_hour}$ (kg)		0.00	0.2355	0.3053	0.1958	0.2274	0.1321
M_v (kg)		0.00	0.2355	0.5214	0.6895	0.8745	0.9755

Table 4.8 Measured Data: 4-3-05(D=0.06m,V=0.03m), peas: 3kg & on wet 2.78kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 1.9 Nauts & Instantaneous: 0 kmph) & Direction: SW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		25.5	27.9	28.6	30.4	29.4	28.9
T_F (°C)	T_{F1}	26.9	31.4	32.6	33.0	30.1	29.2
	T_{F2}	26.8	31.4	32.6	33.0	30.1	29.2
	T_{F3}	27.6	32.2	33.3	33.5	30.9	30.0
	T_{F4}	26.9	31.5	32.7	33.1	30.2	29.1
	$T_{F\,(avg)}$	27.1	31.6	32.8	33.1	30.3	29.4
T_C (°C)	T_{C1}	21.1	23.8	27.4	28.7	26.1	26.9
	T_{C2}	21.6	24.4	26.9	29.2	26.6	26.4
	T_{C3}	21.0	23.7	27.4	28.8	26.1	26.9
	T_{C4}	21.8	24.9	27.1	29.0	26.4	26.6
	$T_{C\,(avg)}$	21.4	24.2	27.2	28.9	26.3	26.7
T_P (°C)	T_{P1}	26.8	37.4	38.6	38.9	36.0	34.1
	T_{P2}	27.6	38.2	39.4	40.4	36.7	34.8
	T_{P3}	27.0	37.6	38.6	39.8	36.1	34.2
	T_{P4}	26.8	37.4	38.7	39.6	35.9	34.1
	$T_{P\,(avg)}$	27.0	37.7	38.8	39.7	36.2	34.3
H_{Tz} (mV)		7.32	8.81	10.31	10.84	5.80	5.64
H_{dz} (mV)		3.42	2.40	2.55	3.44	3.73	3.84
H_{bz} (mV)		3.90	6.41	7.76	7.40	2.07	1.80
Sample (grams)	S_1	41	39	38	37	36	36
	S_2	41	40	39	38	37	36
	S_3	41	40	39	38	37	35
	S_4	42	40	39	37	36	36
	$S_{(avg)}$	41.3	39.8	38.8	37.5	36.5	35.8
η % (1 hour)		0.00	13.26	3.78	2.89	2.18	1.99
η %		0.00	13.26	9.11	8.14	9.40	12.88
η_d %		9.00					
$M_{v\text{-}1\_hour}$ (kg)		0.00	0.1011	0.0699	0.0897	0.0741	0.0571
$M_{v\,(kg)}$		0.00	0.1011	0.1685	0.2527	0.3201	0.3707

Table 4.9 Measured Data: 9-3-05(D=0.06m,V=0.01m), peas: 4kg & on wet 4.93kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 1.6 Nauts & Instantaneous: 4 kmph) & Direction: EN

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.1	28.4	30.2	31.5	32.7	32.4
T_F (°C)	T_{F1}	28.0	29.3	31.7	32.5	33.3	32.9
	T_{F2}	27.9	29.3	31.7	32.4	33.3	32.9
	T_{F3}	28.7	30.0	32.5	33.2	34.1	33.7
	T_{F4}	28.0	29.4	31.8	32.5	33.4	33.0
	$T_{F(avg)}$	28.2	29.5	31.9	32.7	33.5	33.1
T_C (°C)	T_{C1}	21.9	22.2	26.7	28.2	29.0	30.2
	T_{C2}	21.4	21.7	26.3	28.7	29.5	29.8
	T_{C3}	21.9	22.1	26.7	28.3	29.1	30.2
	T_{C4}	21.6	21.9	26.5	28.5	29.3	30.0
	$T_{C(avg)}$	21.7	22.0	26.5	28.4	29.2	30.0
T_P (°C)	T_{P1}	27.9	34.8	37.7	39.0	39.8	38.4
	T_{P2}	28.7	35.6	38.4	39.7	40.6	39.2
	T_{P3}	28.1	35.0	37.8	39.1	40.0	38.6
	T_{P4}	27.9	34.9	37.7	39.0	39.8	38.5
	$T_{P(avg)}$	28.2	35.1	37.9	39.2	40.0	38.7
H_{Tz} (mV)		8.42	10.57	10.32	10.83	9.85	9.71
H_{dz} (mV)		2.04	2.61	2.41	2.56	2.64	2.35
H_{bz} (mV)		6.38	7.96	7.91	8.27	7.21	7.36
Sample (grams)	S_1	55	52	48	45	43	41
	S_2	55	52	48	46	43	41
	S_3	55	52	48	45	43	41
	S_4	55	52	48	46	43	41
	$S_{(avg)}$	55.0	52.0	48.0	45.5	43.0	41.0
η % (1 hour)		0.00	30.11	18.71	8.16	6.69	4.93
η %		0.00	30.11	30.95	27.05	26.56	26.97
η_d %		25.49					
M_{v-1_hour} (kg)		0.00	0.2689	0.3792	0.2568	0.2709	0.2293
M_v (kg)		0.00	0.2689	0.6275	0.8515	1.0756	1.2549

Table 4.10 Measured Data: 10-3-05(D=0.06m,V=0.01m), peas: 4kg & on wet 3.77kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 3.2 Nauts & Instantaneous: 0 kmph) & Direction: N

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.3	28.5	29.9	31.5	33.4	30.2
T_F (°C)	T_{F1}	28.1	29.6	32.1	32.8	33.5	32.0
	T_{F2}	28.1	29.5	32.1	32.7	33.5	32.0
	T_{F3}	28.9	30.3	32.9	33.5	34.2	32.8
	T_{F4}	28.2	29.6	32.2	32.9	33.6	32.1
	$T_{F\ (avg)}$	28.3	29.8	32.3	33.0	33.7	32.2
T_C (°C)	T_{C1}	22.0	22.4	27.0	28.5	29.1	29.4
	T_{C2}	21.6	21.9	26.6	29.0	29.6	28.9
	T_{C3}	22.0	22.3	27.0	28.6	29.2	29.4
	T_{C4}	21.8	22.1	26.8	28.8	29.4	29.1
	$T_{C\ (avg)}$	21.8	22.2	26.8	28.7	29.3	29.2
T_P (°C)	T_{P1}	28.1	35.2	38.1	39.3	40.0	37.4
	T_{P2}	28.9	35.9	38.9	40.1	40.8	38.2
	T_{P3}	28.2	35.3	38.3	39.5	40.1	37.6
	T_{P4}	28.1	35.2	38.1	39.4	40.0	37.4
	$T_{P\ (avg)}$	28.3	35.4	38.3	39.6	40.2	37.6
H_{Tz} (mV)		8.42	10.65	10.32	10.73	10.38	9.65
H_{dz} (mV)		2.04	2.61	2.41	2.75	2.44	2.43
H_{bz} (mV)		6.38	8.04	7.91	7.98	7.94	7.22
Sample (grams)	S_1	42	41	39	38	37	37
	S_2	42	41	40	38	38	37
	S_3	42	40	39	38	37	36
	S_4	42	40	39	38	37	37
	$S_{(avg)}$	42.0	40.5	39.3	38.0	37.3	36.8
$\eta\%_{(1\ hour)}$		0.00	15.07	5.73	3.84	1.82	1.07
η %		0.00	15.07	12.16	11.49	10.40	9.94
η_d %		9.52					
$M_{v\text{-}1\_hour\ (kg)}$		0.00	0.1346	0.1164	0.1201	0.0744	0.0506
$M_{v\ (kg)}$		0.00	0.1346	0.2468	0.3590	0.4264	0.4713

Table 4.11 Measured Data on 14-3-05(D=0.06m, V=0.02m), peas: 4kg & on wet 4.93kg (1st day)

Time: 8:30, Wind Velocity (Daily Average: 2.2 Nauts & Instantaneous: 0 kmph) & Direction: -

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.0	28.6	30.1	31.3	32.4	32.3
T_F (°C)	T_{F1}	28.4	29.4	32.6	34.0	34.1	33.0
	T_{F2}	28.3	29.4	32.5	34.0	34.0	33.0
	T_{F3}	29.1	30.2	33.3	34.8	34.8	33.8
	T_{F4}	28.4	29.5	32.7	34.1	34.1	33.1
	$T_{F(avg)}$	28.6	29.6	32.8	34.2	34.3	33.2
T_C (°C)	T_{C1}	22.2	22.3	27.4	29.6	29.6	30.3
	T_{C2}	21.7	21.8	26.9	30.1	30.1	29.8
	T_{C3}	22.2	22.2	27.4	29.7	29.7	30.3
	T_{C4}	21.9	22.0	27.1	29.9	29.9	30.0
	$T_{C(avg)}$	22.0	22.1	27.2	29.8	29.8	30.1
T_P (°C)	T_{P1}	28.3	35.0	38.6	40.8	40.6	38.6
	T_{P2}	29.1	35.8	39.4	41.6	41.4	39.4
	T_{P3}	28.5	35.1	38.8	41.0	40.8	38.7
	T_{P4}	28.4	35.0	38.7	40.8	40.7	38.6
	$T_{P(avg)}$	28.6	35.2	38.9	41.1	40.9	38.8
H_{Tz} (mV)		9.32	10.42	10.18	10.83	9.46	9.65
H_{dz} (mV)		2.43	2.61	2.74	2.55	2.64	2.35
H_{bz} (mV)		6.89	7.81	7.44	8.28	6.82	7.30
Sample (grams)	S_1	55	52	47	45	43	41
	S_2	55	52	48	45	43	41
	S_3	55	51	47	45	42	40
	S_4	55	52	48	46	42	41
	$S_{(avg)}$	55.0	51.8	47.5	45.3	42.5	40.8
η % (1 hour)		0.00	31.56	20.38	7.61	7.65	4.56
η %		0.00	31.56	33.84	28.47	28.60	28.71
η_d %		26.56					
$M_{v\text{-}1\_hour}$ (kg)		0.00	0.2913	0.4049	0.2335	0.2996	0.2030
M_{v} (kg)		0.00	0.2913	0.6723	0.8740	1.1205	1.2773

Table 4.12 Measured Data: 15-3-05(D=0.06m,V=0.02m), peas: 4kg & on wet 3.77kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 1.4 Nauts & Instantaneous: 0 kmph) & Direction: SW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.1	28.6	29.7	31.7	33.2	30.3
T_F (°C)	T_{F1}	28.6	29.6	32.9	34.2	34.3	33.2
	T_{F2}	28.5	29.6	32.9	34.2	34.3	33.2
	T_{F3}	29.3	30.4	33.6	35.0	35.1	33.9
	T_{F4}	28.6	29.7	33.0	34.3	34.4	33.3
	$T_{F (avg)}$	28.8	29.8	33.1	34.4	34.5	33.4
T_C (°C)	T_{C1}	22.4	22.4	27.7	29.8	29.9	30.5
	T_{C2}	21.9	22.0	27.2	30.3	30.4	30.0
	T_{C3}	22.3	22.4	27.6	29.9	29.9	30.4
	T_{C4}	22.1	22.2	27.4	30.1	30.2	30.2
	$T_{C (avg)}$	22.2	22.2	27.5	30.0	30.1	30.3
T_P (°C)	T_{P1}	28.5	35.2	39.0	41.1	40.9	38.7
	T_{P2}	29.3	36.0	39.8	41.8	41.7	39.5
	T_{P3}	28.7	35.4	39.2	41.2	41.1	38.9
	T_{P4}	28.6	35.2	39.0	41.1	41.0	38.8
	$T_{P (avg)}$	28.8	35.5	39.3	41.3	41.2	39.0
H_{Tz} (mV)		8.64	10.76	10.12	10.83	9.85	9.72
H_{dz} (mV)		2.21	2.68	2.52	2.56	2.55	2.37
H_{bz} (mV)		6.43	8.08	7.60	8.27	7.30	7.35
Sample (grams)	S_1	42	41	39	37	37	37
	S_2	42	40	39	38	37	36
	S_3	42	40	39	38	37	36
	S_4	42	40	39	38	37	37
	$S_{(avg)}$	42.0	40.3	39.0	37.8	37.0	36.5
η % (1 hour)		0.00	17.56	5.86	3.94	1.89	1.12
η %		0.00	17.56	13.48	12.44	11.33	10.89
η_d %		10.21					
$M_{v-1\_hour (kg)}$		0.00	0.1571	0.1171	0.1208	0.0749	0.0509
$M_{v (kg)}$		0.00	0.1571	0.2693	0.3815	0.4488	0.4937

Table 4.13 Measured Data: 16-3-05(D=0.06m,V=0.03m), peas: 4kg & on wet 4.93kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 1.8 Nauts & Instantaneous: 0 kmph) & Direction: SW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.9	30.6	32.2	33.7	34.6	34.1
T_F (°C)	T_{F1}	28.9	29.9	33.6	34.0	34.7	34.1
	T_{F2}	28.9	29.9	33.6	34.0	34.6	34.0
	T_{F3}	29.6	30.7	34.4	34.8	35.4	34.8
	T_{F4}	29.0	30.0	33.7	34.1	34.7	34.1
	$T_{F(avg)}$	29.1	30.1	33.8	34.2	34.9	34.3
T_C (°C)	T_{C1}	22.6	22.7	28.3	29.6	30.2	31.2
	T_{C2}	22.1	22.2	27.8	30.1	30.7	30.8
	T_{C3}	22.5	22.6	28.2	29.7	30.3	31.2
	T_{C4}	22.3	22.4	28.0	29.9	30.5	31.0
	$T_{C(avg)}$	22.4	22.5	28.1	29.8	30.4	31.0
T_P (°C)	T_{P1}	28.8	35.6	39.9	40.8	41.4	39.8
	T_{P2}	29.6	36.4	40.7	41.6	42.1	40.5
	T_{P3}	29.0	35.8	40.1	41.0	41.5	39.9
	T_{P4}	28.9	35.6	39.9	40.8	41.4	39.8
	$T_{P(avg)}$	29.1	35.8	40.1	41.1	41.6	40.0
H_{Tz} (mV)		9.31	10.33	10.20	10.75	10.10	9.44
H_{dz} (mV)		2.45	2.64	2.75	2.40	2.75	2.34
H_{bz} (mV)		6.86	7.69	7.45	8.35	7.35	7.10
Sample (grams)	S_1	55	51	47	45	42	40
	S_2	55	51	47	44	42	41
	S_3	55	51	47	45	42	40
	S_4	55	52	48	45	42	41
	$S_{(avg)}$	55.0	51.3	47.3	44.8	42.0	40.5
η % (1 hour)		0.00	36.77	19.55	8.57	7.62	3.90
η %		0.00	36.77	35.30	30.19	29.32	28.79
η_d %		26.99					
M_{v-1_hour} (kg)		0.00	0.3361	0.3848	0.2608	0.3030	0.1761
M_v (kg)		0.00	0.3361	0.6947	0.9188	1.1653	1.2997

Table 4.14 Measured Data: 17-3-05(D=0.06m,V=0.03m), peas: 4kg & on wet 3.77kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 1.3 Nauts & Instantaneous: 0 kmph) & Direction: N

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		27.0	28.5	30.0	31.6	33.4	31.0
T_F (°C)	T_{F1}	29.1	30.1	33.9	34.2	34.8	34.2
	T_{F2}	29.1	30.1	33.9	34.2	34.8	34.1
	T_{F3}	29.9	30.9	34.7	35.0	35.6	34.9
	T_{F4}	29.2	30.2	34.0	34.3	34.9	34.2
	$T_{F(avg)}$	29.3	30.3	34.1	34.4	35.0	34.4
T_C (°C)	T_{C1}	22.8	22.8	28.5	29.8	30.3	31.3
	T_{C2}	22.3	22.3	28.1	30.3	30.8	30.8
	T_{C3}	22.7	22.7	28.5	29.9	30.4	31.3
	T_{C4}	22.5	22.5	28.3	30.1	30.6	31.0
	$T_{C(avg)}$	22.6	22.6	28.3	30.0	30.5	31.1
T_P (°C)	T_{P1}	29.1	35.8	40.3	41.1	41.5	39.9
	T_{P2}	29.9	36.6	41.1	41.8	42.3	40.7
	T_{P3}	29.3	36.0	40.4	41.2	41.7	40.0
	T_{P4}	29.1	35.9	40.3	41.1	41.6	39.9
	$T_{P(avg)}$	29.3	36.1	40.5	41.3	41.8	40.1
H_{Tz} (mV)		9.12	10.23	10.00	10.72	9.50	9.23
H_{dz} (mV)		2.25	2.10	2.64	2.50	2.95	2.15
H_{bz} (mV)		6.87	8.13	7.36	8.22	6.55	7.08
Sample (grams)	S_1	42	40	39	37	36	36
	S_2	42	40	38	37	37	36
	S_3	42	40	39	38	37	36
	S_4	42	40	39	38	37	37
	$S_{(avg)}$	42.0	40.0	38.8	37.5	36.8	36.3
η % (1 hour)		0.00	19.94	6.07	4.06	1.96	1.19
η %		0.00	19.94	15.04	13.48	12.24	11.95
η_d %		10.99					
$M_{v\text{-}1\_hour}$ (kg)		0.00	0.1795	0.1178	0.1216	0.0754	0.0513
M_{v} (kg)		0.00	0.1795	0.2917	0.4039	0.4713	0.5161

Table 4.15 Measured Data: 21-3-05(D=0.06m,V=0.03m), paddy: 3kg & on wet 4.2kg, 1st day

Time: 8:30, Wind Velocity (Daily Average: 1.3 Nauts & Instantaneous: 2 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.1	32.0	35.4	38.3	36.5	34.5
T_F (°C)	T_{F1}	31.0	33.0	37.2	39.4	37.2	35.1
	T_{F2}	31.0	33.0	37.1	39.4	37.2	35.0
	T_{F3}	31.8	33.7	37.9	40.2	38.0	35.8
	T_{F4}	31.1	33.1	37.2	39.5	37.3	35.1
	$T_{F(avg)}$	31.2	33.2	37.4	39.6	37.4	35.3
T_C (°C)	T_{C1}	24.3	24.9	31.2	34.5	32.5	32.1
	T_{C2}	23.8	24.4	30.7	35.0	33.0	31.7
	T_{C3}	24.2	24.8	31.1	34.6	32.5	32.1
	T_{C4}	24.0	24.6	30.9	34.8	32.8	31.9
	$T_{C(avg)}$	24.0	24.7	31.0	34.7	32.7	31.9
T_P (°C)	T_{P1}	31.0	39.3	44.1	47.4	44.4	40.9
	T_{P2}	31.8	40.0	44.9	48.1	45.2	41.7
	T_{P3}	31.2	39.4	44.3	47.5	44.6	41.1
	T_{P4}	31.0	39.3	44.2	47.4	44.4	41.0
	$T_{P(avg)}$	31.2	39.5	44.4	47.6	44.6	41.2
H_{Tz} (mV)		9.81	10.24	9.74	10.48	10.51	9.92
H_{dz} (mV)		4.85	5.01	4.42	4.71	4.32	4.86
H_{bz} (mV)		4.96	5.23	5.32	5.77	6.19	5.06
Sample (grams)	S_1	60	55	51	47	45	44
	S_2	60	55	52	48	45	44
	S_3	60	55	51	48	45	44
	S_4	60	55	51	47	45	44
	$S_{(avg)}$	60.0	55.0	51.3	47.5	45.0	44.0
$\eta\%_{(1\ hour)}$		0.00	38.49	15.31	10.80	5.75	2.04
η %		0.00	38.49	32.75	30.76	27.32	24.52
η_d %		23.97					
$M_{v-1\_hour\ (kg)}$		0.00	0.3500	0.2864	0.3073	0.2211	0.0933
$M_{v\ (kg)}$		0.00	0.3500	0.6125	0.8750	1.0500	1.1200

Table 4.16 Measured Data: 22-3-05(D=0.06m,V=0.03m), paddy: 3kg & on wet 3.19kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 4 Nauts & Instantaneous: 2 kmph) & Direction: W

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.0	32.4	35.0	38.1	36.1	34.3
T_F (°C)	T_{F1}	30.8	32.7	37.0	39.2	36.9	34.9
	T_{F2}	30.8	32.7	36.9	39.2	36.9	34.8
	T_{F3}	31.6	33.5	37.7	39.9	37.7	35.6
	T_{F4}	30.9	32.8	37.0	39.3	37.0	34.9
	$T_{F(avg)}$	31.0	32.9	37.2	39.4	37.1	35.1
T_C (°C)	T_{C1}	24.1	24.7	31.0	34.3	32.2	32.0
	T_{C2}	23.6	24.2	30.5	34.8	32.7	31.5
	T_{C3}	24.0	24.7	30.9	34.3	32.3	31.9
	T_{C4}	23.8	24.4	30.7	34.6	32.5	31.7
	$T_{C(avg)}$	23.9	24.5	30.8	34.5	32.5	31.8
T_P (°C)	T_{P1}	30.8	38.9	43.9	47.0	44.1	40.7
	T_{P2}	31.6	39.7	44.7	47.8	44.9	41.5
	T_{P3}	31.0	39.1	44.1	47.2	44.3	40.9
	T_{P4}	30.8	39.0	43.9	47.1	44.1	40.7
	$T_{P(avg)}$	31.0	39.2	44.1	47.3	44.3	40.9
H_{Tz} (mV)		9.92	10.46	10.28	10.93	10.72	9.73
H_{dz} (mV)		4.77	4.93	4.62	4.38	4.66	4.81
H_{bz} (mV)		5.15	5.53	5.66	6.55	6.06	4.92
Sample (grams)	S_1	46	45	44	42	42	41
	S_2	45	44	43	43	42	42
	S_3	46	44	43	43	42	42
	S_4	45	44	43	42	42	42
	$S_{(avg)}$	45.5	44.3	43.3	42.5	42.0	41.8
η % (1 hour)		0.00	9.50	3.74	1.86	0.94	0.41
η %		0.00	9.50	8.18	7.07	6.17	5.73
η_d %		5.48					
$M_{v\text{-}1\_hour}$ (kg)		0.00	0.0876	0.0721	0.0553	0.0375	0.0190
M_{v} (kg)		0.00	0.0876	0.1577	0.2103	0.2454	0.2629

Table 4.17 Measured Data: 23-3-05(D=0.06m,V=0.03m), paddy: 3kg & on wet 3.01kg, 3rd day

Time: 8:30, Wind Velocity (Daily Average: 1.6 Nauts & Instantaneous: 2 kmph) & Direction: NW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.2	32.5	35.2	38.1	36.3	33.5
T_F (°C)	T_{F1}	30.7	32.6	36.9	37.2	36.9	34.8
	T_{F2}	30.7	32.6	36.8	37.2	36.9	34.7
	T_{F3}	31.5	33.4	37.6	38.0	37.6	35.5
	T_{F4}	30.8	32.7	36.9	37.3	37.0	34.8
	$T_{F(avg)}$	30.9	32.8	37.1	37.4	37.1	35.0
T_C (°C)	T_{C1}	24.0	24.7	30.9	32.5	32.2	31.9
	T_{C2}	23.5	24.2	30.4	33.0	32.7	31.4
	T_{C3}	23.9	24.6	30.9	32.6	32.3	31.8
	T_{C4}	23.7	24.4	30.6	32.8	32.5	31.6
	$T_{C(avg)}$	23.8	24.4	30.7	32.7	32.4	31.7
T_P (°C)	T_{P1}	30.7	38.8	43.8	44.7	44.0	40.6
	T_{P2}	31.5	39.6	44.5	45.5	44.8	41.4
	T_{P3}	30.9	39.0	43.9	44.9	44.2	40.8
	T_{P4}	30.7	38.9	43.8	44.7	44.1	40.6
	$T_{P(avg)}$	30.9	39.1	44.0	44.9	44.3	40:8
H_{Tz} (mV)		9.72	10.11	10.12	10.39	10.02	10.91
H_{dz} (mV)		4.35	4.39	4.02	3.91	3.49	3.75
H_{bz} (mV)		5.37	5.72	6.10	6.48	6.53	7.16
Sample (grams)	S_1	43	42	42	41	41	41
	S_2	43	43	42	42	41	40
	S_3	43	42	41	41	40	40
	S_4	43	42	42	41	41	40
	$S_{(avg)}$	43.0	42.3	41.8	41.3	40.8	40.3
η% (1 hour)		0.00	5.84	1.89	1.25	0.97	0.80
η %		0.00	5.84	4.64	4.25	4.17	4.18
η_d %		4.12					
M_{v-1_hour} (kg)		0.00	0.0525	0.0356	0.0360	0.0365	0.0369
M_v (kg)		0.00	0.0525	0.0875	0.1225	0.1575	0.1925

Table 4.18 Measured Data: 24-3-05(D=0.06m,V=0.03m), paddy: 3kg & on wet 2.94kg, 4th day

Time: 8:30, Wind Velocity (Daily Average: 1.7 Nauts & Instantaneous: 2 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		29.9	32.5	35.2	37.8	37.2	34.2
T_F (°C)	T_{F1}	30.7	32.5	36.8	37.2	36.8	34.7
	T_{F2}	30.6	32.4	36.8	37.2	36.8	34.6
	T_{F3}	31.4	33.2	37.6	37.9	37.6	35.4
	T_{F4}	30.7	32.5	36.9	37.3	36.9	34.7
	$T_{F(avg)}$	30.9	32.7	37.0	37.4	37.0	34.9
T_C (°C)	T_{C1}	24.0	24.5	30.9	32.5	32.2	31.8
	T_{C2}	23.5	24.1	30.4	33.0	32.6	31.3
	T_{C3}	23.9	24.5	30.8	32.5	32.2	31.7
	T_{C4}	23.7	24.3	30.6	32.8	32.4	31.5
	$T_{C(avg)}$	23.8	24.3	30.7	32.7	32.4	31.6
T_P (°C)	T_{P1}	30.6	38.6	43.7	44.6	44.0	40.5
	T_{P2}	31.4	39.4	44.5	45.4	44.8	41.2
	T_{P3}	30.8	38.8	43.9	44.8	44.2	40.6
	T_{P4}	30.7	38.7	43.7	44.7	44.0	40.5
	$T_{P(avg)}$	30.9	38.9	43.9	44.9	44.2	40.7
H_{Tz} (mV)		9.32	10.21	10.38	10.46	10.68	10.95
H_{dz} (mV)		4.32	4.27	4.10	3.82	3.96	3.91
H_{bz} (mV)		5.00	5.94	6.28	6.64	6.72	7.04
Sample (grams)	S_1	42	42	41	41	40	39
	S_2	42	41	41	40	40	40
	S_3	42	41	41	40	40	40
	S_4	42	42	41	41	40	40
	$S_{(avg)}$	42.0	41.5	41.0	40.5	40.0	39.8
$\eta\,\%_{(1\ hour)}$		0.00	3.99	1.86	1.23	0.94	0.39
$\eta\,\%$		0.00	3.99	3.68	3.59	3.61	3.33
$\eta_d\,\%$		3.32					
$M_{v-1\_hour\ (kg)}$		0.00	0.0350	0.0354	0.0359	0.0363	0.0184
$M_{v\ (kg)}$		0.00	0.0350	0.0700	0.1050	0.1400	0.1575

Table 4.19 Measured Data: 28-3-05(D=0.06m,V=0.03m), paddy: 4kg & on wet 5.6kg, 1[st]day

Time: 8:30, Wind Velocity (Daily Average: 1.3 Nauts & Instantaneous: 0 kmph) & Direction: N

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.0	32.2	35.3	38.6	36.4	34.2
T_F (°C)	T_{F1}	30.4	32.4	36.2	38.6	36.2	34.1
	T_{F2}	30.4	32.3	36.2	38.6	36.2	34.0
	T_{F3}	31.2	33.1	37.0	39.4	36.9	34.8
	T_{F4}	30.5	32.4	36.3	38.7	36.3	34.1
	$T_{F(avg)}$	30.6	32.6	36.4	38.8	36.4	34.3
T_C (°C)	T_{C1}	23.8	24.5	30.4	33.8	31.6	31.2
	T_{C2}	23.3	24.0	29.9	34.3	32.0	30.8
	T_{C3}	23.7	24.4	30.3	33.8	31.6	31.2
	T_{C4}	23.5	24.2	30.1	34.1	31.8	31.0
	$T_{C(avg)}$	23.6	24.3	30.2	34.0	31.8	31.0
T_P (°C)	T_{P1}	30.4	38.5	43.0	46.4	43.2	39.8
	T_{P2}	31.2	39.3	43.8	47.2	44.0	40.5
	T_{P3}	30.6	38.7	43.2	46.5	43.4	39.9
	T_{P4}	30.4	38.5	43.0	46.4	43.2	39.8
	$T_{P(avg)}$	30.6	38.8	43.3	46.6	43.4	40.0
H_{Tz} (mV)		9.81	10.24	9.74	10.48	10.51	9.92
H_{dz} (mV)		4.85	5.01	4.42	4.71	4.32	4.86
H_{bz} (mV)		4.96	5.23	5.32	5.77	6.19	5.06
Sample (grams)	S_1	60	56	52	48	46	44
	S_2	60	56	52	48	46	45
	S_3	60	55	52	48	45	44
	S_4	60	55	51	48	45	44
	$S_{(avg)}$	60.0	55.5	51.8	48.0	45.5	44.3
$\eta\%_{(1\ hour)}$		0.00	46.95	20.57	14.52	7.75	3.45
η %		0.00	46.95	41.87	40.08	35.94	32.96
η_d %		32.05					
$M_{v-1\_hour\ (kg)}$		0.00	0.4200	0.3784	0.4058	0.2917	0.1538
$M_{v\ (kg)}$		0.00	0.4200	0.7700	1.1200	1.3533	1.4700

Table 4.20 Measured Data: 29-3-05(D=0.06m,V=0.03m), paddy: 4kg & on wet 4.32kg, 2nd day

Time: 8:30, Wind Velocity (Daily Average: 2.7 Nauts & Instantaneous: 2 kmph) & Direction: NW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		29.9	33.0	35.5	37.8	36.2	33.5
T_F (°C)	T_{F1}	30.3	32.3	36.0	38.6	36.2	34.1
	T_{F2}	30.3	32.2	36.0	38.6	36.2	34.0
	T_{F3}	31.1	33.0	36.8	39.4	36.9	34.8
	T_{F4}	30.4	32.3	36.1	38.7	36.3	34.1
	$T_{F(avg)}$	30.5	32.5	36.2	38.8	36.4	34.3
T_C (°C)	T_{C1}	23.7	24.4	30.2	33.8	31.6	31.2
	T_{C2}	23.2	23.9	29.8	34.3	32.0	30.8
	T_{C3}	23.6	24.3	30.2	33.8	31.6	31.2
	T_{C4}	23.4	24.1	30.0	34.1	31.8	31.0
	$T_{C(avg)}$	23.5	24.2	30.0	34.0	31.8	31.0
T_P (°C)	T_{P1}	30.3	38.4	42.8	46.4	43.2	39.8
	T_{P2}	31.1	39.2	43.5	47.2	44.0	40.5
	T_{P3}	30.5	38.6	42.9	46.5	43.4	39.9
	T_{P4}	30.3	38.4	42.8	46.4	43.2	39.8
	$T_{P(avg)}$	30.5	38.6	43.0	46.6	43.4	40.0
H_{Tz} (mV)		9.92	10.46	10.28	10.93	10.72	9.73
H_{dz} (mV)		4.77	4.93	4.62	4.38	4.66	4.81
H_{bz} (mV)		5.15	5.53	5.66	6.55	6.06	4.92
Sample (grams)	S_1	46	45	44	43	43	42
	S_2	47	45	44	43	42	42
	S_3	46	44	43	43	43	42
	S_4	46	44	44	43	42	42
	$S_{(avg)}$	46.3	44.5	43.8	43.0	42.5	42.0
η % (1 hour)		0.00	18.03	3.84	2.53	1.29	1.13
η %		0.00	18.03	12.32	10.38	9.00	8.86
η_d %		8.44					
M_{v-1_hour} (kg)		0.00	0.1635	0.0728	0.0741	0.0502	0.0508
M_v (kg)		0.00	0.1635	0.2335	0.3036	0.3503	0.3970

Table 4.21 Measured Data: 30-3-05(D=0.06m,V=0.03m), paddy: 4kg & on wet 4.11kg, 3[rd]day

Time: 8:30, Wind Velocity (Daily Average: 2.7 Nauts & Instantaneous: 4 kmph) & Direction: W

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.0	31.2	34.9	39.0	37.0	34.1
T_F (°C)	T_{F1}	30.2	32.2	35.9	38.4	35.9	33.8
	T_{F2}	30.2	32.1	35.9	38.3	35.9	33.8
	T_{F3}	31.0	32.9	36.7	39.1	36.7	34.6
	T_{F4}	30.3	32.2	36.0	38.4	36.0	33.9
	$T_{F(avg)}$	30.4	32.4	36.1	38.6	36.1	34.0
T_C (°C)	T_{C1}	23.6	24.3	30.2	33.5	31.3	31.0
	T_{C2}	23.1	23.8	29.7	34.0	31.8	30.5
	T_{C3}	23.6	24.2	30.1	33.6	31.4	30.9
	T_{C4}	23.3	24.0	29.9	33.8	31.6	30.7
	$T_{C(avg)}$	23.4	24.1	30.0	33.7	31.5	30.8
T_P (°C)	T_{P1}	30.2	38.3	42.6	46.1	42.9	39.5
	T_{P2}	31.0	39.1	43.4	46.8	43.7	40.2
	T_{P3}	30.4	38.5	42.8	46.2	43.1	39.6
	T_{P4}	30.2	38.3	42.7	46.1	42.9	39.5
	$T_{P(avg)}$	30.4	38.5	42.9	46.3	43.1	39.7
H_{Tz} (mV)		9.10	9.60	11.90	10.30	10.20	9.80
H_{dz} (mV)		2.50	2.80	2.10	2.60	2.40	2.50
H_{bz} (mV)		6.60	6.80	9.80	7.70	7.80	7.30
Sample (grams)	S_1	44	44	42	42	41	41
	S_2	44	43	42	41	41	41
	S_3	44	43	42	41	41	40
	S_4	44	43	43	42	41	41
	$S_{(avg)}$	44.0	43.3	42.3	41.5	41.0	40.8
$\eta\%_{(1\ hour)}$		0.00	8.38	4.89	2.36	1.31	0.58
η %		0.00	8.38	8.42	7.56	7.40	7.05
η_d %		6.51					
$M_{v\text{-}1\_hour\ (kg)}$		0.00	0.0701	0.0950	0.0730	0.0495	0.0251
$M_{v\ (kg)}$		0.00	0.0701	0.1635	0.2335	0.2802	0.3036

Table 4.22 Measured Data: 31-3-05(D=0.06m,V=0.03m), paddy: 4kg & on wet 4.01kg, 4th day

Time: 8:30, Wind Velocity (Daily Average: 4.3 Nauts & Instantaneous: 4 kmph) & Direction: N

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		31.0	33.4	36.5	38.4	37.5	34.0
T_F (°C)	T_{F1}	30.1	32.1	35.8	38.3	35.8	33.7
	T_{F2}	30.0	32.0	35.8	38.2	35.8	33.7
	T_{F3}	30.8	32.8	36.6	39.0	36.6	34.5
	T_{F4}	30.1	32.1	35.9	38.3	35.9	33.8
	$T_{F(avg)}$	30.3	32.3	36.0	38.5	36.0	33.9
T_C (°C)	T_{C1}	23.5	24.2	30.1	33.4	31.2	30.9
	T_{C2}	23.0	23.8	29.6	33.9	31.7	30.4
	T_{C3}	23.4	24.2	30.0	33.5	31.3	30.8
	T_{C4}	23.2	24.0	29.8	33.7	31.5	30.6
	$T_{C(avg)}$	23.3	24.0	29.9	33.7	31.5	30.7
T_P (°C)	T_{P1}	30.0	38.2	42.5	45.9	42.8	39.3
	T_{P2}	30.8	38.9	43.3	46.7	43.5	40.1
	T_{P3}	30.2	38.3	42.7	46.1	42.9	39.5
	T_{P4}	30.0	38.2	42.5	46.0	42.8	39.4
	$T_{P(avg)}$	30.3	38.4	42.8	46.2	43.0	39.6
H_{Tz} (mV)		9.10	10.70	11.90	11.80	11.10	10.30
H_{dz} (mV)		3.30	3.10	3.20	2.90	2.80	3.10
H_{bz} (mV)		5.80	7.60	8.70	8.90	8.30	7.20
Sample (grams)	S_1	43	42	41	41	41	41
	S_2	43	43	42	41	41	41
	S_3	43	43	42	41	41	41
	S_4	43	42	42	42	41	40
	$S_{(avg)}$	43.0	42.5	41.8	41.3	41.0	40.8
η % (1 hour)		0.00	5.35	3.49	1.47	0.58	0.53
η %		0.00	5.35	5.74	5.00	4.47	4.53
η_d %		4.21					
M_{v-1_hour} (kg)		0.00	0.0466	0.0708	0.0480	0.0243	0.0245
M_v (kg)		0.00	0.0466	0.1166	0.1632	0.1865	0.2098

Table 4.23 Measured Data: 4-4-05(D=0.06m,V=0.03m), paddy: 5kg & on wet 7kg, 1st day

Time: 11:00, Wind Velocity (Daily Average: 2.1 Nauts & Instantaneous: 2 kmph) & Direction: SW

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.2	32.5	35.6	38.4	36.5	34.5
T_F (°C)	T_{F1}	29.9	32.0	35.7	38.1	35.7	33.6
	T_{F2}	29.9	31.9	35.7	38.1	35.6	33.5
	T_{F3}	30.7	32.7	36.5	38.9	36.4	34.3
	T_{F4}	30.0	32.0	35.8	38.2	35.7	33.6
	$T_{F(avg)}$	30.1	32.2	35.9	38.3	35.9	33.7
T_C (°C)	T_{C1}	23.4	24.2	30.0	33.3	31.1	30.8
	T_{C2}	22.9	23.7	29.5	33.8	31.6	30.3
	T_{C3}	23.3	24.1	29.9	33.4	31.2	30.7
	T_{C4}	23.1	23.9	29.7	33.6	31.4	30.5
	$T_{C(avg)}$	23.2	24.0	29.8	33.5	31.3	30.6
T_P (°C)	T_{P1}	29.9	38.0	42.4	45.7	42.6	39.2
	T_{P2}	30.7	38.8	43.2	46.5	43.4	39.9
	T_{P3}	30.0	38.2	42.6	45.9	42.8	39.3
	T_{P4}	29.9	38.1	42.4	45.8	42.6	39.2
	$T_{P(avg)}$	30.1	38.3	42.6	46.0	42.8	39.4
H_{Tz} (mV)		9.40	10.60	10.50	10.80	10.50	9.90
H_{dz} (mV)		2.50	2.30	2.20	2.10	2.50	2.10
H_{bz} (mV)		6.90	8.30	8.30	8.70	8.00	7.80
Sample (grams)	S_1	60	56	52	49	46	45
	S_2	60	56	52	48	46	45
	S_3	60	56	52	49	46	45
	S_4	60	56	53	48	46	46
	$S_{(avg)}$	60.0	56.0	52.3	48.5	46.0	45.3
$\eta\%_{(1\ hour)}$		0.00	53.49	24.65	17.24	9.56	2.66
η %		0.00	53.49	47.55	46.05	43.27	40.09
η_d %		37.29					
$M_{v-1\_hour\ (kg)}$		0.00	0.4667	0.4688	0.5024	0.3608	0.1141
$M_{v\ (kg)}$		0.00	0.4667	0.9042	1.3417	1.6333	1.7208

Table 4.24 Measured Data: 5-4-05(D=0.06m,V=0.03m), paddy: 5kg & on wet 5.48kg, 2nd day

Time: 11:00, Wind Velocity (Daily Average: 4.6 Nauts & Instantaneous: 4 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		30.0	33.5	36.0	37.5	36.0	34.6
T_F (°C)	T_{F1}	29.4	31.9	35.6	38.0	35.6	33.4
	T_{F2}	29.8	31.8	35.6	38.0	35.5	33.4
	T_{F3}	30.6	32.6	36.4	38.8	36.3	34.2
	T_{F4}	29.9	31.9	35.7	38.1	35.6	33.5
	$T_{F(avg)}$	29.9	32.1	35.8	38.2	35.8	33.6
T_C (°C)	T_{C1}	23.3	24.1	29.9	33.2	31.0	30.7
	T_{C2}	22.8	23.6	29.4	33.7	31.5	30.2
	T_{C3}	23.2	24.0	29.8	33.3	31.1	30.6
	T_{C4}	23.0	23.8	29.6	33.5	31.3	30.4
	$T_{C(avg)}$	23.1	23.9	29.7	33.4	31.2	30.5
T_P (°C)	T_{P1}	29.8	37.9	42.3	45.6	42.5	39.0
	T_{P2}	30.5	38.7	43.0	46.4	43.2	39.8
	T_{P3}	29.9	38.1	42.4	45.8	42.6	39.2
	T_{P4}	29.8	37.9	42.3	45.7	42.5	39.1
	$T_{P(avg)}$	30.0	38.2	42.5	45.9	42.7	39.3
H_{Tz} (mV)		9.90	10.60	10.50	10.60	10.80	10.50
H_{dz} (mV)		2.40	2.30	2.50	2.10	2.30	2.20
H_{bz} (mV)		7.50	8.30	8.00	8.50	8.50	8.30
Sample (grams)	S_1	47	45	44	43	43	43
	S_2	47	45	44	44	43	42
	S_3	47	45	45	44	43	42
	S_4	47	45	44	43	43	43
	$S_{(avg)}$	47.0	45.0	44.3	43.5	43.0	42.5
$\eta\%_{(1\ hour)}$		0.00	25.97	4.79	3.22	1.67	1.44
η %		0.00	25.97	16.82	14.14	12.35	11.85
η_d %		11.27					
$M_{v\text{-}1\_hour\ (kg)}$		0.00	0.2332	0.0913	0.0929	0.0630	0.0637
$M_{v\ (kg)}$		0.00	0.2332	0.3206	0.4081	0.4664	0.5247

Table 4.25 Measured Data: 6-4-05(D=0.06m,V=0.03m), paddy: 5kg & on wet 5.25kg, 3rd day

Time: 11:00, Wind Velocity (Daily Average: 2.4 Nauts & Instantaneous: 4 kmph) & Direction: NE

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		31.0	32.0	34.5	38.5	37.6	34.2
T_F (°C)	T_{F1}	29.7	31.8	35.5	37.9	35.5	33.3
	T_{F2}	29.7	31.7	35.5	37.9	35.4	33.3
	T_{F3}	30.5	32.5	36.3	38.7	36.2	34.1
	T_{F4}	29.8	31.8	35.6	38.0	35.5	33.4
	$T_{F\,(avg)}$	29.9	32.0	35.7	38.1	35.7	33.5
T_C (°C)	T_{C1}	23.2	24.0	29.8	33.1	30.9	30.6
	T_{C2}	22.8	23.5	29.3	33.6	31.4	30.1
	T_{C3}	23.2	23.9	29.7	33.2	31.0	30.5
	T_{C4}	23.0	23.7	29.5	33.4	31.2	30.3
	$T_{C\,(avg)}$	23.0	23.8	29.6	33.3	31.1	30.4
T_P (°C)	T_{P1}	29.7	37.8	42.1	45.5	42.3	38.9
	T_{P2}	30.4	38.6	42.9	46.3	43.1	39.7
	T_{P3}	29.8	38.0	42.3	45.7	42.5	39.1
	T_{P4}	29.7	37.8	42.2	45.5	42.4	38.9
	$T_{P\,(avg)}$	29.9	38.0	42.4	45.7	42.6	39.2
H_{Tz} (mV)		9.10	10.50	10.30	10.30	10.20	9.80
H_{dz} (mV)		2.50	2.80	2.30	2.60	2.80	2.90
H_{bz} (mV)		6.60	7.70	8.00	7.70	7.40	6.90
Sample (grams)	S_1	45	43	42	42	42	41
	S_2	45	44	43	42	42	42
	S_3	45	43	43	42	42	42
	S_4	45	43	43	43	42	42
	$S_{(avg)}$	45.0	43.3	42.8	42.3	42.0	41.8
$\eta\,\%_{(1\ hour)}$		0.00	24.10	3.26	2.18	0.86	0.75
η %		0.00	24.10	14.12	11.41	9.69	9.09
η_d %		8.48					
$M_{v\text{-}1\_hour\,(kg)}$		0.00	0.2042	0.0607	0.0614	0.0311	0.0313
$M_{v\,(kg)}$		0.00	0.2042	0.2625	0.3208	0.3500	0.3792

Table 4.26 Measured Data: 7-4-05(D=0.06m,V=0.03m), paddy: 5kg & on wet 5.02kg, 4th day

Time: 11:00, Wind Velocity (Daily Average: 2.8 Nauts & Instantaneous: 4 kmph) & Direction: E

Time (hours)		10.00	11.00	12.00	13.00	14.00	15.00
T_A (°C)		31.2	33.5	37.0	38.5	38.0	34.5
T_F (°C)	T_{F1}	29.5	31.7	35.5	37.9	35.4	33.3
	T_{F2}	29.5	31.7	35.4	37.8	35.4	33.3
	T_{F3}	30.3	32.5	36.2	38.6	36.2	34.0
	T_{F4}	29.6	31.8	35.5	37.9	35.5	33.4
	$T_{F(avg)}$	29.7	31.9	35.7	38.1	35.6	33.5
T_C (°C)	T_{C1}	23.1	24.0	29.8	33.1	30.9	30.6
	T_{C2}	22.6	23.5	29.3	33.6	31.4	30.1
	T_{C3}	23.0	23.9	29.7	33.1	30.9	30.5
	T_{C4}	22.8	23.7	29.5	33.4	31.2	30.3
	$T_{C(avg)}$	22.9	23.8	29.6	33.3	31.1	30.4
T_P (°C)	T_{P1}	29.5	37.7	42.1	45.4	42.3	38.9
	T_{P2}	30.2	38.5	42.9	46.2	43.1	39.6
	T_{P3}	29.6	37.9	42.2	45.6	42.5	39.0
	T_{P4}	29.5	37.7	42.1	45.5	42.3	38.9
	$T_{P(avg)}$	29.7	38.0	42.3	45.7	42.5	39.1
H_{Tz} (mV)		9.10	10.80	11.80	11.90	11.70	10.30
H_{dz} (mV)		2.50	2.80	2.30	2.60	2.40	2.50
H_{bz} (mV)		6.60	8.00	9.50	9.30	9.30	7.80
Sample (grams)	S_1	43	41	41	40	40	40
	S_2	43	41	41	40	40	40
	S_3	43	41	40	40	40	40
	S_4	43	42	41	41	40	39
	$S_{(avg)}$	43.0	41.3	40.8	40.3	40.0	39.8
η % (1 hour)		0.00	23.87	3.05	1.93	0.75	0.68
η %		0.00	23.87	13.18	10.04	8.43	8.23
η_d %		7.71					
M_{v-1_hour} (kg)		0.00	0.2043	0.0608	0.0616	0.0312	0.0314
M_v (kg)		0.00	0.2043	0.2627	0.3210	0.3502	0.3794

CHAPTER V

RESULTS AND DISCUSSION

The drying experiment with a reverse absorber cabinet dryers was carried out with various crops such as : wheat (3kg), peas (2kg, 3kg, 4kg) and paddy (3kg, 4kg, 5kg), and with different vent width (V) and duct depth (D), in sun. The solar radiations variation from the morning to evening during the day was noted. The wind velocity was also noted (taken from the meteorological data, obtained from site: www.iitr.ernet.in). The different parameters used in the study are reported in the Table 5.1.

Table 5.1: Various parameters used in the experiment

Parameter	Value
Paddy	3 kg, 4 kg and 5 kg
Peas	2 kg, 3 kg, and 4 kg
Wheat	3 kg
V (vent width)	0.01-0.03 m
D (duct depth)	0.05-0.06 m
A_d (area of the dryer)	0.43 m^2
L (length of the dryer)	1.14 m
B (width of the dryer)	0.38 m

5.1. UNCERTAINTY ANALYSIS

The uncertainty analysis as proposed by Kline and McClintock [18] is used for the evaluation of uncertainties associated with the measurements and instruments used in the experiments, based on observations of the scatter in the raw data used in calculating the result. The details of the analysis are given in Appendix A. The following values give the uncertainty in the values of important parameters as shown in Table 5.2.

Table 5.2. The uncertainty in the values of important parameters

Parameter	Uncertainty (%)
M_v (moisture evaporated)	± 0.3
η_i (instantaneous efficiency)	± 1.6

5.2. REPRODUCIBILITY OF DATA

The experiment was repeated twice with wheat (3kg) to check the reproducibility of measurement. It is shown in Figure 5.1 to 5.3 (Table 4.1, 4.3) for wheat. The trend of variation is observed to be the same for the two sets. The difference in the two sets is basically due to the difference in the duct depth D, which were 0.06m for first set and 0.05m for second set. Had this parameter D kept same, it would have given the closer variation between the two sets. Hence the measurement shows a good reproducibility of the data.

5.3. THE RESULTS & DISCUSSION

5.3.1. Variation of Temperatures of the Crop, Plate and Fluid

The hourly variation of various temperatures, namely temperatures of the crop, plate and fluid with drying time at a fixed duct depth (D=0.06m) and vent width (V=0.03m) are shown in Fig. 5.4 (Table 4.1) for Wheat (3kg), in Figs. 5.5 (Table 4.7) & 5.6 (Table 4.13) for Peas (3kg & 4kg respectively), in Figs. 5.7 to 5.9 (Table 4.15, 4.19 and 4.23) for Paddy (3kg, 4kg and 5kg respectively). During the sunshine hours, the crop and fluid temperatures are less than the plate temperature in the reverse absorber cabinet for Paddy (3kg, 4kg and 5kg respectively). During the sunshine hours, the crop and fluid temperatures are less than the plate temperature in the reverse absorber cabinet dryer. From these figures, it is observed that the crop temperature increases rapidly from 11:00 am to 13:00 hours and thereafter it starts decreasing slowly upto 15:00 hours. The sharp increase of the crop temperature is due to the fact that the ambient temperature (hence inlet air temperature) increases sharply.

Figs. 5.5 and 5.6 show the trend of variation of the crop temperature (in this case Peas for 3kg and 4kg) is different. In Fig. 5.5 (Table 4.7), it is seen that there is rapid decrease of the temperature of crop between 13:00 hours (when it is maximum) and 14:00 hours, while in Fig. 5.6, the crop temperature (Peas 4kg) keep rising slowly with very little and slow drop in later hours (14:00 to 15:00 hours). On critically observing the environment data (Table 4.7 and 4.13) namely the ambient temperature and the solar radiation on the days of these measurement (i.e. dated 3-3-2005 for 3kg Peas and 16-3-2005 for 4kg Peas), it is seen that there is a sharp drop of solar radiation on 3-3-2005 between data 13:00 hours and 14:00 hours when 3kg Peas experiment was performed. This resulted into the sharp decrease of crop temperature as observed in Fig. 5.5. While in Fig. 5.6 (for 4 kg Peas, dated 16-3-2005 Table 4.13), the continuous increase of crop temperature from 13:00 hours to 14:00 hours is observed which may the due to the fact that the ambient temperature is higher (as compared to that on 3-3-2005 for 3kg Peas). Decrease of the ambient temperature and the solar radiation from 13:00 hours to 15:00 hours for 4kg Peas is small. The energy absorbed by Peas at temperature is higher, thus resulting into the type of variation observed in Fig. 5.6 (Table 4.13).

5.3.2. Effect of Various Parameters on Temperature Variation

5.3.2.1. Variation of Plate Temperature

It is shown in Fig. 5.10 to 5.13,

a. with duct depth : D= 0.06m & 0.05m,

for Wheat 3kg and V= 0.03m is shown in Fig. 5.10 (Table 4.1 and 4.2).

It is seen from the Fig. 5.10, that when the inlet duct depth D is increased, the plate temperature falls throughout the drying time.

b.1. Peas : 2kg & 3kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.11 (Table 4.5 and 4.7).

b.2. Paddy : 3kg, 4kg & 5kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.12 (Table 4.19 and 4.23).

Fig. 5.11 (for Peas) and Fig. 5.12 (for Paddy) reveal that as the mass of the crop to be dried is increased, the plate temperature decreases.

c. with vent size : V= 0.01m, 0.02m & 0.03m,

for Peas 4kg and D= 0.06m is shown in Fig. 5.13 (Table 4.11 and 4.13).

It is seen from Fig 5.13, that the normal trend is as the vent size V increases the plate temperature increases. It may be due to air escaping fast at higher values of V. The unusual observation at 13:00 hours, for V= 0.02m and V= 0.03m, the plate temperature coincides. It is not common that it will occur like this. The unusual value of wind velocity or uneven crop spreading or other environmental factors may have resulted in variation like this.

5.3.2.2. Variation of Fluid Temperature

It is shown in Fig. 5.14 to 5.17,

a. with duct depth : D= 0.06m & 0.05m,

for Wheat 3kg and V= 0.03m is shown in Fig. 5.14 (Table 4.1 and 4.3).

It is seen from the Fig. 5.14, that when the inlet duct depth D is increased, the fluid temperature falls throughout the drying time.

b. with mass of crops

b.1. Peas : 2kg & 3kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.15 (Table 4.5 and 4.7).

b.2. Paddy : 3kg, 4kg & 5kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.16 (4.15, 4.19 and 4.23).

Fig. 5.15 (for Peas) and Fig. 5.16 (for Paddy) reveal that as the mass of the crop to be dried is increased, the fluid temperature decreases.

Fig. 5.15 (for Peas) and Fig. 5.16 (for Paddy) reveal that as the mass of the crop to be dried is increased, the fluid temperature decreases.

c. with vent size : V= 0.01m, 0.02m & 0.03m,

at V= 0.03m and D= 0.06m is shown in Fig. 5.17 (4.9, 4.11 and 4.13).

It is seen from Fig 5.17, that the normal trend seen is as the vent size V increases the fluid temperature increases. It may be due to air escaping fast at higher values of V. The unusual observation at 13:00 hours, for V= 0.02m and V= 0.03m, the fluid temperature coincides. It is not common that it will occur like this. The unusual value of wind velocity or uneven crop spreading or any other environmental factors may have resulted like this.

5.3.2.3. Variation of Crop Temperature

It is shown in Fig. 5.18 to 5.21,

a. with duct depth : D= 0.06m & 0.05m,

for Wheat 3kg and V= 0.03m is shown in Fig. 5.18 (Table 4.1 and 4.3).

It is seen from the Fig. 5.18, that when the inlet duct depth D is increased, the crop temperature falls throughout the drying time.

b. with mass of crops

b.1. Peas : 2kg & 3kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.19 (Table 4.5 and 4.7).

b.2. Paddy : 3kg, 4kg & 5kg,

at V= 0.03m and D= 0.06m is shown in Fig. 5.20 (Table 4.15, 4.19 and 4.23).

Fig. 5.19 (for Peas) and Fig. 5.20 (for Paddy) reveal that as the mass of the crop to be dried is increased, the crop temperature decreases.

c. with vent size : V= 0.01m, 0.02m & 0.03m,

at V= 0.03m and D= 0.06m is shown in Fig. 5.21 (Table 4.9, 4.11 and 4.13).

It is seen from Fig 5.21, that the normal trend is as the vent size V increases the crop temperature increases. It may be due to air escaping fast at higher values of V. The velocity or uneven crop spreading or any other environmental factors may have resulted like this.

5.3.3. Variation of Moisture Removed (Every 1 Hour)

The variation of moisture removed (every 1 hour) of the crop with the drying time at varying duct depth, vent width and the variation of the crops are shown in Figure 5.22 to 5.30, till no more moisture removal or very little moisture removal is observed,

a. Wheat :

From Fig. 5.22 (Table 4.1 and 4.2) and Fig. 5.23 (Table 4.3 and 4.4), for 3 kg sample of Wheat but with D=0.06m and D=0.05m respectively, it is observed that the moisture removal on the second day is much less compared to that on the first day and that at 15:00 hours on the second day, no more moisture removal occurs, indicating that the drying process is complete.

It is generally observed, as it is logical, that the moisture present in the crops decreases as the drying progresses. The drying process was continuously carried out for 2 days (for Peas and Wheat) and for 4 days (for Paddy), keeping the sample left in the dryer overnight. The next day (or days) drying continued.

b. Peas :

From Fig. 5.24 (Table 4.5 and 4.6) and Fig. 5.25 (Table 4.7 and 4.8) for 2 kg and 3 kg samples of Peas for 2 days drying: It is seen that though the moisture removal continues on the 2nd day, it becomes a slow process and the moisture removal is very slow. At the end of the 2nd day, the total moisture removal is 38.6 % for 2 kg Peas and 35 % for 3 kg Peas (the details of the calculation are given in Appendix B).

Variation of moisture removal for 4 kg Peas, with different vent openings (V= 0.01m, 0.02m and 0.03m) are plotted in Fig. 5.26 (Table 4.9, 4.11 and 4.13) for 1st day and Fig. 5.27 (Table 4.10, 4.12 and 4.14) for 2nd day.

It is seen that for all values of vent openings experimented, the moisture removal amount and its rate converge and become the same on the second day (Fig. 5.27).

c. Paddy :

c. Paddy :

From Fig. 5.28 (Table 4.15, 4.16, 4.17 & 4.18), Fig. 5.29 (Table 4.19, 4.20, 4.21 & 4.22) and Fig. 5.30 (Table 4.23, 4.24, 4.25 & 4.26) for 3 kg, 4 kg and 5 kg samples of Paddy for 4 days drying: Time required for drying Paddy is more as compared to those for Wheat and Peas. The drying process was carried out continuously for 4 days, leaving the sample after a day in the dryer itself open to the night environment. In general each crop gains some moisture during the night. Paddy also gains some moisture during the night. The drying process was continued on the next day, till 4 days at the end of which no more or little moisture removal is observed.

5.3.4. Variation of Total Moisture Removed

The variation of moisture removed from the crop with the drying time at varying duct depth, vent width and the variation of the crops are shown in Figure 5.31 to 5.39. The following observations are noticed.

a. Different Crops :

a.1. Wheat :

(i). Wheat 3kg (D= 0.06m),

Total moisture removal for 3kg (D= 0.06m) Wheat sample observed in Figure. 5.31 (Table 4.1 and 4.2) is: 22.8 % (say 23 %) on 1st day and 10.6 % on 2nd day.

(ii). Wheat 3kg (D= 0.05m),

Total moisture removal for 3 kg (D= 0.05m) Wheat sample observed in Figure. 5.32 (Table 4.3 and 4.4) is: 23.3 % (say 23 %) on 1st day and 10.6 % on 2nd day.

The above results thus show that there is no effect of inlet duct depth D on the total moisture removed. It is observed from Fig. 5.31 & 5.32 that:

(i) the total moisture removed increases with time on the first day of drying and the rate of moisture removal is fast.

(ii) while on the second day, the rate of moisture removed is high from 10:00 am to 11:00 am, but later on it is low and from 13:00 hours to 15:00 hours, it becomes

(i). Peas 2kg,

Total moisture removal for 2kg Peas sample observed in Figure. 5.33 (Table 4.5 and 4.6) is: 27.3 % on 1st day and 18.6 % on 2nd day.

(ii). Peas 3kg,

Total moisture removal for 3 kg Peas sample observed in Figure. 5.34 (Table 4.7 and 4.8) is: 26.4 % on 1st day and 13.3 % on 2nd day.

a.2.1. Effect of mass of crop

The above results thus show that there is very small effect of mass of crops of Peas 2kg and 3kg on the total moisture removed on 1st day, but on the 2nd day, total moisture removed is 13.3 % for 3 kg Peas and 18.6 % for 2kg Peas. It may be due to the different solar radiation (Table 4.5 and 4.7).

a.2.2. Rate of moisture removal

It is observed from Fig. 5.33 & 5.34 that:

(i) the moisture removed increases with time on the first day of drying and the rate of moisture removal is fast.

(ii) while on the second day, the rate of moisture removed is high from 10:00 am to 11:00 am, but later on it is low and from 13:00 hours to 15:00 hours, it becomes almost constant. By the end of the second day, leaving apart the moisture which remains in the crop, the drying process can be taken as complete.

Similar trends of drying are observed for wheat shown in Fig. 5.31 and 5.32.

a.3. Paddy :

From Fig. 5.35 to Fig. 5.37 for 3 kg, 4 kg and 5 kg samples of Paddy for 4 days drying. It takes nearly 4 days for drying Paddy crop, while Wheat and Peas dry in 2 days.

(i). Paddy 3kg,

Total moisture removal for 3 kg Paddy sample observed in Figure. 5.35 (Table 4.15, 4.16, 4.17 & 4.18) is 26.7 % on 1st day, 8.1 % on 2nd day, 6.3 % on 3rd day and 5.2 % on 4th day.

(i). Paddy 3kg,

Total moisture removal for 3 kg Paddy sample observed in Figure. 5.35 (Table 4.15, 4.16, 4.17 & 4.18) is 26.7 % on 1st day, 8.1 % on 2nd day, 6.3 % on 3rd day and 5.2 % on 4th day.

(ii). Paddy 4kg,

Total moisture removal for 4 kg Paddy sample observed in Figure. 5.36 (Table 4.19, 4.20, 4.21 & 4.22) is 26.1 % on 1st day, 9.3 % on 2nd day, 7.3 % on 3rd day and 5.1 % on 4th day.

(iii). Paddy 5kg,

Total moisture removal for 5 kg Paddy sample observed in Figure. 5.37 (Table 4.23, 4.24, 4.25 & 4.26) is 24.5 % on 1st day, 9.6 % on 2nd day, 7.1 % on 3rd day and 7.4 % on 4th day.

a.3.1. Effect of different crops

It is observed that total moisture removed on the 1st day for 3kg of Wheat is 23.3 % (say 23 %), for 3kg of Peas is 26.4 (say 26 %) and for 3kg of Paddy is 26.7 % (say 26 %).

Thus for Peas and Paddy the total moisture removed on the 1st day is nearly same, while for Wheat it is less.

The different values of the moisture removed for Wheat, Peas and Paddy are basically due to: (i) The ambient temperature (which is lower for wheat test day), and due to (ii) the solar radiation intensity (Table: 4.1, 4.7 and 4.15).

a.3.2. Effect of mass of crop (Paddy)

There seems to the very little effect of mass of crop (Paddy) on the rate of total moisture removed. The difference is caused due to different ambient temperature and solar radiations.

The marked increased in total moisture removed 7.4 % for 5kg Paddy on the 4th day compared to the those (5.2 % and 5.1 %) for 3kg and 4kg Paddy has resulted due to marked increased in solar radiation (Table 4.18, 4.22 and 4.26); it is 6.60 to 9.50 mV (average: 8.03 mV) for 5kg Paddy, 5.80 to 8.70 mV (average: 7.37 mV) for 4kg Paddy and 5.00 to 6.28 mV (average: 5.73 mV) for 3kg Paddy.

Unlike Wheat, in Peas & Paddy, total moisture removal does not reach a constant value, i.e. drying, though very little, still occurs.

There is very little or no difference observed for 3rd and 4th day drying rates.

b. with Vent Size :

The effect of vent size on the total moisture removed and rate of total moisture removed is shown on Fig. 5.38 (Table 4.9, 4.11 & 4.13) and 5.39 (Table 4.10, 4.12 & 4.14) for 1st day and 2nd day of drying respectively. The following observations are noted:

1. Peas 4kg (V= 0.01m),

Total moisture removal for 4kg (V= 0.01m) Peas sample observed (Table 4.9 & 4.10) is: 25.5 % on 1st day and 12.4 % on 2nd day.

2. Peas 4kg (V= 0.02m),

Total moisture removal for 4 kg (V= 0.02m) Peas sample observed (Table 4.11 & 4.12) is: 25.8 % on 1st day and 13.1 % on 2nd day

3. Peas 4kg (V= 0.03m),

Total moisture removal for 4 kg (V= 0.03m) Peas sample observed (Table 4.13 & 4.14) is: 26.4 % on 1st day and 13.6 % on 2nd day.

It is seen from these Figures 5.38 and 5.39 that when vent size is higher, the total moisture removal is higher for 1st day as well as for 2nd day of drying (the details of the calculation are given in Appendix B).

5.3.5. Variation of Instantaneous Efficiency (Every 1 Hour)

The variation of Instantaneous Efficiency (every 1 hour) of the crop with the drying time at varying duct depth, vent width for various crops are shown in Figure 5.40 to 5.48.

The Instantaneous Efficiency becomes zero. This means that no more moisture removal occurs and the drying process is complete. It may be noted that the Instantaneous Efficiency is defined here as :

The Instantaneous Efficiency becomes zero. This means that no more moisture removal occurs and the drying process is complete. It may be noted that the Instantaneous Efficiency is defined here as :

$$\eta_i = \frac{\textit{Heat utilized in drying (i.e. Moisture removed x Latent heat of evaporation of water)}}{\textit{Solar Radiation Incidenton the dryer operation area}}$$

So, when no more moisture removal occurs, the instantaneous efficiency reduces to zero.

5.3.5.1. General Observation :

From Fig. 5.40 to 5.48, it is seen that :

(i) The instantaneous efficiency is increases from 10:00 am to 11:00 am and it reaches peak at 11:00 am for all the crops and all days of drying process. It means the maximum removal of moisture occur at 11:00 am for all the crops and all days (i.e. during the first hour of operation of drying).

(ii) After reaching the peak value the instantaneous efficiency starts falling and become minimum on a particular day of drying. That implies the moisture removal is falling down initially (after 11:00 am) sharply and then slowly. Hence the instantaneous efficiency is falling as seen an Fig. 5.40 to 5.48.

(iii) At 15:00 hours on the 2nd day of drying for wheat, the instantaneous efficiency becomes zero (Fig. 5.40 - Table: 4.1 & 4.2 and Fig. 5.41 – Table: 4.3 & 4.4) and for Peas, it reduces to a very low value (1.12 to 1.99 %) i.e. nearly zero. For Paddy, it takes 4 days for drying process to complete, the instantaneous efficiency for Paddy reduces to a very low value too (0.39 to 0.68 %) on the 4th day at 15:00 hours.

Thus it implies that for Wheat drying process is complete on 2nd day and for Peas is nearly complete on 2nd day too. For Paddy, it takes 4 days for almost complete drying. But at the end of 3rd day itself, the drying process may be considered as complete (for 3rd day, $\eta =$ 0.80 % for 3kg, 0.58 % for 4kg and 0.75 % for 5kg as compared to for 4th day values $\eta = 0.39$ % for 3kg, 0.53 % for 4kg and 0.68 % for 5kg). In conclusion, for Wheat and Peas, it takes 2 days for Paddy 4 days for drying process to complete.

5.3.5.2. Variation of the Instantaneous Efficiency with vent size:

Variation of the Instantaneous Efficiency with vent size is shown on Figure 5.44 (Table: 4.9, 4.11 & 4.13) and Figure 5.45 (Table: 4.10, 4.12 and 4.14) for 1st day and 2nd day respectively for Peas 4kg and inlet duct size D= 0.06m.

It is seen that in the initial hours of drying process for 10:00 am to 12:00 noon, there is variation of the instantaneous efficiency with vent size (36.7 % to 30.1 %) but later on for 12:00 hours to 15:00 hours, the instantaneous efficiency does not depend on the vent size on both days of drying.

5.3.6. Variation of Total Efficiency

5.3.6.1. General Observation :

The variation of the total efficiency with drying time at varying duct depth, vent width and the variation of the crops are shown in Figure 5.49 to 5.57. The hourly efficiency in all the cases is higher at the beginning of drying and the efficiency gradually decreases as the drying progresses. This is due to the reason that in early hours of drying the moisture removed is more and hence the energy utilized is higher resulting in higher efficiency. But in later hours, when the moisture in the crop is decreased the energy utilized is lesser leading to lower total efficiency at various hours. Also the heat lost increased as the plate and crop temperatures increases causing drop in efficiency.

On the first day of drying, the total efficiency is higher as compared to that on the subsequent days for all the crops and for all values of inlet duct depth and outlet vent size.

The peak of the total efficiency occurs at 11:00 am just after initial one hour of drying for all the crops and for all conditions. Thereafter the total efficiency falls.

For Paddy, there is small difference between the values of the total efficiency on the 3rd and 4th days of drying.

5.3.6.2. Variation of The Total Efficiency with Vent Size :

5.3.6.2. Variation of The Total Efficiency with Vent Size :

Figure 5.53 and 5.54 show the variation of the total efficiency with drying time for various vent sizes for two days of drying process. It shows that the vent size increases, the total efficiency is higher.

5.3.7. Variation of Daily Efficiency

The Variation of Daily Efficiency with Drying time (1st day, 2nd day, 3rd day & 4th day) is shown in Fig. 5.58 to 5.62.

5.3.7.1. General Observation :

The daily efficiency is higher on the 1st day of drying for all crops as compared to that on subsequent days.

The daily efficiency for 1st day as shown in Fig. 5.58 for (i) Paddy 3kg is 23.97 % (ii) Wheat 3kg is 22.47 % and (iii) Peas 3kg is 21.19 %, i.e. highest for Paddy and lowest for Peas, though the difference is small which may be basically due to environmental factors like solar radiation.

5.3.7.2. Effect of Mass of Crop :

The effect of mass of the crop of Peas and Paddy on daily efficiency is shown on Fig. 5.60 and 5.62 respectively. It is seen from these Figures that the daily efficiency is higher for larger mass of the crop for both Peas and Paddy. But as the drying process progresses for subsequent days, the difference reduces.

5.3.7.3. Effect of the Vent Size :

The effect of the vent size on daily efficiency is shown on Fig. 5.61. for 4 kg sample of Peas. Though the variation of daily efficiency due to vent size is small, it is seen that as the vent size increases, the daily efficiency increases.